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The role of verbal cues in task-goal maintenance

Kirkham, Alexander James

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The Role of Verbal Cues in Task-Goal Maintenance

Alexander James Kirkham

School of Psychology, Bangor University.

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Thesis submitted for the degree of Doctorate of Philosophy in Psychology.

Dr. Paloma Marí-Beffa, Supervisor

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SUMMARY

A series of studies are presented investigating the role of verbal cues towards task goals, and in particular towards the maintenance of these goals.

Through the use of a combination of both list and alternating-runs paradigms, this task-switching research allows the measurement of two distinct indices of cognitive control - mixing costs and switch costs. The work demonstrates how relevant verbal cues reduce mixing costs, an indicator of task and task-sequence maintenance capabilities, whilst not influencing switch costs.

Manipulations of the study designs focus upon different forms of verbal cue strategies. Some cues require active involvement, whilst others are presented passively. The relevancy of the cue is also manipulated, both in terms of task-relevancy and cue-stimulus translation requirements.

Standard analysis methods are used alongside further techniques that provide a greater insight into how verbal cues provide benefits. These are discussed in terms of vigilance decrement, and provide evidence that relevant verbal cues also prolong attention and cognitive control compared to those that do not.

The processing of verbal and visual cues are investigated with ERP techniques. The results provide evidence towards distinct processing methods for each cue modality, and further suggest that to use visual cues correctly requires comparatively larger amounts of attentional resources than with verbal cues.

The studies demonstrate how the self-instructions that we use in daily life effectively help us to perform tasks with greater ease. This is achieved by improving task maintenance, sequence recollection, and hence cognitive control in general.

CHAPTER 1

INTRODUCTION

The town of Sainte-Foy-la-Grande lies in the midst of the Bergerac region of South-East France, near to Bordeaux. Peaceful streets, market stalls, and shops welcome you with their selections of pastries, coffee, and hats. Within the town there are signs providing direction towards all the local amenities, and one man's former house — that of Paul Broca. When you locate the building [although not hidden, the signage provides surprisingly little direction], a plaque can be found dedicated to the man who changed our knowledge of the inner workings of the brain so many years ago[1].

Although this thesis is not focused solely upon the work of Paul Broca, the vast majority of work presented here involves to some degree the region of the brain for which he is so well known. This may give the impression that this body of work is heavily focused on language processing, but again this is not the case. The main focus of the work presented relates to the performance of tasks, and more specifically how this performance can be degraded and/or facilitated. The main method through which this has been investigated is with the use of additional language-based influences, and in the context of locating this particular building it is easy to see how these influences can impact upon task performance. Attempting to locate a building that you have no visual detail for amongst the narrow streets of provincial France, forces one to make use of every resource available. Without conscious awareness it may become evident that you start reciting aloud street names, stating directions to yourself, or even verbally ensuring that you look in the correct direction when crossing the street. This analogy may give a light-hearted and simplistic impression, but the core factor remains – to assist in your performance of this task, you make use of all available resources.

[1]See Appendix B for details

Tasks

The above example is simplistic in the message it portrays, however it is a real life situation and crucially, one that we commonly use. By breaking down the processes involved we can determine that although the overall goal is to find the appropriate house, this isn't how the goal is completed *per se*. Instead it is sensible for us to separate this goal into smaller chunks, completing each as we go and once completed, moving onto the next. In this respect we can consider each of these smaller goals as individual tasks – reading a sign, walking down a street, turning at a junction, crossing a road, and so on. Again, each of these tasks can be separated further. Take crossing the road, for example. A simple process, but one that requires multiple tasks: approaching the road; stopping at the pavement edge; checking for traffic; repeating the checks; and finally crossing the road swiftly and safely. A straightforward example, but one that demonstrates the number of processes required in such a task.

With the global task of crossing a street requiring the completion of multiple smaller tasks, each again with their own internal stages, these can be termed *task-sets* – a set, or collection of processes that are necessary to be conducted in order for the task as a whole to be completed. Crucially with the above example each of the global task stages is composed of a task-set, and yet to perform the overall goal, each task-set must be performed in the correct order, and adequate switching between these must occur.

Task-switching

Task-switching paradigms have been used for empirical research into cognitive processes since the early 20^{th} Century (Jersild, 1927). Over the past 75 years the methods used to investigate these paradigms have changed dramatically, yet the paradigms themselves have remained relatively similar in format. Naturally progression has been made in the development of new paradigms, but the original theories and formats remain as relevant today as when they were developed.

When Jersild began investigating how the process was performed, the terminology was not founded, as such he began to investigate theories behind *mental set and shift*; or, task-sets and task-switching. During Jersild's studies, participants were required to complete tasks with three sets of numbers; with the first they performed mental calculations of one form (e.g. the addition of 5 to each number); with the second they performed a second task, e.g. subtraction of 5 from each number. Finally with the third they performed both of the calculations, alternating between each on successive trials (e.g. addition of, and subtraction of 5 from each number). Jersild found that the completion time varied dramatically between the single calculation lists and the alternating calculation list, where the latter took significantly longer to complete.

Logically this was interpreted as a result of having to perform multiple calculations with the alternating list; more specifically it was attributed to the requirement of retaining multiple mental-sets / task-sets, and further implementing them on the correct trials. Clearly this methodology is suitable for basic measures of task-switching capability, and highlights the impact of not only maintaining multiple task-sets, but also implementing them at the appropriate time. However, there are some issues with this particular paradigm in that the comparisons being drawn cannot be considered as comparable in some respects. During the single task block the participant is attending to only one task and *repeating* it continuously, the alternative task is irrelevant; yet during the alternating block both tasks are relevant and must be maintained, yet crucially *no repetitions* are taking place, only switches. For comparisons of repeat and switch trials to be appropriate they must always be performed under the same cognitive load and demands; if this is not the case, the comparisons are inappropriate. In this respect, the measurements that Jersild was making were *alternation costs*, although it remains the case that in some fields of thought these remain termed *switch costs*. Costs are a topic that will be returned to later in this chapter, but prior to this it is sensible to assess different forms of methodology.

Paradigms of task-switching

There are many different paradigms used in task-switching research, with each lab having their own preferences. However the majority fit into one of several formats that shall be covered here; each has benefits, but also costs, and it is a matter of discretion as to which is chosen in the experimental circumstances.

List design

As previously discussed, first brought to attention by Jersild (1927) the list paradigm is the most simple of designs. Performance using this method consists of completing trials in multiple blocks of single tasks (e.g. AAAA..., BBBB...) followed by a block where the trials consist of the same tasks in an alternating fashion (ABABAB...). Average completion times for trials in the single-task blocks are calculated and compared against average completion times for trials in the alternating-task block. Although the tasks are identical from the single-task blocks to the alternating-task block, the average time per trial in the alternating-task block is inevitably slower than the single-task counterpart. As was previously mentioned, during completion of the single-task blocks, the participant is solely focused upon the single task, where the secondary task is either unknown (i.e. is to follow), or is segregated and effectively ignored. With this single-task focus the participant is more capable at concentrating upon the requirements and can devote all attentional and working memory resources towards completing this task. However, during the alternating-tasks block of trials such dedicated focus and attention is not feasible; a certain amount of attention and focus must be retained for the upcoming task, or more specifically the maintenance of what the task involves. As a result of this task maintenance, and to an extent preparation for the upcoming trial, responses to these alternating-task trials are substantially slower than those in the single-task blocks. In essence if the amount of task information that needs to be sustained is increased, working memory processing efficiency decreases, resulting in the cost-per-response seen.

Alternating-runs design

Although the list design is still in use today, and it is a stable and robust format, there remain some problems. During the single-task trial blocks, repetitions of the tasks are taking place on every trial, and as such focus is devolved solely to that task and required responses. Yet during the alternating-task blocks each consecutive trial requires responses solely directed towards a fresh task that although not novel, is not a repetition of the previous; in other words it is a switch. Drawing comparisons on this basis is not entirely sound, if we consider working memory to be like so many other aspects of the world, ‘practice makes perfect’, and hence repetitions of trials are likely to benefit from either a recency impact, or indeed a practice impact. Such recency/practice benefits are not available to the same extent during a block where tasks alternate consecutively; the participant is constantly preparing for an upcoming trial that is different to the one most recently performed, so any benefits are likely to be minimised and not as fruitful. Evidently some benefits will be obtained if the participant has the working memory capabilities to maintain the task sequence adequately and potentially prepare for trials ahead of time, but it remains the case that the comparisons are not suitable on an experimental level. R. D. Rogers & Monsell

(1995) took the decision to include repetition trials within their mixed-task blocks of trials, but remained consistent by using a predictable sequence (AABBAABB...). Resulting from this decision there are now two trial formats housed with the mixed-task block – switch trials and repeat trials: AABBAABB - repeat trials underlined; AABBAABB - switch trials underlined.

The benefit of using this format for the design is that when combining this paradigm with the single-task trial blocks of the list design, further analyses can be conducted on the data in terms of extra measures of cognitive control. Whereas in the list design only a single measure can be calculated (the switch cost), using a combination of the single-task blocks and the alternating-runs mixed-task block allows the switch cost to be measured, but also an additional measure - the mixing cost. These costs shall be detailed later in this chapter, but there are strong benefits of having multiple measures over a single measure, especially since the single measure contains contaminants of the remaining measure.

Randomised design

An alternative to the alternating-runs paradigm is to use a randomised task format. In such a design it is the case that there will be both switch and repeat trials, however there will be no set sequence to the trial order, unlike in an alternating-runs design. As a result although the same cost measures can be obtained, their specificity in terms of cognitive control and task maintenance are adapted to demonstrate other indices.

There remain issues with this design, in some contexts – since there is no set sequence to the run of trials this raises another issue in terms of comparisons, rather in the same manner as with the list design. Single-task trial blocks consist of only repetitions, and as a result the participant is knowledgeable as to the sequential demands. Yet during the mixed-task blocks there is no sequential pattern, each trial is as unexpected as the last; therefore the preparations that can be made for each trial in the single-task blocks cannot be made in the mixed-task block. Obviously this is only related to instances where comparisons are being drawn against single-task trials, as a means of assessing cognitive control performance. It is more likely that experimentation using this paradigm be focusing upon the abilities of the participant to specifically switch between tasks rather than as a comparative means of assessing differences in repeat and switch trials in terms of task maintenance. Although these may seem highly similar, this form of paradigm places greater emphasis upon adaptability towards tasks, in that there is no indication of which task is upcoming. Whereas the alternating-runs paradigm places more emphasis upon resilience towards task maintenance, where the sequential demands are known and preparations can be made; hence comparisons towards single-task situations are more appropriate and demonstrate cognitive control measures.

Switch costs

This measure is one of two indexes of cognitive control that shall be examined in greater depth, and is the traditional and more recognisable measure. Originally coined by R. D. Rogers & Monsell (1995) the switch cost label is a self-explanatory term for the reaction time costs incurred when switching tasks, as compared to repeating tasks when using the alternating-runs paradigm. Crucial to this is another term – *task set*, which deserves an explanation for the usage of this will be commonplace. Task requirements are individual to the task that is being performed; for example, attempting to perform addition to a task requiring subtraction, will result in the trial being deemed as incorrect. Hence each task being performed has an individual task set – the specific requirements and objectives for each task are housed within this trial.

In the R. D. Rogers & Monsell (1995) model it is believed that the switch cost is incurred as a result of the time taken to disengage the previous task set, and replace it with the new and current task set. This reconfiguration of task sets is expected to take a period of time, and it is this time that forms the switch cost. Repeat trials do not require this reconfiguration, as they are already ‘in-place’ from the previous trial, thus the difference amounts to a cost when comparing repeat and switch trials.

Residual switch cost

Numerous methods have been attempted to reduce the switch cost, such as: increasing time constraints – response-stimulus-intervals (RSI) (e.g. R. D. Rogers & Monsell 1995), and different cuing strategies (exogenous visual task-cues, endogenous location based cues, exogenous verbal cues), yet regardless of manipulations a cost always remains - a residual switch cost. R. D. Rogers & Monsell (1995) anticipated that by increasing the inter-trial-interval (RSI) would reduce the switch cost due to the increase in preparation time available. Yet although this theory demonstrated strong results in the reduction of switch costs with an increase in RSI, there always remained a substantial residual cost, even where the RSI was 1500ms; a more than adequate period for preparation and task set reconfiguration. This led to their belief that regardless of the RSI length the final process-stage of task set reconfiguration can only be performed at the point where a stimulus is presented. In effect there is both an endogenous preparation process, but task reconfiguration can only be completed successfully with an additional exogenous influence in relation to the stimulus and associated response output.

Other hypotheses are at odds with this theory of residual switch costs. Allport, Styles, & Hsieh (1994) stated that the residual switch cost does not emanate from a final task set reconfiguration and implementation. Instead they argue it is a result of extended activation permeating through the following (and different) task set activation period, providing interference – task set inertia. In lateral inhibition terms, the task set for the previous task must have reached a specific level for activation, and once completed the prolonged degradation time of this results in *inhibition* of the new task set, slowing the time taken for the sufficient activation level to be reached, hence a cost. Increasing the inter-stimulus-interval (ISI) period leads to a decrease in switch cost, yet because of the permeating activation level the residual cost remains.

Thus far much focus has been on the switch cost measures, and yet the primary objective of this body of work is upon the other measure that has not yet been discussed - mixing costs.

Mixing costs

Sections of the following are to be found in

Cognitive Control, Eds. J. Grange & G. Houghton.

The processes involved in starting a fresh task are well documented, although the mystery is not solved entirely. However, if we have already started a task, how do we repeat it? Moreover, how do we repeat the task whilst concurrently ensuring attention towards another task is maintained, in case it is required in upcoming trials? This is the issue of mixing costs.

Historical background

Traditionally switch costs have been the favoured measure of task-switching researchers - the increase in reaction time (RT) found when switching attention and responses from one task to another, compared to when a task is repeated (Allport et al., 1994; Bertelson, 1961; Jersild, 1927; Shaffer, 1965; Spector & Biederman, 1976). Past studies of this nature predominantly made use of a list paradigm design whereby RT performance in single task blocks (AAA... and BBB...) was compared to that in a mixed task block where the task alternated on every trial (ABABA...), as originally used by Jersild (1927). The difference in mean RT between the single task blocks and the mixed task block result in a cost attributed to the extra performance demands of the mixed block; the switch cost. With this paradigm the standard requirements for the calculation of switch cost were available, and hence this became the de facto method.

Later researchers noted discrepancies in the measurements obtained with this format however (R. D. Rogers & Monsell, 1995). During the single task block there is no interference from the other task; it is not going to impact upon the task performance. Therefore participants effectively segregate the alternate task away from their working memory. During the mixed task block however they are required to not only switch between tasks, but crucially also maintain both, despite one being irrelevant on each trial. There is little disputing that this maintenance of multiple tasks demands greater cognitive requirements than is necessary during blocks of single tasks. Therefore the results that were being attributed towards a switch cost measure may be more associated towards the cognitive demands of task maintenance than the switching that is being performed. To combat this it became increasingly common to find research that made use of the list design but with crucial manipulations to alleviate some of these concerns. Although the overall structure of many of the paradigms remained unchanged to a large extent, it became common to make use of additional repetition trials within the mixed block. Initially it was the case that the mixed block transferred from a set pattern of alternating on each trial, to a design combining both switch *and repeat* trials in a random sequence (Shaffer, 1965). Although this method has continued to be used regularly (Mayr, 2001; Mayr & Keele, 2000; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Miyake, Emerson, Padilla, & Ahn, 2004; Monsell, 2003; Rubin & Meiran, 2005; Rubinstein, Meyer, & Evans, 2001; Tornay & Milán, 2001), the importance of task sequence has not been forgotten.

Since in the initial list paradigm it was obvious to all that upon completing a trial the task would alternate, the new design did not provide the same level of comparison since task uncertainty became a crucial factor. With an increase in task uncertainty the amount of task preparation that could be performed prior to each trial is heavily impeded. The participant is unaware of whether the upcoming trial is a repeat or a switch from the previous; as such they must take care to ensure a strong performance in either circumstance. Although it may appear to be a moot point, with the list paradigm this is a situation that is not encountered; the task sequence is predictable. Although it is a fair argument that the maintenance and recollection of the task sequence is relatively cognitively demanding, if the participant is capable of this their performance will be superior, compared to a circumstance where limited task preparation is available for a certainty of upcoming task.

The development of the alternating-runs design (R. D. Rogers & Monsell, 1995) gave rise to further research using predictable sequence task switching designs (e.g. AABBAABB...) (De Jong, 2000; Mayr & Kliegl, 2000; Waszak, Hommel, & Allport, 2003; Wylie & Allport, 2000). With the alternating-runs paradigm the predictability of the task-sequence is maintained, and crucially it additionally provides a mixed-task block where repetitions are preserved within this sequence, allowing comparisons to be drawn to the single-task pure-blocks. This is not to state that the alternating-runs paradigm design is superior to the random-cuing paradigm. Both have their own merits and it is a consideration that must be drawn by the researchers, depending upon what their research aims are as to which to use. Regardless, with both of these paradigms, or variations if one wishes, when coupled with the pure-block trials the possibility of investigating mixing costs is now available.

Justification

During the earlier days of our research into executive control we were conducting studies with a patient population (Parkinson's disease), and a control group of undergraduate participants. The experiments were task-switching studies using a combination of both the list and alternating-runs paradigms, and required responses to simple bivalent stimuli according to colour or shape. Prior to all trials, a cue was presented to alert the participant to the required response characteristic ('Blue/Red' or 'Square/Circle'). All trials were completed in silence with ample preparation intervals. Upon completing the study it was to our initial surprise we noted large switch costs for the undergraduate participants, while switch costs for the patients remained minimal.

Logically we could not conclude that the patient group results were demonstrative of brilliance in switching ability, whilst the younger participants were comparatively poor. Upon closer inspection we began to see indicators arising within the *mixing costs*; the increase in RT found between repeat trials within a mixed-task block, compared to repeat trials in the single-task blocks. Where mixing costs were relatively small for the younger participants, they were substantially larger for the patient group. Although this is an interesting point, it does not articulate the importance within.

The core argument behind the measurement of mixing costs, *in addition to switch costs*, is that to accurately measure switch costs between manipulations requires that a defined baseline be given from which they are measured. In this respect, the mixed-block repeat trials are often used as the baseline, but as outlined this measurement is susceptible to movement depending upon the manipulations being tested. The mixed-block repeat trials are effectively experimental trials, they are not the root of the measurement, but indeed an index in their own right. They do not provide a stable foundation from where measurements ascertaining the effect of the switch cost can be drawn; a point raised by Wylie and Allport (2000, page 221-222).

Hence the effect that was being exhibited by the patients with regard to switch cost was not demonstrative of a superb *switching* ability, but instead of a *minimal repetition benefit* resulting in highly similar responses for both the repeat and switch trials. The younger participants had substantially smaller mixing costs, hence they were achieving great repetition benefits, which therefore appeared as larger switch costs. In this respect the results demonstrate that the younger participants were capable of maintaining the correct task sequence; hence they were aware that realignment for a forthcoming trial was not always required – the trial would be a repeat. As a result they received strong repetition benefits in the form of fast RTs to these trials. On the switch trials there remains a relatively large cost as a result of the cognitive demands of switching task sets; this will remain regardless of the adequacy of the task-maintenance being achieved. In comparison, the patient population were not capable of maintaining the task-sequence; therefore they were realigning themselves upon completion of every trial, unaware of whether the following trial would be a repeat or a switch. As a result every trial was treated as a switch, with only minimal benefit if it happened to be a repeat. For this reason mixing costs were great, and switch costs minimal as both forms of trials were treated in the same

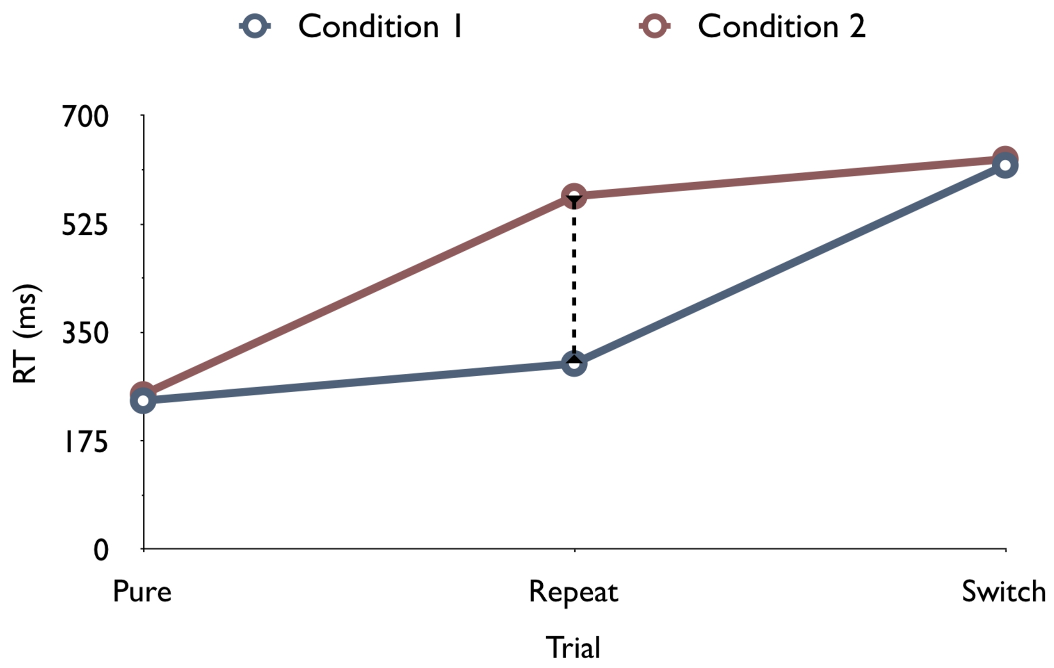

Figure 1. : A hypothetical example of two distinct manipulations of task-performance. Although both conditions have comparable pure trial and switch trial RTs, the mixed-block repeat trials differ dramatically. As a result the mixing costs provide entirely different baselines for the switch cost calculations. In this example Condition 1 has mixing costs of 60ms and switch costs of 320ms, whilst Condition 2 has the same values, but reversed. If we were to base our beliefs solely upon the value of the switch costs we may presume that Condition 2 has stronger switching capabilities than Condition 1. Yet, by taking into account mixing costs, we can instead note that Condition 2 has poor sequence maintenance abilities, and hence are likely to be switching on each trial, resulting in minimal switch costs. Although only a hypothetical example, this illustrates the importance of measuring mixing costs, since the baseline from which switch costs are measured is susceptible to large movements that can result in changes to this value.

manner, ensuring results for both formats were highly similar (see Figure 1).

That is not to say that the mixing cost is without issue. Clearly there are still likely to be differences between conditions and groups of participants. Yet by measuring mixing costs, the baseline is now conducted in a format of minimal interference, where only one task is required to be attended to. Hence there is little contamination and we are more able to measure the intended effects upon cognitive control. By analysing both measurements we are able to gain a much greater insight into how manipulations impact these two different indexes of cognitive control.

Methodological considerations

How to measure mixing cost

Traditional task-switching studies compared performance between blocks of single-task repetition trials (pure blocks) and a mixed block consisting of only switch trials, a list paradigm (Allport et al., 1994; Bertelson, 1961; Jersild, 1927; Shaffer, 1965; Spector & Biederman, 1976): the switch cost. In order to calculate mixing cost it is a requirement that the mixed block consists of switch trials *and* repeat trials (De Jong, 2000; Mayr & Keele, 2000; Mayr & Kliegl, 2000; Mayr, 2001; Meiran, 1996, 2000; Meiran et al., 2000; Miyake et al., 2004; Monsell, 2003; R. D. Rogers & Monsell, 1995; Rubin & Meiran, 2005; Rubinstein et al., 2001; Shaffer, 1965; Tornay & Milán, 2001; Waszak et al., 2003; Wylie & Allport, 2000).

The measurement of mixing costs relies upon comparisons between the responses given towards the pure block trials and the mixed-block repeat trials. Although both trials are repeats, costs are obtained from the mixed-block and serve as an index of the extra cognitive demands required to maintain multiple tasks within working memory, despite only attending to one on any given trial. There are two crucial considerations to make when measuring mixing cost. Firstly, there *must* be pure-block trial runs for each task, without these there is no defined baseline – this provides the value upon which all proceeding measures are based. Secondly, regardless of the design implemented in the mixed-task block, there *must* be both repeat and switch trials, without the repeat trials mixing costs in their defined form cannot be measured.

The mixed block

The extent of the mixing cost impact can be affected depending upon the paradigm chosen. It should not come as a surprise that where an alternating-runs paradigm is used, mixing costs are usually smaller than if a random-cuing paradigm is used; an example of task expectancy impacts (Los, 1996). Although both paradigms contain repeat and switch trials, the alternating-runs design benefits from the predictability of the task sequence. If the participant is capable of maintaining the task sequence within working memory they can be expected to be aware of the upcoming task trial, and hence prepare adequately to facilitate a swift response. In the case of the random-cuing design the participant is unaware of the upcoming trial task, so they have no means of preparing for a correct response, hence the mixing cost being impacted (Dreisbach, Haider, & Kluwe, 2002; Meiran, Hommel, Bibi, & Lev, 2002; Ruthruff, Remington, & Johnston, 2001).

Using this paradigm the preparation process could be described as being analogous to playing tennis; after playing a shot the player generally returns to the centre of the baseline, uncertain of the direction of the return. By returning to the centre they are in the best location for if the ball is returned in the opposite direction, similar to preparing for a switch trial. However by doing so they deny themselves the benefit of holding their position for if the ball is returned in the same direction, similar to a large mixing cost response. Using the random cuing paradigm format it is usual to find larger mixing costs and smaller switch costs than in an alternating runs format; in essence every trial is treated as switch trial, although some repetition benefits do remain, perhaps as a result of a task-recency effect.

Another consideration to make when deciding to measure mixing and switch costs is the task complexity. Although an increase in task complexity will increase overall RT measures as a result of the increased cognitive demands, it may also impact the cost measures too. The pure-block measures are not susceptible to any issues other than the increased RTs, however the complexity will affect the mixed-block to a greater extent. Comparatively the switch trials may be impacted to a lesser degree than the repeat trials within the mixed-block. Although this may seem counter-intuitive since both are subject to the same rigours, it is for exactly this reason that issues may arise. If the task complexity is extremely challenging then the majority of working memory processing will become dedicated to the task itself, rather than relaying any information regarding the task sequence. In this instance the participant will lose track of the task sequence and return to their central position after every trial. As a result the mixed-block repeat trials will become similar in their performance to that obtained with the switch trials, since they are essentially being treated as the same. In this sense it is likely that a form of hierarchical task processing will occur where maintenance of the task requirements may take precedent over any sequence maintenance considerations.

The pure block

Although the mixed block has many issues that must be deliberated, researchers cannot be passive about the pure block either. In some respects the decisions involved in the pure block requirements are even greater than those in the mixed block. It is important to consider the disparity in the number of trials between the pure blocks and the mixed block, and how this will impact the analyses that can be performed.

Take for example a standard paradigm with which traditional analyses will take place. For example, in each of the pure blocks there may be 40 trials, and in the mixed block there may be 160 trials; this would equate to 80 pure block repeat trials, and 80 mixed block repeat trials (A. J. Kirkham, Breeze, & Marí-Beffa, 2012). With this decision comes the benefit that there are an equal number of repeat trials in the mixed block from each of the pure blocks. However, with each of the pure blocks not being subject to the additional cognitive demands of multiple task maintenance (as during the mixed block) then this comparison may not be entirely well balanced. Each pure block is independent from the other insofar as that each is treated as such, effectively segregated and not causing interference towards each other. Therefore the argument can be drawn that two separate 40 trial blocks do not equate, and hence cannot be compared to the demands of 80 repeat trials in the mixed block. To alleviate this concern, other options include the possibility of increasing the number of pure block trials to 80 for each task, for example. Although using this method results in twice as many pure block repeat trials per task as those same task repetitions within the mixed block. However it does result in a clearer matching of repeat trial RTs than when using 40 trials, if only for the equal trial frequencies, albeit now unequal to the number of repetitions of each single task within the mixed block. Finally, in other instances it could be considered suitable to equal the number of pure block trials for each task so as it matches the total number of trials within the mixed block (both repeats and switches). This is however only recommended when specific forms of analysis are required – with such a large number of pure block repeat trials, fatigue can become a factor that will ultimately impact performance.

These points, and decisions based on these, are subjective and should be adopted according to the analyses that will be conducted. For purposes of a standard task-switching study comprising of analyses of mixing and switch costs, the initial design may be favoured. Although the mixed block contains twice as many repeat trials as each *individual* pure block, and hence a large disparity, benefits will be gained in terms of fatigue minimisation. Furthermore, during the pure block trials the participant is focusing solely upon the one task, thus performance is likely to be optimised, peaking with relative speed. Considering the majority of research analysis in this sector involves the calculation of mean RT measures, if this peak is reached readily the measure is unlikely to change dramatically regardless of the number of trials, unless fatigue becomes a factor.

Hence matching on this basis may be the most logical approach, although the trial frequency discrepancy does remain.

Yet at the other end of the scale, as briefly alluded to, if a researcher was to match the pure block trial frequency in each task to the frequency of overall trials in the mixed block, fatigue may become an issue. While this may not cause a problem with some participants, it could result in degraded performance measures, impacting costs obtained. Although this may read as an unsuitable approach given the gross change in the trial frequencies, there remain situations where this could be thought of as being suitable.

If a researcher is investigating fatigue in terms of task sequence maintenance, i.e. mixing costs over an entire block of trials, being one such occurrence. If the number of pure block trials remained at 40, as in the first instance, each pure block is individual, and as such can only be treated in this manner. The only correct way in which to assess these pure blocks is to either calculate a RT value based on either (a) a joint cross-calculation across both pure block tasks (resulting in a total of 40 mean pure block trial RTs), or (b) individual RTs for each task in the pure blocks (40 pure block RTs for each task, equating to 80 trial RTs). Regardless of the option chosen, the same problematic situation is encountered; that of correct 1:1 trial matching to the mixed block repeats. For theoretical purposes consider that option (a) has been chosen, this gives 40 mean RTs for the pure blocks (combined), which we now match against the mixed block repeat trials. However, because of the discrepancy in trial numbers as compared to the mixed block, and the format of the alternating runs paradigm, we can only compare across the first 40 repeat trials. If calculating in terms of fatigue it is important to match the number of individual trials in each comparison; a 1:1 structure. Hence the 40 pure repeat trials match to the first 40 trials in the mixed block, only 20 of which are repeats; thus we get an even greater discrepancy. Using Option (b) results in only a minimal advantage, since although the number of repeat trials are identical, in terms of fatigue due to total trials numbers, it remains incomparable (80 pure block trials remains inconsistent to the 160 mixed block trials).

The solution is to use the option of equal frequency pure block trials for each task, to the frequency of trials in the mixed block (both repeat and switches). Although this results in a huge discrepancy in terms of the number of pure repeat trials performed, compared to the mixed block repeats, it is the only way to secure a cross-comparison that is accurate and fully aligned. By performing this number of trials ensures that it is possible to match pure block fatigue with mixed block fatigue. Although this results in four times as many pure block trials as comparable mixed block repeat trials, it nevertheless ensures that consistent fatigue analyses can be conducted.

None of these methods are ideally suited to a general outcome of cognitive control investigation, since each have benefits and costs. Yet the crucial factor is to ensure that the most applicable selection is chosen according to the criteria of the investigation being performed.

The relation between mixing and switch costs

From the justification for the measurement of mixing costs, as detailed earlier, it is evident that the two measures are highly interconnected and reliant upon each other, and yet relatively little interest is paid towards the mixing cost. Indeed, in A. J. Kirkham, Breeze, & Marí-Beffa (2012) we make reference to the issue of the interconnected nature of the two cost measures, and raise two distinct theories of dependence which will be outlined here; statistical and processing dependency.

Statistical dependency

When using a combination of the list and alternating runs paradigms there are two pure blocks of trial tasks and one mixed block which combines the two. Given that during the pure blocks of trials there is little to no interference from the alternative (and irrelevant) task, the responses to these trials are likely to be fast, and accurate. In these instances the responses obtained are likely to strike a floor level RT, where participants will not respond any faster; they are focused on the task, and can provide all required attention, hence obtaining fast responses. In the same train of thought, during the mixed block, responses to the switch trials are likely to be the slowest of all trial forms. There is major interference from the alternative task, given that it has just repeated, and this is likely to impede performance towards the new task. Further, there are the standard requirements of switching between tasks to compete with; switch trials tend to be slower than repeats even when large cue stimulus intervals are present — there remains a residual switching cost.

For these reasons the switch trials are most vulnerable to ceiling reaction times; participants will tend to not perform any slower than during these trials. In some instances it is possible to have multiple experimental conditions where pure block RTs and mixed block switch RTs do not differ significantly in terms of condition, and yet have significantly different switch costs. This highlights the importance of the mixed block repeat trials, and subsequent RTs, since this is where the greatest variation associated to the experimental conditions is found (see Figure 1). In this instance the most appropriate way of analysing the data is through the mixing cost, since the mixed block repeat trials are the experimental level for this cost, not the switch cost.

Processing dependency

This form of dependency is where the justification for the measurement of mixing costs has its strongest founding. If statistical dependency is not a necessary consideration (as in the instance of having no ceiling effect on the switch trials, for example), a similar dependency in the cognitive processes that underlie both mixing and switching costs can still be observed. This can be illustrated by taking the simplistic approach of considering that a low mixing cost reflects the ability of advancing a repeat trial when switches are likely (i.e., by maintaining task sequence), while the switch cost (in the alternating runs paradigm only) reflects the time taken to activate the new rule. The usual interpretation of the switch cost is that differences in this effect reflect differences in the ability to switch, as opposed to differences in the ability to repeat; hence the repeat condition acts as a control. A serious problem here is that this control condition moves according to the demands of the study and conditions, and this must be addressed before any conclusion can be drawn from the switch cost. Indeed, the mixed repeat condition is not a control, but the experimental condition for the mixing cost.

A more intuitive way of seeing this dependency is as follows: If the ability to maintain a sequence is disrupted (increasing the mixing costs), then the participant needs to activate a new rule on every trial. If they are incapable of maintaining the sequence and task order, they are more likely to perform a switch on each trial, regardless of if the upcoming trial is a repeat, since they are unable to recall that this is the case. In this context, repeat and switch trials are highly similar, resulting in a minimal switch cost. The absolute lack of a switch cost linked to an abnormally high level of mixing cost was found in our lab when testing Parkinson's disease patients, as was described earlier, and highlights the importance of assessing both measures separately, else it is possible to draw incorrect conclusions.

Impacting the mixing costs

Although mixing costs are the core component of the present body of work, they are not the sole aspect in that they provide much information, but are susceptible to change according to the task being performed. For example, as has been stated, mixing costs provide indications as to the capability of the participant to maintain task sequence structures, and hence be knowledgable about upcoming repetitions of tasks; leading to reductions in mixing costs. However a further core factor in this body of work is how the mixing costs can be impacted, be this through a facilitation of performance (a relatively novel tactic), or through degradation of performance (more commonly found).

Since *degradation* of performance is more commonly tested in past research than facilitation it is logical to begin here.

Increasing the mixing cost

The core focus of the present research relates to the use of auditory factors in task performance, and degradation through such means has been widely investigated, although often not with regard to mixing costs specifically. It has long been known that overall task performance can be negatively impacted by some aspects of auditory factors, or verbal utterances. For example through the use of articulatory suppression.

Articulatory Suppression

Although there are many forms of articulatory suppression, the core methodology behind each remains identical: the repetition of irrelevant words whilst performing a task. For example, task-irrelevant words such as 'Monday, Tuesday, Wednesday...' (Baddeley, Chincotta, & Adlam, 2001), non-word repetitions 'blah blah blah' (R. Brown & Marsden, 1991), or number sequences (Baddeley, Lewis, & Vallar, 1984). Whilst the debate as to precisely how these repetitions impact upon performance can be disputed (in terms of task maintenance/recollection), the core reasoning as to the basis for these points is relatively stable. During the performance of a task it is likely the case that the phonological loop provides an internal framework for the sustaining and maintenance of task requirements or performance needs. However when articulatory suppression is being concurrently performed, the phonological loop in part, if not wholly, is 'filled' with both the irrelevant information, but also the requirements to generate these verbalisations. Where it would be ordinarily possible to keep track of your task strategy using internal formats, this is not possible. It does not however remove all capabilities to perform the task, instead it slows progress whilst performance continues. In this sense articulatory suppression can be seen as being a strong factor within a mixing cost context, increasing these costs whilst switch costs remain unaffected (Saeki & Saito, 2009). Indeed, since articulatory suppression is a form of verbalisation, this does not come as a surprise finding; with verbalisations being theorised as providing a significant role in the sustaining of tasks, rather than facilitating switches to alternative tasks (Bryck & Mayr, 2005; Rubinstein et al., 2001). The important factor to remember when using articulatory suppression is that although it results in degraded performance, task completion is still possible, it does not render it impossible. This should not be surprising given that it is possible to complete tasks in everyday life whilst holding conversations that are not connected to the task being performed, the experimental circumstances involved do not make any difference to this factor.

The finding that switch costs are not impacted whereas mixing costs are, is an interesting finding, and one that is further demonstrated later within this volume of work, but also helps to demonstrate the involvement of the phonological loop within performances of tasks. Clearly the phonological loop is only one component involved in working memory processing, and it would be naïve to believe that each component is entirely responsible for one factor of the processing involved in task performance. Yet it is likely the case that each may be more aligned towards specific tasks than others. It is inevitable that all components work together towards a common aim, each facilitating others' to complete the tasks with greatest efficiency. With one component unstable, as in the case of performing articulatory suppression, the other components are required to perform with greater intensity to provide the overall task completion outcome. Hence with the phonological loop being filled with irrelevant verbal information, task sequence maintenance is impeded and must be provided by the remaining components thus leading to differences in mixing cost, but with no substantial impact upon switch costs since the required components remain unaffected and able to perform their role.

Decreasing the mixing cost

Although it is common to find past research that has demonstrated increases in mixing cost through degradation of performance, there is comparatively little past research that shows facilitation of performance. However, with verbalisations being shown to impact mixing costs in particular, it is likely (and indeed this body of work continues to demonstrate) that relevant verbalisations can, in some circumstances, reduce mixing costs and enhance task sequence maintenance.

Task cues

Although much of the present body of work focuses on facilitation processes external to the task being performed, some aspects of the task itself can also provide strong influences to performance. In simplistic terms this is not surprising, as if one was to consider performing a task where a set of arbitrary cues indicate one task, and another set of similarly arbitrary cues indicate a secondary task, distinguishing between each would be very challenging, and performance would suffer accordingly. Yet research is rarely performed where unnecessarily complex barriers are placed to ensure task capability is heavily diminished, so although such a situation is uncommon the core point remains valid. In the same respect, by further examining the work of Jersild (1927) it can be noted how performance is substantially improved when participants were presented with a cue upon each trial indicating which task to perform, although the tasks themselves were simple. This basic addition, although not crucial to overall performance since adequate task-completion remains possible, provides something akin to a marginal task prompt – almost similar to a 'clarifying reminder'.

Yet although task cues can assist in prompting action, the formatting can be highly influential in the manner in which this occurs. For example, cues need not be directly related to the task in an explicit manner and could rely upon location based parameters to assist in performance. R. D. Rogers & Monsell (1995) used such a method by performing two number-based tasks of an alternating-runs design within a quadrangle, where the top portion indicated one task, and the lower portion the alternative task. Although the cues in this situation were endogenous in that they provided no direct information relating to the task, the binding that was promoted between location and task facilitated improved performance, compared to situations in which participants are required to maintain not only task-specific requirements but also the sequential demands that occur with such a design.

As will be referred to in a later chapter, endogenous cues can also be presented in a visual format. Compared to a text-based visual cue that directly states the parameters to be responded to, a visual cue can provide the necessary direction without an explicit format. Chapter 3 describes how cues can rely upon visual characteristics without necessarily evoking any form of direct verbal connection, unlike more explicit cue formats. In this sense they are more exogenous in their direction towards task-set selection than those that provide information in a location-based scenario, but do not benefit as strongly as location-based cues in terms of task sequence maintenance clarity. However, it is questionable which format provides the most influential assistance. Where location-based cues are used the task-set requirements must be maintained in working memory, while the sequential demands are assisted. With more task-directional cues the reverse situational outcomes can be expected since no information is provided to task-sequence demands whilst task-set requirements are more obvious.

Relevant verbalisations

With past demonstrations of verbalisations targeting mixing costs, it seems logical that *relevant* verbalisations may have the desired impact of providing additional informational input that could actively facilitate performance; in some respects having a *boosting* influence. With respect to the theories outlined previously with regard to articulatory suppression, the impact of stating task-relevant words is evident. By articulating commands directed towards the task that is being performed may act as a form of external task scheduler, or booster, proactively assisting us in directing movements, or maintaining information within short-term memory. For example whilst completing a puzzle such as a Su-Doku it is common to state (under one's breath) the number that you are currently working on – maintaining your current progress. It is unlikely that you would begin selecting numbers arbitrarily, but it is however likely that where the task is overly complex, forgetting of the currently in-search number could occur. A simple example, but one that demonstrates how relevant verbalisations assist in the maintenance of currently performed tasks. In the forthcoming chapter the theoretical basis of how verbalisations assist is expanded upon.

A standard measurement protocol - Silence

Research using task-switching paradigms commonly relies upon silent performance for all measures. Whilst many other manipulations are tested, little attention is paid to the verbal demands involved in performing task-switching studies. Although it may seem a moot point, such studies are often performed in silence, and whilst this is the traditional method it still retains some intrinsic issues that are not often addressed. The role of verbalisations within everyday life has already been addressed, yet not all verbalisations are articulated outwardly. In many situations we may rely upon inner-speech, that is our self-directed internal verbalisations, something analogous to an internal dialogue. We as researchers cannot define what our participants are internally verbalising whilst performing our studies. Whilst it often becomes apparent when speaking with participants after completing studies that they have used inner-speech to direct their performance, this cannot always be guaranteed, nor will we know if such a tactic is used consistently on every trial. We must take into account that there are moments in the performance of studies where participant attentions deviate, and it as this point that inner-speech is likely the predominant factor. Whilst we can encourage strong performance throughout the trials, we cannot determine if inner-speech has directed responses thoroughly. To this end, silent performance is something of an unknown factor, we can discuss it with participants but we are never certain if they are being truthful, nor if they are even aware themselves of their continued usage. For this reason outward articulations have been chosen as experimental manipulations, since in these situations it is clear to the researcher if correct performance is being conducted. Whilst silent performance features in many of the presented studies, these are compared to performances with other verbalisation formats; to detail differences and costs/benefits associated to these comparative formats.

Clarity of the measures

Within Chapter 5 (introduced in Chapter 4) a unique insight into the data acquired from task-switching studies is discussed. The primary measurements shown throughout this body of work use traditional and standardised formats, i.e. core measures of mixing and switch costs. Yet within this chapter a further measurement standard is demonstrated that permits a greater, and stronger insight into the obtained data. Rather than focusing upon the defined measures obtained from calculating global means according to different elements of the data, instead CDF analysis (Ratcliff, 1979) is used. This novel adaptation permits the *internal* measures of each of these indices of cognitive control to be shown. Using traditional methods the spread of responses, and hence costs, are collapsed into single measures thus losing much of the value of the raw data. Whilst these traditional methods are still valuable, the measures contained within may also permit a greater insight.

CDF analysis is formed by ranking responses (fastest to slowest) from entire blocks of trials and 'splitting' these into bins of a specified number. Within these bins the mean or median value can be calculated (both provide strong measures), and hence measures of cognitive control can be determined throughout more data points. Traditionally such analysis was time-consuming and not adapted by many researchers, but thanks to recent advances CDF analysis is more accessible and easily conducted using CDF-XL (Houghton & Grange, 2011). Whilst this may seem a potentially flawed process in that the values are ranked according to RT rather than over a natural time-framework, it instead provides insight in terms of task preparedness. It can be theorised that where the fastest RTs are obtained the participant is fully prepared to present a response to the provided trial – they are knowledgeable of the upcoming task and have prepared the correct task-set to give a fast and accurate response (De Jong, 2000; Grange & Houghton, 2011).

With RTs being thought of reflecting preparedness towards trials, this may have an impact upon the mixing and switch costs, and how these are indicative of cognitive control. It is not incomprehensible that the mixing and switch costs obtained may fluctuate throughout responses to the blocks of trials. This is much in line with the viewpoint of Broadbent (1958) who stated that where continuous attention is required towards a task, shifting towards and away from the task may occur frequently; resulting in both strong and weak measures of cognitive control. The benefit of conducting analyses in this manner means that this theory can be tested, and more importantly can be measured across different forms of task-performance conditions. As has been introduced, one of the primary areas of interest within this body of work is to determine how to facilitate task-performance, and reduce mixing costs. By performing CDF analysis will not only allow a stronger insight into the data as a whole, but crucially allow investigation into whether benefits are global and consistent, or instead if these improvements exist as a small (but extreme) proportion of trials.

The neurological impact of verbalisations

The theoretical framework concerning how verbalisations assist in the performance of tasks may appear to be simplistic. Yet, far from being a straightforward theory, the notion of heavily interconnected neural circuitry emanating from (and to) the prefrontal regions of the brain to regions responsible for action evocation, such as the basal ganglia are not new (Middleton & Strick, 2000b,a, 1994; Ullman, 2006), and could explain some of the findings. Although the neurological connectivity is highly relevant to many of the topics presented here, the core focus of such discussion relates predominantly to the processes encountered with Parkinson's disease patients. To demonstrate the neurological connectivity of the relevant language areas of the brain, to the regions predominantly responsible for motor outputs (although also taking into account working memory processing), participants with Parkinson's disease are often used, due to the specific symptoms and areas of affect. For this reason the topic is discussed in Appendix A with particular attention paid to parallel circuitry that may promote greater goal-directed task efficiency in these patients, but also explains the connectivity within persons whom do not have the symptoms.

Insights into task-based cortical activity

Although the core operations-based neurological impacts are predominantly focused upon Parkinson's disease research, this does not preclude investigation of base-level cortical activity. What cannot be ignored is the relative location of interest for research such as is being presented here. Cognitive control, and in this respect task-switching also, is thought to be predominantly focused within the prefrontal cortices (D'Esposito et al., 1995; Fuster, 1997). Yet because of the design of a task-switching study requiring the use of multiple task-sets, and importantly the participant engaging with these and selecting the correct option at the response stage, other areas of interest are also apparent.

Although located within a similar cortical region, the anterior cingulate cortex (ACC) may be a region of particular interest. It has been routinely considered that the ACC may play a role in the monitoring of conflict, and crucially provide top-down processing where a conflict situation arises (Barch et al., 2001; T. Braver, Barch, Gray, Molfese, & Snyder, 2000). Whilst it cannot be stated that the ACC is solely responsible for the resolution of any conflict, it has been theorised that it may work in conjunction with the dorsolateral prefrontal cortex at the task-set selection/response stage of trials (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Liston, Matalon, Hare, Davidson, & Casey, 2006).

For this reason an intriguing possibility is raised, if the use of relevant verbal strategies does provide facilitation towards task-goals, is this evidenced at the cortical level? More precisely, what is shown at this level with respect to different task-response strategies? It makes good sense to investigate these thoughts, and indeed this is conducted using ERP techniques in Chapter 6. Not only does this provide an interesting insight comparing response stage measures from previous chapters to measures obtained at the cue-processing level, but it also permits a closer examination of the *potential* base-level impacts of this processing. This is discussed with respect to both cognitive control viewpoints such as conflict resolution, but also in terms of cue-encoding and potential differences between the methods applied with regard to the format used.

Motivation, rationale, and aims

Whilst the topic of task-switching could be considered one of pure low-level cognitive control, the thesis presented here has roots in neuropsychological research. Although the point has been suggested, the core motivation and rationale for the work has not yet been clearly defined. Despite the focus being very much aligned towards cognitive control, the impetus for this present volume originated from a single discussion with a Parkinson's disease (PD) patient who stated anecdotally how she used verbal commands to initiate actions. As with many patients with the condition, action initiation is often problematic; this particular person however realised that by commanding herself to action, the initiation issues were eased somewhat. The example given was struggling to stand up and walk to the door; but by stating simple verbal utterances such as "I will stand up and walk to the door", this somehow assisted in this action performance. Whilst this is not connected to task-switching per se, the use of verbal commands nevertheless prompted considerations as to how and why this could assist. A greater investigation into the potential neurological underpinnings is detailed in Appendix A.

When task-switching research (combined with verbal cues, as a result of this conversation) was conducted, it was noted that PD patients produced dramatically different results to control participants, as was declared earlier. Whilst this is interesting in multiple respects, it nevertheless served to highlight how important verbal commands could be in daily life to everyone, not only patients. Much research is conducted into task-switching, but it predominantly focuses upon how to inhibit performance, to make it more challenging for participants. Clearly verbal commands were providing some assistance, particularly with respect to task sequence maintenance and hence resulting in reductions in mixing costs. As the name suggests, task-switching research is mainly focused upon the *switching* element [and hence switch costs] with very little attention paid to other aspects of cognitive control, i.e. task/sequence maintenance and mixing costs. Whilst it is not the objective or aim of the present work to discredit previous research, it is hoped that more than a cursory consideration be made of the mixing costs, in conjunction with and not disregarding the switch costs in future works. It seems logical given the arguments and theories presented within this work that both mixing costs and switch costs are heavily interconnected, and indeed that switch costs are founded upon the mixing costs themselves. For this reason an investigation of mixing costs should be performed alongside that of switch costs where such situations and paradigm designs allow, to enable a more thorough and conclusive outcome to be determined.

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Final thoughts

Within this chapter many of the topics that will be covered in the forthcoming chapters have been outlined. In some respects detail is brief – this is to avoid excessive repetition in later chapters, but should convey the focus of the forthcoming studies. Broadly, many of the topics discussed here have been considered in the design of the following studies, and selections of methodologies and manipulations thereof adjusted according to the requirements of the research aim and analyses.

Taking a step back from the specific issues discussed to instead focus upon task performance with relevant and irrelevant verbalisations, here follows the first of the presented studies. In this following chapter the topic of task-switching and verbalisations is reintroduced with a narrower and more succinct focus, drawing upon the most important aspects of the research inputs and impacts. Although some of the detail presented mirrors that which has already been discussed, it nevertheless provides a more defined and focused viewpoint that is specific to the experiments detailed, of which provide the grounding for all subsequent research presented within this volume.

CHAPTER 2

TASK PERFORMANCE FACILITATIONS: VERBAL INSTRUCTIONS.[2]

[2]Published in Acta Psychologica: Volume 139, January 2012 under the title of: The impact of verbal instructions on goal-directed behaviour – Alexander James Kirkham, Julian Michael Breeze, & Paloma Marí-Beffa.

Abstract

It is common to use verbal instructions when performing complex tasks. To evaluate how such instructions contribute to cognitive control, mixing costs (as a measure of sustained concentration on task) were evaluated in two task-switching experiments combining the list and alternating runs paradigms. Participants responded to bivalent stimuli according to a characteristic explicitly defined by a visually presented instructional cue. The processing of the cue was conducted under four conditions across the two experiments: Silent Reading, Reading Aloud, Articulatory Suppression, and dual mode (visual and audio) presentation. The type of cue processing produced a substantial impact on the mixing costs, where its magnitude was greatest with articulatory suppression and minimal with reading aloud and dual mode presentations. Interestingly, silently reading the cue only provided medium levels of mixing cost. The experiments demonstrate that relevant verbal instructions boost sustained concentration on task goals when maintaining multiple tasks.

Introduction

When working towards a task of some complexity it is not uncommon to verbalise our intentions, in a form of self-direction, or self-instruction (Vygotski, 1962). Consider assembling a piece of furniture; in addition to following the prescribed instructions, we may often find ourselves stating aloud the process of assembly "attach piece A to piece B with bolt C", for example. Why these vocalisations are used, or if they provide any benefit, is uncertain; particularly when it is a commonly held belief that best performance in a task is found when it is fulfilled in silence, to give the task our full attention. Therefore, the issue remains of whether vocalising instructions permits a greater level of cognitive control.

The theory of a central executive for working memory has been widely used to explain behaviour in this context (Baddeley, 1986; Baddeley & Hitch, 1974). One of its components, the sub-vocal rehearsal loop, provides assistance in sustaining verbal information in working memory to be used in subsequent actions (Baddeley & Wilson, 1985; Gathercole & Baddeley, 1993). To understand its functioning, consider having to memorise a phone number. To do so exclusively on its visual information can be very challenging and it is likely that one would perform outer or inner-speech recitals of the number to enhance the likelihood of committing it to memory (Levy, 1971). Not only does the sub-vocal rehearsal loop perform this task, but it also translates non-speech and non-auditory materials (such as on-screen text, for example) into an internalised verbal form; this can then be held in working memory for later use (Gathercole & Baddeley, 1993).

The degree to which inner-speech is used cannot, by the nature of it, be measured; it is internal. Discussions with participants have previously highlighted their use of it in silent tasks (Emerson & Miyake, 2003), but its potential role has also been investigated by implementing disruption tactics. If participants engage in inner-speech when completing a task in silence, then performing an irrelevant concurrent articulation would theoretically interfere with performance. In support of this, it has been found that when irrelevant secondary articulations are performed, task competency deteriorates. This strategy is known as Articulatory Suppression, and it has been applied in the form of repetitions of irrelevant syllables (Saeki & Saito, 2004), numbers (Baddeley et al., 1984), words (Baddeley et al., 2001; Bryck & Mayr, 2005), and letters (Emerson & Miyake, 2003).

When a participant is asked to perform irrelevant vocalisations during paradigms involving two or more tasks, their performance is badly affected, in the form of larger reaction times (RT) and/or an increase in the number of erroneous responses (Bryck & Mayr, 2005; replications of Baddeley et al., 2001; Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki, Saito, & Kawaguchi, 2006). However, as noted by Baddeley et al. (2001), when a single task is performed (e.g. addition of 5 to successive numbers on a list), articulatory suppression does not significantly impact performance. Such vocalisations mostly influence responses when having to maintain multiple response configurations and/or sequential response patterns (i.e. during task-switching paradigms) (Bryck & Mayr, 2005). Therefore, there is a general consensus that verbal strategies are used to aid performance whenever a high level of competition between tasks is expected. Their specific role may still depend on the nature of the actions, with verbal strategies being associated with planning, sequencing, action control, motor functions and imagery, and temporal processing (Ullman, 2006).

The role of verbal strategies in task-switching designs

Most studies evaluating the impact of vocalisations in task-switching performance have used the list design. Here participants repeat each task individually in separate pure blocks of trials (AAA… and BBB…), and a mixed block where a switch is required on each trial (ABAB…). Performance is clearly better in the pure blocks than in the mixed blocks (Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki et al., 2006). This deterioration in performance between the pure and mixed blocks, despite being based on identical task repetitions, reflects the additional memory load or computations needed when handling potential switches in the mixed block. The list design has produced an enlightening series of studies characterising how articulatory suppression can impede performance in the mixed block. For example, we now know that this form of switching cost is affected by articulatory suppression with endogenous cues (Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004), and with cues requiring greater levels of decoding (Miyake et al., 2004; Saeki & Saito, 2009). Interestingly, it is not influenced by variables commonly affecting trial-by trial performance, such as the interval between the cue and the target (Goschke, 2000; Saeki et al., 2006). Instead, its influence is greatest when manipulating variables that affect the entire block (or list), for example, when the switches are unpredictable as in the case of a random cuing paradigm (Miyake et al., 2004; Saeki & Saito, 2009).

Despite the list design providing a valid measure of executive control, it nevertheless comprises at least two different sources of costs, namely the mixing and the switch cost. One way to illustrate these two components is by including repeat trials in the mixed block. Although the original list paradigm traditionally avoids the inclusion of repetitions in the mixed block, this is central to other paradigms, for example the alternating runs design (R. D. Rogers &

Monsell, 1995), where both repeat and switch trials are combined within the mixed block (AABBAA…). With this new strategy, both repeat and switch trials are measured under the same context with similar requirements of monitoring and memory load (Spector & Biederman, 1976). This new measure of switch cost reflects transient adjustments between task configurations from trial to trial (R. D. Rogers & Monsell, 1995). With this type of strategy, results have failed to demonstrate any contribution of verbalisations to switch costs (alternating runs, Bryck & Mayr, 2005; random runs, Saeki & Saito, 2009). Therefore, any verbal contribution to cognitive control must be found upon processes that affect the list design exclusively.

Saeki & Saito (2009) applied a modified version of the list design, a random cuing paradigm, (also including a pure and a mixed block), but allowing task repetitions in the mixed block. With this procedure it is possible to dissociate processes involved in trial-by-trial transient adjustments (differences between repeat and switch trials within the mixed block, or switch cost), from more strategic control mechanisms affecting performance in the pure and mixed blocks separately. If we compare the repeat trials in the pure block with those in the mixed block, the latter are usually slower, in what has been termed the mixing cost (T. S. Braver, Reynolds, & Donaldson, 2003; Los, 1996). With this modified list design, Saeki & Saito (2009) confirmed that articulatory suppression increased the mixing costs, whilst leaving switch costs unaffected. These results further support the idea that verbalisations play a role in sustaining more than one active task in working memory (Bryck & Mayr, 2005; Saeki & Saito, 2009), as opposed to facilitating switches to a new task (Rubinstein et al., 2001). This illustrates the need to specifically measure mixing costs separated from switch costs when addressing this issue (Emerson & Miyake, 2003; Kray, Eber, & Karbach, 2008 and Marí-Beffa, Cooper, & Houghton, 2010. See, Monsell, 2003 and Vandierendonck, Liefooghe, & Verbruggen, 2010 for recent reviews on other task-switching paradigms).

The connection between mixing and switch costs

An additional reason for studying mixing costs separated from switch costs is that the pure estimation of the latter can become contaminated by variations in the size of the former. This issue, previously alluded to by others (Rubin & Meiran, 2005; Ruthruff et al., 2001; M. H. Sohn & Anderson, 2001) mostly refers to the processing dependency between these two indexes in which high levels of mixing cost can induce a reduction in switch costs without reflecting an improved switching performance.

Indeed, the usual interpretation of the switch cost is that any changes in this effect reflect differences in the ability to switch, not in the ability to repeat; hence the repeat trials act as a control. However, variations in the mixing cost may affect these repeat trials. Clearly, if we suspect variations in the levels of mixing cost, the mixed repeat trials cannot be considered as controls for switch, but experimental conditions for the mixing cost. For example, consider an extreme case of a participant that is incapable of maintaining the sequence and task order of trials during the mixed block. This lack of anticipation will make every trial unexpected and treated equally. In this context, it is possible that repeat and switch trials become highly similar, resulting in a minimum switch cost that cannot be interpreted as exceptionally good switching performance, but poor execution on repetition trials. For all these reasons, we will mainly focus on the influence of verbalisations upon variables affecting block performance, better measured by the mixing costs (see Marí-Beffa et al., 2010, for a similar approach).

Verbalisation as a booster of cognitive control

Most previous studies investigating verbalisations with goal-directed behaviours have done so by determining the detrimental impact of articulatory suppression on task performance. Clearly this approach demonstrates how task monitoring can be achieved without verbalisations, or by severely impeding them. Few studies have attempted to directly investigate how or why verbalisations can aid performance. The articulatory suppression strategy can provide a good model to study the role of non-verbal working memory systems in task control, since it removes any potential contamination of the articulatory loop (Ullman, 2006). However, it cannot be used to understand how verbalisations can directly assist performance. The only condition where these verbalisations are often indirectly inferred is silent reading. Declared as a control condition, the internal nature of such verbalisations makes it impossible to be assessed. Our position is that we need to involve verbalisations directly to understand how they assist in task monitoring and performance. In this sense, only a few studies have investigated the benefits of verbalising task-relevant words, finding evidence of facilitation in comparison to articulatory suppression (Goschke, 2000; Kray, Eber, & Lindenberger, 2004; Kray et al., 2008; Miyake et al., 2004). From these, only Kray et al. (2008, 2004) and Miyake et al. (2004) included a silent reading condition, which allows assessment of whether the pattern observed corresponds to costs from the articulatory suppression condition, or from benefits associated to relevant outward verbalisations. These issues will be central in our research.

The positive influence of verbalisations on task switching can be illustrated by the fact that, even with concurrent irrelevant verbalisations, participants are still very capable of performing the tasks. This is important when considering the use of relevant inner or outer speech; it is not imperative that we use it. When used, it is performed in what could be described as a ‘boosting’ capacity — providing an enhancement of our capabilities. As such, the use of the phonological loop, with either inner speech or relevant verbalisations, assists in providing a verbal representation, or verbal label, of the task to be performed (N. Z. Kirkham, Cruess, & Diamond, 2003; Kray et al., 2008; Müller, Zelazo, Hood, Leone, & Rohrer, 2004). However, as this use of the phonological loop is not mandatory, we have no guarantees that the participant necessarily uses it in the silent condition. Additionally, the frequency with which this strategy is used may depend on the task demands, becoming minimal when the cue is external and non-verbal (Emerson & Miyake, 2003; Miyake et al., 2004; Saeki & Saito, 2004, 2009), or when switches are predictable (Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki et al., 2006).

In the forthcoming studies we combine both the list and alternating runs designs to produce three trial formats: pure block repeats, mixed block repeats, and mixed block switches. The difference between pure and mixed block repeat trials (mixing cost) provides an index of the ease of sequencing and task order control, whilst the difference between the mixed block repeat and switch trials (switch cost) is used here to measure task rule implementation. To study the impact of verbalisations we used words as external cues, where three tasks are defined: Articulatory Suppression, Silent Reading, and Reading Aloud. The inclusion of Articulatory Suppression highlights the interference generated by irrelevant vocalisations on task control. The difference between Silent Reading and Reading Aloud allows evaluation of potential boosting benefits of external verbalisations.

Experiment 1

This experiment evaluates the detrimental effect of articulatory suppression on task switching capabilities. In addition, we measure the potential benefits of engaging in relevant articulations by reading aloud the instructional cue. These two conditions are compared against silent reading, serving as an intermediate control. In this study, all instructional cues are explicit and exogenous, in a highly predictive sequence of trials with long cue-target intervals. These conditions isolate the use of verbal-strategies, minimising the contamination of concurrent memory-based strategies that could be elicited when engaging in more demanding and/or endogenous task requirements. Note that in this experiment we use a conservative approach — we include conditions that traditionally have failed to demonstrate the benefit of verbalisations on performance. To promote the use of articulation strategies we use task-relevant words as explicit task cues. The use of these words removes the requirement of translation, as would be required with less transparent task cues, yet still capitalises upon the integration of the phonological loop to decode the words into an inner-speech form (Gathercole & Baddeley, 1993). This will ensure that participants use articulation strategies to their fullest extent, rather than having to labour processes directed towards decoding the task cue prior to initialising the correct task set.

Method

Participants

24 undergraduate students of Bangor University were remunerated with course credits for their participation. All participants were required to have normal, or corrected-to-normal vision, and speak English as their first language.

Stimuli and apparatus

The experiment was displayed on a 19in CRT monitor, and performed on a PC with a VGA card using E-Prime 1.1 (PST Software) computer software.

Participants sat 60cm from the display. The stimuli consisted of 2 shapes (square and circle) shaded in 2 possible colours (blue and red). The square was 2.6° high and 2.6° wide. The circle measured 2.6° in diameter. The colours of the stimuli were red (R:255, G:0, B:0) and blue (R:0, G:0, B:255). Each trial presentation consisted of a single stimulus being displayed in the centre of the screen on a white background. Prior to the stimulus display, a task cue was displayed in the centre of the screen. The task cue read 'BLUE/RED' (4.9° wide and 0.8° high), or 'SQUARE/CIRCLE' (7.3° wide and 0.8° high) in Courier New font. The response keys for the experiment were the letters C and N on a standard QWERTY keyboard.

Design and procedure

Each trial began with a task cue displayed in the centre of the screen for 1000 ms, followed by a 500 ms blank-screen interval. The stimulus was then displayed until response, followed by a 150 ms blank-screen interval, accompanied with a buzzer tone if an incorrect response was given. Three blocks of trials were performed: two pure repeat blocks of 40 trials each, one for colour and one for shape, and one mixed block of 160 trials in an alternating runs sequence. As a result, in the mixed block there were 80 repeat trials (40 colour and 40 shape), and 80 switch trials (also equally split). Mixing costs were calculated by computing the average response time of the repeat trials in the mixed block minus the average response time of the repeat trials in the pure blocks. Switch costs were calculated as the difference between the average response times of the switch and repeat trials in the mixed block.

Participants performed all trial blocks under three counterbalanced conditions: Silent Reading (of the task cue), Reading Aloud (of the task cue) and Articulatory Suppression. The experimenter was in the room during the experiment to ensure participants performed the task. In the Silent Reading condition participants performed the task in silence. During Reading Aloud, participants read aloud each task cue (when displayed) at a “standard conversational level”. During the Articulatory Suppression condition participants stated aloud the word “blah” at a rate of approximately 2 Hz (R. Brown & Marsden, 1991; Saeki & Saito, 2004), also at the specified volume. Standardised instructions were presented on screen. Participants were instructed that they were to respond to stimuli according to a task-cue that would be presented. The task-cue would state Blue/Red or Square/Circle. In the event of Blue/Red appearing on-screen participants should respond to the forthcoming stimuli, pressing C if it was blue and N if it was red. Alternatively, if Square/Circle appeared on-screen, they should respond by pressing C if it was a square and N if it was a circle. They were informed that they should ignore the irrelevant property and only respond to the task-cue prompted characteristic. Participants were also asked to respond as quickly as possible, but to ensure good accuracy.

Participants were made aware that initially there would be two pure blocks of trials where the secondary property would not be required. After the two pure blocks, participants were informed that both task sets “would now be mixed together”, and that they “will be performing the paradigm in an AABBAA format, for example Colour-Colour-Shape-Shape-Colour-Colour and this will require you them to remember both rules throughout the block”.

Participants were tested individually and completed all conditions in a single session, taking approximately 45 min.

Results

All incorrect responses and those immediately following (n + 1) were removed — any incorrect response would affect the alternating runs sequence. Any responses that were greater than 3 SD above the mean of each individual participant were also removed prior to reaction time data analysis (additional 1.6% removed). The following percentages of trials were removed in total: Reading Aloud - 11.7%; Silent - 8.7%; Articulatory Suppression - 16.1%.

Reaction times

Averages of trimmed RTs per participant were analysed through a three-way repeated measures ANOVA for the variables, Task (Reading Aloud, Silent Reading, Articulatory Suppression), and Trials (Pure Repeat, Mixed Repeat, Mixed Switch). Analyses using an additional basis of congruency (to account for the bivalent stimuli) were performed but did not highlight any significant interaction with Task $F < 1$. Therefore these measures were collapsed and not included within the final analysis.

Overall differences across Task were demonstrated [$F(2,46) = 18.37$, $p < 0.001$, $\eta_p^2 = 0.44$]. Reading Aloud was significantly faster than both Silent Reading by 63 ms [$t(23) = 3.85$, $p = 0.001$], and Articulatory Suppression by 132 ms [$t(23) = 5.19$, $p < 0.001$]. Silent Reading was also significantly faster than Articulatory Suppression by 68 ms [$t(23) = 3.04$, $p = 0.006$]. There were also substantial differences across the Trials [$F(2,46) = 48.24$, $p < 0.001$, $\eta_p^2 = 0.68$], reflecting 55 ms of mixing cost [$t(23) = 4.66$, $p < 0.001$], and 65 ms of switch cost [$t(23) = 8.14$, $p < 0.001$].

A significant interaction was found across both Task and Trials, demonstrating that the RT of Trials was influenced by the Task [$F(4,92) = 3.31$, $p = 0.014$, $\eta_p^2 = 0.13$]. Therefore, further analyses were conducted on the mixing and switch costs separately.

The size of the mixing cost changed dependent on the Task [$F(2,46) = 3.56$, $p =$

Condition	Pure repeat	Mixed repeat	Mixed switch	Mix cost	Switch cost
Silent	454	514	592	60**	78**
	[17.34]	[23.34]	[31.33]		
	96.8	*96.4*	*93.9*	*0.4*	*2.5*
Art. Supp	518	594	653	76**	59**
	[25.31]	[33.42]	[38.63]		
	94.3	*92.3*	*88.2*	*2.0*	*4.1*
Reading Aloud	417	447	506	30*	59**
	[13.16]	[16.99]	[19.97]		
	95.2	*95.2*	*92.6*	*0*	*1.1*

Table 2:: Experiment 1: RT (ms), [standard error] / * < 0.01, ** < 0.001. Italics = % of accurate responses (also includes accuracy costs in applicable columns).

0.036, $\eta_p^2 = 0.13$]. Analyses stated that Reading Aloud produced significant benefits in mixing costs compared to Articulatory Suppression [F(1,23) = 5.68, p = 0.026, $\eta_p^2 = 0.19$], and to Silent Reading [F(1,23) = 5.19, p = 0.032, $\eta_p^2 = 0.18$]. There was no difference between Silent Reading and Articulatory Suppression [F < 1].

The size of the switch cost did not change significantly depending upon the Task [F(2,46) = 1.64, p = 0.20, $\eta_p^2 = 0.067$].

Accuracy

Analyses of overall accuracy indicated significant differences across Task [F(2.46) = 18.50, p < 0.001, $\eta_p^2 = 0.45$]. Silent Reading produced 95.7% accurate responses, 1.4% greater than Reading Aloud [t(23) = 2.50, p = 0.020], and 4.1% greater than Articulatory Suppression [t(23) = 5.66, p < 0.001]. Reading Aloud produced 2.7% more accurate responses than Articulatory Suppression [t(23) =

3.55, $p = 0.002$].

Significant differences were obtained across accuracy for Trial also [$F(2,46) = 27.64$, $p < 0.001$, $\eta_p^2 = 0.54$]. Pure block repeat trials averaged an accuracy of 95.4%, whilst mixed block repeat trials averaged 94.6%. The mixing cost of < 1% was not significant. Mixed block switch trials obtained an accuracy of 91.6%, resulting in a switch cost of 3% [$t(23) = 5.74$, $p < 0.001$].

The interaction between Task and Trial did not reach significance [$F(4,92) = 2.46$, $p > 0.05$, $\eta_p^2 = 0.097$].

Discussion

This experiment was designed to evaluate whether relevant verbalisations could aid performance in goal-directed behaviours. It was assumed that the silent condition, normally used to evaluate the contribution of sub-vocal rehearsal strategies, might not be stringent enough to guarantee the use of this form of (inner) verbalisation. Whether, or how often, participants use inner speech in this manner cannot be quantified; it is also uncertain whether this strategy varies across individuals, or across trials. To compensate for this, participants read aloud the instructional cue displayed on-screen. The application of this overt verbalisation resulted in significantly faster overall responses, and crucially a significantly reduced mixing cost, and hence interaction, against all other conditions, including Silent Reading. From these present results it could be considered that the application of overt relevant verbalisations provides assistance and facilitation to the sequential task-order demands of the paradigm that simply cannot be supplied under either Silent Reading or Articulatory Suppression. In this respect it is likely that processing dependency is a crucial factor, allowing this facilitation of performance. As a result, participants are aware of whether the upcoming trial is a repeat, thus ensuring speeded responses and a significantly smaller mixing cost.

Experiment 2

Results from Experiment 1 showed that Articulatory Suppression resulted in significantly larger RTs than either of the other tasks. Additionally, the nature of the study is to investigate potential facilitation of goal-directed behaviours — the performance of Articulatory Suppression, although enlightening, is not used to investigate such traits.

With Reading Aloud producing significant RT benefits in comparison to Silent Reading, despite sharing similar processes prior to the evocation of verbalisations, theories as to why this may occur must be investigated. Although participant hearing levels were not measured, there is little doubt that when we verbalise we hear ourselves speak. Therefore it may be possible that any benefits obtained from reading aloud may result from a form of dual-encoding – input from both visual and auditory factors – rather than from the verbalisation itself. In this current experiment we implement a task where an auditory cue was presented using headphones. This condition replaced Articulatory Suppression as no further information could be gained from its inclusion.

Method

Participants

In this experiment, a new group of 28 undergraduate students of Bangor University were recruited and remunerated with course credits.

Stimuli and apparatus

All stimuli and materials were identical to those in Experiment 1. In addition, auditory elements were generated using the Apple Macintosh VoiceOver program to create vocalisations of the task cues ("Blue Red" and "Square Circle"). These were recorded and normalised to -1 dB. During testing, all audio was presented at a comfortable level using headphones. The headphones were worn throughout all tasks and blocks of trials to provide consistency, and were also used to present the error tone.

Design and procedure

The task conditions were Silent, Silent with Auditory Input (Audio), and Reading Aloud. These were performed using the same procedure and design of Experiment 1. In the Audio condition, participants performed the task in silence, but the task cues presented on-screen were concurrently presented aurally through headphones.

Results

Using an identical procedure to Experiment 1, all incorrect responses and those immediately following (n + 1) were removed. Any responses that were greater than 3 SD above the mean of each individual participant were also removed prior to reaction time data analysis (additional 1.6%). The following percentages of trials were removed in total: Silent - 12.8%; Audio - 11.7%; Reading Aloud - 12.5%. Three participants were removed prior to analysis as investigations of boxplots indicated these participants as outliers.

Reaction times

Averages of trimmed RTs per participant were analysed through a three-way repeated measures ANOVA for the variables, Task (Silent Reading, Audio, Reading Aloud), and Trials (Pure Repeat, Mixed Repeat, Mixed Switch). As with Experiment 1, analyses using an additional basis of congruency were performed, but did not highlight any significant interaction with Task $F < 1$. Therefore these measures were collapsed and not included within the final analysis.

Overall differences between Tasks were found [$F(2,48) = 5.01$, $p = 0.011$, $\eta_p^2 = 0.17$]. Audio was significantly faster than Silent Reading by 21 ms [$t(24) = 3.15$, $p = 0.004$]. Reading Aloud was also significantly faster than Silent Reading by 19 ms [$t(24) = 2.32$, $p = 0.029$]. There was no significant difference between the Audio and Reading Aloud tasks [$t(24) = 0.29$, $p = 0.78$]. There were also substantial differences across the Trials [$F(2,48) = 61.12$, $p < 0.001$, $\eta_p^2 = 0.72$], reflecting 35 ms of mixing cost [$t(24) = 4.94$, $p < 0.001$], and 53 ms of switch cost [$t(24) = 8.94$, $p < 0.001$].

A significant interaction was found between Task and Trials, demonstrating that the RT of Trials was influenced by the Task [$F(4,96) = 3.36$, $p = 0.013$, $\eta_p^2 = 0.12$]. Further analyses were conducted to determine the mixing and switch costs.

The size of the mixing cost changed dependent on the Task [$F(2,48) = 4.50$, $p = 0.016$, $\eta_p^2 = 0.16$]. Analyses stated that Audio produced significant benefits in mixing costs compared to Silent Reading [$F(1,24) = 8.16$, $p = 0.009$, $\eta_p^2 = 0.25$]. Reading Aloud also produced significant benefits to Silent Reading [$F(1,24) = 4.31$, $p = 0.049$, $\eta_p^2 = 0.15$]. There was no influence on mixing cost between Audio and Reading Aloud [$F(1,24) = 0.25$, $p = 0.62$, $\eta_p^2 = 0.010$].

The size of the switch cost also changed significantly depending upon the Task [$F(2,48) = 7.45$, $p = 0.002$, $\eta_p^2 = 0.24$]. Both Audio and Reading Aloud showed significant impact on switch costs compared to Silent Reading [$F(1,24) = 13.86$,

Condition	Pure repeat	Mixed repeat	Mixed switch	Mix cost	Switch cost
Silent	411	463	497	52***	34***
	[11.36]	[16.32]	[16.58]		
	96.1	*95.4*	*92.6*	*0.7*	*2.8*
Audio	397	421	490	24*	69***
	[10.88]	[13.86]	[18.19]		
	95.8	*94.7*	*92.8*	*1.1*	*1.9*
Reading Aloud	401	429	484	28**	55***
	[12.37]	[15.73]	[18.75]		
	94.6	*95.8*	*91.6*	*+1.2*	*4.2*

Table 3:: Experiment 2: RT (ms), [standard error] / *< 0.02, ** < 0.01, *** < 0.001. Italics = % of accurate responses (also includes accuracy costs in applicable columns).

p = 0.001, $\eta_p^2 = 0.37$] and [F(1,24) = 5.16, p = 0.032, $\eta_p^2 = 0.18$] respectively. There was no influence on switch cost between Audio and Reading Aloud [F(1,24) = 2.63, p = 0.12, $\eta_p^2 = 0.099$].

We further explored the source of the interaction between switch cost and task by directly comparing task influences on each of the trial forms. Importantly, the type of task did not influence the switch trials [F(2,48) = 0.75, p = 0.48, $\eta_p^2 =$ 0.030] and instead, it produced maximum impact on the repeat trials [F(2,48) = 12.15, p < 0.001]. During these trials the silent condition produced significantly slower reaction times than both Reading Aloud [t(24) = 3.18, p = 0.004], and Audio [t(24) = 4.81, p < 0.001]. There were no differences between the Reading Aloud and Audio tasks in the repeat trials [t(24) = 1.10, p = 0.28].

Accuracy

Analyses of overall accuracy indicated no significant differences across Task

[F(2,48) = 0.84, p = 0.44, $\eta_p^2 = 0.034$]. Significant differences were obtained across accuracy for Trial forms [F(2,48) =16.64, p < 0.001, $\eta_p^2 = 0.41$]. Pure block repeat trials averaged an accuracy of 95.5%, whilst mixed block repeat trials averaged 95.3%. The mixing cost of < 1% was not significant [t(24) = 0.33, p = 0.74]. Mixed block switch trials obtained an accuracy of 92.3%, resulting in a switch cost of 3% [t(24) = 4.56, p < 0.001]. There was no significant interaction between Task and Trial [F(4,96) = 2.01, p = 0.099, $\eta_p^2 = 0.077$].

Discussion

Following on from the results of Experiment 1, it was unclear whether the results obtained for the Reading Aloud condition were a result of the articulation given by the participant, or as a result of the participant hearing themselves state aloud the task cue. A fresh condition was implemented, whereby audio task cues were presented in place of the participant reading them aloud. This new condition replaced the Articulatory Suppression condition of Experiment 1.

Interestingly, both Reading Aloud and Audio conditions demonstrated significant benefits (through reduced mixing costs) compared to Silent Reading. Furthermore, there were no significant interactions obtained between these two conditions.

Additionally, there were highly similar response times obtained for the pure repeat and switch trials across all three conditions. Yet despite these similarities, significant effects of mixing cost (and resultantly, switch costs) are obtained between the Silent Reading condition and both Reading Aloud and Audio conditions independently.

Of special note is the pattern of mixing costs/switch costs emerging from the audio condition where a small mixing cost (24 ms) corresponds with a significantly larger switch cost (69 ms). As mentioned earlier, it is the repeat trials in the mixed block that seem to be responsible for both effects. Indeed, the switch cost can be interpreted both as the difficulty to switch (task preparation) and ease of repetitions (repetition benefits), becoming two dissociable components (Allport et al., 1994; Ruthruff et al., 2001; M. H. Sohn & Anderson, 2001). It is likely that the audio condition specifically induced repetition benefits in the mixed block without influencing the switch trials to the same extent. M. H. Sohn & Anderson (2001) found that the preparation interval improved RTs selectively in the switch trials. Foreknowledge of whether the upcoming trial was a switch or a repeat resulted in marked benefits; mostly in the repeat trials (see Experiment 1, Fig. 3 in M. H. Sohn & Anderson 2001). The influence of foreknowledge on repeat mixed trials is in line with previous theoretical explanations for mixing costs. As described by Bryck & Mayr (2005), the mixing cost reflects the inability to keep the sequence of trials in sustained attention. Our data supports that auditory instructions aid the maintenance of trial sequences by providing foreknowledge of what is coming next and that its biggest influence is observed in the repeat mixed trials.

To sum up, reading aloud the task cue, or indeed hearing the task cue, appears to facilitate a prompt response to mixed repeat trials, indicating that task-order sequences are being maintained with the use of these processes.

General discussion

In these experiments the role of verbal and auditory representations of task cues on goal-directed behaviours was explored. An alternating runs paradigm (R. D. Rogers & Monsell, 1995), coupled with elements of the list paradigm (single-task repeat trials), was used for all experiments. In all variations and conditions, participants responded to either the colour or shape of bivalent stimuli in accordance with an instructional task cue.

Experiment 1 investigated whether relevant verbalisations could aid performance, in comparison to articulatory suppression. As expected, the slowest and most error prone responses were in the Articulatory Suppression condition (Baddeley et al., 2001; Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki et al., 2006). The fastest reaction time (RT) performance was produced when reading aloud the task cue. Despite substantial mixing cost effects in all three tasks, Reading Aloud produced a significantly smaller mixing cost than both Articulatory Suppression and crucially, Silent Reading.

Experiment 2 provided the inclusion of an Audio condition, designed to specifically assess whether the benefits obtained by reading aloud the task cue in Experiment 1 could be due to the auditory feedback of this process. As in Experiment 1, Reading Aloud produced faster overall responses than Silent Reading. This result was also obtained in the Audio condition — though there was no significant difference between Reading Aloud and Audio. Decisively, as in Experiment 1, mixing costs were present in all three tasks, but Silent Reading produced a significantly larger mixing cost compared to both Reading Aloud and Audio. There was no difference in the mixing costs obtained from the Reading Aloud and Audio tasks.

Mixing-cost findings

In the introduction, theoretical viewpoints were outlined that could explain a connection between the mixing cost and the switch cost, leading from processing and statistical dependencies. We believe that the experiments presented here justify the discussion and future research of this connection.

Although both experiments show clear signs of mixing cost effects, we believe that Experiment 2 shows the most interesting aspects of the current research. There is little disputing the similarities between both the methods employed (Silent, Reading Aloud, and Audio), and more specifically the results obtained. All are common, everyday protocols and all are focussed upon providing improved performance — completing a task in silence, with self-direction, or indeed with auditory directions being provided. Since all conditions are similar, and involve no irrelevant verbalisations (unlike Experiment 1), it is likely that this is why such similar results have been obtained for both the pure repeat and switch trials. Accordingly, it can be concluded that, within the confines of this experiment, both floor and ceiling reaction times (respectively) have been reached for each condition. In spite of this, there remains a significant effect of mixing cost between the conditions; an effect obtained because of the significantly slower mixed-repeat trial RTs of the Silent Reading condition. The slowing of these RTs in turn results in an effect upon the switch cost since this inflation has not occurred with the remaining conditions (e.g. Reading Aloud and Audio). In this sense statistical dependency is present; where mixed-repeat trial RTs are swift a large increase is required to reach the ceiling level of switch trials (e.g. a large switch cost), however where these RTs are slower, a smaller increase is required, resulting in a smaller switch cost. The speeded responses obtained for the mixed-repeat trials for both Reading Aloud and Audio ensures that a large switch cost is found. However, because the mixed-repeat trials of the Silent Reading condition were elevated in comparison, the switch cost for this condition is much smaller, resulting in this significant effect. This is clearly not a result of an improved ability to switch in the Silent Reading condition, but instead a result of the diminished ability to perform repeat trials.

For a switch cost interaction to be fully justified all RT responses towards the mixed-repeat trials should be comparable, providing a level base from which switch costs can be measured. Due to the significant interaction of mixing cost in this instance, this is not an acceptable basis from which to determine such measures. In this sense, these results could be attributed towards a processing dependency factor. Yet, performance during Silent Reading does not deteriorate to the point where mixed-repeat and switch trial RTs are comparable. However, there is still undoubtedly a slowing in responses, which can be attributed to a diminished ability to maintain task-order sequences as competently as with the other conditions.

It is important to highlight that in comparisons between Experiments 1 and 2, the Silent condition seems to change particularly in the switch costs, with no substantial difference in the mixing costs. This effect appears solely in the Silent condition, with Reading Aloud producing near identical costs in both experiments. Considering that all conditions are manipulated within subject, this makes us question whether the impact of articulatory suppression may have an influence on how the silent reading task is carried out. Although lacking the power needed for these analyses, our data indeed suggests that participants who performed the silent condition after articulatory suppression displayed larger switch costs than those that followed reading aloud. This leaves open the possibility that individual strategies may have a direct influence on the switch cost.

However, this is difficult to be assessed in the silent condition since there is no explicit strategy required of the participant (i.e. reading aloud or articulatory suppression). Reading aloud, on the contrary, exhibits stable costs across both experiments. These differences further support our belief that a silent condition is not a suitable control when studying the contribution of language on cognitive control. Instead, all conditions should utilise explicit linguistic actions that can be monitored. It should be stated that we do not believe there is a general language contribution, rather that each process exhibits its own peculiarities. For instance whether the cue is presented visually or through auditory means may provide a different influence upon response capabilities; this will need to be studied further. In any case, our results demonstrate that in order to understand any contribution of language, we need to make a decision about precisely which aspect of language to study. Neither articulatory suppression nor silent reading (the two tasks most commonly used in this form of study) serves this purpose.

The impact of verbal and auditory cues on mixing costs

Few previous studies have used an alternating runs design combined with a single task pure block (Kray et al., 2008). Yet without the mixed repeat trials (as also found with random cuing designs) it is not possible to measure mixing costs. The pure block provides measures of single-task performance, and of repeated and consistent practice with the same stimulus–response (SR) mappings. One task-set is used in each pure block, meaning there is little interference from competing task sets. When the same task is repeated within an alternating runs block, practice becomes inconsistent, due to interference and competition from other task sets.

Experiment 1 confirmed that articulatory suppression makes it harder to manage conflict between tasks in the mixed block. It is often stated that articulatory suppression has a negative impact on performance with regard to switch costs (Baddeley et al., 2001; Emerson & Miyake, 2003; Goschke, 2000; Saeki & Saito, 2004; Saeki et al., 2006). The measure of switch cost under debate here has been obtained from the list paradigm, where mixing costs and switch costs are confounded. The present study instead highlights that articulatory suppression exerts a very strong negative influence on the mixing cost, but not on the switch cost.

The articulatory suppression task only provides an indirect means to address the role of verbal representations on sustained goal-directed attention. Furthermore, the Silent task does not provide a compelling verbal condition to compare against articulatory suppression. As evidenced from our studies, mixing costs are reduced when task cues are read aloud compared to silent reading. Since these relevant articulations assist in the performance of a task, it is unclear why participants achieved the results they did during silent reading, as sub-vocal articulation was always an option. After the experiment, participants were asked if they had engaged in inner-speech during the Silent Reading condition; all participants responded unanimously that this was the case (see also Emerson & Miyake, 2003). It is possible that although this approach may have been used, it could have been inconsistent, as we have no direct means of confirming this.

As for the benefits obtained from reading aloud the task cue, we must not ignore that overt verbalisations require additional demands compared to silently reading them. Basic reading processes should be common in both conditions with the differences occurring mostly during the final stages, where the additional verbalisation takes place only for reading aloud. If anything, we expected the extra cognitive demands occurring during reading aloud to deteriorate performance. In spite of this, the participants responded faster than when they were silent.

Experiment 2 showed that the sound output from overt verbalisations, and thus input for auditory processing, might be responsible for the improved performance. In this study, comparable benefits (to those also found when reading aloud) were obtained through auditory presentation of the task cues. However we cannot be sure whether this auditory input and processing is exclusively responsible for the reduced mixing cost.

In principle, it could be that auditory input alone (obtained with both Reading

Aloud and Audio) provides this benefit. Alternatively, it could be that both auditory and articulatory processes aid performance in the mixed block in conjunction, or as separate processes that do not interact with each other. Undoubtedly, our results demonstrate that different verbal mechanisms can boost performance during the mixed block. These benefits add to those observed in silent reading and seem to specifically target the mixing costs.

The mechanisms concerning how this works are a question of debate. One possibility is that verbalisations help reduce the interference of the irrelevant property in the mixed block. During the pure block, the irrelevant dimension is never attended to; therefore very little interference would emerge from incompatible trials. In the mixed block, however, both dimensions are relevant as they are mapped onto the two participating tasks. This increased interference in the mixed block may contribute to the mixing cost (Rubin & Meiran, 2005), and the use of verbalisations may assist in the correct task-relevant decoding of the stimuli. A clear prediction from this account is that the type of task would have a strong impact on incongruent trials, but not on the congruent ones. On the contrary, we found that an identical pattern to the one reported here was observed for the congruent trials, where interference was minimal. Indeed, congruency did not interact with any of the cue tasks. This result further supports the idea that verbal representations do not act on processes affecting individual trials, influencing instead the entire block.

An interesting possibility is that verbalisations aid sustained concentration on tasks during the mixed block, reducing the impact of boredom, fatigue or distraction. Although our blocks were possibly not long enough to be sensitive to these influences (see, for example, two hour long testing sessions used in Linden, Frese, & Meijman, 2003, examining mental fatigue), we tested whether there was any difference between the first and second halves of the mixed blocks. We failed to observe any clear pattern to support this, although acknowledge that for this purpose longer blocks should be tested.

Finally, it is possible that verbal representations are critical in the maintenance of sequences of rules in working memory (Bryck & Mayr, 2005). This idea comes from paradigms that encourage endogenous control in conjunction with articulatory suppression, where participants need to remember the previous task in order to prepare for the next (Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004). From this theoretical perspective, verbal working memory helps to maintain task sequences, allowing swifter responses in the mixed block. With our experiments, using a highly predictive alternating runs design with ample intervals for preparation and unambiguous explicit cues, it could be argued that this reduces the working memory load as required for task sequence maintenance. However it does not remove it altogether. Often, where exogenous cues are used, they remain on-screen until a response is given (Bryck & Mayr, 2005; Miyake et al., 2004); this reduces the necessity for verbal working memory. As a result, articulatory suppression has little negative impact. By removing the task cues from the screen before the target appears makes the use of verbal working memory more likely, since this may facilitate the maintenance of the appropriate task response rule.

In addition, the word (task) cue may contribute to the activation of verbal articulatory code. There is already evidence that oral responses are activated to a greater extent than other forms of responses. For example, it has been demonstrated that Stroop interference is greater from words when responding orally, as opposed to pressing keys (e.g. Redding & Gerjets, 1977, see MacLeod, 1991, for a review). Our task cues benefit from the use of verbal strategies because, as words, they stimulate verbal articulatory processing. It is important to note that the use of these strategies can be seen as unnecessary, however, an additional boost of verbal or auditory processing of the task cue can clearly benefit performance.

Although very few previous studies have used such explicit and transparent cues, we believe that we have used this method to our advantage. Making the task as straightforward as possible enabled participants to engage from the very first trials, ensuring that they were not inadvertently fatigued, and that the results obtained were clear and pronounced. As previously detailed, it could be argued that explicit cues minimised the requirements for the preparation of task-set sequencing and reconfiguration. If indeed such cues negated the need for these preparatory processes our results would not have demonstrated the interactions between conditions that are present. The use of these cues primarily allows the preparation of reconfigurations to be more succinct and speeded, ensuring that the participants are capable of a more fluid sequencing process. Clearly this was not always the case; conditions with verbalisations permitted a greater level of cognitive control and task-order maintenance than those without.

In order to demonstrate that the results obtained are specifically related to the maintenance of sequential task rules (Bryck & Mayr, 2005), the use of an alternating runs design is imperative. Although other studies have made use of pure repeat trial blocks combined with paradigms requiring repeat trials in a mixed block (random cuing: Miyake et al., 2004), the alternating runs design is the only suitable paradigm for drawing conclusions of this nature. If the participant is oblivious to the format of the paradigm and upcoming trial (switch or repeat) then it is not possible to determine any such conclusions (e.g. as with the random cuing design). The maintenance of sequential task rules is only possible if a determinable sequence is used. Although we couple our explicit task cues with our predictable pattern of presentation, this only serves to reinforce the findings obtained. If our experimental conditions had produced no significant difference in mixing costs, particularly between the silently presented trials and those consisting of either verbal or auditory manipulations, then there would be no grounds for our conclusions. However, the case remains that despite the above acknowledgements of task simplicity, task-order maintenance appears to be facilitated by additional verbal instructions, as evidenced by the reduction in mixing cost.

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Whilst the results obtained in the present chapter indicated that performance in task-switching paradigms could be improved through task-sequence maintenance facilitation, it was uncertain whether this was due to the explicit cuing protocols used - i.e. a clear directional cue such as “blue / red”. In this sense the role of language as an interpreter was straightforward and uncomplicated since the cue presented both optional responses, with minimal translation required. To ascertain if this lack of translational requirement was a crucial factor in the facilitation of task performance, manipulations of the task were concluded to be essential. In the forthcoming chapter studies are presented that take into account cue translation, and hence the role of language as an interpreter of the optional responses based upon a given cue for each trial. A replication of experiment 2 from chapter 1 is presented here as experiment 1, with manipulations requiring greater translation and language involvement (experiment 2) and less intense translation with minimal language involvement (experiment 3).

CHAPTER 3

VERBAL AND NON-VERBAL TRANSLATION OF TASK-CUES.[3]

[3] To be submitted under the title of: Verbal and non-verbal instructions: The role of language as an interpreter. – Alexander James Kirkham, Julian Michael Breeze, & Paloma Marí-Beffa.

Abstract

In the previous chapter it was demonstrated that performance in complex tasks could be assisted, and indeed facilitated with the use of verbal instructions as translated from visual task cues. Mixing costs appear to gain the most benefit from these verbal translations, and are indicative of increased capabilities to maintain task sequences and associated task sets. Yet it is unclear whether the ease with which a provided cue can be translated into a language format impacts the overall effectiveness of this verbal statement.

To evaluate the role of language as an interpreter of task cues, three task-switching experiments measuring mixing and switch costs were conducted. Participants responded to bivalent stimuli according to the characteristics defined by a visually presented instructional cue. The processing of the cue was conducted under three conditions in all of the experiments: Silent Reading, Reading Aloud, and Audio (dual mode - visual and audio) presentation. The visual cue was manipulated in each experiment to require a differing level of translation to allow correct task performance, including words (Exp. 1 & 2) and icons (Exp.3). Results demonstrate that concentration to maintaining task sequences (reduced mixing costs) is better achieved with the use of relevant verbalisations only when the task cues contain verbal elements (i.e., words). With iconic cues (i.e., pictures) the use of language is superfluous. These manipulations failed to show a clear influence on switch costs. Results reveal the possible existence of separate working memory systems linking task cues to actions that can be recruited depending on the nature of the cue.

Introduction

It is common to hear accompanied young children reciting particular sayings when crossing roads. We are taught from a young age to adhere to a set of instructions involving looking in both directions multiple times, before embarking into the road. During this young age we are actively encouraged to verbalise these instructions aloud, hence it is common to hear related phrases. It could be presumed that stating aloud these commands emphasises the importance of the procedure, and to hopefully assist in committing the process to memory, ensuring it is used on every road crossing in the future. However, there are numerous other instances within daily life when we as grown adults also verbalise commands to ourselves; often to provide assistance and sustain concentration on the task that we are performing.

To understand the role of verbalisations in cognitive control it can be useful to compare a situation of high cognitive demand, where verbalisations can be useful, with a low cognitive demand context where verbalisations might be seen as superfluous or unnecessary. For example consider a context in which the same task (e.g. report if the colour of an object is Blue or Red) is continuously repeated, a pure block of trials. In such a context, learning is consistent and performance quickly improves with practice, requiring minimal supervision or additional support from verbalisations. A quite different situation arises when, in the same block of trials, participants need to respond to two different tasks using the same stimuli (a mixed block). In such a context, learning is not consistent because the rules change and working memory needs to be recruited to retrieve the relevant rule for a particular trial. Further, it must maintain both task rules for the duration of the block. It is in this high demand mixed block where verbalisations can be beneficial, contributing in principle to the retrieval and maintenance of task sets.

In previous work A. J. Kirkham, Breeze, & Marí-Beffa (2012) used a task-switching paradigm to analyse the influence of verbalisations in these two separate contexts. To do so, in the mixed block two trials of a particular task (e.g. identify the colour: Blue or Red) were followed by two trials of a different task (e.g., identify the shape: Square or Circle) within an alternating runs paradigm (R. D. Rogers & Monsell, 1995). The difference in execution between task repetition trials ($\mathrm{C\underline{C}S\underline{S}C\underline{C}S\underline{S}}$) and task switches ($\mathrm{\underline{C}C\underline{S}S\underline{C}C\underline{S}S}$) is called the switch cost and it can be seen as an index of the time taken to configure the new task set from one trial to the next. As both tasks are mixed in the same block, this measure of switch cost would reflect transient adjustments required from trial to trial, such as rule retrieval in working memory, without being influenced by strategical or more sustained factors that need to be applied to the entire block. In this sense, it is more interesting to look at performance in the repeat trials within the mixed block. These trials do not require new stimulus-response (S-R) mapping adjustments and they do not involve the retrieval of a new rule from working memory, but nevertheless, performance is deteriorated when compared to similar repetitions in the pure block. This is what it is called the mixing cost and it reflects the influence of more sustained factors, such as rule maintenance, required for all the trials in the mixed block (T. S. Braver, Reynolds, & Donaldson, 2003; Los, 1996). Using this paradigm, A. J. Kirkham et al. (2012) found that verbalisations aided performance in the mixing cost but not in the switch cost.

Impacts of verbalisations on cognitive control

When trying to explain the role of verbalisations in task control, theoretical interpretations of working memory processes often lead back to volumes of work concerning the central executive (Baddeley, 1986; Baddeley & Hitch, 1974). With respect to this it is important to highlight a particular component of the model, the sub-vocal rehearsal loop. This provides several functions that allow the user to sustain verbal information in working memory, and also translate non-auditory materials into an internal verbalisation that can then also be sustained for later use (Baddeley & Wilson, 1985; Gathercole & Baddeley, 1993).

For this reason it is often presumed that when instructional cues are presented on-screen (in the form of words that can be verbalised) participants utilise this ability through inner speech. Many studies use this form of silent inner speech reading as a control condition (Emerson & Miyake, 2003; Kray, Eber, & Lindenberger, 2004; Kray, Eber, & Karbach, 2008; Miyake, Emerson, Padilla, & Ahn, 2004). Yet we argued that despite this traditionally being used as a control, researchers cannot determine how often, if at all, the participant is using this method of verbalisation, or if participants are using inner speech for entirely different, and irrelevant purposes. For this reason we stated that in order to determine the impacts of verbalisations on cognitive control, the participants must verbalise externally.

How verbalisations impact cognitive control is debatable, and at present there is no widely accepted viewpoint on this topic. When an alternating runs paradigm is being used, no impact on switch costs are normally found as a result of verbalisations (Bryck & Mayr, 2005; A. J. Kirkham et al., 2012). Furthermore, similar results have been obtained with a random-runs paradigm format [also comprising of repeat and switch trials in a mixed block] (Saeki & Saito, 2009). Of most interest from this particular study was the finding that not only were there no impacts on the switch costs, but instead verbalisations appeared to affect mixing costs specifically. Since these results appear to demonstrate the importance of verbalisations with regard to the mixing cost, rather than the switch cost, this supports the belief that verbalisations are more suited to sustaining multiple tasks (or task-sets) in working memory (Bryck & Mayr, 2005; Saeki & Saito, 2009), rather than providing facilitation towards new tasks

(Rubinstein, Meyer, & Evans, 2001). For this reason it is crucial that mixing costs and switch costs be studied specifically and individually (Emerson & Miyake, 2003; A. J. Kirkham, Breeze, & Marí-Beffa, 2012; Kray, Eber, & Karbach, 2008; Marí-Beffa, Cooper, & Houghton, 2010). In this respect mixing costs being calculated by the difference between pure block trials and mixed block repeat trials, and switch costs by the difference between the mixed block repeat trials and mixed block switch trials. Although each measure should be considered as independent, it is important to state that they are connected through dependencies (either *statistical* or *processing* in format); readers are encouraged to examine justifications for each within A. J. Kirkham et al. (2012) for details and applicable information.

Despite many studies investigating the debilitating impact of irrelevant verbalisations on cognitive control, others have looked at how verbalisations (both self-initiated and externally presented) can facilitate cognitive control (Chevalier & Blaye, 2009; Goschke, 2000; A. J. Kirkham, Breeze, & Marí-Beffa, 2012; Kray, Eber, & Lindenberger, 2004; Kray, Eber, & Karbach, 2008; Miyake, Emerson, Padilla, & Ahn, 2004). In these instances additional conditions were implemented that required participants to verbalise relevant words. However only A. J. Kirkham et al. (2012); Kray et al. (2004, 2008), and Miyake et al. (2004) compared these relevant verbalisations to a silent reading condition.

In our previous work we asserted that not only do relevant verbalisations improve cognitive control, by reducing mixing cost measures significantly; but that this effect could also be found when instructional cues were presented aurally. By presenting a recording of the task cue allowed an insight into whether the reduction in mixing cost measure was a result of the process of explicitly verbalising the words, or instead the auditory input as a result of this verbalisation. It was determined that there was no significant difference between these conditions, and both provided a near-identical benefit with regard to mixing costs compared to when participants were using inner-speech.

In this previous work the task cues were highly explicit and minimal translation was necessary to ensure a correct response (the task cues were 'Blue / Red' and 'Square / Circle'; the same as the responses that could be given). In this current manuscript we present a series of three experiments aimed at highlighting how translational elements of a task cue can influence processing. During the aforementioned experiment, minor translation was required to ensure a correct, and rapid response. As the participant viewed the task cue the linguistic processing of these words began almost immediately. However, despite this rapid processing some translation requirements remain; the task cues are only words on a screen, and these must be converted into internal representations of colours and shapes for the participant to match to those elicited by the stimuli. Since the words themselves are highly explicit in their detail and state the characteristics to be responded to, the translation required is relatively minor, yet it still remains. The purpose of the forthcoming experiments is to investigate how changing the translational requirements of the task cue affects performance.

Translation of task cues

It is a reasonable assumption that as the complexity of a task cue increases, the more cognitively demanding it also becomes to decode it's meaning and thus provide a correct response. Yet an increase in task cue complexity does not necessarily result in dramatically increased ambiguity. As a result of basing our previous experiments upon explicit task cues requiring minor translation, this ensures that we are free to increase the task cue translation requirements, yet still retain a lack of ambiguity. For the purposes of explanation it is possible to categorise translational requirements in a 'multiple-step' framework. Our previous referenced experiment could be considered as having a '1-step framework', in that only one translation is required: task cues of 'Blue / Red' and 'Square / Circle' indicate the required characteristic that must be responded to. Only one translation is required to move from these word cues to the actual response upon seeing the stimulus: for example, translate the on-screen words 'Blue / Red' into a meaning of the colours, see blue, respond. As such it is possible to increase the translation requirements without increasing the ambiguity of the task cue. One such example is to change the task cues to 'Shape' and 'Colour'. This would therefore result in a '2-step' translation: see the word 'Colour' on-screen, translate this into 'blue or red', further translate these into the meaning of the colours, see red, respond. The task remains clear and comprehensible, lacks any great cognitive demands, yet also ensures that a greater degree of translation is required to perform correct responses.

Using the same train of thought it is also possible to obtain a '0-step' translation. By using relevant images that possess no translational elements, and effectively encompass a picture-matching task, a suitable task cue can be designed. In this sense each task cue image can contain only the relevant characteristics to the forthcoming trial, therefore removing all ambiguity towards the task. Although no translation is required for this form of task cue, it nevertheless will require decoding. An automatic processing of a picture cue into a compatible response is not possible; it must be processed in order to ascertain the correct task set required for a response. However this decoding is not anticipated to require any language processes, and as such cannot be classified as a translational format.

It is important to state that the multiple-step framework outlined here is not intended to be related to the working memory factors as presented in terms of 'task-performance procedures' (verbal or non-verbal additional elements of task performance) *per se*. Although it cannot be disputed that the step framework *must* be related to task performance, and hence is implemented by the working memory processes, the framework is hereby outlined in different terms. In a sense it is intended to provide a simplistic, yet theoretically sound, viewpoint as to the internal processes of task set selection, whilst being distinct from any of the additional measures/performance tactics. Despite being connected to a great extent, the internal task-set selection is based upon a) the presented cues, and b) the additional task performances, as distinctly separate entities, and whilst they may combine to produce facilitated performance, such a combination is not a pre-requisite for successful task completion. If we were to consider performance in tasks where articulatory suppression is used, we note that task performance is adequate, and indeed complete. Whilst the cues are presented, the additional factor of articulatory suppression removes the ability of the participant to use verbal working memory strategies to a large extent since these are 'filled' with irrelevant detail. Yet performance of the task can continue, and whilst not to the same high-standard of other situations, remain adequate. Clearly the cue-presentation step framework (in this example being 1-step) is distinct from the additional task-performance procedure, else such task completion would not be achievable.[4]

In the interests of respecting compatibility between experiments of this nature, all three should be performed with identical conditions; in this instance these being reading aloud a task cue, hearing a task cue, or performing in silence. For the task cues requiring translation this does not raise any predicaments since the nature of these (word) cues allows such performance. However in the case of a 0-step translation, such as the picture task cues, this raises an issue. In this instance the additional verbalisation must be learnt, and although it may be relevant to the task cue it could be considered as being distracting, since with a 0-step translation such verbalisations may be superfluous and unhelpful. However, although this may be seen as an unfortunate factor it may be helpful

[4]The author wishes to thank an anonymous reviewer for highlighting an initial explanation as being unconvincing. At that time the explanation gave the impression that the two factors were complementing, rather than working independently towards task completion objectives.

to consider this in another form as providing information on different processing methods. By using both visual and verbal inputs during this form of experiment it is potentially possible to determine the significance each plays within the processing of relevant information towards a task. For example, our previous work demonstrated the importance of verbal domains on goal directed behaviours, although visual domains were also in use because of the presence of the task cues on-screen. However, because of the nature of these visual elements, being words, these were not subject to the same levels of visual processing as an image with no elements that must be verbalised.

In the forthcoming detail we now present three experiments designed to tackle this issue of translation. We retain a near identical methodology to that found in Experiment 2 (A. J. Kirkham et al., 2012), with the use of three tasks of Silent Reading, Reading Aloud and Audio presentation of the task cues. A replication of the aforementioned Experiment 2 is present here for the purpose of statistical comparison, as Experiment 1 - a mild 1-step translation. A stronger, 2-step translation can be seen in Experiment 2. Finally a 0-step translation is found in Experiment 3.

Experiment 1

The experiment is designed to evaluate the impact of overt verbalisations, and auditory presented verbalisations, with regard to any facilitation of cognitive control that may be gained, in comparison to when the participant performs the same task in silence.

It is expected that the results will demonstrate the same impact on mixing cost as was obtained previously (Kirkham et al, 2012). In this study we retain a highly predictive sequence of trials with long cue-target intervals, ensuring that if the participants are capable of maintaining the sequence adequately this will be evident in a reduction of the mixing cost.

Method

Participants

28 undergraduate students of Bangor University were remunerated with course credits for their participation. All were required to have normal, or corrected-to-normal vision, and speak English as their first language.

Stimuli and apparatus

All experimental procedures were displayed using E-Prime 1.1 (PST Software) and a 17 in TFT display (resolution. Participants were sat 60 cm from the display. The stimuli used consisted of 2 shapes (square and circle) shaded in 2 possible colours (blue or red). The square was 2.4° high and 2.4° wide. The circle measured 2.4° in diameter. All colours were standard formats of RGB [red = R:255, G:0, B:0; blue = R:255, G:0, B:255). For each trial a single stimulus was presented in the centre of the screen on a white background. Prior to the display of the stimulus, a task cue was presented in the centre of the screen. The task cues read 'BLUE / RED' (3.5° wide and 0.5° high), or 'SQUARE / CIRCLE' (5.7° wide and 0.5° high) in Courier New font. All responses were made on a standard QWERTY keyboard, using the keys C and N. Audio Cues - All audio cues were recorded and normalised to -1dB using standard audio recording software. To generate the verbal cue, the words were generated using built-in Apple audio synthesis software. All audio cues were presented to participants at a constant and comfortable volume.

Design and procedure

Each trial began with a fixation-cross presented for 250ms, followed by the task cue, which was presented for 1000ms. Another fixation-cross appeared for 500ms and then the stimulus was displayed until a response was given. A 150ms blank-screen interval followed the response accompanied by a buzzer tone in the case of an erroneous response. All elements were aligned to the centre of the screen and only one element was present on-screen at any time.

Three blocks of trials were completed; two pure blocks (counterbalanced between Colour and Shape responses) of 40 trials each, and one mixed-block of 160 trials in an alternating-runs sequence. Mixed blocks comprised of 80 repeat trials (40 colour and 40 shape), and 80 switch trials. Mixing costs have been calculated by computing the average response time of the repeat trials in the mixed block minus the average response time of the repeat trials in the pure blocks. Switch costs have been calculated as the difference between the average response times of the switch and repeat trials in the mixed block.

Participants performed all trials under three counterbalanced conditions relating to their use of the task cue: Silent Reading, Reading Aloud, and Audio presentation. In the Silent Reading condition participants performed the experiment in silence. During Reading Aloud participants read aloud each task cue at a 'conversational level'. During the Audio presentation, participants were asked to remain silent for the duration but when the task cue was presented on-screen an additional audio recording of the task cue was concurrently presented through speakers present in the room. Volume levels of presentation were maintained for all participants. To ensure participants performed the task correctly, particularly with respect to Reading Aloud, all trials were conducted in a testing room equipped with microphones that were monitored by the researchers in an adjoining room; all participants were made aware of this. Participants were presented with standardised instructions specifying that they were to respond to stimuli according to the characteristics stated within the task cue. If the task cue stated 'Blue / Red' participants were asked to respond to the forthcoming stimulus by pressing C to blue, or N to red. Alternatively, if the task cue stated 'Square / Circle' they were asked to press C to a square, and N to a circle. All participants were advised to ignore the irrelevant property of each stimulus and to only respond to the prompted characteristic. They were requested to respond swiftly and with as good accuracy as possible. All participants were made aware of the sequence of trials, and what to expect in each block of trials with regard to the format of the alternating runs paradigm; they were given standardised instructions to this effect. All participants were tested individually and completed all conditions in a single session lasting approximately 45 minutes.

Results

All incorrect responses, and those immediately following, were removed - allowing the alternating runs sequence to remain stable. This resulted in 10.89% of trials being removed. All responses that were greater than 1500ms were also removed prior to the reaction time data analysis - this resulted in an additional 1.25% of trials being removed. In total the following percentages of trials were removed: Silent Reading 12.24%; Auditory 11.28%; Reading Aloud 12.51%. 2 participants were removed as their average RTs fell as outliers.

Reaction times

Averages of RTs per participant were analysed using a three-way repeated measures ANOVA for the variables of Task (Silent Reading, Auditory, and Reading Aloud), and Trials (Pure Repeat, Mixed Repeat, and Mixed Switch). Analyses also examined Congruency (to account for the bivalent stimuli), however this did not highlight any significant interaction with Task

Condition	Pure repeat	Mixed repeat	Mixed switch
Silent	413	476	527
	[10.85]	[16.38]	[20.24]
	91.06%	*86.59%*	*85.96%*
Audio	407	433	506
	[11.44]	[15.67]	[18.42]
	91.49%	*87.55%*	*87.12%*
Reading Aloud	406	440	497
	[13.28]	[16.61]	[19.05]
	88.89%	*87.07%*	*86.25%*

Table 4:: Experiment 1: Mean RT (ms), [standard error] and italics as accuracy values for each condition and Trial form.

[F(2,50)=0.25, p=.78, η_p^2 =.010], nor with Task and Trials [F(4,100)=0.18, p=.95, η_p^2 =.007]. Therefore this measure was not included within the final analysis.

Overall differences between Tasks were found [F(2,50)=4.74, p=.013, η_p^2 =.16]. Audio was significantly faster than Silent Reading by 23ms [t(25)=2.86, p=.008]. Reading Aloud was also significantly faster than Silent Reading by 24ms [t(25)=2.56, p=.017]. There was no significant difference between the Audio and Reading Aloud tasks (1ms) [t(25)=0.11, p=.91]. There were also substantial differences across the Trials [F(2,50)=70.37, p<.001, η_p^2 =.74], reflecting 41ms of mixing cost [t(25)=5.80, p<.001], and 60ms of switch cost [t(25)=8.90, p<001].

A significant interaction was found across both Task and Trials [F(4,100)=2.76, p=.032, η_p^2 =.10], indicating differences in mixing costs and/or switch costs. The size of the mixing cost changed dependent upon the Task [F(2,50)=5.71, p=.006, η_p^2 =.19]. It was concluded that Audio produced significant benefits in mixing costs compared to Silent Reading [F(1,25)=8.71, p=.007, η_p^2 =.26]. Reading

Aloud also provided similar benefits compared to Silent Reading [F(1,25)=7.07, p=.013, η_p^2 =.22]. There was no difference in mixing cost between Audio and Reading Aloud [F(1,25)=0.42, p=.53, η_p^2 =.016].

The size of the switch cost was not influenced by the Task [F(2,50)=1.73, p=.19, η_p^2 =.065].

Accuracy

Analyses of overall accuracy indicated no significant differences between Tasks [F(2,50)=0.81, p=.45, η_p^2 =.031]. Significant differences were obtained for Trial however [F(2,50)=18.41, p<.001, η_p^2 =.42]. Pure block repeat trials produced an accuracy of 90.48%, whilst mixed block repeat trials averaged 87.07% accuracy. This mixing cost of 3.41% was significant [t(25)=4.02, p<.001]. Mixed block switch trials obtained an accuracy of 86.44%, resulting in a switch cost of 0.63%, yet this was also significant [t(25)=3.43, p=.002].

The interaction between Task and Trial was not significant (F<1).

Discussion

Experiment 1 serves as a replication of previous results, further highlighting the importance of analysing mixing costs in addition to the traditional switch costs. Moreover it provides support to our previous findings stating the benefits obtainable when using relevant verbalisations in cognitive control tasks. Word cues indicated the characteristic to which a response was required upon presentation of the target. These words were presented prior to each trial, but they were also spoken aloud during the Reading Aloud condition, and presented through auditory means during the Audio condition. For this reason we refer to both the Audio and Reading Aloud conditions as being overt verbal cues and the Silent Reading condition as being *covert verbal cues.* Despite all three conditions sharing highly similar pure repeat RTs, the crucial measure resulting in substantial differences lies within the values obtained for the mixed repeat trials. With both Reading Aloud and Audio also sharing highly similar values for this measure, and Silent Reading resulting in a significantly slower RT in comparison, the significant mixing cost result is achieved. It is worth noting the similarities between the switch costs for all three conditions, and how this does not result in a significant interaction. These results strongly suggest that, at least with explicit word cues, verbal cue processing can be used to actively maintain more than one rule in working memory. Overall RTs in the mixed blocks are faster with the verbal tasks compared to silent reading, with this benefit equally affecting repeat and switch trials. If language were used to activate the relevant rule from trial to trial, then similar benefits should have been observed in switch costs. But it did not. Instead, overt verbal articulations provided sustained benefits affecting all trials in the mixed block, supporting the role of language in the maintenance of task goals.

If this role is confirmed, then we can expect that its benefit will be greater when the cue requires greater translation. In this sense the previous study is highly conservative and uses only a minor translation. For the forthcoming experiment a stronger translation is required that is expected to result in an increase in the effect obtained.

Experiment 2

This second experiment serves to provide a comparison to the previous experiment that had highly explicit word cues that required only minor translation into a tangible response format. In this version we have maintained an identical methodology but now the cue exclusively signals the task, without defining the response alternatives. Due to this version requiring more translation of the word cues into actual responses we expect to see an increase in mixing cost values, while still retaining the same overall pattern. That is, with the Reading Aloud and Audio tasks providing greater benefit than the Silent Reading condition.

Method

Participants

28 undergraduate students of Bangor University were remunerated with course credits for their participation. All were required to have normal or corrected-to-normal vision and speak English as their first language.

Stimuli and apparatus

All experimental procedures were identical to those in Experiment 1, with the exception of the presented task cues. The new task cues read 'COLOUR' (2.3° wide and 0.5° high), or 'SHAPE' (2.8° wide and 0.5° high) in Courier New font. All audio cues were adapted to the new task cue words, but all recording and presentation processes remained identical.

Design and procedure

All procedures were maintained according to the same format as used in Experiment 1.

Results

One participant was removed due to a correct response percentage of <75%. An additional 3 participants were removed as their average RTs fell as outliers. As with Experiment 1, all incorrect responses, and those immediately following, were removed. This resulted in 11.74% of trials being removed All responses that were slower than 1500ms were also removed prior to the reaction time data analysis - this resulted in an additional 2.21% of trials being removed. In total the following percentages of trials were removed: Silent Reading 15.21%; Auditory 12.05%; Reading Aloud 13.80%.

Reaction times

Averages of RTs per participant were analysed using a two-way repeated measures ANOVA for the variables of Task (Silent Reading, Auditory, and Reading Aloud), and Trials (Pure Repeat, Mixed Repeat, and Mixed Switch). As with Experiment 1, Congruency did not interact with either Task [F(2,46)=0.59, p=.56, η_p^2 =.025], nor Task and Trials [F(4,92)=0.50, p=.74, η_p^2 =.021].

Overall differences between Tasks were found [F(2,46)=10.39, p<.001, η_p^2 =.31]. The Audio presentation condition was significantly faster than Silent Reading by 50ms [t(23)=3.94, p=.001]. Reading Aloud was also significantly faster than Silent Reading by 48ms [t(23)=3.67, p=.001]. There was no significant difference between the Audio and Reading Aloud tasks (2.9ms) [t(23)=0.25, p=.80]. There were also substantial differences across the Trials [F(2,46)=71.13, p<.001, η_p^2 =.76], reflecting 68ms of mixing cost [t(23)=6.79, p<.001], and 97ms of switch cost [t(23)=7.94, p<001].

A significant interaction was found across both Task and Trials, demonstrating that the RT of Trials was influenced by the Task [F(4,92)=3.05, p=.021, η_p^2 =.12].

Condition	Pure repeat	Mixed repeat	Mixed switch
Silent	469	572	660
	[13.41]	[24.53]	[29.97]
	96.41%	*94.17%*	*90.47%*
Audio	442	496	610
	[9.99]	[17.67]	[30.74]
	95.94%	*95.63%*	*91.46%*
Reading Aloud	458	505	595
	[15.39]	[18.04]	[24.92]
	94.64%	*94.53%*	*91.09%*

Table 5:: Experiment 2: Mean RT (ms), [standard error] and italics as accuracy values for each condition and Trial form.

The size of the mixing cost changed dependent upon the Task [F(2,46)=7.72, p=.001, η_p^2 =.25]. It was concluded that Audio produced significant benefits in mixing costs compared to Silent Reading [F(1,23)=7.90, p=.010, η_p^2 =.26]. Reading Aloud also provided similar benefits as compared to Silent Reading [F(1,23)=9.21, p=.006, η_p^2 =.29]. There was no influence on mixing cost between Audio and Reading Aloud [F(1,23)=0.64, p=.43, η_p^2 =.027].

The size of the switch cost was not influenced by the Task [F(2,46)=1.05, p=.36, η_p^2 =.044].

When comparing these results with those from Experiment 1, overall responses here were 78ms slower than previously, when the cues signalled the response options [F(1,48)=12.38, p=.001, η_p^2 =.21]. Importantly, a significant interaction of trials across Experiments was obtained since in Experiment 2 the cue is expected to require greater participation of language to translate it than with the more transparent cues used in Experiment 1 [F(2,96)=7.99, p=.001, η_p^2

=.14]. When the data were analysed separately for mixing costs [F(1,48)=5.02, p=.030, η_p^2 =.10], it was determined that these differences were mostly found in the mixing cost generated during the silent reading condition, where the task cue (colour/shape) generated 40ms greater mixing costs than the more transparent response cue studied in Experiment 1 [F(1,48)=4.53, p=.038, η_p^2 =.086]. For the Audio condition, this increase of 28ms in mixing cost was only marginally significant [F(1,48)=2.92, p=.094, η_p^2 =.057], virtually disappearing to just 13ms of increase in the Reading Aloud condition (F<1). When analysing the switch cost, results revealed a global increase with the higher translation task cue in Experiment 2 [F(1,48)=7.25, p=.010, η_p^2 =.13], but of similar magnitude across the three cue task conditions (Silent Reading, +36ms, F(1,48)=3.62, p=.063, η_p^2 =.07; Audio, +41ms, F(1,48)=4.26, p=.044, η_p^2 =.082; Reading Aloud, +35ms, F(1,48)=3.50, p=.067, η_p^2 =.068).

To sum up, the results show that when comparing two word cues with different levels of transparency with respect to the task rules, the least transparent one (that requires more translation) increases both mixing and switch costs. However, only the mixing costs seem to be sensitive to the type of task used to decode these cues. More explicit verbal processing in the form of reading aloud or auditory co-presentation improves performance only in the mixing costs, where benefits were greatest for Reading Aloud and minimal for Silent Reading.

Accuracy

Analyses of overall accuracy indicated no significant differences between Tasks [F(2,46)=1.089, p=.35, η_p^2 =.045]. Significant differences were obtained for Trial however [F(2,46)=23.44, p<.001, η_p^2 =.51]. Pure block repeat trials produced an accuracy of 95.66%, whilst mixed block repeat trials averaged 94.77% accuracy. This mixing cost of <1% was not significant [t(23)=1.56, p=.13]. Mixed block switch trials obtained an accuracy of 91.01%, resulting in a switch cost of 3.77%

[t(23)=5.49, p<.001].

The interaction between Task and Trial was not significant [F(4,92)=1.64, p=.17, η_p^2 =.067].

Discussion

This experiment aimed to replicate findings from Experiment 1, with a manipulation ensuring the task now required a stronger degree of translation. This was achieved by the use of relevant, but less explicit, word cues presented for each trial, in the same manner as with Experiment 1. Through the use of overt verbal cues we again find that mixing costs are reduced substantially when compared to covert verbal cues. Furthermore, we find no substantial influence of cue strategies on the switch cost. In this respect we state that such findings provide support for our belief that overt verbal cues provide further assistance and facilitation of sequential task-order demands. These demands are not met as competently when covert verbal cuing strategies are used. Despite this, the participant is still capable of performing the task with covert verbal cues; any impression of incompetence when using such strategies is not intended, simply that better performance can be facilitated through the use of overt verbal cues. Curiously however the increase of mixing cost for the Silent task was substantially larger than was expected. During the Silent task the participant is free to recruit inner-speech, and hence language to improve their performance; and yet the values obtained give the impression that this may not be the case. Although mixing costs are increased for all tasks, the increase seen here is far more substantial than with the overt verbal cues. This may indicate that participants are not recruiting the inner-language processes that they could be, or alternatively that these are not providing as great an impact on the final response measures as the explicit overt verbalised cues. The most logical explanation for this lack of impact is the translational requirements of the task cue; where overt verbal task cues are used an additional boost to the translation framework is given, resulting in a compound effect of multiple inputs – therefore providing a swifter response. With covert verbal cues this additional explicit input is not available, therefore it relies upon the participant using a language strategy of their own volition – since there are no means of reinforcing such a strategy it is likely that its use is not consistent, and measures suffer. It is already known from Experiment 1 that where task cues provide greater levels of transparency, and less translation is required then this measure is faster, however it is uncertain whether any improvements can be seen where the task cue is even more transparent. In order to provide full coverage of translational implications further investigations were performed where no translation was required.

Experiment 3

As detailed, no translation for this experiment was required. We sought to determine to what extent overt verbal cues could be utilised in the facilitation of cognitive performance, and if they would remain beneficial where no forms that could be verbalised were presented to the participant. To this end, the previously used word cues were replaced with images depicting the characteristics to respond to (colour or shape). It was felt that these images provided sufficient information to complete the task with no translation required; in essence each image would act as a picture-matching task. Overt verbal cues this time stated the task to perform, as in Experiment 2, but using the words "Form" and "Shade" which seemed more comparable in terms of articulation as they contain the same number of syllables.

All other aspects of the study were kept uniform to maximise comparability with the previous experiments. In principle, language should not be required to translate this iconic cue, therefore we should observe similar levels of mixing costs across the three cue task conditions. Any benefit obtained in the overt verbal conditions will be taken as evidence of an additional contribution of language to promote task control.

Method

Participants

30 participants of Bangor University performed the experiment and were remunerated with course credits. All were required to be first language English, with normal, or corrected-to-normal, colour vision. No participants of Experiment 3 had taken part in Experiments 1 or 2.

Stimuli and apparatus

All presentation procedures, equipment, and stimuli were maintained from Experiments 1 and 2. The task cues were now images designed to depict the required response characteristics. The image for ‘Form’ comprised of a combination image of both a circle and square frame (2.4° wide and 2.4° high). The image for ‘Shade’ was a diamond filled with both blue and red shading (2.4° wide and 2.4° high). Colours used in these images adhered to the standard presets of RGB as described in Experiment 1. All other aspects were maintained as per the description within Experiment 1.

Design and procedure

The number of trials and all associated timings were maintained as per Experiments 1 and 2. In contrast to the previous Experiments, some adaptations were made due to the changes in the task cue. During Reading Aloud, since there was no on-screen word present, participants were trained prior to the trial blocks to state aloud the correct word to the image-cue presented. Once they were competent at this, the trial block would begin. As such, with each presentation of the Form image the participant was instructed to state aloud the word “form”. With each presentation of the Shade image the participant was instructed to state aloud the word “shade”. During the Audio trials the same process was followed, with the words “form” and “shade” being presented to the participant in conjunction with the on-screen task cue. As with Experiments 1 and 2, during the Silent Reading condition the participants did not speak, nor heard any audio detail, they relied upon the on-screen task cue to complete the task as required. All other aspects were maintained as previously described.

Results

Three participants were removed due to a correct response percentage of <75%. An additional 1 participant was removed as their average RTs fell as an outlier. As with the previous experiments, all incorrect responses, and those immediately following were removed, resulting in a loss of 13.21% of trials. All trial responses that were greater than 1500ms were also removed- this resulted in an additional 2.49% of trials being removed. In total the following percentages of trials were removed: Silent Reading 15.77%; Auditory 13.56%; Reading Aloud 16.81%.

Reaction times

Averages of RTs per participant were analysed using a two-way repeated measures ANOVA for the variables of Task (Silent Reading, Auditory, and Reading Aloud), and Trials (Pure Repeat, Mixed Repeat, and Mixed Switch). Once again Congruency did not significantly interact with Task [F(2,50)=0.49, p=.62, η_p^2 =.019] nor with Task and Trials [F(4,100)=2.31, p=.063, η_p^2 =.085].

Condition	Pure repeat	Mixed repeat	Mixed switch
Silent	481	525	613
	[14.20]	[18.53]	[22.39]
	95.67%	*94.37%*	*89.62%*
Audio	455	488	580
	[14.10]	[18.36]	[24.66]
	95.77%	*94.18%*	*91.11%*
Reading Aloud	497	513	612
	[20.73]	[18.95]	[24.45]
	92.40%	*94.09%*	*90.58%*

Table 6:: Experiment 3: Mean RT (ms), [standard error] and italics as accuracy values for each condition and Trial form.

Overall differences between Tasks were found [F(2,50)=5.27, p=.008, η_p^2 =.17]. Audio was significantly faster than Silent Reading by 32ms [t(25)=2.67, p=.013]. Audio was also significantly faster than Reading Aloud by 33ms [t(25)=2.88, p=.008]. There was no significant difference between the Silent Reading and Reading Aloud tasks (1ms) [t(25)=0.081, p=.94]. There were also substantial differences across the Trials [F(2,50)=74.10, p<.001, η_p^2 =.75], reflecting 31ms of mixing cost [t(25)=3.40, p=.002], and 93ms of switch cost [t(25)9.82, p<001]. No significant interaction of Task and Trial was found however [F(4,100)=0.51, p=.73, η_p^2 =.020].

Accuracy

Analyses of overall accuracy indicated no significant differences between Tasks [F(2,50)=1.81, p=.18, η_p^2 =.067]. Significant differences were obtained for Trial [F(2,50)=24.18, p<.001, η_p^2 =.49]. Pure block repeat trials produced an accuracy of 94.62%, whilst mixed block repeat trials averaged 94.21% accuracy. This mixing cost of <1% was not significant [$t(25)=0.70$, $p=.49$]. Mixed block switch trials obtained an accuracy of 90.43%, resulting in a switch cost of 3.78% [$t(25)=6.51$, $p<.001$].

The interaction between Task and Trial was significant however [$F(4,100)=3.37$, $p=.013$, $\eta_p^2=.12$]. As a result analyses were performed for both the mixing cost and switch costs of accuracies. The accuracy during mixing trials was significantly affected by Task [$F(2,50)=4.32$, $p=.019$, $\eta_p^2=.15$]. It was determined that there was significant impact on accuracies between Reading Aloud and Silent Reading during these mixed trials [$F(1,25)=5.13$, $p=.032$, $\eta_p^2=.17$]. There was similar impact between Reading Aloud and Audio conditions during these trials [$F(1,25)=5.28$, $p=.030$, $\eta_p^2=.17$]. There was however no such impact during these trials between Silent Reading and Audio conditions [$F(1,25)=0.11$, $p=.75$, $\eta_p^2=.004$].

The accuracy of the switch trials was not impacted by Task [$F(2,50)=0.75$, $p=.48$, $\eta_p^2=.029$].

Cross-Experimental Analyses

A full analysis of each task and associated trials was compiled across the 3 experimental forms. To avoid repetition of results already performed separately for each Experiment, in this section we focus on the comparisons across the types of cues used in different experiments. This clearly changes the differences in type of trial [$F(4,146)=4.85$, $p=.001$, $\eta_p^2=.117$], having a strong influence on the size of the mixing cost. The mixing cost was maximum (68 ms) with the 2-step translation cue, followed by 41ms obtained with the 1-step translation cue and becoming minimal (31ms) with the iconic cue (0-step translation). For theoretical reasons, we separate each individual task with respect to its influence

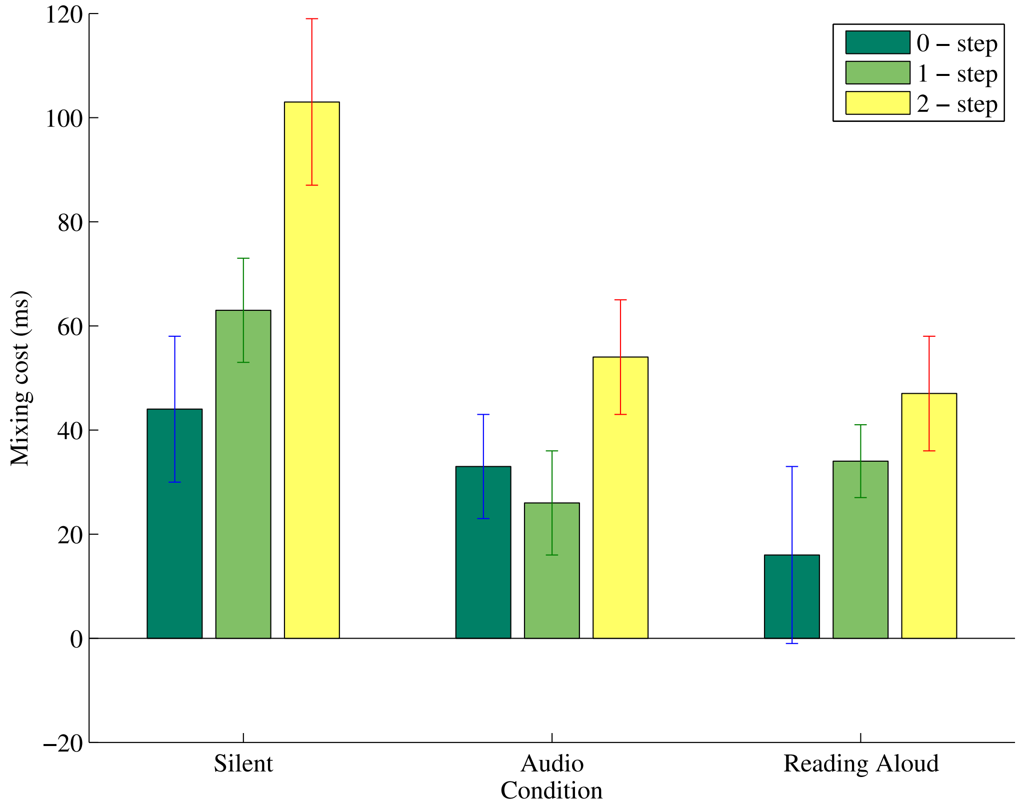

Figure 2. : Mixing costs for all tasks in each Experiment. Error bars indicate standard error values.

on the processing of the three cues.

Silent Reading

In this task the type of cue substantially changed the differences across trials [F(4,146)=3.71, p=.007, η_p^2 =.092] with a strong effect upon the mixing costs (see Figure 2, F(2,73)=4.65, p=.013, η_p^2 =.11). The 1-step translation cues of Experiment 1 permitted significantly reduced mixing costs compared to the 2-step translation cues of Experiment 2 [F(1,48)=4.53, p=.038, η_p^2 =.086]. The 0-step translation cues of Experiment 3 also provided significant benefits in mixing cost reduction to the 2-step translation [F(1,48)=7.17, p=.010, η_p^2 =.13]. There were however no significant differences in mixing cost between the 0-step and 1-step translations. The size of the switch cost was not impacted by the

Experimental condition.

Audio

In a sharp contrast to the pattern found with the Silent Reading task, we found no differences across experiments for neither mixing, nor switch costs. Data displayed in Figure 2 show a trend for the mixing cost to increase with the 2-step cues used in Experiment 2 when compared to the rest of the cues, but it failed to reach significance.

Reading Aloud

No significant interaction of Trials and Experiment was found. Looking at the results plotted in Figure 2, the size of the mixing cost seemed to increase with the translation of the cue, but this trend was not statistically confirmed.

Through analysing the collected results in this cross-experimental manner allows unique insights into the impact of the task-cue format upon response performance. It is clear that the most impact is achieved during performance using Silent Reading of the task-cues, with minimal impact during the Audio and Reading Aloud conditions. These results demonstrate that the overt translation of the cue benefits cognitive control. As previously discussed, during Silent Reading task performance relies upon the participants ability or disposition to verbally translate these cues. However this is a strategy that cannot be confirmed due to its inner nature. During both the Reading Aloud and Audio conditions the participants are pushed into correctly orienting their attention towards the appropriate task-set, either through active or passive methods. As a result, the provided task-cue appears to provide most impact when this orientation is additionally provided. Where it is not, as with Silent Reading, the nature of the cue becomes important, as to the degree of translation required. It is clear that task-set maintenance (as illustrated through the mixing cost) is maximised where task-cue translations are restrained to either a 1-step or 0-step framework. Where a 2-step translation framework is used, performance is negatively impacted. These differences in performance are likely attributable to the increase in cognitive demands required for correct and swift performance in accordance with the increase in translation for the presented task-cues.

General Discussion

Our previous work (A. J. Kirkham et al., 2012) stated that performance during cognitive tasks could be improved and facilitated through the use of overt verbal cues (reading aloud and auditory co-presentation), compared to covert verbal cues (silent reading). This finding was particularly notable as silent reading is often treated as a control for experimental conditions of non-relevant verbal articulations, such as articulatory suppression. Yet as this research has demonstrated, covert verbal conditions are particularly vulnerable when compared to those using an overt verbal format. Of particular note is that this facilitation manipulation impacts only on mixing costs, leaving the switch costs virtually unaffected. Although these findings provided a good insight into the characteristics of performance during working memory tasks, they did not provide a sufficient level of scope as to the relevance to paradigms with differing cognitive demands. The current manuscript aimed to rectify this by providing unique insights into the effects of overt verbal and covert verbal task cue productions upon the abilities of participants to complete working memory tasks of varying degrees of cognitive demand.

Experiment 1 provided a replication to a task present within A. J. Kirkham et al. (2012). This study demonstrates that where a cue is used that is clear and explicit, yet in a word format that requires a minor translation, overt verbalisations (both reading and audio) provide substantial assistance towards the task performance. This is particularly notable with regard to the mixing cost values, in that overt verbalisations provide most benefit to the process of maintaining task sequences. No interaction is seen on switch costs between each condition, with overt verbalisations used or otherwise.

Experiment 2 investigated the effect of the same overt and covert verbal conditions with cues that require a greater degree of translation. Task cues this time provide an input for the activation of the relevant task set without providing any explicit depiction of the required responses (the cues were “colour” and “shape”). This cue modification resulted in increased levels of mixing costs overall, but the pattern of benefit obtained from overt verbalisations remained similar. Again, the overt verbalisations (Reading Aloud and Audio) prompted significantly faster responses and smaller mixing costs than with Silent Reading In essence Experiment 2 replicated the results of our previous work and demonstrated improved maintenance of task sequence where a strong translation of cues is needed.

The aim of Experiment 3 was to test a cue that required no verbal translation. We used iconic cues that illustrated the required response properties for each trial. Using this form of cue removed the semi-autonomous process of reading that would have played a role in Experiments 1 and 2. While the comparisons across cues can be straightforward in the silent condition, the impact of overt verbalisations, particularly Reading Aloud, might be problematic. There is already a volume of research demonstrating that feature naming is a slower process compared to word reading (Cattell, 1886, Stroop, 1935, see MacLeod, 1991), so to minimise differences with the verbal cues all participants were trained prior to task engagement to relate each image to a specific relevant word. Note that naming aloud the task, with no automatic link between the cue and its verbal label, could be seen as a dual task competing with cue decoding. If this were so, we should have observed some deterioration in the Reading (or naming) Aloud condition with iconic cues. Importantly, this was not the case, and verbalising the iconic cue provided benefits comparable to those in the Silent condition.

Multiple pathways of activation

The comparisons between Experiments 2 and 3 are particularly relevant as they address the impact of verbalisations under the two most extreme cases of cue translation. Unexpectedly, there were no differences in overall RT data. It was anticipated that since Experiment 3 required no translation to correctly complete the trials, performance would be superior to that exhibited in Experiment 2; but this was not the case. Indeed, the only significant difference between the two Experiments was obtained for the mixing costs of the Silent Reading/Decoding task, where the greater translation of the cue resulted in increased mixing costs. In this respect, a very important result here is that when the tasks were performed silently, task-sequence maintenance was dramatically improved when an explicit iconic cue was provided, with no effect on overall RTs. For this reason, we need to argue that verbal working memory cannot be the only mechanism engaged in task performance and maintenance, and that visual working memory also plays a role.

Drawing on these results it is highly likely that the text-based task cues and picture task cues follow relatively individual pathways of activation. There is little doubt that all text-based cues require some degree of translation and therefore use of verbal working memory, but it is not so clear how the picture cues are decoded. Initially it was presumed that since the iconic cues represented their associated tasks in an explicit manner, the appropriate task-set would be readily activated with little demands of working memory. Clearly this was not the case as overall RTs with iconic cues were found slower than those with explicit word cues (Exp. 1). The process of decoding the picture cue into the necessary task-set formats cannot be overlooked. Although language is intrinsic with word cues, picture cues may activate a parallel system. Regardless of the type of cue, it needs to activate the representation of the task-relevant target features and their responses; this cannot be performed automatically. For this reason we must confront the possibility that different cues may have individual working memory pathways, ultimately culminating in the same action systems (Gruber & Goschke, 2004). In addition, the co-presentation of an auditory cue further improves performance overall compared to the silent condition regardless of the type of cue, supporting the view of different modality specific systems collaborating towards an action.

Limits of facilitation

One of our starting points was that verbalisations can aid performance when increased concentration is desirable in complex environments to coordinate multiple tasks. However, benefits from verbalisations in our previous work (and here in Experiment 1) were found with task cues that were highly explicit about the responses to make. In these rather simple cue-response associations, the role of language might be seen unnecessary, posing a potential limitation on the size of the benefits observed. One of the goals of this study was to test whether the benefits would increase when the cue-response association is less transparent, therefore requiring more translation. By requiring a moderate translation in Experiment 2, participants were expected to make a greater use of working memory to select the correct response as they were not defined in the cue. Using word cues, such as Colour and Shape, task goals were clear and unambiguous yet required the additional retrieval of the response set from memory. Essentially, where in Experiment 1 participants could take a lackadaisical approach to each trial, relying solely upon the provided task cue to determine the correct response set, during Experiment 2 this was not feasible. Although still relatively simple, the task required participants to retain two task-sets containing four stimulus-response mappings during the mixed block, despite two of these mappings being irrelevant for each trial. How this maintenance is occurring is not for debate here; the fact remains that each response configuration must be accessible for immediate use on forthcoming trials. However, regardless of the storage and selection system, overt verbalisations facilitate performance in a specific manner, that is increasing task maintenance during the mixed block and reducing the mixing cost.

Relevant overt verbalisations towards the task permits task maintenance to be further enhanced by solidifying the task sequence structure more effectively than when overt verbalisations are not recruited (i.e., with silent reading). Importantly, several authors have assumed that subvocal verbalisations are automatically triggered by the word cue during silent reading (Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004). Our data question, at least, the automaticity of those verbalisations which, in any case, we cannot assess. The purpose of this present research was to assess to what extent verbalisations are involved in the translation of the cue. It is evident that as the cue complexity increases, the benefits obtainable with relevant overt verbalisations also increase. Yet where cue complexity decreases, this may not be the case. Experiment 3 highlights that in some circumstances overt verbalisations do not assist in task performance, although this could be considered a sweeping statement. It must not be ignored that despite no significant interaction of mixing cost (or switch cost) upon the tasks, overall improvements in task performance were seen during the Audio condition over and above those found when Reading Aloud or performing the task in silence. So although the overall picture does not present a strong compulsion to favour Audio assisted cues, closer inspection suggests that in some instances facilitation may be provided.

An important factor for consideration is that, despite this potential benefit, is it worth the extra cognitive demand? Although the overall performance benefits are notable, these are related to overall RTs and do not have any significant impact upon task maintenance. It is important to consider that during Experiment 3 no translation is required, therefore any overt verbalisations may be superfluous. Essentially Experiment 3 permits performance in the manner of a picture matching task; the word properties associated to each image are irrelevant in that they provide no additional benefit towards the translation of the cue, since none is required. However, since each iconic cue still requires a degree of decoding in order to ensure the correct task set is chosen for the response, it is possible that the additional audio cue cements the current task set to be chosen. Although language is not required to acknowledge the task cue, these results leave an open question as to the mutual cross-compatibility between the multiple pathways suggested.

Conclusions

Whilst word cues are seen as providing direction towards tasks we only need to consider how our competencies towards such cues can be affected. The fact that a word cue retains visual characteristics that could be treated as an image should not be overlooked. Each word is associated to a different task, so any visual feature that could be used to distinguish the cue (e.g., the presence of a "c" in the word "colour") can be used to guide the action without actually reading the word. Within each task, the same word is always used as a cue, so reading is not necessary. If words were used as icons, then the silent reading condition should be identical across the three experiments. In striking contrast, the silent reading condition is the one demonstrating the largest differences across the three types of cue (see Figure 2), ruling out the possibility of cues being used as icons. Importantly, when the activation of the cue is supported by additional input (Audio and Reading Aloud conditions), the nature of the cue becomes less relevant.

A combination of the inputs from automatic sub-vocal processing to the articulation/hearing of the same cue provides a compounding effect, boosting performance. During Silent Reading we rely upon only one input, and even this may not be used continuously, unlike in the case of Reading Aloud / Audio presentation. However, where translation is not required, as in the case of iconic cues, overt verbalisations are not valued to the same extent, but it is meaningful that they do not interfere with cue decoding. Particularly in the case of naming the task aloud, the verbal task is secondary to the main task of visual decoding, potentially interfering with it. Remarkably, despite the added cognitive load, performance is unaffected. This result suggests some form of cooperation or compatibility between the codes used for both processes. In this respect it could be considered that where iconic cues are used, a form of bottom up processing activates relevant response sets and any additional input makes little difference. In contrast, the word cues triggers reading as a mediating process. Our results reveal the possible existence of multiple cue decoding systems (probably domain-specific working memory systems – Gruber & Goschke, 2004) that are used to provide task maintenance in the presence of goal conflict.

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Although the results presented in this chapter demonstrate that the impacts of verbalisations fall upon the maintenance of task-sequences, it is not clear precisely how these measures relate to the specifics of mixing costs. It is unknown whether these benefits, or negative impacts, are affecting trials on a global level, i.e. across the entire block of trials, or more specifically on a local level, i.e. impacting individual trials within the blocks. Basing the forthcoming research upon the topic of vigilance decrement (discussed in the following Chapter 4), it seemed likely that these impacts were based upon a local theory, and affected by attentional fluctuations. Assessments of performances in tasks implementing beneficial and negative manipulations are investigated in Chapter 5 (following a background literature discussion of Chapter 4) with analyses being conducted in both the traditional format, but also with cumulative distribution function analysis (CDF). Using CDF permits assessments to be made in terms of changes in response latencies across trials and manipulations, and demonstrates movements in mixing cost measures across these.

CHAPTER 4

VIGILANCE DECREMENT OVERVIEW

Vigilance can be summarised as the capability of maintaining attention and concentration towards a task over a prolonged period (Davies & Parasuraman, 1982; Parasuraman, 1986). The decrement aspect refers to a decreasing ability to maintain this concentration for the required period.

Vigilance decrement can be an issue in numerous situations — radar operatives; security factors - x-ray operatives scanning passenger luggage and freight consignments; healthcare roles – anaesthesiologists, surgeons, radiologists; all roles that require vigilance to maintained for long periods of time. The outcome from any person not performing to their required standard could be disastrous.

Work into this field of research began shortly after World War II as a result of reports that radar operatives were missing indicators of enemy movements, especially during extended periods of analysis (Mackworth, 1948). Mackworth investigated with an experimental setup of a clock design and required participants to judge when larger than normal movements occurred. It was concluded that despite the majority of shifts lasting approximately two hours, the operatives were beginning to miss 10-15% of larger jumps after only thirty minutes. A consistent decrease in performance was not observed over time however, since performance plateaued after this point. Adjustment of the overall task duration did not affect this finding; the same decremental vigilance was observed consistently after thirty minutes. Due to the sporadic appearance of experimental 'jumps', in accordance with the similar stimuli found in a radar operative's role it was a highly significant finding. Of equal importance it was observed that by splitting each shift into thirty minutes of analysis, followed by thirty minutes break, a high level of vigilance was recorded that was not significantly different between the time periods.

It is not solely radar operatives that appear to suffer from vigilance decrement after this time period, similar results have also been found with CCTV operatives. Statements from CCTV companies believe that competency can be lost in as little as 20-40 minutes from “CCTV Blindness” (Wallace & Diffley, 1998).

Although complacency with a task could be a factor – the repetition of the same task day-to-day might be considered a possible cause for this decrement, even naïve participants can suffer the same effects. Stern, Boyer, Schroeder, Touchstone, & Stoliarov (1994) studied participants with no prior experience of aviation radar use in similar task over a period of two-hours. It was found that although the experience was new and novel there remained significant physiological changes within the first thirty minutes of performing the task. Notably these changes related to the eye-blinks of the participants; the blink closing-duration (average time from initialising a blink to full eye closure) and time between the eyelid being half closed and reopened to the same level was significantly different between measurements taken after 10 minutes and 30 minutes. The blink-closing duration retained this stable level until measurements were taken after 110 minutes, where again it increased further.

With the time-scale for detrimental effects of sustained vigilance appearing to be around 30 minutes, the question is raised as to whether this is affected by the intensity of the task undertaken.

Theories of cause

Traditionally with vigilance decrement there are two theoretical viewpoints. The first asserts that findings occur as a result of the participant suffering from a lack of arousal to the task – the under-arousal model. Whilst the second holds the opposite train of thought; that there may be too much arousal for the participant to cope with the attentional requirements – the over-arousal model.

Yet it could be questioned whether these seemingly opposing viewpoints are actually relatively similar.

Under-Arousal

The under-arousal model (Manly, Robertson, Galloway, & Hawkins, 1999; Pattyn, Neyt, Henderickx, & Soetens, 2008; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), or 'Mindlessness Model', was devised from the belief that any vigilance decrement effects were the result of the participant being under-aroused to the task they were performing (Frankmann & Adams, 1962, as cited in Warm, Parasuraman, & Matthews, 2008). Built upon the theory of the Supervisory Attentional System (Norman & Shallice, 1986) it is formulated around the theory that as a task becomes repetitive and tedious, task novelty diminishes, and responses become lacking in vigour. Participants become embroiled in a pattern of occasional involvement separated by long periods of irrelevant input that requires no response. As such disengagement from the task occurs – they are under-aroused by the process taking place, causing them to miss many target stimuli.

Over-Arousal

The second viewpoint to be discussed is that of the participant becoming over-aroused to the task being performed (Caggiano & Parasuraman (2004); Grier et al. (2003); Helton et al. (2005); Helton & Warm (2008); Parasuraman (1979); Warm, Dember, & Hancock (1996); for a review of further papers see Warm et al. 2008). Although this viewpoint does not dispute the structure of the tasks being repetitive, tedious and fatigue inducing, it does however question the lack of involvement required from the participant as asserted with the mindlessness theory. Rather than postulating that the participant may begin to suffer from vigilance decrement as a result of effectively 'turning off' from the task, the theory states the opposite. As the participant is waiting for occasional targets amidst unpredictable time intervals, they are concentrating on the task to the extent that they are effectively over-arousing themselves. As a result it is likely that an early degree of 'burn-out' would occur from the amount of effort expended to concentrate fully on the task, causing the participant to miss an increasing number of relevant targets.

Although both viewpoints are theoretically plausible it is somewhat appealing that researchers are open to the theory that strong task performance requires a fine balance to achieve the desired outcome. Pattyn et al. (2008) state the possible use of the Yerkes-Dodson law (Yerkes & Dodson, 1908) in terms of achieving this performance. A level of arousal that is neither too little, nor too great enables an optimal performance since the optimum arousal point is achieved. Hence regardless of the theoretical viewpoints of vigilance *decrement*, a level of strong vigilance towards a task requires that in instances some arousal be present.

Applied Situations

Consider the role of the radar operative; their jobs require that for prolonged periods of time they are watching a screen for anything untoward that might raise concern. However, for the vast proportion of shifts they are watching on-goings that do not raise suspicion. If we relate this viewpoint to the under-arousal theory we can hold the belief that there may be a lack of arousal and attentional demands, and so sustained concentration may wane across the time period.

However, we can also relate this scenario to the over-arousal theory, the attentional demands may be too much for the operative to cope with. If the operative is performing their duty for prolonged periods of time with a heightened level of arousal (watching the screens intensely, seeking out even the most minor of details), then it is likely that their performance will deteriorate rapidly. A sensible term for this could be vigilance fatigue.

Warm et al. (1996) presented a series of findings stating that despite the jobs of such operatives being repetitive, it is more likely that the over-arousal theory occurs. Conducting research using the NASA Task-Load Index[5] (NASA-TLX) (Hart & Staveland, 1988), results of great interest are found. Gluckman, Warm, Dember, Thiemann, and Hancock (1988) (as cited in Warm et al., 1996) found that with tasks concerning signal detection, in high signal salience conditions the perceived workload was lower than in a low signal salience condition where the perceived workload was much greater. Put simply, in circumstances where there were fewer elements to respond to, the participant had a greater perceived workload, presumably because of the stronger need for concentration required to detect these applicable elements. Such changes to salience have also been known to have significant effects on the time-onset of vigilance decrement: where salience of the stimuli is badly degraded, decrement can occur within 5 minutes (Nuechterlein, Parasuraman, & Jiang, 1983). To track any changes to the perceived workload across time Dember et al, (1993) (as cited in Warm et al., 1996) replicated the work of Nuechterlein et al. (1983) but provided measurements over five time periods. Despite the different salience conditions of the signal, of which the previous results were replicated, workload ratings increased in a highly similar manner for both across the time periods. Warm et al. (1996) raises the hypothesis that with findings such as these it is likely that further determinants also have an impact on perceived workload, such as

[5] a highly stable measure of workload in vigilance (Becker, Warm, Dember, & Hancock, 1995), that can be associated with numerous job areas.

asthenopia or fatigue from maintaining a suitable posture for monitoring behaviour. Since these determinants are not related to the task being performed [but are additional factors], the finding that they affect vigilance decrement to a similar level regardless of task is not surprising.

However, there have been questions concerning the implementation of multiple tasks, and the impact that this has on vigilance decrement. The need to perform multiple tasks requires the use of working memory structures, and more specifically the maintenance of these tasks. Research has shown that this has a major impact on vigilance decrement, particularly when tasks and stimuli are presented in a specific manner. Parasuraman (1979) noted that engaging participants in a task requiring either successive or simultaneous discrimination elicited different responses, particularly when the event-frequency of trials was also altered. During this study successive trials were formed where participants had to retain information relating to the previous trial (the volume of 1000-Hz tone), and determine whether a second tone was 2.1dB louder than the previous. Simultaneous trials contained all the information required to complete the trial without any working memory load – distinguish if a 1000-Hz tone was within an intermittent noise frequency. It was found that when the event-frequency was high, vigilance decrement factors would result in a poorer performance over time, but only in the successive trials.

Similarly, Caggiano & Parasuraman (2004) also noted that successive trials result in vigilance decrement through assessments of task characteristics. Participants were asked to perform a series of tasks with a two-back working memory element that comprised of either a colour (non-spatial) or location (spatial) element, and a vigilance detection task. It was found that regardless of the vigilance sensitivity similarities in the early stages of the task between the spatial and non-spatial conditions, the spatial condition substantially impacted vigilance decrement in later stages of testing. Interestingly it was noted that in the colour task more than 50% of participants reported using a verbal strategy to help assist in their responses.

This is of particular interest when we consider the impact of sound in general on the capabilities of participants to perform tasks. Becker et al. (1995) assessed sensitivity to perception on the basis of differing levels of sound interference. Irrelevant sounds were used during the experiment and portrayed an aircraft approaching from the left and departing to the right of the participant. Three different levels of sound intensity amplitudes were used (no sound, 70 dBA and 95dBA) and they were presented to participants when sat inside an acoustic booth. Although there was no effect of vigilance decrement over a forty-minute testing period between groups, there was a significant effect of noise, with decreasing levels of perception sensitivity recorded with an increase in noise level. In addition, measurements using the NASA-TLX indicated an increase in perceived workload as the noise level increased accordingly.

Although this choice of noise usage may seem niche, the reasons for this choice are not. We may not consider sitting in an acoustic chamber to be particularly ecologically valid, but these are not extraordinary noise levels. Aircraft noise pollution has long been debated and such research has impact not only for nearby workers, but also to those persons who live on flight paths. Although the strongest of noise amplitudes elicited the worst changes in perception, the 70dBA level also promoted deficiencies compared to the no noise condition; 70dBA is not however a particularly loud noise, it is comparable to a car engine for example, yet even this can affect responses greatly.

On the basis of these findings it would be sensible to consider the impact of auditory functioning on the capabilities of persons performing tasks over prolonged periods of time. Long-standing has been the notion that in order to concentrate on a task one must perform it in silence – to allow full concentration and not be distracted by any external influence. To an extent this may be true; but then it could also be debated whether this lack of relevant input may allow the manifestation of the 'mindlessness' theory, and thus cause performance to wane. It has been shown that in some instances participants use verbal cues to assist in their responses (Caggiano & Parasuraman, 2004). This in itself is interesting since it brings into question the integration of working memory structures with the abilities of the participant to perform the task. However, how does this assist the participant, if at all? Or is it just a pseudo effect whereby the participant believes that it is assisting them? If it is assisting them, in what way is it doing so: quicker reactions, greater ability to detect salience changes, simply a perception of smaller workload, or a combination of these aspects and more? Also, at what point does sound become relevant, or irrelevant and its impact change for the better, or worse?

CHAPTER 5

LANGUAGE AND VIGILANCE – DISTRIBUTIONAL ANALYSES[6]

[6] To be submitted under the title of: Impacts of language on vigilance: distributional analysis of mixing costs.

Abstract

In previous work it has been demonstrated that additional verbalisations can facilitate and/or degrade performance in a task-switching paradigm. The most predominant impact is found to be related to mixing costs, and thus these verbalisations affect the abilities of the participant to maintain knowledge of their position within a task-sequence. As a result they can respond faster (or slower) due to their awareness of whether a trial is a repeat or switch from the previous trial task – where an alternating runs paradigm is used. These impacts may be found on a global level basis, and hence affecting abilities within an entire block of trials – where performance is impacted from the first to the last trial with approximately equal magnitude. Otherwise, it may be that these impacts are found on a local level and thus only affect these abilities on a trial-by-trial basis – where some trials may be performed with vastly different costs to others. It is a possibility that different tactics are used depending upon the current task requirements, yet with standard overall mean measurements it is not possible to distinguish which method is being used – CDF analysis can answer this query.

Performing a replication of previous work (A. J. Kirkham et al., 2012) using a CDF analysis process permitted investigations into how performance changed over a block of trials. Results demonstrated that verbalisations affect maintenance abilities on a trial-by-trial basis, since mixing cost values changed over the block of trials. CDF plots indicate that in the fastest responses all verbal manipulations provide highly similar mixing cost latencies, regardless of relevance to the task. Relevant verbalisations (both articulation and audio) permitted a smaller increase in mixing cost compared to silent performance. Articulatory suppression resulted in the steepest increase in mixing cost latency compared to all other manipulations. The results demonstrate that relevant verbalisations (of both formats) allow maintenance of task-sequence to be

maintained over a larger proportion of trials than when performing in silence, or with concurrent articulatory suppression.

Introduction

Task-switching research predominantly involves the analysis of how competently, and thus swiftly, people can switch between tasks. Often it is the case that experimental analyses are conducted using simple stimuli that are devolved from everyday life; this serves to highlight the low-level cognitive processing involved, and reduces the reaction time measures obtained. It is common to find that most analyses are performed on the switch costs — representative of the differences in reaction time between repeating a task and performing a new task. Yet the repetition tasks upon which these are founded can provide other measures of cognitive control, indicating how competently a participant can maintain multiple task responses, and / or sequences. Yet how these measures are analysed can offer dramatically different suggestions of their impact. The present work aims to demonstrate a relatively new method of cost measurement analysis demonstrating how these measures are susceptible to other experimental influences in addition to those found with the prescribed conditions.

A brief glance over published task-switching literature will undoubtedly highlight the importance of measuring switch costs – the increase in time taken to respond to a task that differs to the previous, compared to a repetition of the same task. Recently several publications have identified the importance of mixing costs in addition to switch costs (A. J. Kirkham, Breeze, & Marí-Beffa, 2012; Marí-Beffa, Cooper, & Houghton, 2010). Although related, these costs are measured according to the increase in time taken to respond to a repetition of a task in a block of mixed task trials (AABBAA. . .), compared to a repetition of a task in a block of single task trials (AAA. . .). To ensure that both mixing costs and switch costs are collected from the same body of work it is crucial that a suitable paradigm is chosen. One suitable selection is a combination of both the list (Jersild, 1927) and alternating runs designs (R. D. Rogers & Monsell, 1995).

These provide both the single task trial blocks (pure blocks) and a suitable mixed task block (mixed block) of the two task forms. The outcome of this selection is that there are pure block repeat trials, mixed block repeat trials, and mixed block switch trials – therefore both mixing and switch costs can be calculated independently .

Although relatively little work has been completed concerning mixing costs specifically, that which has demonstrates the strong impact of verbalisations on this measure. It has been noted that where relevant verbalisations are performed during the task, improvements are seen in the form of reductions in mixing cost value compared to when the same task is performed either with irrelevant verbalisations, or without any verbalisations.

These obtained measures are helpful in providing information relating to task control processing – how competently participants can complete a task based upon their performance towards specific trial forms (repeats, switches), and how these relate to differing processing issues.

Language influences on task-switching capabilities

The majority of task-switching studies that serve to evaluate the use of language and verbalisations use the list design (Emerson & Miyake, 2003; Saeki & Saito, 2004; Saeki et al., 2006). The use of this design has served in particular to highlight the detrimental impact of certain verbalisations (e.g. articulatory suppression) on switch costs. This is particularly evident where task cues may require decoding (Miyake et al., 2004; Saeki et al., 2006), or are otherwise endogenous in their format (Bryck & Mayr, 2005; Emerson & Miyake, 2003; Saeki & Saito, 2004). However, where repeat trials are also included within a mixed block (e.g. alternating runs design, or with a random sequence design), any effect of verbalisation on the switch cost is removed (Bryck & Mayr, 2005; Saeki & Saito, 2009). Resultantly, it can be concluded that any impact of verbalisations on the switch cost must be found with processes that solely affect the list design. Furthermore, we have demonstrated that verbalisations predominantly affect mixing costs instead of switch costs (A. J. Kirkham et al., 2012).

It is often the case that where verbalisations are investigated with task-switching paradigms, articulatory suppression is used as an experimental condition. Articulatory suppression, in its simplest form, is the repetition of irrelevant verbal forms (e.g. Numbers: Baddeley et al., 1984; Words: Baddeley et al., 2001; Bryck & Mayr, 2005, or Letters: Emerson & Miyake, 2003) to serve the purpose of minimising any involvement of language faculties in the performance of a task. By engaging participants in this act, their ability to use the sub-vocal rehearsal loop to provide assistance in sustaining verbal information within working memory is severely diminished. As a result, through the performance of articulatory suppression the benefits of language usage within a task can be highlighted, and are considered as being associated with many cognitive control processes (see Ullman, 2006).

Although use of articulatory suppression strategies is common, it can only be used to determine the influence of language with respect to when it is severely diminished. Other studies, often in conjunction with the use of articulatory suppression, have sought to determine whether the use of language can instead be used to facilitate performance (Goschke, 2000; A. J. Kirkham et al., 2012). Our own work has demonstrated that this is indeed the case, with conditions involving relevant verbalisations towards the task decreasing the mixing cost significantly against those conditions where language cannot be used to the same degree (articulatory suppression). These results further support the previous findings that verbalisations (both relevant and irrelevant) target the mixing costs specifically, leaving the switch costs largely unaffected (except for where these are impacted as a result of the mixing cost). These results appear to provide support to the belief that verbalisations impact the process of sustaining multiple task sets in working memory (Bryck & Mayr, 2005), rather than facilitating switches to new tasks (Rubinstein et al., 2001).

As stated, our previous work demonstrates that language provides significant impact upon task control. However, since these results are analysed using basic, albeit traditional means – i.e. relying solely upon the mean RT – we were unable to state precisely how this was occurring. Interpretations based upon these results may provide support towards any influences on task control being at a global level, at least with respect to the blocks as individual components. In this respect the mixing cost is most likely generated as a result of the interference provided by the multiple tasks, and resultantly the requirement to maintain the correct task-sequence [since the paradigm relied upon an explicit and predictable sequence throughout]. When relevant verbalisations are being performed, this interference is reduced substantially; during articulatory suppression there are no processes providing facilitation to remove this interference, only additional processes that serve to negatively impact even further. For example, if the interference generated is great, participants will be unable to keep track of their position within the trials; thus it is likely that they will be unsure if a trial is a switch or a repeat. As a result, their performance will be degraded since they are likely to treat each trial as a switch, thus maximising mixing costs and minimising switch costs.

However, it may be that language is influencing task control on a trial-by-trial basis. With respect to this theory we can debate the influence of language on the maintenance of vigilance towards the task being performed. If we consider the seminal research of Mackworth (1948), we can determine a primary measure of vigilance decrement: a reduction in the number of signal detections made.

Crucially, the greatest reductions in observations of signal detection were found within the first half-hour of the 2-hour testing session – within reasonable testing protocol timings of many modern studies. The performance of relevant verbalisations could potentially provide an extension to this time frame through the increase in attention that must be given to enable the use of relevant language. It is also a possibility that the probability of a signal occurring may affect vigilance decrement. For example, Broadbent (1958) argues that where continuous attention is required towards a task, it is likely that this attention will shift sporadically over the time of testing (both towards and away from the task), and is particularly susceptible to interference, or as a result of decreased sensitivity towards the task itself. Therefore, because of the dual-task nature of such experiments, particularly where bivalent stimuli are used, interference could be strong and substantially affect performance. This would seem an accurate assumption if we consider the negative effect of articulatory suppression on the mixing cost, and indeed the positive effect of relevant verbalisations on the mixing cost. The performance of relevant verbalisations, in conjunction with an explicit task-cue, reduces the interference caused by the secondary (and irrelevant) task. Additionally, verbalisations could be assisting in the limiting of the reported decreasing sensitivity towards the task; the articulation of the task cue would provide a boost in the recall of the task, and effectively increase sensitivity. If we consider the above points with respect to articulatory suppression however, the performance of this irrelevant verbalisation could effectively increase the likelihood of both of these situations occurring. Undoubtedly the repetition of an irrelevant word would further increase the ambiguity and interference already present; it would also provide an additional irrelevant task to be performed, most likely influencing the predicted decreases in sensitivity towards the task.

CDF-XL analysis of language on mixing cost

The two options detailed concerning how language impacts the mixing cost are relatively challenging to dissociate. By analysing the data in a standard manner does not allow us to determine whether the impact occurs as a result of the trial-by-trial nature, or indeed at a block level resulting from the increased interference as generated by the switch trials. During standard analysis procedures the traditional methods involve calculating an RT based upon mean measurements per participant, per trial format (pure repeat, mixed repeat and mixed switch trials). This is then further averaged across all participants. Although a traditional method for such analysis, it nevertheless disregards a vast amount of data, and more importantly the spread of these responses. Using cumulative distribution frequency measures (CDF) (Ratcliff, 1979), it is possible to dissociate these measures of task control and potentially attribute the findings to one of these two models. CDF analysis allows a method of presenting data without relying solely upon overall mean RT measurements; instead allowing analysis of performance across the entire distribution of RT values. Historically CDF analysis has been a time-consuming experience that few researchers have entertained; however recent advances have made the process simpler (CDF-XL - Houghton & Grange, 2011). To construct the CDFs, RTs for each participant, and each condition, are ordered from fastest to slowest before being split according to a specified number of bins for each set of data. The median values[7] of the RTs that are within each bin are then calculated across all participants; these values can now be plotted, or submitted for further analysis using factors of condition and bin. For further details of CDF-XL, see Houghton & Grange (2011).

[7]Although this is the approach we use in the current paper, CDF-XL also provides quantile cut-off values for a pre-specified number of quantiles. There seems to be no consensus in the literature whether using the "median of values within each bin" approach or the "quantile cut-off" approach is best for CDF analysis, but in past experience both provide qualitatively identical results.

Since CDF analysis allows the viewing of data across the entire spectrum of RTs we can determine how these conform to the models suggested previously. If language influences the mixing costs across the entire spectrum between conditions, then we can conclude that the effects obtained are consistent. In this respect we would expect that the mixing costs would remain within reasonable cut-off boundaries for each bin (i.e. a mixing cost of 50ms in bin 1 would remain a mixing cost of approximately 50ms in bin 7). However, we can also determine if the mixing cost is affected by language only after a certain RT bin boundary, as such being influenced effectively on a trial-by-trial basis. If we consider that each bin is indicative of a different degree of preparedness (De Jong, 2000), then it is feasible to debate that where costs differ between these bins, different strategies are being employed. For example, where the fastest RTs are obtained these trials are considered as being fully prepared (De Jong, 2000; Grange & Houghton, 2011); the participant is knowledgeable of the upcoming task, has activated the required task-set configuration and can thus give a fast and accurate response. However, where the RTs are at the slower end of the spectrum, and crucially if these costs differ significantly from the fastest RTs despite the same stimuli being used, and the same strategies being available, clearly language is influential to differing degrees.

If the influences of language are consistent across the entire spectrum of trials, insofar as they do not differ significantly across the specified bins, but do differ across conditions then it is likely that a global effect of language is being obtained. However if there are significant differences obtained not only across conditions, but also between different bins within the same condition, then it is more likely that alternative strategies are being deployed during the trials. In this instance it can be debated that task control is being influenced by factors such as vigilance decrement as previously discussed.

In the forthcoming experiments, participants performed a series of task-switching studies, comprising of bivalent stimuli (including identical stimulus-response mappings), explicit task cues, and conditions requiring different forms of language influence. The procedure is presented here not with a discussion of standard RT measurement analysis , but instead focusing on the interactions of mixing cost only across conditions/language influence with analysis provided by CDF obtained values. This will permit a greater insight into the influences of language not solely on the performance of a block of trials, but instead determining if these influences affect performance during certain stages of responses.

Experiment 1

In the first experiment analyses of performance with concurrent relevant and irrelevant verbalisations were made. Relevant verbalisations followed the pattern of reading aloud presented task cues, whilst irrelevant verbalisations were in the form of articulatory suppression. The primary objective of the study was to examine the impact of differing forms of verbalisations upon performance across the entire blocks of trials; allowing analyses to be made on the basis of effective task preparation.

Method

Participants

27 undergraduate students from Bangor University took part in the study and were remunerated with course credits. All participants had normal, or corrected to normal vision. They were required to speak English as their first language.

Stimuli and apparatus

The experiment was performed on a PC with a VGA card using E-Prime 1.1 (PST Software) computer software. Participants sat 60cm from the display (19" TFT). The stimuli consisted of two shapes (square and circle) shaded in one of two colours (blue and red). The square was 2.6° high and 2.6° wide. The circle measured 2.6° in diameter. The colours of the stimuli were red (R:255, G:0, B:0) and blue (R:0, G:0, B:255). Each trial consisted of a single stimulus displayed in the centre of the screen on a white background. Prior to the stimulus display, a task cue was shown in the centre of the screen. The task cue read 'BLUE / RED' (4.9° wide and 0.8° high), or 'SQUARE / CIRCLE' (7.3° wide and 0.8° high) in Courier New font. The response keys for the experiment were the letters C and N on a standard QWERTY keyboard.

Design and procedure

Each trial began with the task cue displayed for 1000ms, followed by a 500ms blank-screen interval. Following this, the stimulus was displayed until response, and followed by a 150ms blank-screen interval, accompanied with a buzzer tone if an incorrect response was given. Three blocks of trials were performed: two pure repeat blocks of 40 trials each (colour and shape), and one mixed block of 160 trials in an alternating runs sequence. Resultantly the mixed block had 80 repeat trials (40 colour and 40 shape), and 80 switch trials (also equally split).

Participants performed all trial blocks under two counterbalanced conditions: Reading Aloud (of the task cue) and Articulatory Suppression. The experimenter monitored task performance from an adjoining room via a microphone system that participants were informed of; this was to ensure that the task was being performed correctly. During Reading Aloud, participants read aloud each task cue (when displayed) at a "standard conversational level". During the Articulatory Suppression condition participants stated aloud the word “blah” at a rate of approximately 2Hz (R. Brown & Marsden, 1991; Saeki & Saito, 2004), also at the specified volume. Standardised instructions were presented on screen. Participants were instructed that they were to respond to stimuli according to a task-cue that would be presented. The task-cue would state Blue/Red or Square/Circle. In the event of Blue/Red appearing on-screen participants should respond to the forthcoming stimuli, pressing C if it was blue and N if it was red. Alternatively, if Square/Circle appeared on-screen, they should respond by pressing C if it was a square and N if it was a circle. They were informed that they should ignore the irrelevant property and only respond to the task-cue prompted characteristic. Participants were also asked to respond as quickly as possible, but to ensure good accuracy.

Participants were made aware that initially there would be two pure blocks of trials where the secondary property would not be required. After the two pure blocks, participants were informed that both task sets “would now be mixed together”, and that they “will be performing the paradigm in an AABBAA format, for example Colour-Colour-Shape-Shape-Colour-Colour and this will require you [them] to remember both rules throughout the block”.

Participants were tested individually and completed all conditions in a single session, taking approximately 45 minutes.

Results

Prior to analyses being conducted, all information from incorrect responses was removed; with all other data remaining, regardless of RT. All RT data was separated for each participant into 10 equally spaced Bins for all trials forms (pure block repeat and mixed block repeat). These Bins comprised of the median value of these responses. All processing of the data into Bins was performed using CDF-XL (Houghton & Grange, 2011).

Data was analysed using a repeated measures ANOVA with factors of Task (Reading Aloud and Articulatory Suppression) and Bin (9 bins). The mixing costs were averaged across all participants for each trial form. Bin 10 was not included in any analysis – the Bin contains the slowest responses and is susceptible to high degrees of variance.

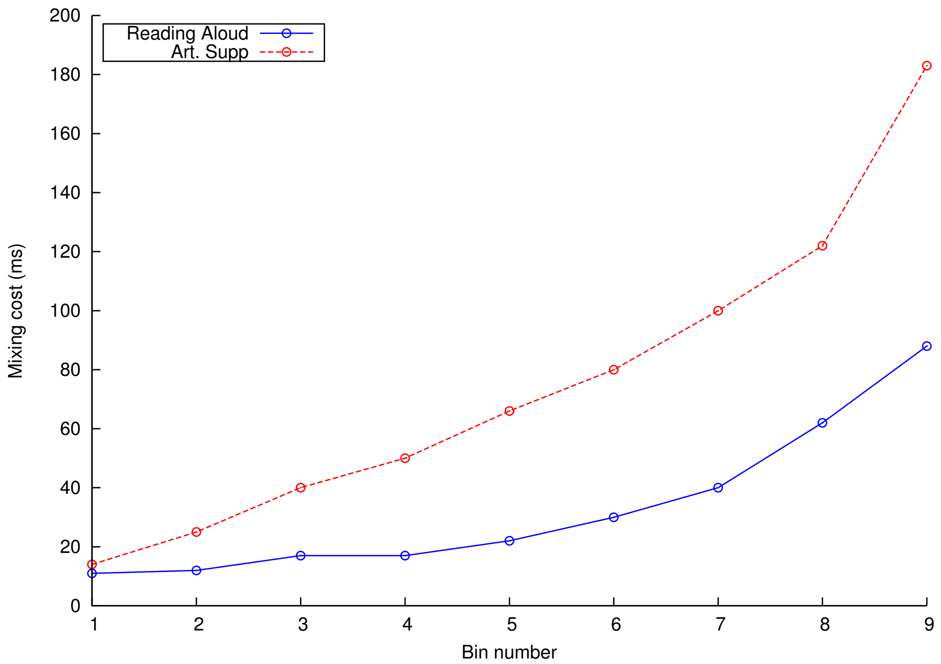

Figure 3. : Experiment 1: Mean mixing costs for tasks of Reading Aloud and Articulatory Suppression for Bins 1 through 9.

A significant effect of Task was obtained [F (1,26) = 28.52, p < .001, η_p^2 = .52], where Reading Aloud had a mean overall RT of 397ms (SD = 54.70, SE = 10.53), and Articulatory Suppression 510ms (SD = 120.65, SE = 23.22).

A significant effect of Trial was achieved [F (2,52) = 31.24, p < .001, η_p^2 = .55], where Pure trials had a mean overall RT of 426ms (SD = 66.27, SE = 12.75), Repeat trials 481ms (SD = 100.08, SE = 19.26) and Switch trials 534ms (SD = 122.48, SE = 23.57). This indicated significant mixing costs of 55ms (SD = 71.16, SE = 13.70) [t (26) = 4.01, p < .001], and switch costs of 53ms (SD =

45.82, SE = 8.82) [t (26) = 5.99, p < .001].

A significant effect of Bin was also obtained [F (8,208) = 168.19, p < .001, η_p^2 = .87].

A significant interaction was obtained across Task x Trials x Bin [F (16,416) = 8.004, p < .001, η_p^2 = .24], indicating that separate analyses could be conducted upon data solely associated to (a) the mixing costs, and (b) the switch costs.

Mixing Costs

Analyses of mixing costs required comparing only pure and repeat trials across Task and Bins. A significant interaction of Task x Trials x Bins [F(8,208) = 5.31, p < .001, η_p^2 = .17] permitted closer examination of the results.

A series of repeated measures ANOVAs were conducted between the Pure and Repeat measures across Tasks within each Bin to distinguish where this interaction was occurring. As can be seen from Table 7, substantial mixing cost differences between the Tasks began to become apparent from Bin 3, but only became significant from Bin 4 onwards. This trend continued throughout all remaining Bins.

Bin	1	2	3	4	5	6	7	8	9
F-value	0.54	1.14	3.18	4.43	5.71	6.03	5.61	4.45	6.92
p	.82	.30	.086	.045	.024	.021	.026	.045	.014
η_p^2	.002	.042	.11	.15	.18	.19	.18	.15	.21

Table 7:: Experiment 1: Results of ANOVA comparisons within each Mixing Cost Bin - determining at what point differences between the costs occur.

Switch Costs

Analyses of switch costs required compared only repeat and switch trials across Task and Bins. A significant interaction of Task x Trials x Bins [$F(8,208) = 4.80$, $p < .001$, $\eta_p^2 = .16$] permitted closer examination of the results.

A series of repeated measures ANOVAs were conducted between the Pure and Repeat measures across Tasks within each Bin to distinguish where this interaction was occurring. Despite the strong interaction result, there are minimal differences found when comparing switch costs between Tasks and within each bin. The results of these individual ANOVA comparisons are seen in Table 8 and clearly demonstrate that differences in Task only become apparent within the final bin, though this finding should be judged with great caution given the large amounts of variance and sudden difference in finding as noted. For these reasons it seems misguided to promote the switch cost findings in the current experiment to a dominant position, and hence although these reflect *some differences*, they are not as core to the crux of the experiment as those much more substantial findings as found with the mixing cost results.

Bin	1	2	3	4	5	6	7	8	9
F-value	0.83	0.72	0.19	0.11	<.001	0.27	1.03	3.45	4.23
p	.78	.41	.67	.74	.99	.61	.32	.075	.050
η_p^2	.003	.027	.007	.004	<.001	.010	.038	.12	.14

Table 8:: Experiment 1: Results of ANOVA comparisons within each Switch Cost Bin - determining at what point differences between the costs occur.

Ratio Analysis

To ensure that the mixing cost interaction between Task and Bin was not a result of the general increase in RT values across the Bins, ratio analysis was performed (Grange, Lody, & Bratt, 2012). Ratios were calculated according to the same principles as the RT data but using the following calculation:

$$\text{Ratio} = \frac{\text{Mixed repeat - Pure repeat}}{\text{Pure repeat}}$$

A significant interaction between Task and Bin remained during this analysis [F (8,208) = 2.11 , p = .037, η_p^2 = .075], demonstrating that the mixing cost interaction between Tasks (as evidenced in the reaction time data) was not a result of a general increase in RT, but instead of the interaction shown towards the tail of the Bins.

Discussion

It is evident that despite the large-scale global differences in mixing cost between these two Tasks, when assessed in a more analytical manner, some of these differences are not as great as presumed. The measurements that are normally assessed in a study of this sort rely upon calculated means – yet as can be seen from the present experiment, these means differ substantially across runs of trials. Clearly, if we relied solely upon the later Bin calculations, we would obtain a drastically different outcome to if we relied upon the initial Bin calculations. Assessment of Bins 1 through 3 demonstrated no significant differences between mixing cost measures for Articulatory Suppression and Reading Aloud, indicating similar performance for both. All significant differences began in Bin 4 and continued through Bin 9. This therefore raises an interesting notion – not all costs are identical, for either Task, and all costs increase as the Bin number increases. However we cannot ignore the obvious, the gradient of cost change of each Task through Bins differs substantially. By assessing the increase in mixing costs of Bins 1 through 5 we can see that Articulatory Suppression increases by 52ms, whilst Reading Aloud increases by 11ms. This increase in cost is not solely limited to the early Bins; assessment of the same costs from Bins 5 through 9 shows that Articulatory Suppression increases by 117ms and Reading Aloud by 66ms. Despite these increases there remains the similar performance given in Bins 1 through 3 across the two Tasks. Drawing upon the theoretical framework given in the introduction, it is highly probable that during the trials within these Bins, similar processing and preparation was performed in both Tasks. Yet if performance is so closely matched here, it raises the consideration as to why differences between the Tasks emanated from this point onwards, and so dramatically.

As has been discussed previously, it is possible for performance to change across a period of trials as a result of vigilance decrement and attentional issues. Logically these performance-deteriorating factors could be responsible for the differences in performance across the Bins. For example, maintaining concentration and attention for a sustained period of time would be tremendously challenging whilst performing concurrent articulatory suppression. Yet whilst reading aloud a task cue on every trial must also contribute to fatigue factors, the benefits obtainable in terms of sustaining attention upon the given task and reducing the vigilance decrement impact, far outweigh this negative factor. As a result, although in some trials (Bins 1 through 3) preparation for the upcoming trial is complete and well maintained, resulting in speeded responses and similar mixing costs for both Articulatory Suppression and Reading Aloud, this processing cannot be performed for all the trials within the block, regardless of trial sequence location. With similar mixing costs being found in Bins 1 through 3, this raises an interesting possibility concerning the preparation for upcoming trials. Since the sequence is predictable and unambiguous it is possible (and encouraged) for participants to prepare for the upcoming trial, and evidently in some instances the nature of the secondary task does not impact this. However with differences between Articulatory Suppression and Reading Aloud becoming evident in later Bins we can speculate as to the competency of task preparation available, particularly within the Articulatory Suppression condition. Due to the interference of this condition it is possible that rather than slowing trial responses at the response stage, instead it is providing a deficiency in the ability to prepare the correct task representation, as demonstrated in the slower Bins.

There are two ways of explaining this however; either Articulatory Suppression is simply too challenging for participants to complete the task without suffering the negative impacts of vigilance decrement, or the benefits of relevant verbalisations (as with Reading Aloud) provide a substantially greater focus and ability to maintain attention on task.

Experiment 2

To determine whether the changes seen in performance between the two previous Tasks of Articulatory Suppression and Reading Aloud were attributable to either: 1. a negative impact of articulatory suppression diminishing the ability of the participants to sustain attention on the task adequately to maintain the correct task sequence [therefore effectively switching on every trial as opposed to recalling whether the upcoming trial is a repeat or a switch]; or 2. instead a result of improved performance due to the relevant verbalisations maintaining the correct task sequence and in turn lowering mixing costs, a selection of new Tasks were chosen for Experiment 2.

Articulatory Suppression was replaced by a Silent Reading task and an Audio co-presentation task. Both of the new Tasks required the same responses from the participants in that all trials were identical, but in the Audio Task additional vocal recordings of the task cues were presented in conjunction with the visual task cues. These two Tasks were chosen, as performance with these would help to indicate a cost-benefit alignment. If the performance differences demonstrated in Experiment 1 were a result of improved task maintenance due to the relevant verbalisations of Reading Aloud, a similar outcome would be expected in Experiment 2 when compared to the Silent Reading task. Although during Silent Reading there would be reduced interference when compared to Articulatory Suppression, the lack of relevant verbalisations is common to both; as a result vigilance decrement considerations emanating from attentional factors should impact both conditions, although not to the same degree. Further, with the introduction of the Audio condition, comparisons can be drawn to those of the Reading Aloud condition – both use verbal task cues, albeit in passive and active formats respectively, and both provide relevant verbal information on a trial-by-trial basis. If indeed the differences in performance seen in Experiment 1 can be attributed to improved performance on the grounds of facilitation and maintenance of task sequence as a result of relevant verbalisations, similar results for both Audio and Reading Aloud can be expected. Due to the active nature of Reading Aloud as opposed to the passive nature of the Audio task, some differences may be apparent, but these should not result in a dramatically different outcome.

Method

Participants

26 undergraduate students from Bangor University took part in the study and were remunerated with course credits. All participants were new to the study, with none having taken part in Experiment 1. All had normal, or corrected to normal vision, and were required to speak English as their first language.

Stimuli and apparatus

All stimuli and apparatus remained identical to that used in Experiment 1, with the exception of the Audio cues. All audio cues were voice-synthesised using standard Apple Voice-Over software, recorded and normalised to -1dB and presented concurrently with the on-screen task cue. The audio cues presented a direct translation of the on-screen task cue, and were designed to replicate the Reading Aloud condition. Presentation volumes were consistent across all participants and were maintained at a comfortable level.

Design and procedure

Aside from the adjustment of tasks – removal of articulatory suppression task, and replacement with silent and audio tasks, all other aspects of the study were maintained identically to those in Experiment 1. Participants were tested individually and completed all tasks in a single session, taking approximately 45 minutes.

Results

All pre-processing of data was performed in an identical manner to that of Experiment 1. Additionally, all processing of the data into Bins continued to be performed using CDF-XL (Houghton & Grange, 2011).

Data was analysed using a repeated measures ANOVA with factors of Task (Silent, Audio, and Reading Aloud), Trial (Pure, Repeat, and Switch) and Bin (9 bins). Bin 10 was not included in any analysis – the Bin contains the slowest responses and is susceptible to high degrees of variance.

A significant effect of Task was obtained [F (2,50) = 5.35, p = .008, η_p^2 = .18], where Silent had a mean overall RT of 443ms (SD = 74.95, SE = 14.70), Audio 414ms (SD = 66.22, SE = 12.99), and Reading 418ms (SD = 72.66, SE = 14.25).

A significant effect of Trial was achieved [F (2,50) = 45.86, p < .001, η_p^2 = .65], where Pure trials had a mean overall RT of 381ms (SD = 45.93, SE = 9.01), Repeat trials 419ms (SD = 68.19, SE = 13.37) and Switch trials 486ms (SD = 101.96, SE = 19.20). This indicated significant mixing costs of 38ms (SD = 39.80, SE = 7.81) [t (25) = 4.85, p < .001], and switch costs of 68ms (SD = 48.67, SE = 9.55) [t (25) = 7.11, p < .001].

A significant effect of Bin was also obtained [F (8,200) = 185.37, p < .001, η_p^2 = .88].

Crucially, a significant interaction was obtained across Task x Trials x Bin [F (32,800) = 2.06, p = .001, η_p^2 = .076], indicating that separate analyses could be conducted upon data solely associated to (a) the mixing costs, and (b) the switch costs.

Mixing Costs

Analyses of mixing costs required comparing only pure and repeat trials across Task and Bins. A significant interaction of Task x Trials x Bins [F(16,400) = 5.08, p < .001, η_p^2 = .17] permitted closer examination of the results.

A series of repeated measures ANOVAs were conducted between the Pure and Repeat measures across Tasks within each Bin to distinguish where this interaction was occurring. These results are shown in Table 9 and demonstrates that differences begin to emerge from bin 6 onwards.

Paired t-tests were performed on all Bins, and confirmed the results as expected from the visual format of the data, see Table 10. Both the Audio and Reading conditions were greatly influenced with respect to a reduction in mixing cost compared to Silent Reading. Although this did not occur until the later stages of the Experiment it is evident however that both provide a consistent influence in

Bin	1	2	3	4	5	6	7	8	9
F-value	0.60	1.15	1.33	1.18	2.15	3.17	4.33	5.27	6.01
p	.55	.33	.27	.32	.13	.051	.018	.008	.005
η_p^2	.024	.044	.051	.045	.079	.11	.15	.17	.19

Table 9:: Experiment 2: Results of ANOVA comparisons within each Bin - determining at what point differences between the costs occur.

comparison to the Silent Reading condition.

	Bin	1	2	3	4	5	6	7	8	9
S vs. A	Mean diff.	9.39	11.44	12.53	14.00	20.26	25.35	35.74	55.08	84.16
	SD	36.62	34.60	35.21	45.17	49.51	53.06	74.17	102.75	138.01
	t	1.31	1.69	1.81	1.58	2.09	2.44	2.46	2.73	3.11
	p	.203	.104	.082	.127	.047	.022	.021	.011	.005
S vs. R	Mean diff.	7.98	6.27	7.05	9.15	13.77	22.95	33.47	49.92	82.03
	SD	50.35	37.83	37.22	46.80	48.96	59.38	69.64	98.29	162.53
	t	0.81	0.85	0.97	1.00	1.43	1.97	2.45	2.59	2.57
	p	.426	.406	.343	.328	.164	.060	.022	.016	.016
R vs. A	Mean diff.	1.41	5.17	5.48	4.84	6.50	2.40	2.27	5.16	2.13
	SD	52.58	42.86	44.67	49.63	54.06	57.46	63.78	84.62	119.50
	t	0.14	0.62	0.63	0.50	0.61	0.21	0.18	0.31	0.91
	p	.892	.544	.538	.623	.546	.833	.857	.758	.928

Table 10:: Experiment 2: Paired t-test comparisons of the 3 Tasks in all Bins - all df = 25. Key: S - Silent, R - Reading, A - Audio.

Switch Costs

Analyses of switch costs required comparing only repeat and switch trials across Task and Bins. Analyses of Task x Trials x Bins resulted in a non-significant outcome [F (16,400) = 0.66, p = .84, η_p^2 = .026]. No further analyses were made.

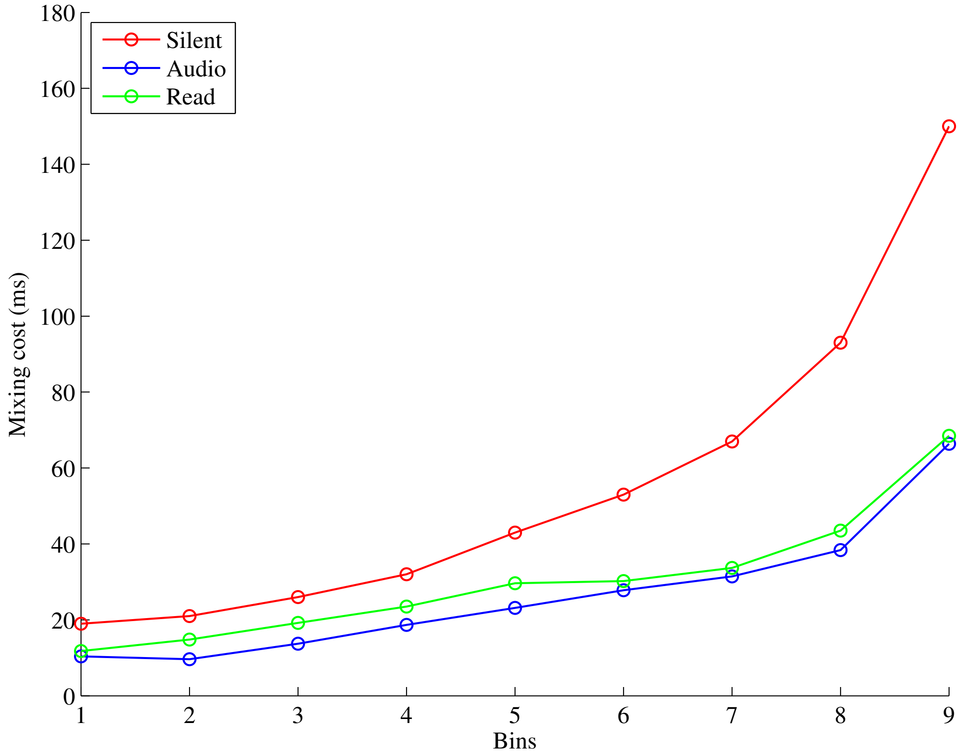

Figure 4. : Experiment 2: Mean mixing costs for all tasks for Bins 1 through 9.

Ratio analysis

As with Experiment 1, ratio analyses were performed upon the mixing cost data. A significant interaction between Task and Bin remained during this analysis [F (16,400) = 2.96, p $<$ .001 $\eta_p^2 = .11$], demonstrating that the mixing cost interaction between conditions (as evidenced in the reaction time data) was not a result of a general increase in RT, but instead of the interaction shown towards the tail-end of the Bins.

Discussion

The results of the ANOVAs within each bin according to mixing cost values clearly demonstrate that the significant overall ANOVA result emanates from the dispersal of mixing cost performance in the later bins (e.g. from bin 6 onwards). Until these later bins there is no significant interaction across Task type and bin number for these measures. However, from this point a clear distinction can be seen that indicates mixing cost performance differs dramatically across Tasks. Closer analysis with the use of individual t-tests comparing Tasks against one-another within each bin was performed to provide clarity concerning where such a result was being provided from. Results obtained for both Reading Aloud and Audio Tasks both differ significantly to those obtained during the Silent Task in the later bins, with Audio providing a marginally greater influence. Comparisons between Reading Aloud and Audio indicated no significant differences within any of the bins. This is a crucial finding as it provides support for the theory that relevant verbalisations sustain strong performance over more trials than where they are not used. Furthermore, this finding provides reduced emphasis for the theory that the results obtained in Experiment 1 are a result of the irrelevant verbalisations increasing RTs disproportionately therefore giving the impression of greater performance when relevant verbalisations are used. Although both Silent and Articulatory Suppression tasks provide no additional information towards the task being performed, the fact that both Reading Aloud and Audio Tasks provide stronger and more sustained performance to just Silent alone provides the necessary information to determine that these tasks facilitate performance rather than performance being reduced through the lack of this additional information.

Experiment 3

In this final experiment a new technique was chosen to maximise the potential of further analyses. In this respect furthering our understanding of how language is impacting performance specifically on a trial-to-trial basis. The decision was taken to maximise the number of trials within each block so as all were equal (e.g. Both pure blocks had equal numbers of trials as the mixed block). The use of this format was intended so as within-block fatigue considerations could be alleviated, but also so as a 1:1 trial format could be achieved; ensuring that fully-matched trial analyses could be performed.

The experimental techniques were implemented within this study, with participants performing the trials whilst Reading Aloud the task cue, performing in silence, or whilst concurrently performing Articulatory Suppression. Due to the increase in experimentation duration, each participant performed a single study format, lasting approximately 1 hour; it was unfeasible to request participants to perform all three conditions and would have led to intense fatigue.

Method

Participants

81 undergraduate students from Bangor University took part in the study and followed the same criteria as with Experiments 1 and 2. All participants were new to the study and had not taken part in either Experiment 1 or 2. 3 participants were removed from one task condition as their results indicated significant outliers.

Stimuli and apparatus

All stimuli and apparatus remained identical to that used in Experiment 1.

Design and procedure

Although each trial format remained identical to those in Experiments 1 and 2, the numbers of trials within each block was dramatically adapted. Three blocks of trials were performed: two pure repeat blocks of 256 trials each (colour and shape), and one mixed block of 512 trials in an alternating runs sequence. Resultantly the mixed block had 256 repeat trials (128 colour and 128 shape), and 256 switch trials (also equally split).

Participants performed all trial blocks in one of three conditions: Reading Aloud (of the task cue), Articulatory Suppression and Silent performance in the same manner as has been described in the previous Experiments. All other aspects remained identical. There were 27 participants included in the analyses of Articulatory Suppression and Silent, whilst there were 24 participants in the Reading Aloud condition.

Participants were tested individually and completed all trial blocks in a single session, taking approximately 45 minutes with adequate time for breaks between blocks.

Results and Discussion

Pre-processing of the data was performed in the same manner as in Experiments 1 and 2 and all data was similarly allocated to 9 bins.

Data was analysed using a repeated measures ANOVA and conducted using Trials (3 levels – Pure, Repeat, Switch) and Bins (9 levels) as within-group variables, and 3 between-groups levels of Silent, Articulatory Suppression, and Reading Aloud.

A significant effect of Trial was obtained [F (2,150) = 83.96, p $<$ .001, η_p^2 = .53], where pure trials had a mean overall RT of 433ms (SD = 92.08, SE = 10.43), Repeat trials 517ms (SD = 176.83, SE = 20.02), and Switch trials 646ms (SD = 230.06, SE = 26.05). These reflected 84ms of mixing cost [t(77) = 5.79, p $<$ .001] and 129ms of switch cost [t(77) = 8.84, p $<$ .001].

A significant effect of Bin was also achieved [F (8,600) = 184.83, p < .001, η_p^2 = .71].

Bin	1	2	3	4	5	6	7	8	9
Mean	306	366	410	452	498	550	618	716	871
SD	44.89	62.62	83.09	105.25	130.40	161.91	202.95	265.37	379.67
SE	5.08	7.09	9.41	11.92	14.76	18.33	22.98	30.05	42.99

Table 11:: Experiment 3: Mean RT measures for each Bin, collapsed across Task. Demonstrates the significant effect of Bin.

A significant interaction of Trial x Bin [F (8, 600) = 49.84, p < .001, η_p^2 = .40] demonstrated that the Bin RT values differed according to which Trial they represented.

Crucially, an interaction of Trial x Bin x Task was also obtained [F (32, 1200) = 1.83, p = .003, η_p^2 = .047], indicating that this increase differed according to the Task being performed, and indeed the impact of Task upon mixing and/or switch costs. This interaction permitted the separate analysis of both mixing and switch costs.

Mixing costs

Using only the Pure and Repeat trials from the Bins allowed analyses to focus solely upon those measures associated to the mixing costs. A significant interaction of Task x Trials x Bins ensured closer examination of the results could be conducted [F (16,600) = 2.19, p = .005, η_p^2 = .055]. Repeated measures ANOVAs performed within each Bin, and across all Tasks highlighted the crucial Bins from where this interaction was appearing.

Analyses comparing Reading Aloud and Articulatory Suppression indicated

Bin	1	2	3	4	5	6	7	8	9
F-value	1.40	3.42	3.98	4.74	5.13	4.99	3.78	2.64	1.82
p	.253	.0.38	.023	.012	.008	.009	.027	.078	.169
η_p^2	.036	.084	.096	.11	.12	.12	.091	.066	.046

Table 12:: Experiment 3: Results of ANOVA comparisons within each Bin - determining at what point differences between the costs occur.

larger mixing costs across Bins for Articulatory Suppression [F (8,392) = 3.40, p = .001, η_p^2 = .065]. Similarly, analyses of Reading Aloud and Silent indicated larger mixing costs across Bins for Silent [F (8,392) = 3.50, p = .001, η_p^2 = .067]. Finally, analyses between Silent and Articulatory Suppression indicated no significant differences in mixing costs across Bins [F(8,416) = 0.73, p = .67, η_p^2 = .014].

While the significant mixing cost x Task interaction findings were interesting it became apparent that focus should be directed towards each Task as an individual entity. Although the relation between each Task and overall performance has some value in comparative terms, the substantial Task differences coupled with long experimentation times limits the importance of any findings. By focusing solely upon performance within each Task permits assessment of cognitive control in a new manner. The core aim of the experiment was to determine the degree to which each verbalisation tactic impacted performance in either a positive or negative manner. By comparing performance measures between pure and repeat trials within each task would determine the extent to which cognitive control was sufficient within each bin, i.e. a small difference (mixing cost) in this measure would equate to a strong capability of maintaining task sequence, evoking faster responses. By measuring performance within each Task individually allows stronger assumptions concerning fatigue and vigilance measures than by comparing between Tasks.

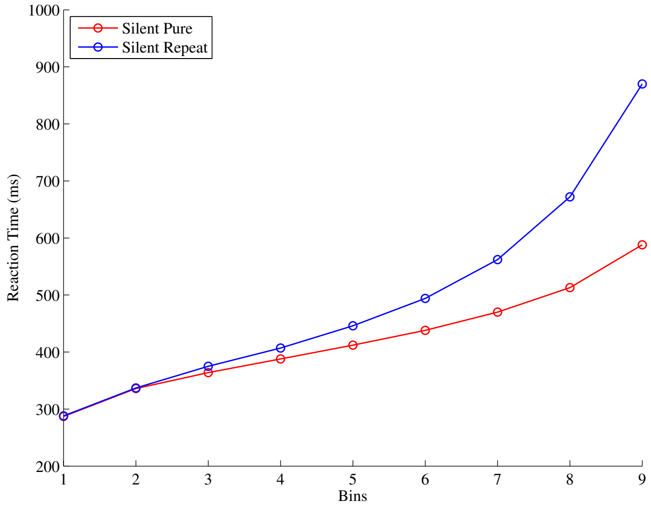

Figure 5. : Experiment 3: Silent - comparisons of pure and repeat RTs within each bin.

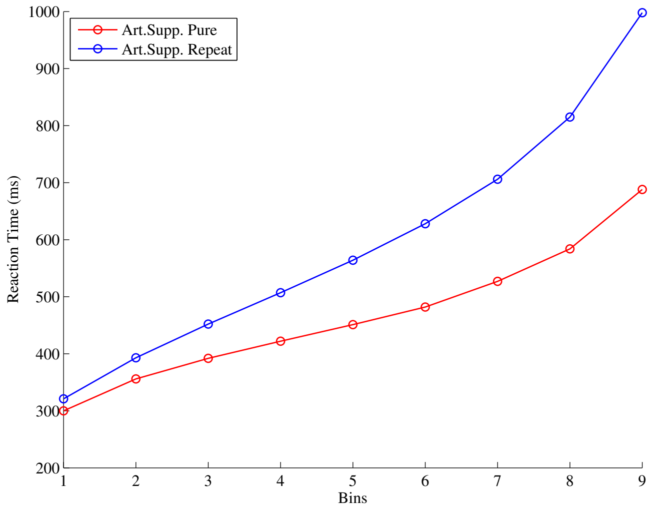

Figure 6. : Experiment 3: Articulatory Suppression - comparisons of pure and repeat RTs within each bin.

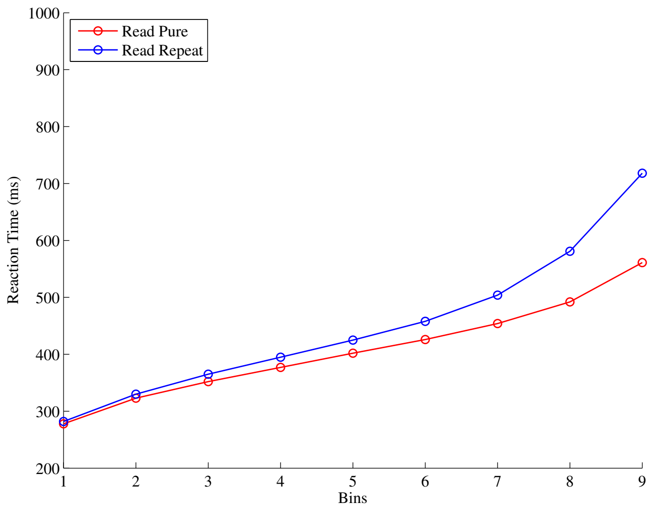

Figure 7. : Experiment 3: Reading Aloud - comparisons of pure and repeat RTs within each bin.

A series of paired t-tests were conducted comparing performance in identical Bins between Pure and Repeat trials for each Task (See Table 13.

Silent									
Bin	1	2	3	4	5	6	7	8	9
Mean diff.	1.67	0.83	10.69	19.52	34.71	55.93	92.29	158.80	281.34
SD	30.26	39.09	48.39	62.52	84.81	113.32	148.76	203.89	321.43
df	26	26	26	26	26	26	26	26	26
t	0.29	0.11	1.15	1.62	2.13	2.56	3.22	4.05	4.55
p	.78	.91	.26	.12	.043	.016	.003	<.001	<.001
Articulatory Suppression									
Bin	1	2	3	4	5	6	7	8	9
Mean diff.	20.59	36.13	59.98	85.08	113.23	146.23	178.89	230.26	309.45
SD	63.34	75.85	106.69	135.73	163.73	199.05	244.72	302.05	368.95
df	26	26	26	26	26	26	26	26	26
t	1.69	2.48	2.92	3.26	3.59	3.82	3.80	3.96	4.36
p	.103	.020	.007	.003	.001	.001	.001	.001	<.001
Reading Aloud									
Bin	1	2	3	4	5	6	7	8	9
Mean diff.	3.83	6.30	12.78	17.54	22.52	31.92	49.74	88.93	157.58
SD	32.94	31.05	37.03	40.45	44.87	51.33	62.19	84.51	147.09
df	23	23	23	23	23	23	23	23	23
t	0.57	0.99	1.69	2.12	2.46	3.05	3.92	5.16	5.25
p	.58	.33	.104	.045	.022	.006	.001	<.001	<.001

Table 13:: Experiment 3: Paired t-test comparisons of the each Tasks in all Bins.

It is evident that both Silent and Reading Aloud tasks resulted in reduced mixing costs across the Bins of trials, compared to those obtained during Articulatory Suppression (Table 13). Indeed, the RT measures for Repeat trials only differ significantly from those obtained in the Pure trials from Bins 5 and 4 respectively, whilst this difference occurs from Bin 2 within Articulatory Suppression. Furthermore a glance at Figure 8 clearly exhibits the substantial differences between the mixing cost difference measures across the Tasks. Although it is not suitable to compare these measures the values obtained by performing the task using different formats is clearly evident.

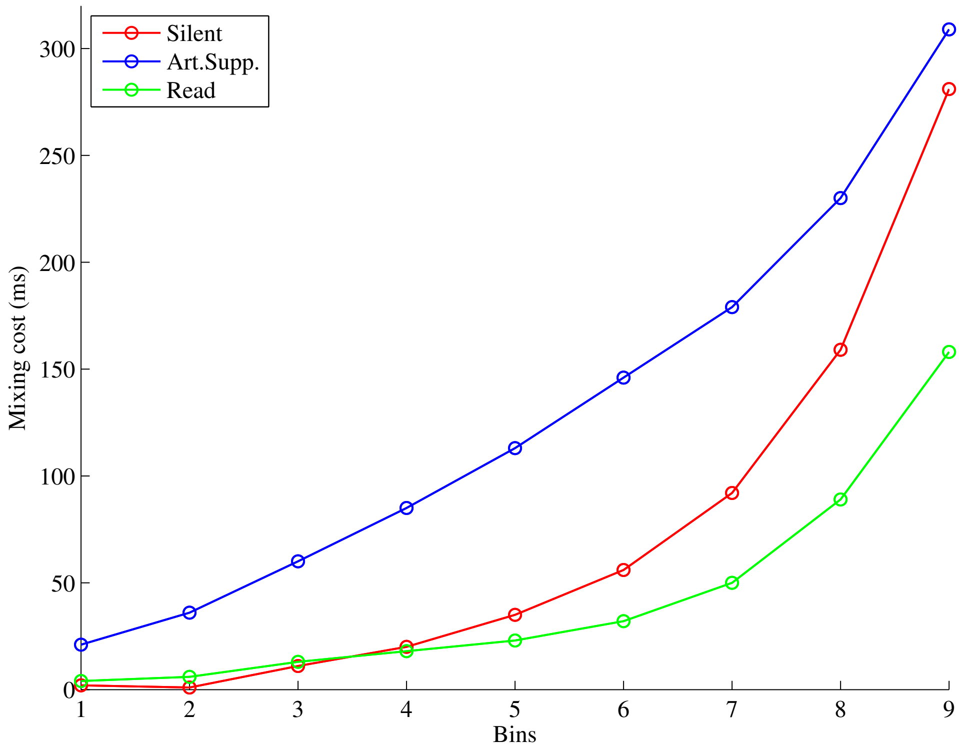

Figure 8. : Visual comparison of mixing cost values across Task within each Bin

Switch costs

Separate analyses were also conducted for the switch costs. The size of the switch cost across Bins was found to not be dependent upon the Task being concurrently performed [F (16, 600) = 1.42, p = .125, η_p^2 = .037]. No further analyses of switch costs were conducted.

Ratio analysis

As with the previous two Experiments, ratio analyses were performed upon the mixing cost data. A significant interaction between Task and Bin remained during this analysis [F (16,600) = 2.59, p = .001 η_p^2 = .064], demonstrating that the mixing cost interaction between conditions (as evidenced in the reaction time data) was not a result of a general increase in RT, but instead of the interaction shown towards the tail-end of the Bins.

General Discussion

Through the non-traditional analysis processes used in the experiments presented, we demonstrate several crucial considerations that must be taken when studying data of this nature. From the data presented it can be determined that where previous studies have noted effects obtained with the mixing cost in particular (A. J. Kirkham et al., 2012), this could be a simplistic outlook. This is not to say that this statement is related solely to mixing costs, it could be attributed to any form of cost that is stated without a greater assessment of how it is composed. Clearly without CDF analysis researchers are making statements that although correct, may not exhibit the full findings of their work.

In our earlier work, we determined that mixing costs are of great interest with respect to verbal instructions and cuing, particularly when having to maintain a sequence of tasks. However, as detailed within the introduction of this paper, although effects of mixing costs were found, we had not considered the distribution of the obtained reaction times until this issue was highlighted (Houghton & Grange, 2011). We are not alone in this overlooking, and are not aware of a substantial number of papers that investigate the distribution of RTs within task-switching paradigms, although a notable few do (Altmann & Gray, 2008; De Jong, 2000; Grange & Houghton, 2011; Schneider & Verbruggen, 2008).

CDF analyses and task preparations

The distribution of RTs is of great importance if we consider precisely what is happening over this spread of responses. If performance was stable across the blocks of trials as a whole, then such analysis would be superfluous; however this is not the case. If we consider that those responses that are fastest [responses are submitted from all participants - such analysis accounts for individual differences] are demonstrative of a prepared response – i.e. the participants were aware of the upcoming task and had prepared suitably, then those that are slower must have been affected by interference or other processes that resulted in slowing. In this instance it is likely that participants are not fully prepared for the upcoming trial (De Jong, 2000; Grange & Houghton, 2011). What is of most interest with regard to the studies detailed here is that regardless of the differences between the experimental conditions, for the fastest bins there are no significant differences between the costs obtained. At these fastest responses, in all conditions participants are adequately prepared for the upcoming trial, it is only as the cost times increase those differences become apparent.

Evidently, with the fastest responses in all conditions participants are adequately prepared to offer the correct response. We believe that this is likely because during these trials, participants are able to maintain the task-sequence that is being performed and hence prepare for the upcoming trial adequately. By maintaining this task-sequence enables the participant to ensure the current task set is available for a swift reaction, resulting a speeded reaction time and minimal mixing cost. It is only as the RTs, and hence costs, increase that the differences between the conditions result in dramatically different mixing cost values. Why exactly the costs split so dramatically is uncertain, since in the fastest responses participants remain capable of maintaining this sequence, regardless of the task being undertaken.

Mixing costs and attentional factors

Focusing on Experiment 1, the increase in mixing costs (between tasks) that suggests reading aloud appears to sustain task-sequences globally (across the entire block of trials) where articulatory suppression cannot, may belie a more complex explanation. Clearly during the fastest responses both conditions are capable of maintaining the task-sequence and ensuring minimal mixing cost, yet this ability dissipates more dramatically during Articulatory Suppression than during Reading Aloud. For this reason we are led to consider the possibility of a more localised effect, that is, a trial-by-trial justification.

Building upon the research detailed in the introduction (Broadbent, 1958; Mackworth, 1948) concerning localised findings there may be some scope for an explanation. We discussed the possibility that during extended periods of time, attention towards a task can dissipate and become less honed. In this respect such dissipation could be a result of attentional fluctuations, but could also be associated to the degree of preparedness for the upcoming trial. We also debated the possibility of greater levels of interference being encountered, potentially also coupled with a decrease in sensitivity towards the stimuli. All of these theoretical viewpoints are possible when we consider the findings of the distribution analyses.

It is somewhat problematic to consider the brevity of concentration, or attention over a prolonged period, and realistically it is not possible to perform deep analysis of these factors in this particular instance. For example, although the number of trials used in each run is adequate for the investigations we are performing, they do not provide enough information with which we can accurately plot mixing costs across the entire length of the trial runs. The pure blocks of trials are not sufficient in length so as to be comparable with trials from the mixed block (taking into account increased fatigue within the extended mixed block); this was an oversight that was later addressed in Experiment 3. However, regardless of this, we cannot presume that all participants will begin to lose concentration towards a task at the same moment, resulting in all slower trials being found towards the final trials of the block. If we consider Broadbent's theories, lack of concentration is not necessarily founded upon a continuous timescale; instead it fluctuates throughout the time period. Even if this is the case and a participant loses concentration, we provide a buzzer alert when an incorrect response is given, helping to promote concentration for a further time period.

For this reason interference levels may be the cause of the results obtained. During Reading Aloud responses are not only faster but also have significantly smaller mixing costs (compared to those with articulatory suppression), at least during the later bins; indicating that participants are capable of maintaining the appropriate task-sequence for not only a longer time-period, but also to a stronger degree. It is important to realise that during articulatory suppression, participants do not entirely lose track of the task-sequence and are capable of performing the correct responses, although they are negatively affected, resulting in slower timings and increased costs. This gives rise to the likelihood that over the course of trials, participants performing articulatory suppression are experiencing greater levels of interference than when reading aloud task cues. However, it may be that this is also an incorrect way of examining the data – rather than explaining the differences on a 'negative-cost' basis, it could be that instead there is a benefit-basis as a result of improved performance through the use of Reading Aloud. To test for this, Experiment 2 examined costs obtained from Reading Aloud, but also Silent Reading, and an Audio co-presentation task.

If the benefit-basis were to be accepted as a reasonable explanation for the findings from Experiment 1, similar results would have to be obtained in

Experiment 2 after substituting the Articulatory Suppression task for a Silent Reading task. Although both are very different in their performance, they both offer no relevant verbal information. Therefore if indeed the relevant verbal statements offer a benefit in performance, similar results in the form of reduced mixing costs would be evident compared to Silent Reading also. To ascertain if this was the case for all relevant verbalisation formats, an additional Audio task was implemented to provide a suitable comparison to Reading Aloud.

The mixing costs obtained for Experiment 2 appear to provide support for this direction of interpretation. Although the effect is delayed considerably when compared to that achieved with articulatory suppression, similar results are still obtained when comparing reading aloud to silent reading. This raises a consideration of the theories posed earlier; although a benefit-basis may be correct in part, it is highly likely that a negative-basis is also at play. If the sole argument of benefit being given as a result of relevant verbalisations were correct, results as per Experiment 1 would be expected. However, although improvements were seen, these occurred much later in the Bins than with articulatory suppression, hence another factor must be an additional aspect. At this point we are drawn back to the interference possibilities outlined. Clearly with respect to a comparison between articulatory suppression and silent reading, interference would be more likely to occur with articulatory suppression; the overall parameters of not only conducting the appropriate irrelevant verbalisations, but also the compounding effect of hearing these must result in a substantial degree of interference compared to a silent reading condition, where no external verbalisations are performed.

Although possible that interference may also result in negative performance outcomes during a silent reading task – it is entirely upon the participant to dictate their internal thought processes, and hence silent articulations, be these relevant or potentially likely irrelevant – it is unlikely the case that this interference be as dramatic as that sustained during articulatory suppression – hence the difference between the tasks. Therefore it is perhaps more likely that the lack of relevant verbalisation input results in a diminished ability to sustain task sequence and competency throughout the Bins. Although interference is at play during articulatory suppression there is little to *outwardly* indicate that it is a prominent factor during silent reading. In this instance it is more likely that attention towards the task dissipates across the trials, resulting in this clear distinction between performance using relevant verbalisations and silent reading. The core factor that links both silent reading and articulatory suppression is the lack of relevant verbalisations; yet during articulatory suppression the additional factor of interference further compounds the dissipation of attention towards the task.

As an interesting addition to Experiment 2, Audio co-presentation of task cues were also given as a separate task to determine the extent to which relevant verbalisations could be used. Clearly the differences between the reading aloud and audio tasks lay in the format of which they were used/presented, however both comprised of the same relevant verbal information and so were considered as comparable. Although it could be considered that the actual performance of reading aloud is more challenging than simply hearing the relevant words there were no differences obtained between the two tasks, either overall or within any of the Bins. Regardless of whether the input of relevant verbalisations is active (reading aloud) or passive (audio) both appear to provide considerable benefits in mixing cost as compared to silent reading.

The use of relevant verbalisations, in either a passive or active format, clearly provides a means to maintain concentration and task sequence knowledge to a greater extent than performing the same trials in silence, despite silent performance of tasks being the traditional format for optimum outcomes. Not only is this conclusion based on overall performance, but by separating obtained results into Bins of median mixing costs across all participants, CDF analysis indicates performance differences across all variations of task. The tasks using relevant verbalisations not only give better overall performance in terms of maintenance of task sequences, but also sustain this for longer, across more Bins than during both articulatory suppression and silent reading.

Influences of matched-length blocks

During Experiment 3 further manipulations were made that provided a more complete overview of the issues covered in the previous two experiments. Articulatory suppression was reintroduced alongside Silent Reading and Reading Aloud tasks. In this final experiment the number of trials within each block was also adapted so as there were equal numbers within each. Although this provided the possibility for increased performance fatigue it did however alleviate concerns about the differences in lengths of trial blocks. The differences between the trial numbers for pure trials and those in the mixed block may be seen as little interest, yet it cannot be disputed that where a block length is limited in comparison to another it may be the case that faster responses are recorded in this instance due to limited fatigue impacts. Whilst ensuring that each block length is standardised results in an increased number of trials[8], and hence an increased amount of fatigue, this resolves important discrepancies. With each block being separated by rest periods it is envisaged that during this time participant fatigue will diminish, and an appropriate restart fatigue level be achieved. Although this may not always be the case, and some participants may find the blocks particularly demanding and thus incrementally more tiring, it is the only format in which applicable cross-block findings can be measured.

[8]A reduction in trial numbers to the lowest of the variations is possible but reduces the value of the data.

It is important to state that due to the increased trial numbers and differences between the tasks overall, it is somewhat illogical to perform cross-task analyses. Considering the task duration approached almost 60 minutes per participant, it is evident that in conditions where participants were performing articulatory suppression their performance will have been affected by fatigue to a greater extent that those performing in Silence. For this reason analyses were conducted in the manner of assessing differences between Pure and Repeat trial formats to determine from which bin significant mixing costs were obtained. It is was discovered that the task that resulted in significant mixing costs *earliest in the bin structures* (bin 2) was unsurprisingly Articulatory Suppression. Given the task requirements this finding was to be expected; the increased demands of reciting irrelevant words whilst performing the task, distracting from the core response objective, can only serve to distract from the task itself if not in terms of complete performance reduction, but in increased difficulty of task sequence maintenance and associated response times. The remaining two tasks also produce significant mixing costs but not until bins 4 and 5 for Reading Aloud and Silent respectively. Although these may be viewed as occurring earlier in the bin structures than perhaps expected, it is important to not take these results out of context. If we compare the mean difference in RTs between the Pure and [mixed block] Repeat trials for both Reading Aloud and Silent tasks, to those obtained during Articulatory Suppression we can note vast differences. The costs found during Articulatory Suppression are substantially larger than those obtained in the remaining two conditions (see Table 13). However this is not to say that there are no differences seen between the tasks of Silent and Reading Aloud. Although similar in the bin mixing costs, in respect of during which bin significant costs are obtained, we can note that the costs increase greater during the Silent task than during the Reading Aloud task, indeed by Bin 7 it can be seen that the difference equates to approximately 2x comparing Reading Aloud to Silent, despite the similarities in the earlier Bins. A visual representation as shown in Figure 8 clearly depicts this substantial increase in cost compared to the more subtle increases seen during Reading Aloud.

Although these results are obtained during runs of trials substantially longer in length than those presented in the previous two experiments, the results remain similar and provide the same theoretical outcome. It seems that regardless of the differences in perceived fatigue across the Tasks, where additional task information is used by the participants improved task performance is demonstrated as a result of increased sequence maintenance capabilities. An additional consideration must be made however, that task induced fatigue may not related to the numbers of trials or demands in this respect. It must be stated that in conversations with participants, those performing the Reading Aloud task gave accounts of substantially increased fatigue compared to those that performed the Silent task. Whilst this may be perceived as an inevitability due to the additional repetitive vocal element with the task, it cannot be overlooked in only this manner. It is clear that there are substantial reductions in mean difference RT measures between these two tasks where Reading Aloud presents the smaller measures, however this is presumed to be a result of the increased concentration on the task as elicited by the vocal cues. So whilst the additional vocal elements undoubtedly contribute to the increased fatigue, it is also likely the cognitive demand necessitated by the vocal cueing and associated priming towards responses also contributes to a potentially even larger extent upon the fatigue measures. This draws an interesting conclusion that whilst reading aloud and hence prompting oneself towards a sequence assists in the capabilities to perform the task well, there is a fine-line between assistance and hinderance. It could be suggested that where task complexity demands greater assistance towards correct responses, vocalising cues (or other directions) could indeed help with improved performance, yet will place an additional stress upon the participant that may not be necessary with a less complex task. Although it could be argued that the current task was relatively simple, the requirements of sequence maintenance elevated this to an extent where vocal cues assisted performance.

It has been demonstrated in the present three experiments that where additional verbal elements are used in conjunction with visual cues, improved task performance can be seen. Although this further supports work presented in earlier chapters, the additional analysis using CDF measures permits a greater level of insight to be gained from the data. Initially it was uncertain whether these task differences were to be found on a global level and as such would impact all trials similarly, or whether these differences could be mapped upon a local level, and as such differ on a trial-to-trial basis. From the results obtained it is clear that the latter is true, with at least a proportion of trials from each comparative task resulting in highly similar cost measures, therefore indicating that task preparation is substantial enough to elicit fast responses regardless of the additional task. Yet it is also clear that the mixing cost measures increase greatly with increases in Bin numbers, particularly where the additional task is unrelated to the actual task performance, as in the case of Articulatory Suppression. Comparisons between task performances where all configurations are related towards the task, or offer no inhibiting elements (Experiment 2) further demonstrate that performance is sustained with the use vocal elements, regardless if these are self-generated verbalisations, or recorded verbalisations presented through audio means. Regardless of the additional element, it is clear that all differences obtained are not demonstrative of global affect across tasks, but rather due to differences in individual trial performances that impact at a more local level and permit stronger performance by increasing sequence maintenance in this format, i.e. by providing an indication at each trial point.

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In the studies presented thus far the focus has been upon behavioural measures, and specifically related to mixing cost latencies between manipulations. In the forthcoming chapter the focus was changed to relate to the assessment of cortical activity through the recording and analysis of ERP measures, in addition to the traditional behavioural measures. Due to the requirements of ERP recording it was necessary to adjust the task manipulations that had been used in the previous studies since articulation verbalisations were not possible with gross distortion of the recorded waveforms. To this end manipulations were constructed that focused attention to either a verbal (audio) cue, or a visual cue, whilst the alternate provided no relevant information. The presented studies highlight measures where the alternate cue is either neutral in that it presents irrelevant but none task-related information, or incongruent in that it presents incorrect information (relating to the alternative task) – in this sense prompting conflict resolution demands.

CHAPTER 6

MIXING COSTS: ERP ANALYSES OF AUDIO AND VISUAL CUE-CONGRUENCY MANIPULATIONS.

Abstract

Where relevant audio cues are presented in conjunction with relevant visual cues, improved performance can be seen in terms of reduced mixing costs, indicating that task-sequence maintenance is improved. It seems likely that through this modality-integration performance is facilitated by permitting a greater ability to maintain task-sequences and task-sets within working memory, whilst decoding potential response conflicts. Although these results are interesting in that they serve to highlight the co-operative format of the two modalities, it is unknown how such integration occurs. To address this query ERPs can be used, since with such a technique it is possible to gain insight into cortical areas of activation for each modality, combined with strong temporal measures. This may allow theories to be devised concerning how the two modalities interact with one-another to facilitate such strong task performance when used together.

Two distinct studies were conducted where visual and audio cues were presented in conjunction, where only one modality provided information relating to the task being performed. Tasks examined performance in an alternating-runs task-switching paradigm where responses were required to stimuli in respect of either their colour, or shape. Experiment 1 provided the alternative cue modality in a neutral format, in that it provided no information relating to the tasks. Experiment 2 provided the alternative cue modality in an incongruent format; it provided information relating to the opposite (and incorrect) task – i.e. a visual cue directing attention to the colour task, with an audio cue directing towards the shape task. Behavioural results indicated highly similar performance measures for both tasks within each experiment. Analyses of ERP measures indicated marginally larger potentials in Experiment 1 for the visual cuing formats over the audio cuing formats, within the frontal and fronto-central regions. Experiment 2 demonstrated much larger differences; potentials for the

visual cuing formats were *substantially* larger than those for the audio cuing formats and were observed in multiple regions for longer time periods. These included frontal regions, but also left parietal regions. These increases are thought to indicate increased phonological rehearsals, but also crucially increased cue-conflict decoding mechanisms. The results obtained provide evidence of differing processing methods for visual and audio cue modalities and appear to demonstrate the increased attentional requirements for visual cuing over audio cuing, despite similar response timings.

Introduction

Although past research has investigated the behavioural impacts of mixing costs, how and why they occur, and theorised upon how they are affected, relatively little is known about the neurological changes in evidence during their formation. For example, we have previously asserted that mixing costs occur as a result of the requirements of maintaining task-sequences, yet the indices of these measures are only available post-response with standard behavioural methodologies. Despite these measures being of great value they are nevertheless confounded by certain factors, for example issues with task set reconfiguration. R. D. Rogers & Monsell (1995) state (with regard to the process of switching tasks - yet the point remains valid for repetitions where task sequence maintenance could be lost) that reconfiguration for a new task set can only be completed when the stimulus is shown to the participant, regardless of the amount of preparation given towards the switch; hence why a residual cost is always apparent whether preparation time is 200ms or 2000ms. The reasoning behind this is that the previous task set permeates and remains partially active until the stimulus appears and the new task set can be reconfigured fully. This can be considered to be a moot point, since regardless of the task the residual cost remains, therefore this should not confound measures across tasks to a large extent; however it highlights one of the negative points of behavioural measures - although preparation and processing begins prior to the stimulus appearing, we cannot determine any of the ongoings before a response is provided [9] For this reason it seems a logical progression to use a fresh methodology, in addition to behavioural measures, to provide information relating to this preparation period - in this case ERP measures.

[9] See also Mayr and Keele (2000) for an alternative theory of reconfiguration and residual cost - backward inhibition of a previously completed task set, and the requirement to overcome the persisting inhibition to allow reconfiguration of this same task set to occur. Both viewpoints highlight the same factor and are relevant to the argument, despite following alternative theoretical lines.

Neurological Regions of Interest and Mixing Costs

Cognitive control can be determined through any number of methods, but regardless of whether they are experimental in their formation (e.g. the Wisconsin Card Sorting Task or the Stroop test), or even in a day-to-day outlook (e.g. making a cup of tea, or baking a cake), the processes remain similar; the requirement to combine multiple strategies and modalities, to be aware of your current position, and to maintain the knowledge of other responses that may be required. Poor performance in any of these forms of tasks could be inferred as difficulties with cognitive control and performance, yet the manner in which this poor performance is exhibited can be in several forms, e.g. perseveration with a task for a period longer than required, or difficulties in switching between the tasks themselves. Although persons with cognitive control issues have multiple symptoms, many share a core neurological issue - problems with their frontal and prefrontal cortices (Milner, 1963; Owen et al., 1993). These findings, coupled with other research has often led researchers to the belief that the core areas of cognitive control, and thus working memory, lie within this area (D'Esposito et al., 1995; Fuster, 1997)[10]. Therefore it is a likely situation that during tasks involving strong working memory functioning, such as task-switching, that these regions are likely to be active (Aron, Monsell, Sahakian, & Robbins, 2004; Brass et al., 2003; Dove, Pollmann, Schubert, Wiggins, & Cramon, 2000; Dreher & Berman, 2002; M. Sohn, Ursu, Anderson, Stenger, & Carter, 2000; Szameitat, Schubert, Müller, & Cramon, 2002).

Although the prefrontal and frontal cortices are undoubtedly heavily involved in the role of cognitive control, clearer distinctions must be drawn. Currently cognitive control has only been discussed in terms of broad statements, yet the inner-roles of such control involve multiple forms that require closer inspection.

[10]For a comprehensive review of Prefrontal cortex functionality, see Miller & Cohen (2001).

For example, in the Stroop test it is important to *retain* both task-set forms in working memory (respond to the word, or the colour of the text), *maintain* the current task-set that is being performed, and crucially control for *conflict (and the monitoring thereof)* between both of these task-sets in order to select the appropriate response. Although possible to state that the vast majority of all of these processes occur within the frontal and prefrontal cortices, and it is not anatomically incorrect to do so, a clearer picture can be drawn in relation to the anatomical locations involved in each of these. Take for instance the example of *conflict monitoring* within a Stroop test paradigm - with two task-sets being active under identical stimuli it is crucial that the correct response is made to the properties that are applicable. Monitoring of the stimuli in situations such as this is not as clear-cut as when stimuli are only applicable to one response format; in this sense a conflict is present. Evidence suggests that a separate anatomical entity is responsible (at least in part) for the monitoring of such conflict, providing top-down processing information relating to the tasks, particularly where there is incongruous detail present - in this sense providing higher order cognitive processing — the anterior cingulate cortex (herein referred to as the ACC) (Barch et al., 2001; T. Braver et al., 2000; Pardo, Pardo, Janer, & Raichle, 1990; Peterson, Fox, Posner, Mintun, & Raichle, 1989)[11]. Although important it is not necessarily the case that the ACC is solely responsible for resolving this conflict, but could work in conjunction with the dorsolateral prefrontal cortex (DLPFC) to highlight the importance of more careful task-set response selections at the present time (Botvinick et al., 2001; Liston et al., 2006).

The combination of ACC and dorsolateral prefrontal cortex (DLPFC) activation is not perhaps as clear and concise as has been depicted however. The use of the

[11]Although the disparity between a verbal-based task and a Stroop task is highlighted in Pardo et al. (1990) this remains a strong comparative in the performance of cognitive tasks; the overwhelming urge in such a task, as with Stroop, is to state aloud the word seen - the requirement to generate a new (but semantically related) word ensures the cognitive complexities are relatively similar.

Stroop paradigm undoubtedly assists in determining when activation occurs, and the dissociation between the two, and perhaps the most crucial of the research was conducted by MacDonald, Cohen, Stenger, & Carter (2000). In this seminal research, MacDonald and colleagues worked towards the goal of dissociating these two seemingly interconnected components of cognitive control, with fascinating insights being gained. Rather than presenting a Stroop paradigm in the traditional sense, an adapted version was given which provided instruction on each trial (i.e. respond to the ink colour, or the word). Through this split-level design analyses could be conducted that investigated both the preparatory period, and the response period. Interestingly it was discovered that DLPFC activity occurred during the instructional preparatory period when requesting a response to the ink colour, but not when requesting responses to the word itself. There was no activity noted from the ACC during this period. Furthermore, it was determined that with participants for whom substantial activations were observed in the DLPFC, decreased Stroop interference was noted. In this respect, the greater the activation the easier task performance was. It seems plausible that in this instance the DLPFC appears to be regulating top-down cognitive control, and is engaged for the role of maintaining attentional requirements. During the response period DLPFC activity was also observed, however this did not differ according to the congruency of the Stroop task; ACC activity was not consistent however. Incongruent ink colour trials produced substantially greater activation in the ACC region than congruent trials. In this respect, much in line with other researchers' beliefs (Barch et al., 2001; T. Braver et al., 2000), it seems that the ACC has a substantial role in conflict monitoring. Within MacDonald and colleague's research it was shown (although not statistically significant) that participants who demonstrated greatest Stroop interference also exhibited the most substantial ACC activations. Hence although the two components are often considered as providing close regulation towards task-goals in conflicting paradigms, it appears that the dissociation is also a core factor. Whilst the DLPFC provides top-down cognitive control during preparation for response, it is the ACC that monitors for, and evaluates any conflict present which may require further cognitive control processes.

With the role of the ACC being crucial to the successful completion of cognitively demanding tasks such as those found within a task-switching paradigm, where multiple response rules must be maintained and activated at the correct time, it is imperative that some explanation is given (as above), but it is also important to not let such research cloud the main crux of the present work. Yet, in some trains of thought this is an inevitability and one that must be accounted for, particularly given the methodology employed presently.

Although cognitive control has been investigated to an extent with ERP methodologies, the majority of this work has focused on the changes that become apparent as a result of conflict found at the response stage - that is, the conflict that is elicited upon presentation of a stimulus. The unique findings in much of this research has highlighted that a distinct deflection can be observed between 200 - 350ms post-stimulus presentation (commonly referred to as ‘N2’, or ‘N200’) and is thought of being an outcome from the detection of conflicts relating to the response stage of a trial (Yeung, Botvinick, & Cohen, 2004). Such observations are found more specifically when the participant has to perform in a non-typical manner, e.g. a no-go trial in a go/no-go paradigm (Eimer, 1993; Kok, 1986); even when a response is not explicitly required (Pfefferbaum, Ford, Weller, & Kopell, 1985). Further, this activation is typically observed in the fronto-central cortical regions, such as FCz and Fz. Such findings have been observed in numerous studies, using a range of paradigms and methodological considerations, demonstrating that the finding is robust. For example, a larger N2 is observed in incongruent trials compared to congruent trials in an Eriksen flanker task (Kopp, Rist, & Mattler, 1996). Yet this may give a misleading impression, it is important to state that such a component is *not necessarily* the result of an *unexpected* trial stimulus - instead it is often found where greater cognitive control is required to either suppress responses (e.g. in a go/no-go scenario), or to enable an incongruent response (e.g. in the Eriksen flanker task). Indeed, such components are observed even in situations where the alternative (and N2 eliciting prompt) has a varying frequency (Nieuwenhuis, Yeung, Wildenberg, & Ridderinkhof, 2003), thus negating any considerations that the component is a result of an unexpected trial format.

What may become apparent is that these findings coincide with the work of (Botvinick et al., 2001), who asserted that the ACC was heavily integrated into the conflict-decoding process management. Although these two theories may appear to conflict themselves, due to the location of the most predominant N200 components this may not be the case. Indeed, it is quite probable that the N200 component may be elicited by the ACC decoding any conflict present (Veen & Carter, 2002).

Until this point the only situation for ACC activation to be given consideration is when it may be assisting in the resolution of conflict to permit a correct response. This however is not the only situation in which activation from this area can be observed. In the instance that an incorrect response is given, it could be considered that any conflict monitoring and/or resolution has not been suitably performed; and whilst this may be true, activation is again observed from the ACC region. In the instance of an erroneous response a negative potential can be observed and is referred to as error negativity (Ne) (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990), or error related negativity (ERN) (Gehring, Coles, Meyer, & Donchin, 1990; Gehring, Goss, Coles, Meyer, & Donchin, 1993); the two terms have been agreed as describing the same component and are use interchangeably (Falkenstein, Hoorman, Christ, & Hohnsbein, 2000).

The research of Falkenstein et al. (1990) observed both negative (Ne) and following this a positive (Pe) potential when incorrect responses were given. It was presumed that the ERN was produced as a result of signal mismatching. The degree to which this is shown in the ERN amplitude was thought dependent upon the degree of mismatch between the intended and performed action (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Coles, Scheffers, & Holroyd, 2001). Yet the cause of the ERN potential is a highly contentious issue of which no definite conclusion has been made. A further theory of the ERN deflection emerges from the conflict monitoring theories as previously discussed in terms of pure ACC activation (Botvinick et al., 2001; Yeung et al., 2004). In many respects this is a sensible theory as awareness of response requirements do not halt at the stage of response activation; such awareness, and hence monitoring for conflicts continues despite the response being activated. As a result there is likely a duration where incorrect and correct responses are both activated (Botvinick, Cohen, & Carter, 2004). In an anecdotal sense this is likely the cause of the realisation that we have made an error before we are alerted to it, e.g. when dialling a telephone number; we are aware of the sequence and yet sometimes an error is made. We are likely to realise this at the point of pressing the incorrect digit without necessarily any feedback to prompt this realisation. Combined with other research evidencing a Ne deflection with correct responses also (Nieuwenhuis et al., 2003; Veen & Carter, 2002; Yeung et al., 2004) (see previous paragraph on N2/N200) activation in this manner of comparing mismatching responses seems logical. It is probable, from basing beliefs upon this research, that conflict monitoring is likely to be a major function of the ACC, be this in the duration immediately prior to, during, or even after response. The monitoring of the stimuli, and responses (whether correct or incorrect) and associated conflicts occurs throughout the trial duration and could be responsible for the observed ERN. A final (as presented here) theoretical consideration involves a reinforcement learning function that serves to modify subsequent behaviours as a result of an incorrect process being committed previously (Holroyd & Coles, 2002). Whilst the specific details of how the reinforcement learning process is generated through the mesencephalic dopamine system is beyond the scope of this present work, the theory is sound and is further enhanced by the strong binding to Feedback Related Negativity (FRN), as is briefly described shortly. For further information on the wide-scope of ERN research a comprehensive evaluation is presented in Wessel (2012).

Whilst the ERN is observed even without any feedback to indicate an error has been made, a further component is visible when it is indicated to the participant. This potential is similar to the ERN but is labeled Feedback Related Negativity (FRN) and is observed upon error indicating feedback (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; Miltner, Braun, & Coles, 1997). One of the more robust viewpoints as to the result of the FRN is that it ensures adaptation for future responses, and hence reinforces learning behaviours (Holroyd & Coles, 2002) through an evaluation of outcomes. The FRN is therefore observed when the outcome obtained is clearly worse than expected, as in the case of a monetary loss in a gambling task, for example (Gehring & Willoughby, 1997). The size of the FRN deflection is *not* thought to be affected by the degree of loss or bad outcome however (where a larger monetary loss may have resulted in a larger FRN potential), and instead activates as the result of a 'binary-characterised' good versus bad outcome of response (Hajcak, Moser, Holroyd, & Simons, 2006). Whilst it is uncertain if both the ERN and FRN originate in the same region of the ACC, another issue with conflicting theories, what cannot be disputed is that both are highly integrated within cognitive control and likely to be susceptible to activation in the forthcoming work.

There is little disputing the core roles of the prefrontal/frontal cortices, and indeed the ACC in the performance of complex cognitive tasks – therefore the appearance of ERP potentials in these regions are to be expected. However, since in the present work source localisation is not possible it will be difficult to differentiate between precise areas of activation.

For example, the ACC consists of Brodmann areas 24, 32, and 33 which if processed using electrodes placed atop the skull will permeate through the prefrontal regions of interest - see Figure 9. Although anatomically dissociable the spatial resolution of ERP measures will likely result in peaks being apparent in similar electrode locations. Although this may be determined as a methodological issue, it can nevertheless provide a wealth of information with regard to the processing underlying it. Given the theoretical roles of both the pre/frontal cortices and the ACC, and how they differ [to an extent][12] it is a possibility that components may be distinguishable given the characteristics of the tasks undertaken.

Despite the methodological issues with ERP measures it remains possibly the most suited means of assessing performance traits in a task-switching format such as is presented here. The ability to measure potentials in terms of millisecond precision far outweighs the negative issue of spatial resolution in terms of assessing cortical impacts from task format manipulations.

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The ability to measure mixing costs, although not a recent development, is not one that has been capitalised to the same extent as the ability to measure switch costs. Depending upon the chosen task-switching paradigm it is possible to index both mixing costs and switch costs within the same paradigm (R. D. Rogers & Monsell, 1995) (alternating-runs) and under the same load and context (Spector & Biederman, 1976), which is highly appropriate given that both are measured using the same trials. However, given that each form of cost is associated to

[12]with the pre/frontal cortices being central to the cognitive control elements, whilst the ACC appears to be more focused upon conflict monitoring and resolution tasks

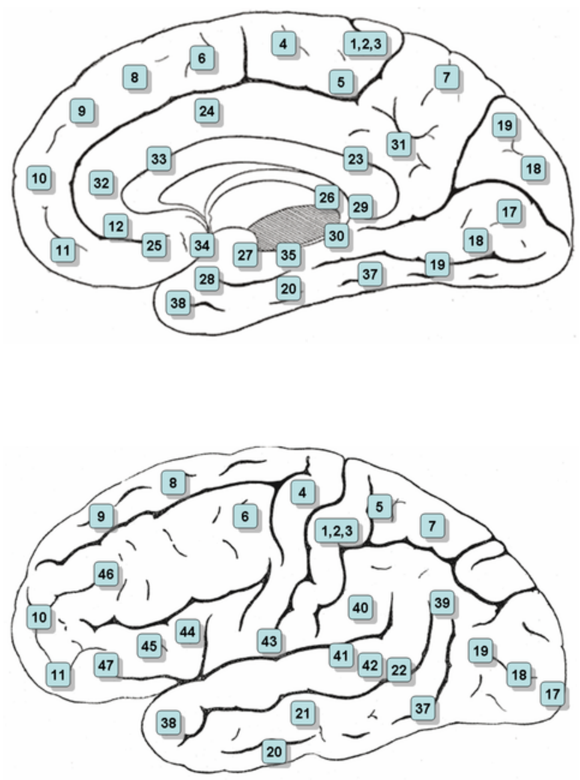

Figure 9. : Brodmann areas map

different contexts and factors it is applicable to measure and treat each as individual entities; switch costs being indicative of the time taken to reconfigure and respond to a fresh task-set, and mixing costs being attributed towards the maintenance of task-sets and sequential factors. In the respect of the present work it seems prudent to focus entirely upon mixing costs as these represent the core research aim, and further are more integral to the theme of cognitive control than switch costs given that *control* is not only semantically tied, but also figuratively tied to the maintenance factors of mixing costs.

Basing the present work upon the factors discussed in A. J. Kirkham et al. (2012) the research aims are to build upon the theories discussed in that manuscript in terms of the cognitive processes underlying the results obtained, using a fresh methodology. In this previous research it was determined that where audio task cues are presented prior to the onset of a stimulus, mixing costs are reduced compared to when there is no audio element made available and reliance of task set selection/maintenance is made solely upon a visual cue and internalised speech commands (if used). The same semblance of mixing cost reduction is obtained when outwardly-given verbalisations are made in connection with the presented visual cues, thus emphasising the importance of auditory processing regardless of whether it is self-generated or provided by a third-party. The reasoning for this reduction in mixing cost is theorised as being a result of a greater implementation of cues into the working memory structures — effectively 'boosting' the effect of the cue in facilitating sequential maintenance. Yet it is unknown precisely how this is occurring, and whether it is formulated by the direct transfer of audio information (in both audio and verbal task manipulations) into the working memory structures, or if it is found through other non-direct routes.

Focusing solely upon comparisons between trials with audio cues and those with only visual, it is a reasonable assumption to draw that processing of the audio-based cue is performed with greater speed and efficiency than the visual cue. By their very nature they are encoded into phonological stores with greater ease and require substantially less transformation than those of a visual modality which must be encoded into a phonological format and processed through rehearsal means (Shallice & Vallar, 1990; Sperling, 1967) before potentially being placed into a rehearsal loop (Baddeley, 1986). With such discrepancies between the two modalities it is clear that some differences will be apparent, and that these appear in the form of mixing costs indicates that it is primarily the sequential demands that are reduced with audio cuing, rather than having any such impact upon the ability to initialise switching between tasks. Given the vastly different formats of the cues it is not inconceivable that although both cue formats result in the same outcome (i.e. a response towards the stimuli using the correct task-set), and thus it is highly likely that both impact upon the same structures in the final stages of the process, that each format follows a unique and dedicated cortical pathway, or processing stream (Penney, 1989)[13]. Despite both of these theories being individual in their basis, it is possible that both could effectively be connected to a large extent — although encoding the visual information into a phonological format, a process made easier with audio cues, needs to be performed the processes involved prior to this stage may be performed along separate streams. While the initial processing (in separate streams, or through other means) cannot be considered as an irrelevance it is nevertheless an aspect of the present research that is unlikely to be answered conclusively. Instead rather than focusing primarily upon *directly* distinguishing different pre-processing pathways of activation, the core objectives remain to determine the differences between audio and verbal cuing modalities, although some elements of this pre-processing will inevitably become apparent.

Core areas that will be of interest will also include [in addition to the DLPFC and ACC] the posterior regions of the temporal lobe such as the intraparietal sulcus (IPS), posterior regions of the parietal lobes, and the supramarginal gyri, for purposes of recoding and storage/retrieval of phonological information (Henson, Burgess, & Frith, 2000; Jonides et al., 1998). Although the assertion can be made that in both situations of audio and visually presented cues activations may involve similar regions of interest (since it is inevitable that both formats will require the same processes of rehearsal, storage and retrieval of the phonological information), it is highly likely that the visual cues will produce greater potentials, particularly in the frontal regions responsible for the encoding/recoding of the visual information into a phonological format (Baddeley, 1986; Henson et al., 2000). Furthermore it is also likely that the posterior regions will exhibit increased potentials relating to the storage of this

[13] Although the research of Penney (1989) states this viewpoint the author is careful to detail that in respect to their multiple theories that individually they could be asserted as being related to other non-distinct-pathway theories, but that the evidence overall points towards this being the case.

information. Although storage will be required for both the audio and visual (post-encoding) cues it is likely that the visual cues will still require a more substantial form of storage. Despite the phonological information being identical for each, the extra requirements of internal phonological generation will likely result in greater demands relating to this stage, since the audio cues may possess a more direct stream to the working memory regions especially given the belief that auditory formats may be more enduring than visual formats (Penney, 1989).

Basis of research

At this point a brief summary may be beneficial since the nature of what is being investigated is far-reaching and branches into many areas. The core focus of the forthcoming research will investigate differences in performance during a simple task-switching paradigm during which trials are cued using either audio or visual formats. Measures will be taken that index performance in terms of RT and accuracy, and furthermore allow analysis in terms of mixing costs for both - indicative of abilities to maintain sequences of task-sets. Additionally, performance of these tasks will be conducted with ERP techniques that may assist in drawing theories towards regions of activations across time for both of these cue formats, and differences in potentials in several electrode locations. Crucially the focus lies solely upon performance towards the cues, and not the stimuli. For this reason the two measurement types are individual and cannot be compared (RT & Accuracy and ERP potentials) per se, except in terms of impact of processing upon response outcome.

The results from A. J. Kirkham et al. (2012) indicate the strong likelihood of a combined-cuing boost towards responses where both audio and visual cues are presented in conjunction with each other. Notwithstanding the interesting nature of these results, disentangling the cognitive processing underlying each modality would be impossible with a design such as this. For this reason the decision has been taken that within Experiment 1, each cue modality will be presented (both audio and visual) at the same time, however only one will be applicable to the task-set of the block. As such the methodology for cuing can be considered as neutral, whereas in A. J. Kirkham et al. (2012) it can be considered as congruent. By ensuring the irrelevant modality of cuing is not related to the tasks should ensure that its impact is minimal, but will enable comparisons to be drawn at a later stage to other cuing strategies.

Global Experimental Methods

EEG Recording

All EEG measures were recorded continuously from 64 electrode sites of the International 10/20 system and referenced to the mastoid region (TP10). All electrodes were sintered-silver chloride electrodes and were fitted to an elastic electrode cap. VEOG channel recordings were made using a bipolar eye channel with two individual electrodes placed approximately 1cm above and below the left eye. The output signal from the electrodes was amplified with a 16-bit Synamp amplifier with a gain of 500 times and a sampling rate of 1000Hz. All electrode impedences were below 7kΩ. The continuous EEG was recorded using Neuroscan Acquire on a PC. A connection between the stimulus presentation PC and the EEG recording PC allowed the time of task events and responses to be detailed within the EEG recording.

Stimuli and Apparatus

The experiments were performed by all participants in a Faraday caged testing room to facilitate the ERP measures; those participants who were not partaking in the ERP measures, but the behavioural measures only also performed the experiment in this facility. The experiment and all behavioural measures were recorded using E-Prime 1.1 that was installed on a PC and displayed on a 17" TFT monitor. All participants sat approximately 60cm from the VDU. The stimuli used consisted of a square (2.6° on each edge), and a circle (2.6° in diameter); both of which were shaded either blue (R:0, G:0, B:255) or red (R:255, G:0, B:0). A stimulus consisted a single shape, shaded in either blue or red, and presented in the centre of a white screen. 1000ms prior to the stimulus onset a relevant cue was presented in one of two modalities: audio or visual, with a distractor present in the alternative modality. The relevant cues stated 'Blue/Red' or 'Square/Circle' in Courier New font for the visual cue (visual display angles of: 4.9° x 0.8° and 7.3° x 0.8° respectively), and presented through speakers at a comfortable volume for the audio cue[14]. The response keys for the experiment were the letters C and N on a standard QWERTY keyboard.

Design and Procedure

Each trial consisted of the cue being presented for 1000ms, and following this a blank-screen period of 1000ms. At this point the stimulus was displayed on-screen and remained until a response was provided (accompanied by a buzzer sound if an incorrect response was given). Following all responses an inter-trial blank-screen period of 150ms was given. Three blocks of trials were performed - two pure blocks of 100 trials each (colour and shape oriented), and one mixed

[14]Audio cues were generated using inbuilt Apple voice generation software, and were normalised to -1dB.

block of an alternating-runs sequence with 400 trials (200 colour and 200 shape), with equal numbers of repeat and switch trials.

Participants performed all trial blocks in two counterbalanced conditions: Relevant audio cue and relevant visual cue. Standardised instructions were provided to all participants and instructed them to respond to the stimuli according to the relevant cue for that particular condition (either audio or visual). If responding to the colour of the stimuli, the letter C was mapped for a response to blue, and N to red. If responding to the shape of the stimuli the letter C was mapped for a response to a square, with N mapped for a response to a circle. The participants were made aware of the structure of the trial blocks, and were tested individually in sessions lasting approximately 60 minutes (including both conditions).

ERP Analyses

Where the RT analyses focus upon responses at the stimulus onset period, ERP analyses in this instance instead focus upon the cue-onset period. By analysing this time period allows distinctions to be drawn comparing cue-processing activations of Audio and Visual cues between both Incongruent and Neutral cue-congruency formats.

It is important to state that the ERP analyses are conducted in a fundamental fashion, in that processing of the data is conducted in the format described below, with no further localisation. In this respect it is imperative that where topographic maps are presented these are generated solely from the electrode position and do not have source localisation techniques employed. For this reason all statements relating to potential areas of interest should be viewed with a degree of caution. Where such statements are presented these are in conjunction with previous research and literature which may provide a more compelling argument for the locations suggested.

Processing of data

Continuous EEG data was filtered offline to the frequencies of 1-30Hz using a bandpass filter. Using the filtered data epochs of 1000ms were extracted, comprising of -200ms pre-stimulus to 800ms post-stimulus presentation. Baseline corrections were applied upon the 200ms pre-stimulus interval for all epochs. Epochs were extracted based upon the categorisation of the trial (pure or mixed-block repeat), permitting comparisons to be drawn between these. Eye-blink artifacts were corrected before epoch extraction was performed; this was conducted using a linear derivation transformation based upon a minimum of 30 eye-blink selections. The extracted epochs were averaged across trial formats to give a single pure and single repeat trial epoch waveform. These averages comprised of only correct responses (in-line with behavioural data), and contained a minimum of 30 valid trials per trial format, per participant. Averages were computed for all conditions in each experiment, i.e. pure and repeat for both visual and audio cuing modalities in each experiment. All epochs were re-referenced from the mastoid TP10 electrode to a global reference.

Electrodes F3, F4, P5, and P6 were selected to exhibit the ERP epoch waveforms generated. Electrode sites F3 and F4 were selected to demonstrate a basic cross-cortex comparison that may be apparent based upon potential subvocal cue generation as could be expected within the left DLPFC (Baddeley, 1986; Henson et al., 2000). These sites were also chosen as they may exhibit elements of ACC activation for conflict-monitoring and decoding of the presented cues in-line with required task-set selections. Electrode sites P5 and P6 were selected as they may also provide a suitable comparison, since these are likely to show potentials generated through the inferior parietal regions. In this respect activations from the storage and repetition of phonological information may become visible in these regions, particularly in P5 as associated with the left inferior parietal area (Henson et al., 2000; Jonides et al., 1998). Specific windows of interest were declared as 200-250ms post stimulus onset as this may exhibit differences in ERP waveforms as distinguished by competing/conflicting cue information and thus conflicting task-set activations within the ACC and DLPFC regions respectively. A window of 300-400ms was also selected for the frontal regions since increased potentials here may demonstrate more substantial subvocal rehearsals as could be required in the visual cuing conditions. A final window of 250-400ms was selected in more mid-posterior areas (as achieved with electrodes P5 and P6) with the intention of assessing potential increases in phonological storage of information.

Comparisons of data across conditions within experiments are shown in the form of topographical images that serve to exhibit *potential* areas of activation at the specified time-periods. These are shown in the form of using the audio condition as the baseline of the measures, and subtracting the values of the visual condition from this. Analyses are given in the form of t-test value-areas indicating where substantial differences in ERP activations are seen on the topographical images. With comparisons being made in this format, where negative areas are shown these are indicative of greater activation for the visual cuing modality than the audio cuing modality; all t-test analyses are shown in +/-3 values. Although source-localisation has not been used it is hoped that these images demonstrate possible areas of substantial differences between the two cuing modalities used, and serve to exhibit regions of interest that may be associated towards the different processing strategies required for each.

Experiment 1

Method

Participants

In total 22 participants were included in the study, comprising of 12 participants in the ERP and a further 10 who performed the same experiment without the ERP element. All spoke English as their first language, had normal or corrected-to-normal colour vision and were remunerated with course credits.

Additional cue-factor

In Experiment 1, the additional cue-factor was neutral in formation, in that it did not provide any information relating to the possible task-sets (i.e. colour or shape responses required). The irrelevant/distractor cues comprised of a series of random consonants WGNLMY/LPBJWX (7.3° x 0.8°) for the visual element. The irrelevant audio cue was generated by chopping and interlacing elements of both the correct audio cues (blue/red and square/circle) to generate an approximate average sound with a similar waveform.

Behavioural Results

Reaction Times

All incorrect responses and those immediately following (n + 1) were removed. Any responses that were greater than 1500ms were also removed prior to reaction time analyses. Averages of these trimmed RT measures were analyses using a repeated measures ANOVA of the following format: Task (2 levels - applicable Audio and Visual cuing) and Switch (2 levels - Pure and Repeat).

No significant differences in Task were observed [$F(1,21) = 0.29$, $p = 0.60$, $\eta_p^2 = 0.014$] indicating overall task performance between Audio and Visual cuing modalities was highly similar. A significant effect of Switch was observed [$F(1,21) = 17.65$, $p < 0.001$, $\eta_p^2 = 0.46$] indicating that the average 398ms (SE = 11.84, SD = 55.52) response times for Pure trials were significantly faster than the average 454ms (SE = 23.06, SD = 108.18) elicited by the Repeat trials. No significant interaction was obtained between Task x Switch [$F(1,21) = 0.53$, $p = 0.48$, $\eta_p^2 = 0.025$].[15]

Accuracy

A significant effect of Task was observed [$F(1,21) = 5.72$, $p = 0.026$, $\eta_p^2 = 0.21$] indicating overall task performance for Audio (M = 94.96%, SE = 0.53, SD = 2.50) was significantly greater than that achieved for Visual cuing (M = 93.29%, SE = 4.40). A significant effect of Switch was also observed [$F(1,21) = 7.09$, $p = 0.015$, $\eta_p^2 = 0.25$] indicating that the average 94.73% (SE = 0.59, SD = 2.79) correct responses for Pure trials were significantly greater than the average 93.53% (SE = 0.82, SD = 3.84) correct responses obtained in the Repeat trials. A significant interaction was obtained between Task x Switch [$F(1,21) = 6.84$, $p = 0.016$, $\eta_p^2 = 0.25$] elicited by an accuracy mixing cost of 2.54% for Visual cuing [$t(21) = 3.16$, $p = 0.005$], rather than the positive increase of 0.15% between Pure and Repeat trials in the Audio cuing task [$t(21) = 0.28$, $p = 0.78$].[15]

ERP Results and Discussion

Using data obtained from Experiment 1 where cue-congruency was neutral (i.e. audio cues were presented concurrently with an irrelevant visual cue, and vice-versa), the first analysis focused on the differences in cue-processing between

[15]Summary details of behavioural measures can be found in Table 14.

applicable audio and visual cuing modalities. Visual inspection and associated t-test analyses upon mixing cost waveforms indicated no significant differences between Audio or Visual cue-processing capabilities in the region of particular interest (200-250ms post stimulus onset). The t-test analysis did indicate that more substantial components were active around 300-350ms in the Visual Task, that were likely located towards the frontal and fronto-central regions, though these dissipated considerably during the 350-400ms period (see Figure 12). These increased potentials may be a result of increased subvocal rehearsal (Henson et al., 2000), as would be expected with the visual cuing task, a necessity not required with audio cues. Although it was anticipated that where a visual cue was used a greater level of activation would be seen compared to an audio cue, this was predominantly not the case with the exception of increased subvocal rehearsal strategies. Indeed it was seen that where a relevant cue was concurrently presented with an irrelevant but non-obtrusive element, this could be effectively filtered from processing, resulting in similar components between both audio and visual cuing methods. Focusing solely upon the waveforms for the selected electrodes, we note increased P2-wave potentials for repeat trials in both F3 and F4, however similar increases are noted for both audio and visual cues. Although waveforms from P5 and P6 fluctuate dramatically, there is relatively little to distinguish pure and repeat trial potentials; furthermore there are again minimal differences between audio and visual cuing modalities (see Figures 10 and 11).

Although the majority of results obtained fail to demonstrate any significant interactions between the cue-format tasks and the mixing cost elements of the trials, this should not be considered a negative finding. It is highly informative to note the similarities between these two cue-formatting strategies and it should be noted that this finding is likely to be related to the single influential format that is relevant. Despite greater activations potentially arising from within the lateral premotor cortex regions / middle frontal gyrus for the visual cue task this should not be surprising given the additional subvocal rehearsals expected with this task. It is further interesting that these increased potentials remain present even up to 550ms after the presentation of the cue, providing information that this process may continue for a relatively long duration - presumably to increase the likelihood of retaining the relevant task-set for a prolonged period (see Figure 12). It should not be taken that this finding indicates that the audio task is not undergoing a similar subvocal rehearsal process, as it is still essential for the maintenance of the information, but that this rehearsal is less dominant than with the visual cuing format. While the results obtained in terms of accuracy show some evidence for an improved performance using audio cuing strategies (with a positive mixing cost) over those obtained with visual cues, this shows little information of strong value; if these results had been coupled with influential RT results a stronger distinction could have been drawn. Despite stating this it is not information that should be disregarded, but rather treated with some caution and revisited with later results.

With the results obtained indicating little to differentiate the two task cue formatting styles, in RT *and* ERP measures, the second stage of the study became all the more crucial in terms of deciphering activations.

Experiment 2

The present study built upon the initial Experiment (focusing upon neutral secondary cues - irrelevant but non-intrusive towards the relevant task), but provided incongruent cues for each trial. In this respect when the applicable cue was presented visually, for example, the cue presented in the alternative modality indicated performance that should be directed towards the opposing

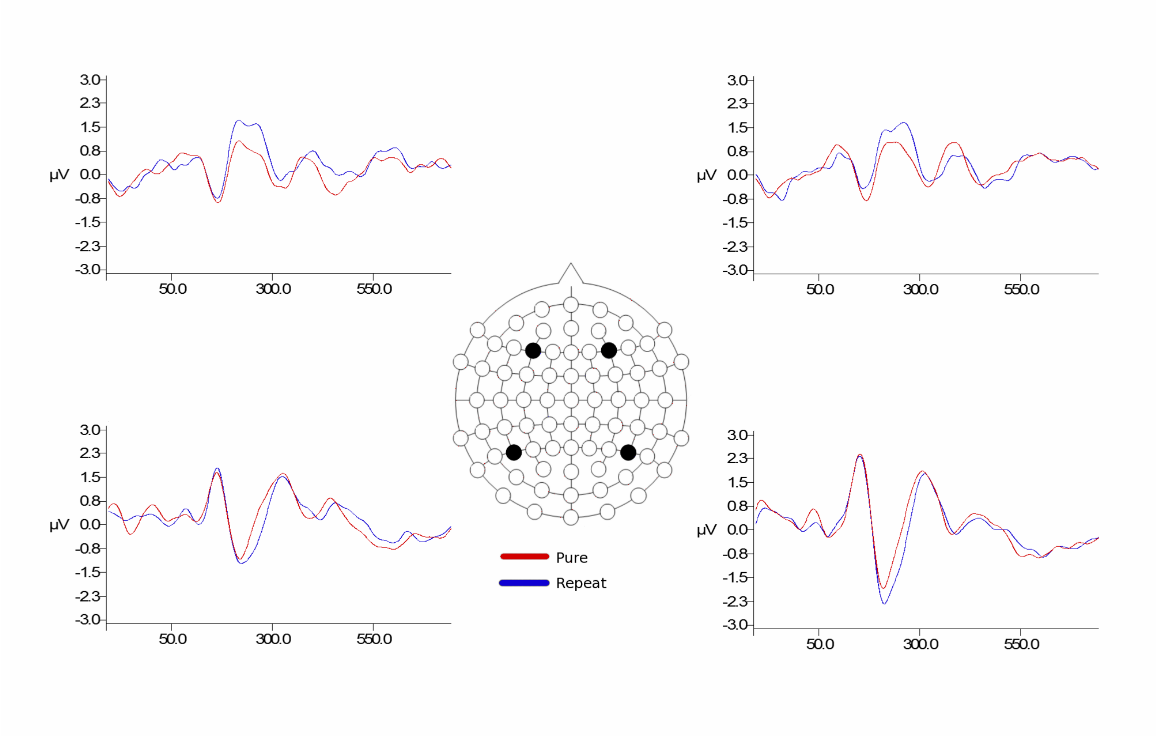

Figure 10. : Analysis 1 — Audio cued ERP waveforms; comparisons of Pure and Repeat trials. ERP wavesforms shown from electrodes F3, F4, P5, and P6.

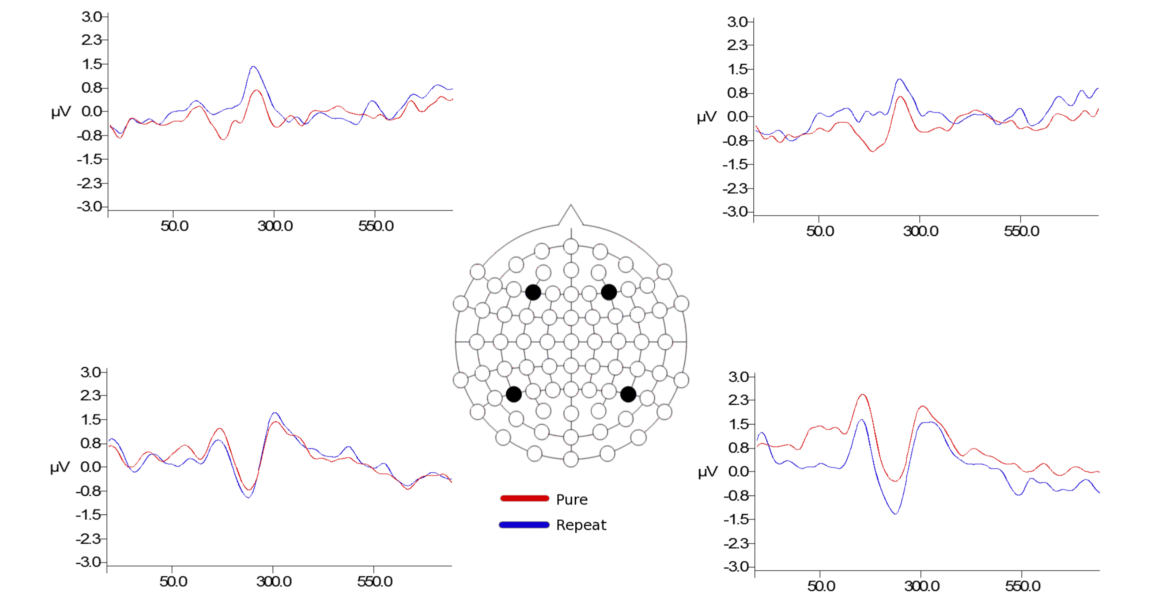

Figure 11. : Analysis 1 — Visual cued ERP waveforms; comparisons of Pure and Repeat trials. ERP wavesforms shown from electrodes F3, F4, P5, and P6.

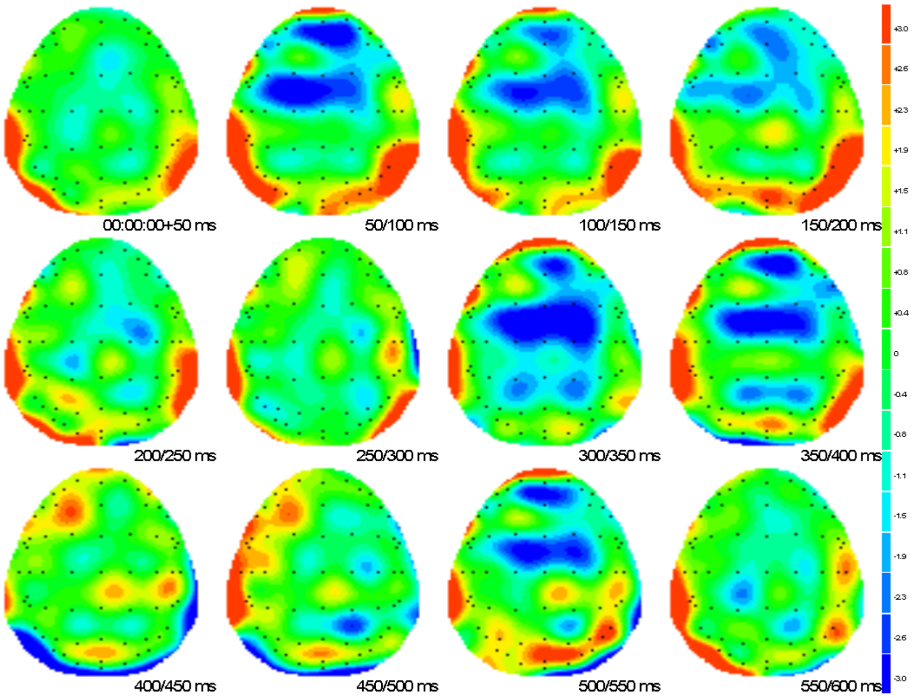

Figure 12. : Analysis 1 — Topographical mappings of t-test values between Audio and Visual cue processing formats

and incorrect task (e.g. a visual cue of 'Blue/Red' accompanied by an audio cue of 'Square-Circle', where the correct task to respond to was that of colour *and not shape.*

Method

Participants

In total 23 participants were included in the study, comprising of 12 participants in the ERP and a further 11 who performed the same experiment without the ERP element. All spoke English as their first language, had normal or corrected-to-normal colour vision and were remunerated with course credits.

Additional cue-factor

In Experiment 1, the additional cue-factor was neutral in formation, in that it did not provide any information relating to the possible task-sets (i.e. colour or shape responses required). However during Experiment 2 the focus was placed upon the additional cue-factor being incongruent in form. The irrelevant cue now directed performance towards the alternative task, i.e. if the audio cue was the focal point of the cue-congruency and stated “Blue/Red” then the irrelevant visual cue stated “Square/Circle”, and vice-versa.

Behavioural Results

Reaction Times

As with Experiment 1, all incorrect responses and those immediately following (n + 1) were removed. Any responses that were greater than 1500ms were also removed prior to reaction time analyses. Averages of these trimmed RT measures were analysed using a repeated measures ANOVA of the following format: Task (2 levels - applicable Audio and Visual cuing) and Switch (2 levels - Pure and Repeat).

No significant differences in Task were observed [$F(1,22) = 2.46$, $p = 0.13$, $\eta_p^2 = 0.101$] indicating overall task performance between Audio and Visual cuing modalities was highly similar. A significant effect of Switch was observed [$F(1,22) = 8.26$, $p = 0.009$, $\eta_p^2 = 0.27$] indicating that the average 393ms (SE = 10.52, SD = 50.47) response times for Pure trials were significantly faster than the average 419ms (SE = 16.49, SD = 79.06) elicited by the Repeat trials. No significant interaction was obtained between Task x Switch [$F(1,22) = 0.12$, $p = 0.73$, $\eta_p^2 = 0.005$].[16]

Accuracy

No significant differences in Task were observed, although the result was

[16] Summary details of behavioural measures can be found in Table 14.

approaching significance [$F(1,22) = 3.83$, $p = 0.079$, $\eta_p^2 = 0.13$] indicating overall task performance accuracy between Audio and Visual cuing modalities was relatively similar. No significant effect of Switch was observed [$F(1,22) = 0.66$, $p = 0.42$, $\eta_p^2 = 0.029$] indicating that the accuracy averages for both Pure and Repeat trials were also very similar. Finally, no significant interaction was obtained between Task x Switch [$F(1,22) = 0.001$, $p = 0.98$, $\eta_p^2 < 0.001$], which was to be expected with mixing costs of 0.57% and 0.53% for Audio and Visual cuing respectively.[18]

ERP Results and Discussion

In this second analysis, data was used from Experiment 2 where cue-congruency was incongruent (i.e. audio cues were presented concurrently with a visual cue directing towards the opposite task-set, and vice-versa), and focused on the differences between applicable audio and visual cuing formats. Analyses of t-tests of mixing costs and visual inspections indicated a significant increase in the 200-250ms potential for the repeat trials against the pure trials in the Visual Task, compared to the same measures in the Audio Task (see Figure 15). Such differences are notable particularly in the region of F3, and to a lesser extent F4 with the posterior regions appearing to be unaffected by the same component increases as can be seen in the waveforms of P5 and P6 (see Figures 13 and 14). The extent of the component activation can be seen in Figure 15. These increased potentials may exhibit a result of the increased complexity of cue-conflicts present within such incongruous situations — indeed, the location of the affected area suggests that the ACC may play a core role in this stage of cue-conflict-decoding. It is also a possibility that the large-scale activations seen in this region could also be attributed to the generation of the phonological code as required with visual cuing, unfortunately as detailed earlier it is difficult to disentangle these processes. However it may be prudent to side upon the argument for these activations, at this time period, to be aligned towards the cue-conflict-decoding of the ACC due to the lateral activity exhibited. Activations continue in the left-hemisphere premotor cortex regions until 600ms; these, as with Experiment 1, could conceivably be related to the subvocal rehearsal required in the visual-cue task. Between the periods of 250-400ms activations can be seen that may emerge from the left inferior parietal regions; such regions are often associated to the storage of phonological information – it is telling that post-400ms these activations reduce substantially and appear to 'spread' back towards the premotor cortex regions, perhaps for repeated rehearsals of the information (see Figure 15). It is not surprising to note that waveforms for F3 and F4 exhibit substantial P2-wave differences between the pure and repeat trials (approximately 200-250ms), but only with visual cues; such differences cannot be noted for audio cued task trials. As with Experiment 1 there is much movement in the waveforms for P5 and P6 electrodes, and again there is little to differentiate between pure and repeat trial waves; yet there appears to be more sustained P2-wave potentials at electrode P5 at approximately 300-400ms for the visual cues compared to the audio cues (see Figures 13 and 14).

The overall increases in activations noted in Experiment 2 compared to Experiment 1 demonstrate the general increases in cognitive requirements, but more specifically the increases required when performing the task when visual cues are applicable, and audio cues are irrelevant. If the increased difficulty had been similar across both modalities the activations noted would not become apparent, and the figures would demonstrate a relatively stable image; yet this is clearly not the case. The strong evidence of activations in the frontal regions provides information concerning the severity of the cue-conflict situation that participants are under when visual cues are accompanied by irrelevant audio cues. There is little disputing that in these situations the direct streaming of audio information permeates the processing of the visual cue, not only in terms of decoding the cue-conflict, but also in the delayed processing of phonological recoding. It provides a strong basis for the theory that filtering visual information is less cognitively demanding than filtering audio information that is presented concurrently. In a sense this is to be expected [although this is not a situation that occurred during testing], it would be feasible for participants to divert their gaze from irrelevant visual information, however this is not possible with audio information. In this respect a direct stream is more likely to prompt automatic activation, regardless of the relevance, hence filtering and decoding cue-conflicts in this format becomes substantially more demanding.

An interesting finding however is that there are no significant differences in task performance in terms of RT or accuracy measures. Therefore despite the substantial differences in cue-processing demands, these are removed within the 1000ms period between cue and stimulus onset, and includes a sufficient amount of time for task-set preparation.

Combined Experiment Analyses

During the analysis of Experiment 2 it became apparent that Visual cuing was more susceptible to interference from an appropriate but irrelevant audio signal, than vice-versa. Hence a logical additional analysis was performed. This involved comparing performance where the Visual cue was applicable but between both the neutral and incongruent additional cue-factor manipulations. Similarly the same analyses were conducted where the Audio cue was applicable. The analyses are presented for each cuing modality below, in separate distinct sections.

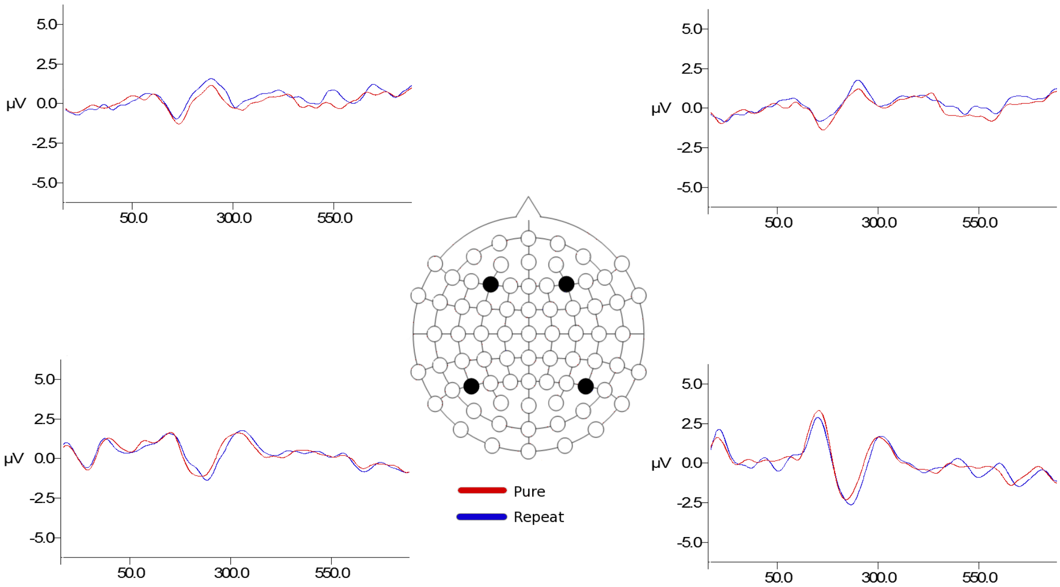

Figure 13. : Analysis 2 — Audio cued ERP waveforms; comparisons of Pure and Repeat trials. ERP wavesforms shown from electrodes F3, F4, P5, and P6.

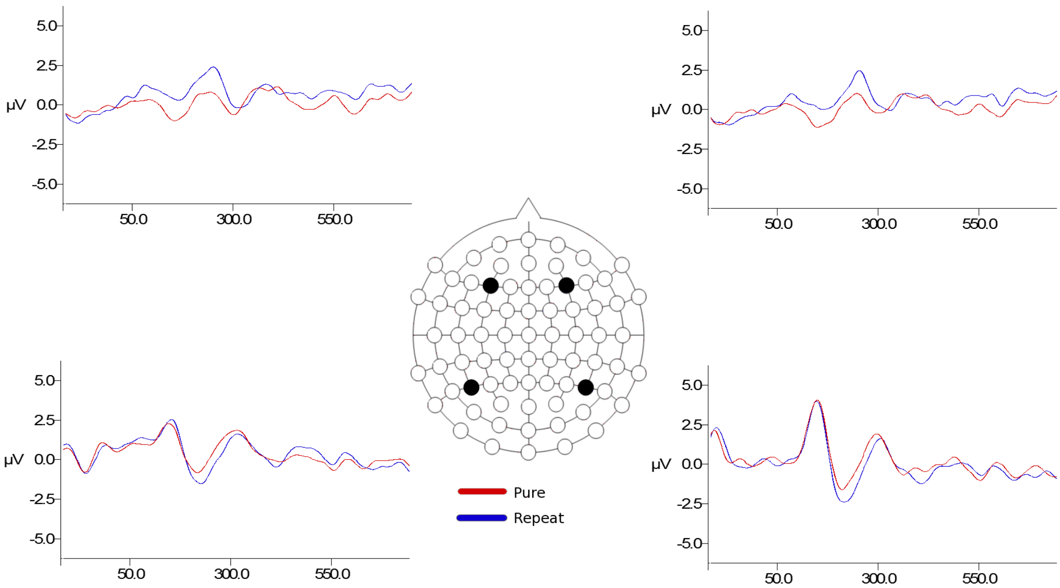

Figure 14. : Analysis 2 — Visual cued ERP waveforms; comparisons of Pure and Repeat trials. ERP wavesforms shown from electrodes F3, F4, P5, and P6.

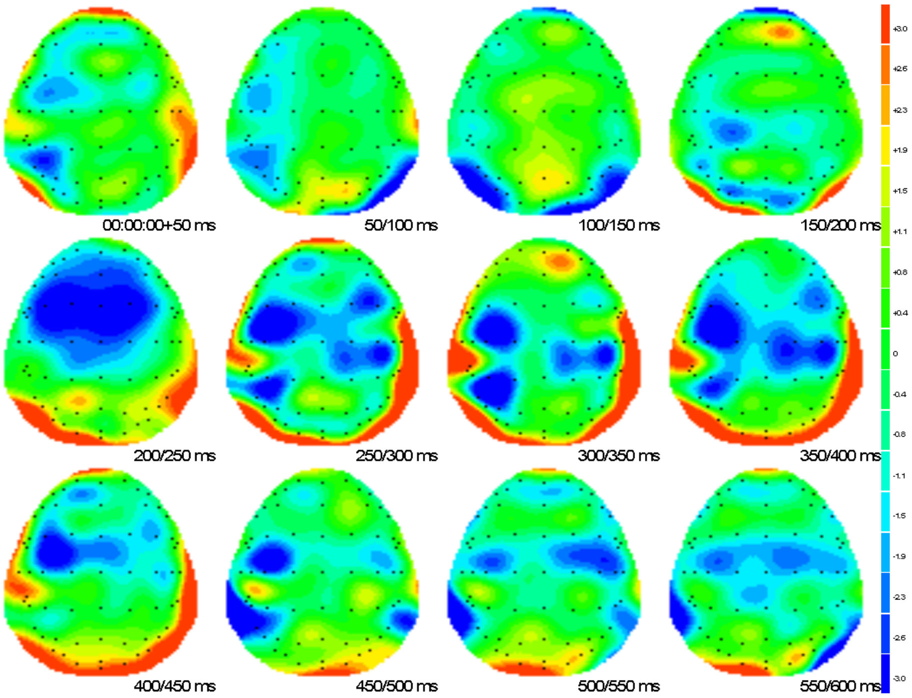

Figure 15. : Analysis 2 — Topographical mappings of t-test values between Audio and Visual cue processing formats

Visual cuing: Neutral vs. Incongruent additional factor

Reaction Times

Using the data as taken from Experiments 1 and 2 analyses were conducted within each cuing modality. RT measures were analysed using a repeated measures ANOVA of the following format: Switch (2 levels - Pure and Repeat with a between subject factor of Experiment (Neutral [Exp 1] and Incongruent [Exp 2]).

Strong differences in Switch were observed [F(1,43) = 18.94, $p < 0.001$, $\eta_p^2 = 0.31$] indicating that the average 396ms (SE = 8.32, SD = 55.85) response times for Pure trials were significantly faster than the average 439ms (SE = 15.61, SD = 104.70) observed for the Repeat trials.

Interactions across Switch and Experiment were not significant however, although were approaching the accepted significance level [F(1,43) = 3.72, p =

0.061, η_p^2 = .08]. Mixing costs were highly significant in the neutral experiment (61ms) [t(21) = 3.72, p = 0.001], and were also significant (although to a smaller extent) in the incongruent experiment (24ms) [t(22) = 2.19, p = 0.039], but clearly this did not fully transpose across Experiment format. [17]

Accuracy

Significant differences in Switch were observed, [F(1,43) = 9.09, p = 0.004, η_p^2 = 0.175] indicating that the accuracy averages for Pure and Repeat trials differed substantially [1.5%] (94.3%, SE = 0.58, SD = 3.90 and 92.8%, SE = 0.74, SD = 4.99 respectively).

A marginally significant interaction was obtained between Switch x Experiment [F(1,43) = 3.87, p = 0.056, η_p^2 = 0.083], which was to be expected with mixing costs of 2.5% for the neutral experiment [t(21) = 3.16, p = 0.005], and 0.53% for the incongruent experiment [t(22) = 0.84, p = 0.41].[18]

Audio cuing: Neutral vs. Incongruent additional factor

Reaction Times

As with the previous section, analyses were conducted within each cuing modality. RT measures were analysed using a repeated measures ANOVA of the following format: Switch (2 levels - Pure and Repeat with a between subject factor of Experiment (Neutral [Exp 1] and Incongruent [Exp 2]).

Strong differences in Switch were observed [F(1,43) = 20.91, p < 0.001, η_p^2 = 0.33] indicating that the average 394ms (SE = 8.54, SD = 57.32) response times for Pure trials were significantly faster than the average 433ms (SE = 13.62, SD = 91.39) observed for the Repeat trials.

[17] Summary details of behavioural measures can be found in Table 14.

Interactions across Switch and Experiment were not significant [F(1,43) = 1.82, p = 0.18, η_p^2 = .04]. Mixing costs were highly significant in the neutral experiment (51ms) [t(21) = 3.68, p = 0.001], and were also significant in the incongruent experiment (28ms) [t(22) = 2.67, p = 0.014], but this difference did not transpose across Experiment format. [18]

Accuracy

There were no significant differences in Switch were observed, [F(1,43) = 0.12, p = 0.731, η_p^2 = 0.003] accuracy averages for Pure and Repeat being similar [0.22%] (93.8%, SE = 0.54, SD = 3.59 and 93.6%, SE = 0.58, SD = 3.89 respectively).

Interactions between Switch x Experiment were not significant [F(1,43) = 0.35, p = 0.56, η_p^2 = 0.008], which was to be expected with mixing costs of 0.15% for the neutral experiment [t(21) = 0.28, p = 0.78], and 0.57% for the incongruent experiment [t(22) = 0.53, p = 0.60].[18]

Multiple-Congruency Comparisons

As a means of assessing overall *response* performance between not only the results of Experiments 1 and 2 (neutral and incongruent additional-cue-factors respectively), the decision was taken to include additional results from previous work to allow comparisons to be drawn against congruent results also (from Chapter 2). Although these results are included in this respect it is important to recall that participants from each experiment are often included only within each individual experiment; as a result some variance in the results, particularly in terms of RT is to be expected. Yet the information to be gathered from these results could allow further statements to be drawn regarding cue-congruency,

[18] Summary details of behavioural measures can be found in Table 14.

processing and in-turn how RTs are influenced with respect to task-set maintenance, although some scope for future analysis of fatigue with each would be of great benefit.

Behavioural Results

RT Analyses

All incorrect responses and those immediately following (n + 1) were removed. Any responses that were greater than 1500ms were also removed prior to reaction time analyses. Averages of these trimmed RT measures were analyses using a repeated measures ANOVA of the following format: Task (2 levels - applicable Audio and Visual cuing) and Switch (2 levels - Pure and Repeat), an additional between-subjects factor of Experiment (1: Neutral, 2: Incongruent, 3: Congruent) was also inputted.

Overall differences across Task were obtained [F(1,67) = 8.29, p = 0.005, η_p^2 = 0.11], where responses using an applicable Audio cue were 12.38ms faster than where a Visual cue was used. An interaction was demonstrated between Task and Experiment [F(2,67) = 5.25, p = 0.008, η_p^2 = 0.14], indicating that performance in the Tasks differed significantly according to the Experiment (and thus cue-congruency) that was being performed. This interaction was assessed to a greater extent by analysing performance across Tasks between different levels of Experiment. Analyses of Tasks by Experiments 1 and 2 indicated no significant results [F(1,43) = 2.15, p = 0.15, η_p^2 = 0.048]. Analyses of Tasks by Experiments 2 and 3 indicated a marginally significant interaction [F(1,46) = 3.08, p = 0.86, η_p^2 = 0.063], whilst a final interaction of Tasks by Experiments 1 and 3 indicated a highly significant interaction [F(1,45) = 10.53, p = 0.002, η_p^2 = 0.19].

A significant effect of Switch was obtained [F(1,67) = 46.87, p < 0.001, η_p^2 =

Cue-Congruency	Focal-Cue	Pure repeat	Mixed repeat	Mix cost
Neutral	Audio	402	453	$51^{‡}$
		[13.05]	[22.66]	
		94.89	*95.04*	*+0.15*
	Visual	393	454	61
		[11.99]	[25.05]	
		94.56	*92.03*	*2.53*†
Incongruent	Audio	387	415	28^{*}
		[11.18]	[14.99]	
		92.74	*92.17*	*0.57*
	Visual	400	424	24
		[11.79]	[18.96]	
		94.06	*93.53*	*0.53*
Congruent	Audio	397	422	25^{*}
		[10.88]	[13.87]	
		96.05	*95.35*	*0.70*
	Visual	411	463	52
		[11.36]	[16.33]	
		95.80	*94.65*	*1.15*

Table 14:: Experiment 1: RT (ms), [standard error] / † = 0.05 * <= 0.02, ‡ = 0.001. Italics = % of accurate responses (also includes accuracy costs in applicable columns). NOTE: Congruent measures are obtained from previous work and are not collected using ERP methods.

0.41], where Pure trials (M = 399ms, SD = 52.25, SE = 6.25) were 39ms faster overall than Repeat trials (M = 438, SD = 87.12, SE = 10.41) [t(69) = 6.69, $p < 0.001$]. This did not transpire into any reactions with either Experiment [F(2,67) = 2.20, p = 0.12, $\eta_p^2 = 0.062$], Task [F(1,67) = 2.79, p = 0.10, $\eta_p^2 = 0.040$], or indeed Task x Experiment [F(2,67) = 1.84, p = 0.17, $\eta_p^2 = 0.052$].

Accuracy

Although Task did not produce any significant effects [F(1,67) = 0.59, p = 0.45, $\eta_p^2 = 0.009$], an interaction of Task with Experiment was obtained [F(2,67) = 5.99, p = 0.004, $\eta_p^2 = 0.15$], again indicating that accuracy differed according to the Task being performed. Separate analyses were conducted comparing results from different Experiments. Analyses of Tasks by Experiments 1 and 2 indicated a significant interaction [F(1,43) = 8.88, p = 0.005, $\eta_p^2 = 0.17$]. Similarly, an interaction between Task and Experiments 2 and 3 was also significant [F(1,46) = 5.12, p = 0.028, $\eta_p^2 = 0.10$]. Analyses between Task and Experiments 1 and 3 however showed no significant interaction [F(1,45) = 2.42, p = 0.13, $\eta_p^2 = 0.051$]. The finding that only significant interactions were obtained when the Incongruent task format was under scrutiny highlights that accuracy substantially decreased only in this instance comparative to the results obtained under Neutral or Congruent formats.

A significant effect of Switch was obtained [F(1,67) = 6.91, p = 0.011, $\eta_p^2 = 0.093$], where Pure trials (M = 94.72%, SD = 3.10, SE = 0.37) produced 0.89% greater overall accuracy than Repeat trials (M = 93.83%, SD = 3.57, SE = 0.43) [t(69) = 2.65, p = 0.011]. This did not transpire into any reactions with either Experiment [F(2,67) = 0.30, p = 0.75, $\eta_p^2 = 0.009$], Task [F(1,67) = 2.39, p = 0.13, $\eta_p^2 = 0.034$], or indeed Task x Experiment [F(2,67) = 1.51, p = 0.23, $\eta_p^2 = 0.043$].

Discussion

In these present experiments investigations into cortical activity was the primary intention, assessing for differences between performances of trials in which audio or visual cues directed responses. Assessments were made on the grounds of mixing costs, an index measure specifically directed towards the costs induced by maintaining task sequences, in both terms of responses towards stimuli (RT and accuracy measures), but more importantly the cortical processing emanating from the presentation of applicable cues.

Experiment 1 investigated the differences in preparation and responses towards stimuli when task cues were presented in either visual or audio modalities and accompanied by a further neutral (and hence irrelevant) cue in the other modality (i.e. a relevant audio cue accompanied by a neutral visual cue stating no relevant information towards the tasks). Although large differences could have been anticipated between these two task conditions, relatively few were obtained. One striking, and substantial difference between the audio and visual cue modalities was found between 300-350ms in the frontal / fronto-central regions and may be accounted for by increased subvocal rehearsals within the visual cue task compared to the audio cue task (Henson et al., 2000). With this finding aside there were minimal differences that could be accounted for by changes to the cue modality, indicating that processing of the cues involved relatively similar cognitive demands across all regions.

Experiment 2 expanded upon the modalities employed in Experiment 1, by manipulating the *accompanying* cue so as to direct performance to the opposite (and incorrect) task (i.e. a relevant audio cue directing performance towards the colour task was accompanied by an incongruent visual cue directing performance towards the incorrect shape task). In this instance substantial differences were obtained between the applicable visual and audio modality cuing methods. The most striking of these occurred between 200-250ms and appears to be predominantly affecting areas responsible for phonological generation, but also crucially for decoding cue-conflicts – the ACC (Botvinick et al., 2001). It is possible that this activation is caused by the increased demands associated with disentangling the visual cue from the irrelevant audio cue; the presentation of audio information is likely to be more direct and hence influential than any provided by visual information (Penney, 1989) albeit in the initial stages of processing. Continued increased potentials appear to be evident in the left inferior parietal regions until 400ms and may be presumed to be related to the increased demands placed upon the phonological storage regions (Henson et al., 2000). It is a strong possibility that processing of cues (particularly visual) is more cognitively challenging when accompanied by relevant but incorrect additional cues. Importantly however these extra demands do not contribute to differences in responses to the stimuli they are associated with - no substantial differences in RT or accuracy were obtained between visual and audio cue modalities.

In some respects however the increased component activations seen in experiment 2, and considered as potentially being representative of increased ACC processing, may not be a conclusive statement. As explained within the introduction, ACC activation as a result of cue-conflict decoding mechanisms is typically seen in the form of increased N2/N200 components. Whilst there is some negative movement seen in this region of the waveform, the overbearing observation is instead that of an increase in the P2 component. This is particularly notable as a larger component with the visual-relevant cuing modality, when placed in concurrent cue-presentation with irrelevant verbal elements. Although research into the basis for increased P2 components is in its infancy, there remains some strong research that relates to the findings presented here. In particular the findings of Raney (1993) are of interest and conclude that when cognitive load increases P200 components also increase – in this instance these measures relate to the capabilities of participants to read words. In this respect, the P200 component increases seen in experiment 2 are highly similar in basis. There is little disputing that the cognitive demands associated with decoding the two conflicting cue formats is increased compared to where no such conflict is present, as in experiment 1. Furthermore, as shall be discussed shortly, it is likely that a form of audio-prominence features in relation to the relevant audio-cues, making the cognitive load for tasks where the audio element is irrelevant (visual cue relevant) substantially more demanding. So whilst there is little conclusive evidence that may demonstrate ACC activation in terms of N2/N200 processing through average waveforms, instead we can see substantially increased potentials as a result of the increased task demands. This in turn may serve to obscure any N2/N200 potentials that may otherwise be apparent.

Audio vs. Visual Processing

Audio Dual-Stream

Hickok & Poeppel (2007) raise an interesting theory in relation to the cues utilised in the primary audio cuing versions of these tasks. They argue that a dual-stream system is used for processing of audio signals; with a ventral stream for speech recognition, and importantly for the present research a dorsal stream for speech perception. Although a dual-stream system has been widely accepted for visual instances, the same has not been stated for audio instances, and in particular speech. Although the scope of the review by Hickok & Poeppel (2007) is far-reaching, particular aspects are highly relevant in terms of the activations seen in this present study. Although both streams provide a basis for performance in terms of audio processing within the present study, the dorsal stream activations are particularly important and will provide the main discussion points here. They argue that the dorsal stream feeds into the posterior regions of the frontal and temporal lobes, and is partly responsible for generating articulatory representations from inputted speech signals – a process performed within the frontal lobes. Furthermore they argue that whilst the ventral stream is predominantly bilateral in formation, the dorsal stream is largely focused within the left hemisphere – explained in part by the impact that lesions to the dorsal frontal and temporal lobes have upon speech production, and further why damage to the left-hemisphere can result in degraded speech perception capabilities.

Audio Prominence

It is clear that in situations where audio signals are presented to participants there is little alternative but to pay attention to them, particularly in the instances where they may be directing performance towards a task, e.g. in the incongruent cuing tasks. In this sense it is somewhat analogous to the Cocktail Party Effect (Moray, 1959; Wood & Cowan, 1995), in that the information presented reorientates attention. Yet in both of these cited studies approximately only 33% of participants reported hearing their own names. Clearly in the instance of the present study the severe impact of the differences between visual and audio irrelevant cuing strategies appears to indicate a much greater influence, since if each modality impacted to the same extent fewer differences would be evident. A later study by Conway, Cowan, & Bunting (2001) attributed this low perception of one's name to a low working memory capacity, and argues that this makes the process of inhibiting irrelevant information more challenging than for participants with a high working memory capacity. Given the cross-section of our participants, and the substantial differences obtained between the two modalities, the theory that all participants (or a substantial enough number to achieve these results) had low working memory capacities is more than questionable. Rather it gives rise to the belief that whilst comparisons between such phenomena and the current study are valid, the differences between the situational impacts of each may contribute to the dramatic results obtained. To explain, during studies of the Cocktail Party phenomena participants are in situations where irrelevant information is presented, and hence their attention is predominantly directed towards the information only when their name is heard; the remainder of the time the information being presented is of no relevance and to an extent it can be filtered out. Yet during the present study the audio information being presented is of direct relevance to the tasks being performed, albeit not on the given trial; therefore with the information being related, although incorrect, the filtering processes cannot be performed as successfully. This is the case particularly when we consider the trial sequences of the study - it is likely that where participants have performed a response towards the stimuli for a shape trial if this was a repeat then the following trial will require a response to colour, yet have an audio cue directing attention towards a shape response. Since inhibition is not instantaneous and effectively diminishes progressively, some activation will remain, only to be enhanced by the audio presentation. So whilst in some situations it can be argued that working memory capacity has a strong influence on the likelihood of detecting relevant information within an irrelevant stream, during the present study working memory capacity (regardless of the individual differences amongst participants) is subject to much greater demands from the competing cue modalities. Hence filtering the relevant from the irrelevant is more challenging, and participants may be more likely to succumb to the information presented in the audio stream. The above case is particularly relevant when we recall that audio information is likely to be more enduring than visual information (Penney, 1989). When we also consider that the audio information requires minimal phonological generation and encoding compared to a visual cue it comes as no surprise that such formats may be processed with greater ease.

Audio Dorsal-Stream Pathway: Interactions with functions

Returning to Hickok & Poeppel (2007), functional imaging may assist in deciphering some of the pathways of activation present during speech perception, and further may clarify some of the results obtained. Their work includes a slight progression upon the dorsal-pathway suggested and integrates aspects of a sensorimotor format; in that the pathway builds upon the requirement for an audio-motor connection. They argue with great rationale that the production of speech requires a binding between the formulation of phonetics at a cortical level, to a motor output as produced using motor regions of the cortex – essentially a developmental stage in learning how to transfer verbal codes into specifically tuned motor movements. Whilst this may appear to be a disconnected tangent from the processes being discussed, activations as evidenced using imaging techniques begin to shed light upon characteristics of speech and audio perception, and furthermore provide insights into the processes involved in transformations of visual codes into phonetic formats.

B. Buchsbaum, Hickok, & Humphries (2001) and Hickok, Buchsbaum, Humphries, & Muftuler (2003) have identified activations that appear to represent an audio-motor circuitry by requesting participants perform subvocal articulation. Several regions of interest were determined such as the superior temporal sulcus (STS) which demonstrated bilateral activation, posterior frontal regions and also an area of the Sylvian fissure between the parietal and temporal lobes which was predominantly active in the left hemisphere (Spt). Although Hickok and Poeppel's take on the role of the STS being related to the sensory coding of speech is intriguing, perhaps the most pertinent aspect of their findings comes from the activity within the Spt [in relation to the present study]; notably their belief that the Spt is heavily involved in the translation of sensory codes into motor outputs, see also Hickok et al. (2003). They state, in conjunction with B. R. Buchsbaum, Olsen, Koch, & Berman (2005), that the Spt region is also heavily involved in the translation and coding of visually presented words into a phonological format. Clearly this leads to an interaction, or to an extent a collision, with the audio cuing modality condition; especially when we consider that region Spt is housed within the planum temporale (PT). The PT is an area believed to be involved with early stage auditory processing (Binder, Frost, Hammeke, Rao, & Cox, 1996), speech production and phonological working memory[19] (Wise et al., 2000), and also visual formats of language and motion (Griffiths & Warren, 2002; Howard, Brammer, Wright, Woodruff, & Bullmore, 1996; Nakada, Fujii, Yoneoka, & Kwee, 2001).

Visual issues

It seems clear that in terms of the visual cuing formats, the Spt is likely to be key to processing the cues into a phonological format. When we consider the high level of involvement of the Spt in audio cues also, it begins to build a picture of interactions, or even interference across the cue formats.

With the presentation of visual cues, in order to use these completely requires fulfilment into working memory. During standard procedure this is likely to be conducted by subvocal rehearsals after transformation into a phonological format. Yet as is evident from previous research, this process of transformation is conducted using systems that are also involved with converting audio information into motor outputs. Although in the instance of a correct visual cue and corresponding incorrect audio cue, it would be advantageous for the visual cue to be preferential for the Spt at this stage of early processing it is unlikely that all cue-conflict resolution will have been conducted. Therefore it is likely that each modality will be competing for the resources of this region. However, since audio information requires minimal processing prior to the Spt stage, in that phonological formatting is already complete, it is likely that audio signals will gain use of the Spt prior to the visual cue decoding which requires a

[19] A largely accepted theory, but one that also has unanswered questions; see Marshall (2000) for an amusing viewpoint

separate preliminary stage to determine language relevance. When we take into account the highly relevant, yet incorrect nature of the audio cues it is little surprise that a greater level of activation is necessitated in the visual cuing task, compared to the audio cuing task. With regard to audio cuing with irrelevant visual cues, it is also a strong likelihood that all audio processing will have been completed in the Spt region, thus ensuring that minimal interference is obtained from the visual cue.

Yet this raises another interesting issue with the visual cue format. There is little disputing that visual information is easier to filter, or remove from attentional resources than audio information. It would be perfectly feasible to simply look away from the visual cues, and therefore remove any impact of their display. It should be added that in no instance was this observed with any participants, but as a theoretical possibility it cannot be overlooked. Equally it is possible to effectively filter out visual information on a less obvious basis; rather than looking away, participants are capable of orienting their gaze towards less relevant areas of the cue - effectively using a staring technique that renders visual information less obvious and alluring; this could have occurred and we have little way of knowing this. Regardless, what cannot be argued is that it is far easier to orient attention away from visual information than it is from audio information. With audio information there is little way to remove attentional demands, the presentation of information is more direct and aside from generating a substantial alternative audio stream it is processed with great ease. In this respect it is more intrusive than a visual command in our processing capabilities, more alerting, more readily accessed. When placing each modality against each other, it is little surprise that visual processing requires a more robust and substantial cortical flourish when placed in competition with audio processing.

Post-processing measures

It is important to realise that despite the large differences found between task modalities, in both the neutral cuing (Experiment 1) and incongruent cuing (Experiment 2) formats in the processing stages, there is little to no difference discovered in terms of behavioural measures. In this respect not only are response times highly similar, but further there are no substantial differences in mixing costs obtained between these two modalities, although differences are apparent between the additional cuing format tasks – mixing costs are greater in the neutral task than in the incongruent task, although these are not significant. In some respects this is somewhat surprising as it was initially thought that mixing costs would be smaller for the neutral condition. Yet this raises a fresh theory for consideration; although the neutral condition may appear to be simpler to perform, the increased attentional demands of the incongruent task may in fact raise performance in task sequence maintenance. The requirements of consistent and prolonged concentration in order to ensure the correct task response selection is made may induce improved performance in that minimal attentional dispersion occurs. This is not to state that performance in the incongruent condition is easier however; indeed it is more likely that performance in this task induces fatigue at a more rapid rate as compared to the neutral condition, as was discovered during conversations with participants. Taking into account previous investigations into distributional analyses (See Chapter 5) it is likely that in the neutral task vigilance decrement is a strong factor, with attention shifting sporadically to and from the task. Although this occurs, such a task does not require substantial working memory capabilities – the secondary cue is irrelevant and provides no conflicting task information, therefore it is possible to pay minimal attention to the prescribed cue, and retain strong performance. Yet during the incongruent task this is not feasible, a strong attentional focus is required for the duration of the study and as such vigilance decrement is less likely. If vigilance/attentional decrement did occur, performance is likely to degrade and incorrect responses be achieved; hence participants are likely to engage with the required attentional demands to minimise the likelihood of these outcomes.

One aspect of the follow up analyses conducted has been sidelined until this point, and yet it deserves a mention – the comparisons of the present studies to previous work where only congruent cuing strategies were used. When examining Table 14 we can note than the results obtained from behavioural results are similar in outcome to both the neutral and incongruent results for specific modalities. For example, we can see that mixing costs for the visual cuing modality are highly similar to the measures obtained for the neutral cuing modality of Experiment 1, whilst the audio cuing modality closely resembles the same measures as those in the incongruent cuing modality of Experiment 2. Although this might appear to be initially confusing as to the cause, since presumably there is little to detract attention in a congruent cuing format, the underlying causes are theoretically relevant and likely. The visual cuing in this instance (visual cue only; no audio cue) is likely to be highly similar to the neutral outcome since there is little regulating attentional demands, and reliance upon the provided cue is necessary but un-intruded upon. For this reason attention needs not be forthright and directed continuously towards the task, a lesser degree of concentration is required – therefore vigilance decrement could occur whilst maintaining strong performance; rather like the same instance within the neutral task. However the results obtained for the audio modality congruent cuing task (in that both the visual and audio cues provided were identical) theorised previously as supporting a multiple-modality ‘boost’, do not follow the results obtained for the neutral experiment, and follow those obtained for the incongruent experiment instead. In many respects the ‘boosting’ theory remains applicable even in the light of these new results. Where mixing cost performance measures are improved in the incongruent experiment as a result of the increased levels of the attention and concentration required, a similar theory is valid for comparisons of these results to the congruent results. Whilst it is imperative that participants utilise the full attentional demands within the incongruent tasks, the same is not applicable in the congruent tasks but rather they are assisted in their task performances. The use of dual-modality cues provides a multiple input strategy that ensures no conflict is provided and both facilitate performance. For this reason it seems logical to determine that whilst vigilance decrement could occur within this situation, the multiple inputs from the cues may diminish this likelihood and effectively reduce reaction times. Clearly fatigue measures between the two examples (incongruent and congruent) are likely to be dramatically different, yet both result in strong performances because of increased attentional requirements and increased task-sequence maintenance assistance respectively.

An important consideration to be made at this point is that the similarities in response times and associated measures are solid, despite the substantial differences noted in activation levels. Regardless of the cognitive requirements within each (as outlined above), all are comparable within experiment and this leads us to a final assertion. The cue-stimulus interval was maintained at 1000ms in all tasks and both experiments, and permitted enough time for presentation of the audio cues to be completed. It was presumed that 1000ms was a time period that allowed task preparation to be completed without being excessive. In future work it may be feasible to reduce this time since processing of both forms of cue appear to be completed well within 1000ms. This is evident from both the ERP activation maps, but also since RTs and mixing costs are matched within each experiment.

From the outset of the present work it was considered that results obtained in tasks where verbal cues were providing relevant detail would have larger potentials in selected regions, and have larger mixing costs than those in which audio cues were directing performance. It was determined that in situations where only a single relevant (and non-conflicting) cue was presented there was little to distinguish the two formats in terms of ERP potentials, nor reactions to stimuli following these. Where cues were presented in a conflicting manner of both visual and audio formats, strong differences in ERP potentials were noted and may have included regions associated to conflict-resolution, phonological rehearsal/storage, and working memory. These could indicate that performance in the primary visual cue (with conflicting audio cue) tasks were more susceptible to increased cognitive requirements, resulting in these findings. Nevertheless there was no significant interaction of task with mixing cost in terms of reactions to trial stimuli.

The use of EPR techniques in this work has allowed a greater analysis of the cortical processing within a task-switching paradigm, especially given that the trial-reaction results in each task format are so closely matched. This gives rise to the viewpoint that a 1000ms cue-stimulus time-period provides a more than satisfactory preparation period that permits all necessary conflict-processing to be completed. Yet it cannot be considered to be an accurate reflection of the time taken prior to responding to tasks in everyday life – whilst a 1000ms period is suited for some experimental situations, it is an unsatisfactory preparation period for reacting to instances such as may be encountered during driving, for example. Further research may wish to examine the impact of a reduction in cue-stimulus interval, or the use of a fluctuating interval so as consistent preparation within each trial is not feasible. Whilst this may invariably break the distinction between cue and stimulus-reaction measures it may provide a substantial body of work that would assist in determining speeded cue-conflict situations and highlight how the brain performs under intense conflict pressures. As a final consideration, future research may wish to examine ERP measures when using congruent-cuing methods, such as those described here (in terms of behavioural measures only); aside from completing the series of measures, and hence allowing comparisons between all, it would allow insight into the regions of interest during the 'boosting' of dual-input (audio and visual) and single-input (visual only) cuing methods.

CHAPTER 7

GENERAL DISCUSSION

Over the preceding chapters there have been many topics discussed; yet all are bound by a core focus – the processing and facilitation of performance within multiple task frameworks.

Whilst there have been many variations upon the additional elements of the tasks being performed, the task itself has remained relatively unchanged throughout all of the experimental manipulations. This has ensured that whilst adaptations have been made, the core processing involved in all experiments has remained consistent and comparable. Although this may give the impression of a highly specific thesis with limited scope for further replication in alternative scenarios, this decision was made objectively and for good reasons. The task objectives have been held consistent and simple for all tasks in that responses are only required to the colour or shape of stimuli, and with only two options for each category. This ensured that for each trial, in all experiments, there were only 4 response options. The reasoning for limiting the response options, and holding the task as a constant, is that prime performance was requested from all participants, in that only the fastest and most accurate keypress / responses that the participants were capable of providing were wanted. By limiting the number of options, and reducing the amount of task-confusion to a minimum, helped to ensure that task capability was maximised. With each trial being as simple as possible helped to ensure that all studies focused upon analysing *baseline* measurements, and hence optimal cognitive performance, rather than taking into account other issues that could have impeded performance. By reducing task-confusion to a minimum helped to ensure that all facilitation and/or degradation of measures obtained were the maximum that could reasonably be expected from each participant with the task manipulations undertaken.

A Retrospective Insight

During the introduction it would have become clear that the focus of the following studies were aimed at dissecting and analysing performances towards task-switching paradigms. Although task-switching is a relatively broad area of focus, the primary objective was not to narrow the research scope upon the traditional viewpoint of switch costs in relation to such task performances; where switch costs theoretically demonstrate the increase in latency of responses when switching between tasks, and hence factoring in reconfigurations of task-sets to permit such actions. It was felt that this particular area often receives a large amount of interest, and yet can in some paradigms be based upon other factors that receive substantially less attention. These factors were the core focus of the present thesis.

Examination and Selection of Paradigms

There are a range of task-switching paradigms commonly used in research of this nature, all remaining prevalent and useful, yet all focus upon core areas of interest as a result of the benefits/hinderances that each possesses. For the purposes of the present research the decision was taken to use a combination of the list (Jersild, 1927) and alternating-runs (R. D. Rogers & Monsell, 1995) paradigms. This permitted a baseline measurement to be taken from the list design, and applying it in a comparative manner to results from the alternating-runs design. As a result there were always two tasks within each experiment. Baseline performance was measured using the list paradigm by recording responses to trials of individual tasks in blocks, named *pure trials/blocks* (i.e. AAA and BBB in individual blocks). Performance towards trials in these blocks was expected to be exceptional as there were no competing tasks for a response, therefore swift and accurate responses were anticipated from all participants. Necessary precautions of counterbalancing these pure trial blocks were made throughout all experimental studies to ensure that overlap from the previously performed task was minimised. Means of responses towards these trials were calculated and recorded as a baseline upon which all responses in the forthcoming blocks of mixed trials would be compared. Following completion of the pure blocks of trials, an alternating-runs block was presented, combining both of the previous tasks (i.e. AABBAABB). This was crucial to the focus of the thesis. Where it is common to continue with the list design paradigm and use a mixed block of consistently switching trials (i.e. ABABAB), this may not always be considered a strong comparison to make to the pure block measures. Within each pure block tasks are continuously repeated, the participant is not expected to retain the other task in working memory, they are effectively segregating this task-set and placing no attentional resources towards its use. Furthermore, they are not required to perform any alterations on-the-fly towards the current task-set activation, in a sense minimising working memory usage, and certainly not switching to an alternative task. Therefore it seems somewhat illogical to compare performances of this consistent repetition format to performances where tasks are changing on each successive trial. By implementing an alternating-runs paradigm to compose the mixed block of trials ensures that measures can be recorded that take into account the different processing elements of repetition trials, *and* switch trials within the same block.

Although it cannot be denied that the repeat trials within such a block, are handled in a different manner to the repeat trials within a pure block, comparisons based upon current task-set maintenance can still be performed. Clearly there are discrepancies between the two repeat formats in that within the pure block performance is guided towards a single task, with no need to activate the task-set for the alternative task. Yet during the mixed block, although repetitions are being performed, and in this respect the task-set is being maintained for such usage (highly similar to the pure block trials), the alternative task *must also remain in working memory.* With two tasks being necessary for response instead of a single task, the emphasis is placed upon participants to retain both task-set response configurations within working memory for ease of task performance depending upon the trial presented. A further consideration that must be made is that unlike other paradigm formats (e.g. randomised design) the pattern of tasks are held constant, with a switch on every second trial, following a repeat of the previous. In this case it is therefore possible for participants to perform with greater ease (faster RTs and more accuracy) if they are capable of maintaining the task-sequence, and crucially their current place within this. As a result, the demands placed upon participants are substantially greater within the alternating-runs block, than within the pure blocks. Optimal performance can only be given if maintenance of *both* a) the task-set response configurations / stimulus-response mappings, and b) the task-sequence itself, can be achieved. Despite these concerns, it is the most appropriate paradigm for measuring responses comparing pure trials to repeats, and repeat trials to switch trials.

Maintenance Measures

With measures being taken from the pure block trials, mixed block repeat trials, and mixed block switch trials [herein referred to as *pure*, *repeat*, and *switch*], analysis of the differences in response latencies to each can uncover a multitude of different findings. During the introduction it was discussed that on the basis of these trial responses appropriate costs could be measured – mixing costs being the increased response latency between pure and repeat trials, and switch costs being the increased latency between repeat and switch trials. Throughout the thesis the focus has been primarily upon the mixing costs, since these are not only representative of maintenance factors, but also provide the basis for the calculation of switch costs.

Task-Sets

With only two task-sets in use throughout each of the experimental manipulations, each with two responses, the number of stimulus-response mappings required for correct performance was minimal. Yet because the cues provided upon each trial offered little information with respect to the correct mappings *per se*, such mappings were required to be maintained within working memory[20]. Although this may be construed to be a simple process, and one that does not require particularly demanding memory strategies, the benefits of this decision relate to precisely this simplicity. With these demands being minimal ensures that the processing requirement capabilities of the participant are retained, hence strong performance measures can be expected. It is a reasonable assumption that to ensure the largest effects, be these positive (facilitation of speeded responses) or negative (slowing of responses), requires that task-sets be used that are minimally cognitively demanding. By using simple tasks, and simple two-response option task-sets helps to provide a clear distinction that may otherwise have been confounded by extra factors. Yet the retaining of these task-sets/response mappings must be made within the working memory executive, theoretically within the visuo-spatial sketchpad due to the visual format of the stimuli, thus providing a measure of working memory demand that is a requirement of *each* trial regardless of the task. When taking into account the traditionally accepted structure of the working memory executive it is not surprising that the requirements of each trial still permit the use of phonological

[20]The more explicit cues provided a greater amount of information that could be mapped towards responses, although this was never explicit.

working memory structures in addition to the required visuo-spatial sketchpad. Although the executive itself is presumed to imbibe connectivity from both the phonological and visuo-spatial structures, it must be a prerequisite that it can permit the inputs in a simultaneous fashion; else tasks involving both structures could not be performed (i.e. in the example of tasks involving concurrent articulatory suppression). Therefore, by ensuring that the task-set requirements of the working memory be relatively simple, ensures that all subsequent measures taken, with elements involving the phonological stages of the working memory executive in addition, demonstrate the impacts upon performance facilitation/degradation rather than possible contamination of the task-set requirements themselves.

Task-Sequences

The pure blocks of trials are a relatively straightforward process for participants, since responses are only required to the characteristics of a single task-set. In the instance that they are performing the secondary pure block, there may be occasions where the previous task-set interferes in response-encoding, resulting in a potentially incorrect keypress. Yet these occurrences are often minimal due to the consistent/repetitive and considerable number of trials within each block (furthermore minimised by the counter-balancing of these blocks). As a result it is often the case that in these blocks of trials, the fastest (and most accurate) responses are recorded; although some consideration must be drawn towards elements such as fatigue and boredom within these blocks, also because of the repetitive format. However, during the mixed block of trials (AABBAA) such simple repetition is not available, and both task-set responses must be maintained. Although the topic of the task-sets themselves has been debated, the maintenance of the sequence of such task-sets must also be sustained. This is a matter that can sometimes cloud the debate of experimental studies such as are performed here. Although the tasks themselves are simple in design, the cognitive requirements to perform the sequence maintenance operations are often more susceptible to demands than the tasks themselves. Whilst the participant is aware that they must retain the response strategies for each task-set, the additional requirements for task-sequences can often result in a 'flustered' performance. For example, within a paradigm such as the random-cuing format the notion of task-sequence is not encountered – participants are unaware of any sequence being performed (if indeed any has been programmed). Therefore following the completion of each trial they often return to a 'centre-point', a baseline, permitting rapid responses to either a repetition or a switch of task. In this sense they are effectively switching on each trial, with minimal impacts demonstrated upon repeat trials, therefore resulting in tremendous mixing costs, but not necessarily any switch costs – the two measures are indistinguishable as a result of the response tactics in use. In the case of an alternating-runs design it makes little sense to return to such a 'centre-point', since there is a sequence, and hence preparation for the forthcoming trials can be made so long as the participant is capable of maintaining the sequence correctly. Presuming that participants wish to perform to their peak ability can often be a demanding request (upon both the researcher in the hope that this is the case, and the participant who has to complete the tasks), yet by making use of the explained sequence could permit excellent measures to be recorded. However, the performance of a study such as those outlined here can in this respect be deemed as more demanding than those using the random-cuing design for example, for precisely the reasons given. In this sense, participants are requested to maintain both processes within working memory, *and* allocate these correctly depending upon the current stage of the trial (preparation for – task-sequence; performing of – task-set).

Facilitation of Maintenance

Since the core focus of the presented studies was to determine impacts upon the maintenance elements of task-performance, and due to the high cognitive demands of maintaining both the task-set response formats, and the task-sequences for each block of trials, it was sensical to focus upon means of alleviating some of the demands placed upon participants. Based upon conversations with persons for whom initiating actions towards goal-directed behaviours can be challenging (Parkinson's disease [PD] patients – see Appendix A for further details), it was detailed that on occasion actions could be assisted after a self-declared verbal command was stated directing the person towards the action, e.g. "I am going to walk towards the window". Although initially it was not clear [neurologically speaking] as to how such a verbal command could prompt actions in this manner, such knowledge led to the formulation of the experimental designs and initial theoretical bases.

Pilot studies with PD patients using an identical task-switching design illustrated that with some participants mixing costs could be reduced compared to others; thus demonstrating that elements of the task were being maintained to a greater extent than with other participants. Taking into account that maintenance of task-sets must occur within every trial of each block, this matter seems something of a side issue; it must be encountered (and overcome) regardless of the position within the task-sequence. Therefore combining this theory with the finding that differences in mixing cost can be generated, indicates that maintenance is related to a stronger degree in terms of task-sequence maintenance. Although the initial conversation detailing assistance in the initiation of movement, gives the indication that such verbal statements may prove advantageous in terms of switching tasks, when coupled with the pilot findings it instead prompts the belief that it may relate to all manner of actions. Whilst there may be little disputing the benefits garnered by this participant when using verbal statements, the results presented demonstrate that benefits *in general* can be generated through this tactic, and most specifically in relation to task-sequence maintenance.

Throughout this thesis there has remained the decision to facilitate task performance, favouring this option over the more commonly found degradation of performance. Yet to provide complete coverage it was necessary to perform experimental manipulations that covered both potential degradation and facilitation, in addition to presumed neutral [standard performance tactics] impacts. With such contrasts any positive/negative impacts were demonstrated clearly and unambiguously. In terms of degradation the process to induce this was articulatory suppression, and required participants to repeatedly verbalise an irrelevant word for the duration of the task, as was performed in previous research, i.e. "blah blah" (R. Brown & Marsden, 1991). Although not a typical word with everyday usage it was important to select a saying that could be performed in a uniform manner between all participants, with no variation in pronunciation, and of most importance could have no relation to any task being undertaken, however tenuous the link. In terms of facilitation it was concluded that the most relevant verbal manipulation that should be used would be to state aloud relevant cues for each following trial (in conjunction with the visually presented word also). In this sense a double-cuing tactic would be undertaken for each trial, presumed to 'boost' the power over a single visually-presented cue by making use of the multiple processes within the working memory executive – both the visual-spatial sketchpad (for the visual cue) and the phonological sector (for the verbal statements of the cue). It is clear that whilst both sectors would be used within a verbal manipulation of the task design, the same processing could be accounted for within manipulations using articulatory suppression also. The core difference between the two formats being that the phonological sector of the working memory executive was being manipulated to provide either relevant or irrelevant information with regards to task completion. It is important to reiterate from a previous chapter that these two systems, although combined and working towards an identical goal, are distinct and not inherently associated for all processes. Hence performance could continue when articulatory suppression was being performed, as although this may have been distracting and resulted in inflated measures and latencies, it could nevertheless be separated from the processing that was required for correct task performance. A similar topic was discussed in a later chapter (Chapter 6) where incongruent cues were presented alongside congruent cues (e.g. congruent visual with incongruent auditory). Clearly if the two systems within the working memory executive were required to focus upon the same processes, performance of this task would not be feasible as the two cues are in conflict for the correct response [a similar theory to how we can perform multiple tasks such as cooking and talking without being overly distracted]. This is an important topic since it is necessary to accept that task performance remains possible (and strong) even with irrelevant working memory processing being performed concurrently. Yet there are no benefits to this, only hinderances that although distracting and demanding do not entirely inhibit the correct processing required for the task.

Yet regardless of these manipulations in terms of positive/negative impacts, it was crucial to provide a baseline from which these measures could be recorded – to determine precisely how beneficial (or otherwise) these performance tactics were for the participants. It is often the traditional method to use a silent condition, where the tasks are performed with no verbal or auditory information. Although many of the studies presented here also used a silent condition since this provided the most reliable baseline to be measured, this is also not without issue. Throughout this work the topic has been discussed where silent performance may not rely entirely upon processing without verbal information *per se.* When performing a task (and indeed in conversations with participants this has been confirmed) it is not uncommon to perform inner-verbal statements, or inner-speech, to guide and enhance task performance. Whilst not conforming to the standard everyday thought of verbalisations, such inner-speech nevertheless prompts discussion as to whether (and how) the use of these processes may impact task performance. It is important to remember however that as researchers we cannot dictate the format of inner-speech within our participants. In the same respect that we have no means of ensuring that they are not thinking about (and using inner-speech) for entirely irrelevant matters in relation to the task being performed, that may or may not have a negative impact on the measures obtained. Hence although silent performance of a task is the standard, and traditional means of providing a baseline measurement, it does have problems that unfortunately cannot be alleviated, or determined on a per-participant basis.

Although task manipulations involving verbalisations were common in many of the studies, an expansion upon this was also used that permitted measures to be taken that did not involve self-stated verbalisations but utilised the same phonetic characteristics. In a selection of the studies an auditory cue was used instead of, or in addition to [between conditions] the self-stated verbalisations. In these instances the cue was presented at a comfortable volume and aimed to imitate the intrinsic audio elements of a standard verbalisation, without the necessary involvement of the participant themselves. This was a novel manipulation[21] that had not received attention in previous studies but that was felt would provide valuable information with regard to task performance impacts. Although results with self-stated verbalisations were valid and demonstrated strong impacts, it was unknown whether these were the result of a specific process found only when articulating outwardly, or whether the same

[21] as detailed within anonymous peer reviews of Chapter 2.

impact could achieved without this process. It was demonstrated that comparable results were obtained in the audio-cued manipulations to those where verbal articulations were made. This indicates that the impacts (and indeed benefits) obtained through verbalisations are related more to the applied processing within the phonological regions of the working memory executive than to the actual process of articulation itself, in terms of the attentional and cognitive demands of articulation.

It seems likely that the pathways of activation for both forms of verbal information are identical, despite involving different initial stages of processing. Whilst both appear to utilise the same phonological regions of working memory, the necessary processes aligned to the stage preceding this are obviously different. During the articulation manipulations the participants must recognise and decode the visual information (presented in word form), re-encode this information using the phonological processes of working memory, and recite aloud. However during the audio manipulations the processes of decoding information and re-encoding into a phonological format are not necessary, since it is presented in a format that can be implemented into the phonological systems of the working memory executive [potentially] directly, and used with great speed. Although these two formats appear relatively dissimilar in the initial stages, it appears that they both follow a similar later strategy, hence both permitting such similar latencies and costs between these two variations.

What is unclear however is why, despite the presumed differences in the initial stages (with less cognitive demand required for the audio manipulations), these latencies became so similar upon responses. For this reason it could be theorised that whilst the articulation condition provides a distinct route into the correct working memory pathway based upon the phonological processing performed by the participant, there may be a form of fail-safe process for the audio condition. By essentially ascertaining if the information presented is correct, by analysing this in conjunction with the presented visual cue would allow the participant to determine if the information provided is accurate. In this sense such a process could be seen as being a minor form of a conflict-resolution technique, a secondary-level clarification to ensure that the correct response is given. Although this is a mere theory, it does explain the results portrayed within the later ERP results, demonstrating a potential activation of the ACC, perceived as being related to the cue-conflict decoding processes. Although in this example the two cues were conflicting, participants were aware of which cue was correct and yet the conflict-resolution process was still performed. For this reason it seems likely that even where both cue formats are provided and present identical information, a similar process of conflict decoding will remain, albeit with less of an impact. Such a conflict decoding process would not be required where the participant is providing the articulation information, since this an irrelevant step, no conflict is present.

Cues as facilitators?

In Chapter 3 the focus was drawn upon the cues presented for each trial, to ascertain if manipulating these could impact task performance alongside verbalisations; taking into account the necessary uses of language as a translator. It was a consideration that with the consistent display of visual word-cues that these may become adapted as visual cues, rather than attention being paid to them as words that required language processing. However it was discovered that this was not the case, and that regardless of the amount of times the word cue was displayed, silent performance indicated that translation of cues remains consistent. By adapting the presented cues to require greater/less translation, yet retaining minimal ambiguity, provided general performance differences in that those requiring greater translation produced larger mixing costs for all manipulations. Although this was not entirely surprising due to the increase in cognitive demands associated with a greater amount of translation, what was unexpected was the result in terms of comparison between minimal translation and no translation [language-based]. By presenting participants with visual cues requiring no language involvement (i.e. a visual matching task), it was anticipated that mixing costs would be reduced to the dramatically, since maintenance of the task-set/response configurations was effectively removed. This was not the case, and performances were in line with conditions where cues required minimal translation and language usage.

Where such visual-image cues are used however, verbal instructions promote minimal differences in response capability; indicating that whilst it is important that they do not conflict with the visually presented detail, they are not valued to the same extent as when using visually presented word cues. These findings suggest that there may be a form of cooperation, or compatibility, between the encoding forms. Where image cues are visually presented it may be that bottom-up processing occurs and activates the relevant response sets, whilst any additional processes such as verbalisations makes minimal impact upon this. When presenting word cues however, it may be that language involvement [reading] is triggered as a mediating process. The results provided potentially reveal the existence of multiple cue-decoding / domain-specific working memory systems (Gruber & Goschke, 2004), that provide and assist in the process of task maintenance.

Holding the line

Whilst the studies presented here provide substantial evidence for the contribution of relevant verbalisations towards the facilitation of task performance, through the promoting of greater task-sequence maintenance, it was initially unclear how this process was working. Using traditional analyses it could not be determined if the differences between verbal manipulations were across all trials, in all blocks, or whether (and in-line with) vigilance decrement factors could be influential, and that these differences fluctuated across the trials. In this sense if the first theory was correct, the differences in mixing cost latency would be consistent across all trials, within the block. If the second theory was correct, then it was likely to see movement (not necessarily in-line with consecutive trial sequences) across the trials in terms of mixing cost latency. It was determined, and evidenced in Chapter 5 that the second theory is correct, building upon the research provided in Chapter 4.

It appears that where relevant verbalisations are used, as with articulation and audio input, not only does the overall mixing cost reduce substantially compared to where irrelevant verbalisations are used, or with silent performance, but that this reduction lasts for considerably more trials. Using CDF analysis techniques (Houghton & Grange, 2011), it was determined that in a proportion of trials *all* manipulations (relevant, irrelevant, and neutral) had highly similar mixing costs. In this respect it was theorised that where fast responses were provided (and hence smaller mixing costs obtained), then preparation for the upcoming trial had been successful; in this sense task-sequence maintenance had been achieved. With all manipulations achieving similar mixing costs for a small proportion of trials, this was an interesting finding, and one that demonstrated a new theory for task-sequence maintenance facilitation. Whilst it was initially considered that relevant verbalisations would permit stronger and more accurate sequence maintenance than irrelevant verbalisations, these findings demonstrated that this was not the finite conclusion. Indeed, when separating the trial responses into bins (using CDF-XL – Houghton & Grange 2011), we can note that whilst the initial bins share highly similar mixing cost values for both relevant and irrelevant verbalisations, the relevant verbalisations permit the maintenance of task-sequences to be held for many more trials. As a a result, if these bin mixing cost values are plotted, we can note that whilst the irrelevant verbalisation mixing costs increase dramatically over the progression of the bins, the relevant verbalisation mixing cost values do not increase as substantially – creating a smaller gradient (see Figure 8). It should be stated that in later bins relevant verbalisations also obtain increases in mixing cost value, that appear dramatic, but that this increase is restrained until this point. A further point that must be stated is that the bins, although increasing in value upon the plots, do not align to trial numbers *per se*. Assignment of a value to a particular bin is made on the foundation of the RT value - with the fastest responses in lower bin value numbers (i.e. Bins 1-3), and the slowest responses in greater bin value numbers. As is discussed in Chapter 4, response latencies are likely to fluctuate from fast to slower across a block of trials, and yet the fastest trials are presumed to make full use of task-sequence preparation, hence preparedness for an upcoming trial (i.e. a repeat) is expected. Due to the fluctuation in response latencies, such preparedness could occur with any trial within a block, not necessarily at the start of the block when fatigue may be lowest; for this reason the CDF analyses are calculated in this manner.

The core message to take from this particular Chapter however, is that although verbalisations do assist in the reduction of mixing costs, and through the facilitation of task-sequence maintenance, it is not necessarily in a global fashion that this occurs. Instead it permits a prolonged ability to maintain task-sequences that is otherwise depleted when performing the same task in silence, or with irrelevant verbalisations.

Cortical analyses

Although the detail and results gained from the behavioural measures was interesting, it was felt that to provide a complete overview would require a more in-depth assessment of cortical activity whilst performing a variant of the study. Using adapted manipulations suitable for ERP recording (i.e. audio cues rather than self-articulation), a further two studies were conducted. The primary objective of the research was to assess for differences in cortical activation between manipulations where visual information was relevant, and audio information was irrelevant, and vice-versa.

It was determined that in addition to increased behavioural measures where visual cues are used to guide responses, compared to audio cues, similar findings were noted in terms of increased waveforms – indicating increased cortical activity. Within the first experiment the relevant cues were accompanied by an irrelevant, but not conflicting, alternative modality cue. In this instance, the differences between visual and audio relevant cues were marginal, but remained apparent. Predominantly the increased waveforms/activation was found in the frontal and fronto-central regions, indicating a presumed general increase in working memory activation. However, in the second experiment, when the two cuing modalities were placed into conflict, greater differences were evident.

When presenting relevant cues, accompanied by irrelevant and conflicting alternative modality cues (i.e. visual for task A, but audio for task B, where task A is correct), further activation differences can be seen. Indeed, within this experiment more substantial, prolonged, and expansive activations are found, and that may be presumed to illustrate activations of a different kind. Increased activations around 200-250ms can be seen comparing pure and repeat trials between visual and audio manipulations, where these increases are dominant with visual cues. The location of these activations (F3 and F4) suggests that the ACC could be a core factor in this stage of cue processing; particularly in terms of cue-conflict decoding/resolution, which is to be expected with cue presentations of this type. What is further interesting is that there appears to be greater activations within the left inferior parietal regions for the visual manipulation, particularly around 250-400ms; potentially as a result of increased phonological rehearsal. Such findings seem likely in terms of the additional phonological processing required, given the presented audio information is incorrect, and as discussed earlier it may be that the processing of conflicting information is repeated in terms of an additional fail-safe process.

Generally, what can be stated from the results of these investigations, coupled with the previous research, is that relevant verbalisations not only promote increased task-sequence maintenance capabilities, but that the reasoning for this may be related to a decrease in the amount of cognitive demand necessary for performing tasks in this nature. When no relevant verbal information is available, and the participant must rely upon inner-speech, or their own preferential tactics for responses, the cognitive requirements increase dramatically resulting in inflated response measures and can be seen through larger cortical waveforms. Whilst a general increase in waveform can be expected in this sense, what was most interesting was the increases in activation in regions associated with cue-conflict. With the methodology for experiment 1 (Chapter 6) being analogous to those previous studies using articulatory suppression (irrelevant, but not conflicting verbal information), it would not be unfeasible to expect dramatic differences between the audio and visual manipulations, and yet this was not found. Instead the most obstructive manipulation for participants was when conflicting cues were presented. Although this is not surprising, the degree of difference between these two formats was unexpected since both render the phonological regions of working memory processing irrelevant in terms of correct response set selection.

Final thoughts

The work presented here provides strong evidence for the continuation of research into the mixing cost within task-switching paradigms, not necessarily to the detriment of switch costs, but with at least a similar amount of dedication. Hopefully the evidence presented demonstrates that the basis of switch costs are the mixing costs, and without taking into account these measures we may be presenting information that is not entirely clear, and that may be contaminated by these alternative factors.

It seems clear that in terms of facilitation of responses, verbal commands produce substantial benefits far exceeding the general beliefs of them assisting in everyday task performances, hence their common usage. What was unclear prior to the presented research was that these verbalisations, be these articulated, or presented in an auditory format, appear to facilitate task-sequences, rather than prompting action in a responsive manner. In this sense, they target the mixing costs as an outcome of enabling the participant to maintain their current position within a task-sequence, hence allowing awareness of whether a following trial is a repeat or switch of the previous. This helps to avoid a 'switching-on-each-trial' scenario that would otherwise be encountered, as with other paradigms such as the random-cuing design. Whilst in some situations they may also assist in the evocation of fresh task-set activations, such as with some patients (see Appendix A), it is most likely that with control populations maintenance activities are the primary targets.

What remains evident throughout all of the presented studies, is that regardless of the task, performance with concurrent relevant verbalisations (in either format), ultimately results in improved performance compared to the standard design of performance in silence. Despite these findings, all communications with participants stated that they used inner-speech; although as has been discussed, we as researchers can never be certain as to their continued usage of this.

The studies and results presented here demonstrate that for consistent and strong performance, relevant verbalisations provide substantial assistance and ultimately facilitation towards goal-directed behaviours.

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APPENDIX A

VERBAL COMMANDS AND PARKINSON'S DISEASE OVERVIEW

Until now the nature of the chapters have been composed of predominantly experimental results and discussions, with little explanation of how these may be beneficial to persons outside of recollection of tasks and sequences. Yet as with the majority of experimental research, the origins of the work have their foundations in an applied situation. It was briefly mentioned within the core introduction that much of the research presented here was founded upon work conducted with Parkinson's disease patients. It is with this in mind that the forthcoming chapter aims to explain the reasonings and foundations for this research, and just how these patients impacted this work.

For this reason the forthcoming chapter is formulated in a more theoretical manner than those previous, with the intention of providing an insightful viewpoint of the reasonings for the additionally presented research data. It is important to retain realistic expectations for this research data, in that it is intended as a foundation for future research, and not a conclusive final-statement on the matter. The work conducted and that continues to be conducted on Parkinson's disease research is invaluable, and the work presented here provides little comparison to much of this in terms of determining causation and treatment for the disease. Yet it should be stated that it is not without impact, but in a palliative format, as a potential means to improve the daily lives of patients with much greater further influence as shall be discussed later.

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In discussions with a PD patient it was mentioned that she often found initiating movements easier when providing a verbal direction to herself, rather similar to "I am going to walk over to the window", for example. With the difficulties in initiating action movements a typical symptom of PD, this anecdote piqued my interest to a great degree. It was clear to the patient that she felt such verbal utterances greatly assisted her in performing all manner of actions, and without this she would struggle to go about her daily life with the ease she currently found. Additionally it was also mentioned that when doing other tasks such as gardening, or walking along the promenade she found it easier with music, almost as though it served as a form of metronome to regulate her movements. It seems clear, albeit anecdotally, that there appears to be influences emanating from verbal and auditory regions of the brain, to the motor regions, potentially via the basal ganglia.

With the emergence of activated motions as a result of a verbal stimulus, this appears to correspond with previously hypothesised links between the prefrontal cortex and the basal ganglia (Alexander & Crutcher, 1990). Although there has been little solid evidence of this with human subjects, it is evident that if indeed there is a cortical connection between these regions, it is likely for this reason that such changes can be found within a PD patient's movements. For this reason basic versions of the tasks previously presented were administered to a range of PD patients. Within the forthcoming chapter these are discussed predominantly in terms of theoretical viewpoints rather than full statistical analysis.

THE USE OF VERBAL COMMANDS IN PARKINSON'S DISEASE.[22]

[22]Investigations of verbal commands with a Parkinson's disease population: A theoretical overview and insight.

Abstract

Studies involving primates have hypothesised that a language-orientated circuit originating in the basal ganglia and looping through BA 44 & 45 (Broca's area) may exist. PD patients were recruited for participation since the disease impacts basal ganglia functioning; any benefits gained from a connection to BA 44 & 45 may be easier to determine. An alternating-runs task-switching study was performed using two articulation techniques: one requiring relevant verbal statements, the other using articulatory suppression (irrelevant verbal statements); thus determining differences between where the loop could provide benefits, against where it could not. Left and right-hemisphere affected PD participants were compared against age-matched controls. Both the age-matched controls and right-hemisphere PD participants performed with slower responses in the articulatory suppression condition, as compared to the relevant verbal condition. Of greater interest is that relevant verbal commands appear to improve task-sequence maintenance resulting in reduced mixing costs, but only with the control and right-hemisphere participants. Due to degeneration within the left-hemisphere basal ganglia, such improvements cannot be seen with these participants. The study suggests evidence of the cortical circuit existing within human populations, but is susceptible to lateralised basal ganglia damage.

Introduction

Although Parkinson's disease is often characterised by a resting tremor, it is not solely segregated to such motor symptoms. Importantly to this chapter, and associated to the previous chapters, it also often results in cognitive difficulties, particularly in respect to performing multiple tasks (Flowers & Robertson, 1985; Pollux, 2004; Rochester et al., 2004; Woodward, Bub, & Hunter, 2002). As to the causation for the decrement in cognitive ability it is somewhat uncertain, but taking into account the classical cell-degradation of the substantia nigra and the related symptoms, it is highly likely that this is also the root cause.

Patients typically exhibit PD symptoms when $\approx$68% of the substantia nigra cells in the lateral ventral tier of the pars compacta are lost, in addition to a further loss of 48% of caudal nigra cells (Fearnley & Lees, 1991). Because of this cell decrease dopamine production also decreases. With this reduction in dopamine generation, the basal ganglia suffers from a lack of dopamine input. With the inhibitory and excitatory pathways emanating from the basal ganglia being finely tuned to specific amounts of dopamine, any fluctuation ultimately results in changes in patient behaviours and functioning. Typically such changes can include dyskinesia, bradykinesia, co-ordination problems, timing issues and problems combining multiple movements (Benecke, Rothwell, Dick, Day, & Marsden, 1986; Poizner et al., 2000).

Yet as has been stated, some aspects of cognitive difficulties can also become apparent in patients, and are likely to be a result of the influence of the basal ganglia also. Although it is most often associated with motoric influences, it is also likely to be influential in goal-directed behaviours, planning and executive functions in general (Graybiel, 1997) as a result of connectivity with the prefrontal cortex (Middleton & Strick, 2000b).

Task-Switching and issues with RT research

When researching task-switching processes within a PD domain, we are often left with unavoidable confounds which may have substantial implications upon the results obtained. For example, with this form of research the most important measures are usually registered from responses or reactions to stimuli, and often given through an initiation of a movement, e.g. a keypress. Clearly there are issues afoot with taking measures in the form of motor responses from a group of persons for whom initiating said movements may be difficult. For example, it has been demonstrated that increased RTs can be obtained within task-switching studies when comparing L-Dopa 'Off treatment' conditions to 'On treatment' conditions (Hayes, Davidson, Keele, & Rafal, 1998; Shook, Franz, Higginson, Wheelock, & Sigvardt, 2005). Yet, there are further issues that are not as instantly evident as these, and for which adjustments cannot necessarily be made. For example, bradyphrenia is an additional issue that cannot be recognised with such ease, and is characterised by a slowing of thought that can result in increased response latencies. Hence with regard to task-switching measures, increased reaction times (RTs) may be a result of a decreased ability to perform the necessary movements, or as a result of a slowing in cognitive processing whilst permitting fast responses, or finally as a combination of the two factors.

A further issue with PD research in this domain is that of fatigue. Where in a standard population it may be expected that performance would improve over the duration of the study, as practice would assist in facilitating faster responses to stimuli, the opposite may be expected with a PD population. Due to the substantial requirements of performing tasks over prolonged durations, coupled with possible difficulties in initiating actions, increased levels of fatigue may become problem issues (Schwab, 1960, see R. Rogers et al., 1998). This is not necessarily a global theory, as all participants are different and some are more susceptible to fatigue than others, but it is nevertheless an issue that must be confronted in such research.

Taking a viewpoint away from slowing of responses, there are other cognitive issues that must be confronted with task-switching research in particular. Perseveration, for example has been demonstrated as occurring within PD populations (Lees & Smith, 1983). Another related issue that could become prominent is that of inhibition. It has been demonstrated that in some instances PD participants show improvements during task performance, but that on occasions this is somewhat limited and other dysfunctional characteristics are shown. For instance, despite improved performance participants may sometimes return to a previous, and incorrect task, in a sense struggling to retain a new task-set and reverting to a previous (Flowers & Robertson, 1985). In some respects this could be related to issues with lateral inhibition; where competing processes must be assigned to either an inhibition (to stop responses) or excitation (to allow responses) category (Tipper & Cranston, 1985). Clearly if participants are unable to retain their current and correct task set, and return to a previous task set, this suggests that there may be impairment issues with their internal conflict monitoring capabilities. As has previously been discussed in Chapter 6, such processing are likely to occur within the anterior cingulate cortex (Barch et al., 2001; T. Braver et al., 2000; MacDonald et al., 2000; Pardo et al., 1990; Peterson et al., 1989); therefore suggesting that there may be decreased activation in this region, theoretically driven by the influence of the basal ganglia.

Further evidence of conflict monitoring issues within PD populations were later highlighted by Pollux (2004). In an adaptation of Goschke (2000), RTs were measured comparing responses to congruent and incongruent task stimuli over differing RSI lengths (100ms and 2000ms). During the congruent condition, RT results were comparable to control participants; however with trials in the incongruent condition, RT results from the PD patients were substantially larger. With regard to differing RSI lengths, the control participants used the extra time provided in later blocks (2000ms) to prepare for the forthcoming trial, therefore reducing switch cost RTs. This observation was made with both the congruent and incongruent trial formats. The PD patients demonstrated reductions in switch costs for the congruent trials, but this reduction was not apparent within the incongruent trials. Pollux explained this finding as being demonstrative of reduced task representation when conflicting information was presented for working memory processing. Pollux further posits that these findings may be linked to frontostriatal circuitry and it's role in focussing attention correctly. In order to limit conflict issues such as these, it may be suggested that providing an external cue may minimise this impact, since the most substantial impairments are evident when relying upon self-initiated preparation and action (Meiran, Friedman, & Yehene, 2004; Werheid, Koch, Reichert, & Brass, 2007).

Verbal Commands

As stated previously, anecdotal evidence suggests that patients may be able to facilitate more efficient working memory functioning through the use of self-initiated verbal commands. Although this theory has been studied and detailed in earlier chapters with regard to control participants, the palliative benefits that could be achieved for PD patients should this become a proven methodology are of great importance. The details of how verbal commands may impact upon working memory processing are well detailed in previous chapters, and the reader should consult these for an explanation of influence within Baddeley's working memory model, and impacts upon RTs in general (See Chapter 2, Pages 33-39, for further details). Nevertheless improvements in RT performance that could be demonstrated by P.D. patients may outweigh that of control participants. Although counterintuitive it must be remembered that each is presumed to respond from a different RT baseline, and that improvement is measured in terms of cost fluctuations, rather than overall RT measures. With the hypothesised cortical connections serving to link the basal ganglia and the prefrontal cortex this articulatory process may provide an extra upsurge in the transfer of applicable information, and facilitate a more speeded response. With control participants possessing fully functioning basal ganglia, this additional process will not provide as much benefit as that which can be expected from the patient population.

To enable a full comparative analysis of the potential benefits obtainable from using verbal commands, it is important to use an additional condition with which these results can be compared. As in previous chapters Articulatory Suppression will perform this role well. It must be stated however that with regard to using this method and PD patients, detrimental performance measures are likely to be exhibited. If indeed a cortical link is found between the prefrontal language regions and the basal ganglia, articulatory suppression may lead to dramatically larger costs and overall RTs. Whilst similar factors are evident with control participants, effects are likely to be exacerbated with a patient population. As discussed, any relevant verbal commands are likely to provide a substantial boost to the basal ganglia, hence permitting an increase in movement ability. Yet in the same theory, by replacing the relevant commands with irrelevant commands (articulatory suppression) should lead to this information being transmitted to the basal ganglia also, and since it contains no relevant movement information could result in further conflict and response confusion. It is important to ensure that the patient participants are comfortable in their surroundings during such experimentation, as the inability to perform the task in this manner could potentially become stressful.

Neurological Connectivity Theories

Until now relatively little has been explained in terms of the theoretical connections between the basal ganglia and the frontal cortical regions responsible for executive functioning. Yet with the basal ganglia being in part responsible for evoking voluntary motor responses, and improvements in these motor responses being potentially aligned towards verbal commands, it is possible that a connective loop may be present between the language regions (BA 44 & 45) and the basal ganglia. Although theoretical, the concept of far-reaching cortical connection loops originating from the basal ganglia is not unfounded. Although originally presumed to take inputs from multiple cortical locations, and output to the motor regions only, the concept of basal ganglia connectivity has been debated for many years (Evarts, 1969, see Strick, 2004). Later concepts have expanded upon this pathway argument, and now argue that rather than being single-route pathways leading to the basal ganglia, and outputting solely to motor regions, these links are in the form of parallel-activating loops that contribute information to-and-from multiple regions for purposes including motor responses *and* cognitive functions concurrently (Alexander, DeLong, & Strick, 1986; Alexander & Crutcher, 1990; Doya, 2000; Middleton & Strick, 1994, 2000b,a).

The basal ganglia and Broca's area

The core focus of this belief requires the hypothesised connectivity of Broca's area (BA 44 & 45) and the basal ganglia, most likely linked through thalamocortical circuitry (Ullman, 2006). Although theoretical in terms of human research, primate research has demonstrated a highly similar linking process where thalamocortical circuits project from the basal ganglia to all

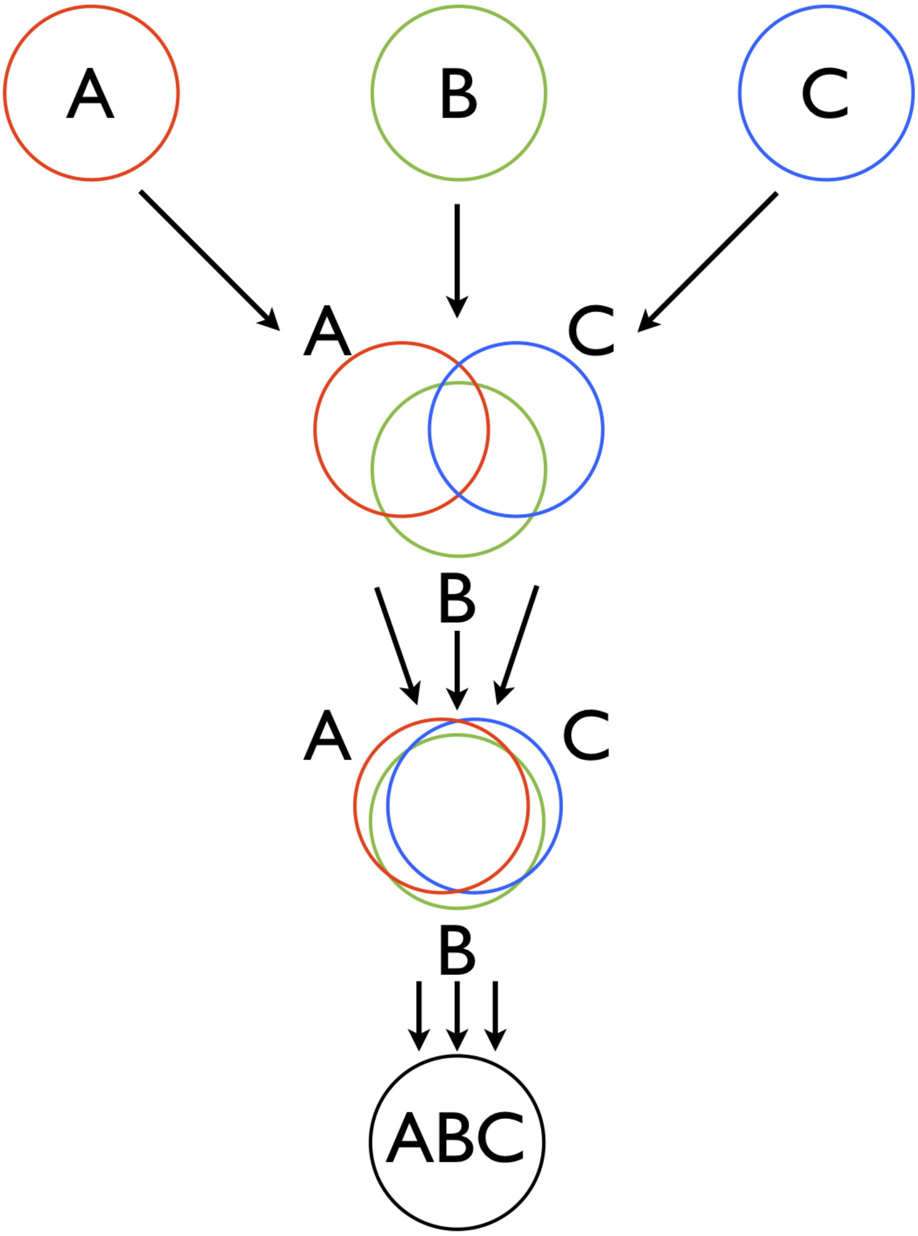

Figure 16. : A visual depiction of the parallel neurological circuitry as defined in Alexander & Crutcher (1990).

frontal regions of the cortex (Middleton & Strick, 2002). Included within these regions are areas such as F5 (a homologue of Broca's area BA 44), which is involved in multiple roles including action and motor control (Fincham, Carter, Veen, Stenger, & Anderson, 2002; Rizzolatti & Arbib, 1998). By building a picture combining the theories of Ullman (2006) and Baddeley's (1974) research into phonological loops, it can be considered that where verbal working memory is used, PD participants may display unique responses compared to control participants. If indeed the theoretical circuitry is available for use in working memory tasks, dramatically different responses can be expected from the PD participants compared to where it is unavailable, e.g. where articulatory suppression is being performed. For example, it has been discovered that participants may have difficulties using endogenous attentional processing compared to where exogenous processing is used (R. G. Brown & Marsden, 1988). When endogenous processing is used, participants are required to retain task-set responses internally, relying solely upon working memory functioning. Yet as has previously been discussed, PD patients typically have deficiencies in attentional resources, thus if the task demands exceed the attentional resources available, performance will be impeded. Such situations will be challenging to all participants, but when we consider the use of articulatory suppression removing all availability of internal speech, and placing even further demands on the attentional resources, it can be expected that PD participants will find the task very difficult. However since evidence suggests that task performance can be improved with the use of exogenous techniques to facilitate attentional processing, we are likely to determine even greater differences between these two tasks (relevant verbal vs. irrelevant articulatory suppression). In essence where differences may be moderate for control participants, with obvious distinctions between relevant and irrelevant verbal conditions, these differences may be exacerbated for the PD participants due to the dramatic differences between the task demands and cost/benefits obtainable with each, which are highly dependent upon the symptomology of PD.

Experiment

Participants and recruitment procedure

14 selected participants took part in the study, of which 6 were experimental participants (diagnosed with PD), and 8 were age-matched control participants. All were recruited through a database held at the School of Psychology, and all were remunerated for the their time. Ethical approval for the recruitment of PD patients was granted through the local NHS REC (Regional Ethics Committee). All participants were presented with a Patient Information Sheet (PIS) prior to commencement of the study; this detailed the methods involved. Following this, all participants were required to consent to experimental testing in-line with the current Mental Capacity Act (UK Governance, 2005) (MCA); this was conducted through a process of discussing the research aims and seeking voluntary clarification and approval from the participant. All processes were conducted under outlines as requested by the REC. All participants gave clear informed consent.

Once consent had been given, a Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) was performed with all participants. This was chosen to ensure that all participants had functioning cognitive abilities, and exhibited no substantial evidence of degenerative neurological disease. It was decided that only participants who scored 27 points or greater would be permitted to continue with the study. The results of the MMSE were not disclosed to the participants, but all scored more than the required points.

Stimuli, Apparatus and Responses

Task stimuli were bitmap images of either a square or circle, and shaded either blue (R: 0, G: 0, B:255) or red (R: 255, G: 0, B: 0). The square image measured 73 pixels on each edge, and the circle 73 pixels in diameter. All shapes had a 1 pixel black border (R: 0, G: 0, B: 0) outline to provide additional contrast. All were constructed using Windows Paint. Task cues were generated using E-Prime 2.02, and presented words using the font 'Courier New' at a size of 18pts. All cues were shaded black (R: 0, G: 0, B: 0), and aligned to the centre of the screen display using the inbuilt tools in E-Prime. The VDU resolution was specified as 640 x 480 pixels from within E-Prime and was presented on a 15" display.

Each task stimulus required a response from the participant, according to which task was currently being performed - responding to the colour or the shape of the stimulus. Where the task necessitated a response to colour, a blue image required a keypress of 'C', and a red image a keypress of 'N'. Where the task related to the shape of the stimulus, a square images required a keypress of 'C', and a circle a keypress of 'N'. The current task was indicated through the presentation of relevant words in the form of the task cues *Blue/Red* for colour trials, and *Square/Circle* for shape trials. Participants were requested to respond to the stimuli as quickly as possible, whilst maintaining a good level of accuracy. If an incorrect answer/keypress was provided, a buzzer sound would be presented to the participant to alert them to this.

Design and Procedure

Each trial was identical in formation and timing, only the cue text changed depending upon the trial ('colour' or 'shape'). The cue screen was displayed for 1000ms, followed by a 1000ms blank screen. The task stimulus was then

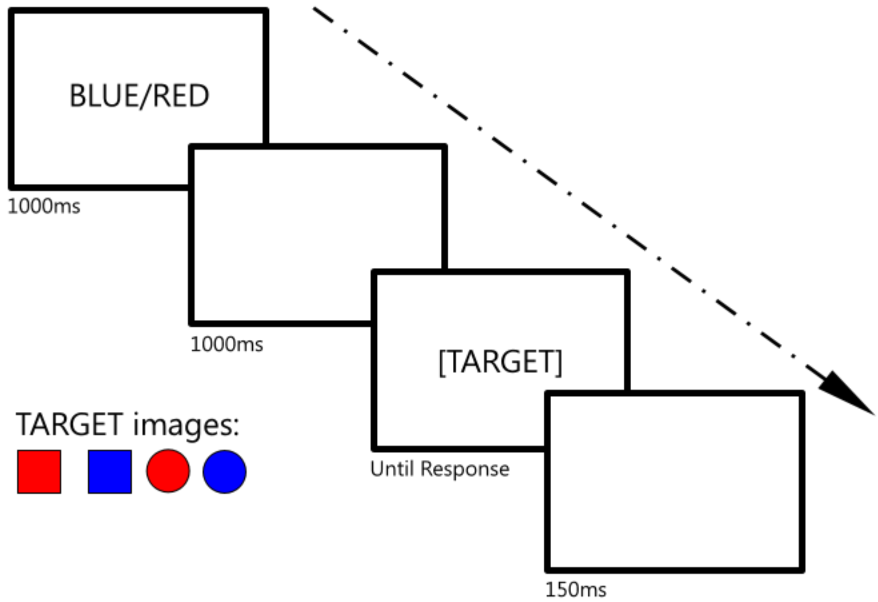

Figure 17. : A standard trial, in this instance depicting a colour task.

presented, and displayed until the participant responded. A blank screen followed for 150ms, regardless of whether the participant responded in correctly or incorrectly.

Participants were required to perform two pure trial blocks, where only one characteristic was responded to (COLOUR or SHAPE) for the duration of the block, before switching to the alternative characteristic for the following block, and one mixed-trial block where both characteristics were responded to, depending upon the cue. The pure-trial blocks were counterbalanced across both formats. The mixed-trial block was performed in an alternating runs paradigm; in this instance COLOUR, COLOUR, SHAPE, SHAPE, COLOUR.... As a result measures were obtained according to RTs for Pure trials, [Mixed-block] Repeat trials, and [Mixed-block] Switch trials. These permitted both Mixing Costs (Repeat RTs - Pure RTs), and Switch Costs (Switch RTs - Repeat RTs) to be calculated.

The study was performed using two conditions in a counterbalanced manner. One condition required participants to read aloud the task cue words when they were presented on-screen (Read Aloud). They were asked to read aloud these words in a forthright manner, clearly articulating the sound. This was to ensure that a relatively uniform sound was achieved from all participants. The other condition required participants to perform articulatory suppression whilst completing the trials (Articulatory Suppression). For this condition, participants were asked to continuously recite the non-word "blah". Repetitions of the word were requested at a rate of approximately 1-2Hz, and followed a similar method to those in R. G. Brown & Marsden (1988).

During both conditions, and with all participants, the same procedure was used. There were 48 pure block trials (24 trials for colour and 24 trials for shape), whilst there were 98 trials in the alternating runs blocks (48 repeat and 48 switch, with an equal number of colour and shape trials in each).

Although the study was initially intended to compare responses between participants with PD, and controls, a further distinction was made. All PD participants were asked to perform tasks as within the Unified Parkinson's Disease Rating Scale (UPDRS); from the use of this test it was determined that the participants predominantly displayed unilateral symptoms. Four of the participants demonstrated symptoms suggestions right-hemisphere affect, with the remaining two suggesting left-hemisphere affect. With all three of the participant groups performing both conditions of the study (Read Aloud and Articulatory Suppression), and three trial measures being calculated (RTs from Pure, Repeat and Switch trials), the study was a repeated measures 3 x 2 x 3 design.

Results

All results were calculated from the median values of the RTs provided by each participant within each singular block. Trials resulting in errors were removed from any analysis. The value of each RT to the stimulus was measured in milliseconds (ms), with each value calculated automatically using the inbuilt response timing tool within E-Prime. In the analyses all data was trimmed according to the same principals; any RT that was <200ms, or >2500ms was removed prior to medians being calculated. It was felt that any value <200ms was likely a result of a chance response and not the result of an explicit response. Any value >2500ms was thought to be potentially flawed, possibly as a result of an enquiry by the participant, or because a rest-break was needed. If values outside of these ranges were included, median RT values may have been subject to greater fluctuation.

A repeated measures ANOVA was conducted upon the global data (encompassing all groups and trials). Although there was no significant effect of Task (Read Aloud vs. Articulatory Suppression) [F(1,11) = .007, p = 0.93, η_p^2 = 0.01], an interaction between Task and Group (Left/Right-Hemisphere Affect & Controls) [F(2,11) = 3.94, p = 0.051, η_p^2 = 0.42] was achieved, indicating differences in responses to tasks depending upon the groups. A significant effect of Trials (Pure, Repeat, Switch) was also obtained [F(2,22) = 19.80, p < 0.001, η_p^2 = 0.64], demonstrating that there were significant differences in the RT measures for each trial form. A further interaction of Trials and Group was marginally significant, given further weight due to the limited participant numbers, [F(4,22) = 2.51, p = 0.071, η_p^2 = 0.31], indicating that the Trial measure differences were affected by the Group factor. Finally, a marginally significant interaction between Task and Trials was obtained [F(2,22) = 2.95, p = 0.073, η_p^2 = 0.21], demonstrating differences in Trial measures according to the

Task	Group	Pure	Repeat	Switch	MC	SC
Art. Supp	Control	633	730	775	97	45
		[44.47]	[76.60]	[89.68]		
	Right-Hemi	663	946	978	283	32
		[117.92]	[157.69]	[192.68]		
	Left-Hemi	782	1049	1011	267	-38
		[50.67]	[87.53]	[166.09]		
Read Aloud	Control	661	662	726	0.63	64
		[50.89]	[90.59]	[82.58]		
	Right-Hemi	628	728	881	99	154
		[75.27]	[114.50]	[84.03]		
	Left-Hemi	940	1137	1232	197	95
		[68.17]	[195.54]	[142.33]		

Table 15:: Experiment 1: RT (ms), [standard error] / * < 0.01, ** < 0.001. Italics = % of accurate responses (also includes accuracy costs in applicable columns).

Task being performed. No three-way interaction of Task, Trials and Group was achieved [F(4,22) = 0.062, p = 0.66, η_p^2 = 0.10].

With the present study, the most crucial results were those involving the factor of Group, since these provided the most valuable information. With there being a marginally significant interaction within the Trials and Group analysis, this suggested that there may be factors relating to the differences in the costs within the trials (particularly mixing costs). Visual examination of the means for trials and groupings provides further support for this belief (see Figures 18, 19, 20).

Therefore separate analyses were conducted for mixing costs and switch costs.

Mixing Costs

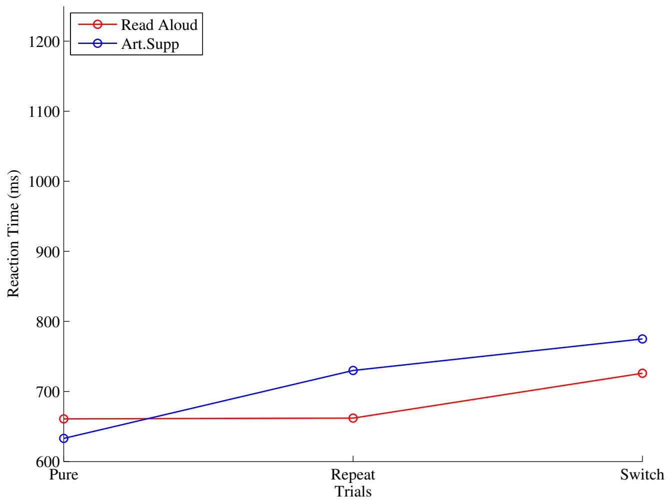

Figure 18. : Control participants - comparisons of Read Aloud and Articulatory Suppression task performances.

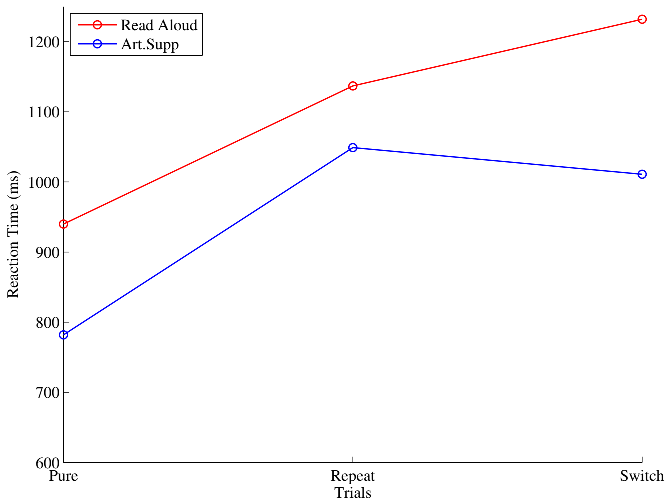

Figure 19. : Left-Hemisphere participants - comparisons of Read Aloud and Articulatory Suppression task performances.

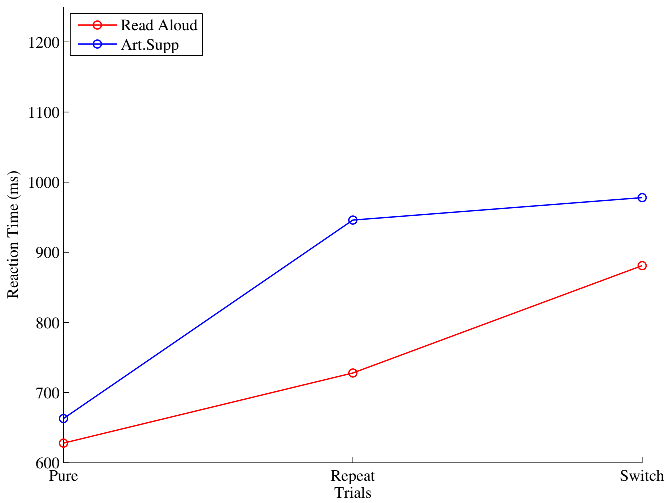

Figure 20. : Right-Hemisphere participants - comparisons of Read Aloud and Articulatory Suppression task performances.

For the purposes of analysing mixing cost measures, only Pure and Repeat trials were analysed across Tasks and Groups. Within this analysis, again a significant interaction between Task and Group was obtained [F(2,11) = 5.08, p = .027, η_p^2 = 0.48], indicating that the RTs for each Task differed depending upon the Group performing them. An interaction between Task and Trials was obtained [F(1,11) = 5.78, p = 0.035, η_p^2 = 0.34], demonstrating that the marginal interaction of the global analysis was more focused upon the mixing cost values from the Pure and Repeat trials; the Task being performed had a clear and strong impact upon the Trial measure values. Unfortunately a significant interaction between Trials and Group was not obtained [F(2,11) = 2.50, p = 0.13, η_p^2 = 0.31]; however it is important to acknowledge that this is because of two factors, one being the highly similar pattern of results between the Control and Right-Hemisphere participants within mixing costs; and the second because of the substantial differences in group size between the Left-Hemisphere and Control participants (both outcomes resulting in insignificant interactions). For clarity, comparisons between the Left and Right Hemisphere participants across Trials (comprising of the mixing cost values, Pure and Repeat) indicates a highly significant interaction given the number of participants in each Group [F(1,4) = 23.04, p = 0.009, η_p^2 = 0.85]. Taking this into account, it can be suggested that the Trial x Group interaction obtained in the global analysis is most likely rooted in the mixing cost results, but to ensure that this is correct Switch Cost analyses were also conducted.

Switch Costs

For the analysis of switch cost measures, Repeat and Switch trials were submitted into the repeated measures ANOVA. A marginally significant interaction between Task and Group was obtained [F(2,11) = 3.59, p = 0.063, η_p^2 = 0.40], demonstrating group differences in overall Task measures. No further significant interactions were obtained, including the crucial Trials and Group interaction [F(2,11) = 0.99, p = .40, $\eta_p^2 = 0.15$].

With such a difference obtained between the Trials/Group interactions of Mixing Costs and Switch Costs, a substantial argument is made in favour of the mixing costs being the crucial measures in relation to the Group findings.

Discussion

The objective of the present experiment was to determine any potential benefits of relevant articulations as a means of guiding and initiating goal-directed responses, as was suggested may be the case during discussions with a PD patient.

Although the initial study aimed to investigate these potential differences between both control and PD participant groups, this was later refined. Upon presentation for the study, all PD participants demonstrated lateralised symptoms of the disease. Previous research has suggested that substantial differences in cognitive performance can be elicited by lateralised symptoms of PD (Bowen, Hoehn, & Yahr, 1972; Spicer, Roberts, & LeWitt, 1988); hence a factor of side-of-affect was defined. As a result, comparisons were drawn between control, left-hemisphere PD and right-hemisphere PD participants.

Neurological implications upon groups

The study initially focused upon whether basal ganglia damage (associated with PD) would negatively impact the theoretical cortical loop encompassing BA 44 & 45 and the basal ganglia structures (Ullman, 2006). What was not anticipated was the emergence of lateralised impacts upon performances, and crucially the differences between these groupings of participants. Although there are large discrepancies between the numbers of participants in the two hemisphere-affect groups, a theoretical discussion of the results obtained remains of great importance.

If we are to compare the results of the Right-Hemisphere PD and control groups, there are undeniable differences, yet the pattern obtained remains relatively similar in structure. The predominant impact is located within the mixing costs, response times are overall faster for the Reading Aloud task than with Articulatory Suppression, and these factors combine to result in better mixing cost performance during Reading Aloud – helping participants to maintain task sequences. Yet, if we compare these results to those obtained from the Left-Hemisphere PD participants, we can note their responses are generally slower, there are relatively similar mixing costs for both tasks, and furthermore Reading Aloud results in slower responses in all trial forms compared to Articulatory Suppression. Although all of these outcomes are interesting, we must conclude that perhaps the most important with respect to the intentions of the present study is the reversal in performance measures from that which was expected – with Reading Aloud having slower responses than Articulatory Suppression. Despite the requirement that the results be *taken with a pinch of salt* due to the very small number of participants, there is nevertheless a strong indication of differences to the results obtained with the Right-Hemisphere participants. Regardless that the Reading Aloud responses were overall slower than with Articulatory Suppression, the mere finding that these responses were similar is crucial, as compared to all other groups where there were substantial differences between the two. It seems clear that the Left-Hemisphere participants found it as challenging to perform the task whilst reading aloud the relevant terms, and that no benefit or facilitation of these responses was available. In this sense it could be theorised that there may have been an obstruction to the hypothetical cortical circuit of information transfer between the language regions and the basal ganglia; much in the same sense as damage to particular loops resulting in a loss of specific functions (Middleton & Strick, 2000a). Simplistically perhaps, it is not inconceivable that the loop associated with the language regions (BA 44 & 45) is housed entirely within the left-hemisphere of the cortex, and hence is connected to the left-region of the basal ganglia. Since the participants with left-hemisphere affect appear to have substantially greater difficulties compared to those with right-hemisphere affect, it is likely that this cortical circuit is not facilitating performance. Although it is possible that the circuit itself is damaged in some form, it is more likely to be the case that the circuit itself is functioning, but the terminus is damaged and unable to use the provided information sufficiently. In this respect with the basal ganglia damage it is likely that it cannot imbibe the circuit information correctly, although transferal along this line is adequate; anecdotally similar to a disrupted train-line for example.

Yet this theory may not provide a satisfactory conclusion. Although the cortical circuitry may be inhibited from functioning correctly, a further issue must be considered. It is clear that cognitive performance can be affected by disruption of the loops, much in the same respect as a loss of specific functions (Middleton & Strick, 2000a), but if the loop is functioning on a basic level and is not disrupted entirely, it is possible that this could result in further degradation. Consider the finding that responses to Reading Aloud are slower than those with Articulatory Suppression; this may be a result of the partial degradation of the loop, or because of the additional processes involving it. For example, when Articulatory Suppression is being performed, the participant is aware that all of the words are irrelevant; they are essentially speaking in a rhythmic fashion. Yet during Reading Aloud they are required to recite relevant words to the task they are performing; essentially bridging verbal and working memory processes. This undoubtedly leads to increased cognitive loading not only from the reading, but from the connections to working memory task-set configurations. In this respect, although in the case of the control and right-hemisphere groups these words help to provide a distinction of forthcoming responses (via the cortical loops to the basal ganglia), the same cannot be performed by the left-hemisphere group; the increased reconfiguration and working memory requirements only serve to make this task more challenging than the irrelevant articulatory suppression. During suppression they are free to shut down the verbal/working memory link and leave any verbalisations to an automatic process; whilst reading aloud the additional demands only serve to further distract from the task-set configuration for responses, leading to an increase in overall response time.

A factor that cannot be overlooked is that of the responses given by the Right-Hemisphere affect participants, particularly in respect to the control group. Although initially assumed that mixing cost benefits may have resulted in similar responses for the PD participants to the control group, this was not the case. It is evident that further issues may be responsible for these differences. One consideration is that the impact of PD results in additional cognitive difficulties (Flowers & Robertson, 1985; Pollux, 2004; Rochester et al., 2004; Woodward et al., 2002), whilst a further could be the general slowing in responses as a result of the motor impacts of the disease. With respect to these it seems more logical that additional cognitive difficulties are to blame for these differences. If motor problems were the root cause then it is likely that response times for each trial format would be highly similar, as the difficulty in initiating a movement is not dependent upon a task, but on an involuntarily block that the participant cannot control. Hence responses for all tasks and all trials would be impeded to a similar extent, potentially resulting in similar response times regardless of the preparation performed. Since there are differences seen in the trial format responses, for both tasks, a clear drive towards a cognitive impedance is logical. From previous research it is understood that PD results in a degradation of cognitive ability, hence a general slowing is likely to have occurred, as seen. Yet the crucial aspect of the findings is that regardless of the general slowing, improvements and differences in response techniques can clearly be seen within the right-hemisphere participants. If we compare the difference in mixing costs between articulatory suppression and reading aloud for both control and right-hemisphere participants, it is evident that reading aloud produces substantially greater impact for the right-hemisphere groups than the controls[23] – as was deliberated within the introduction. Although this does not result in similar response times, the vast improvement clearly demonstrates the positive impact of relevant verbal statements upon the ability to perform tasks, particularly in terms of task sequence maintenance.

Cost Findings

Examination of the results clearly shows substantially larger impacts upon the mixing cost values, than upon the switch cost values. Although statistical analysis of the results provides a more clouded viewpoint, this is undoubtedly due to large differences in participant numbers; an unavoidable, but nevertheless disappointing anomaly. Taking into account evidence provided in the previous chapters, the results in terms of predominant impact upon mixing costs is not surprising; for a general overview and discussion of the influences upon mixing costs, please consult these chapters.

Given the results obtained, and the associated costs, it seems that the theory of processing dependency is a core factor. By focusing upon the results within the right-hemisphere participants group we can note that this outlines the

[23] differences of 184ms for right-hemisphere participants, against 96ms for the control participants

quintessential processing dependency theory. Analysis of performance with articulatory suppression demonstrates a substantial mixing cost with minimal switch cost; although the typical viewpoint would be to consider this as evidence for excellent switching ability, this is not supported by the results of the mixed repeat trials. With such an increase in average RT from the pure trials to the repeat trials, this is indicative of an inability to maintain task sequences, and hence an inability to prepare sufficiently for the upcoming trial format. As a result during the repeat trials, it is most likely that participants are recruiting a technique of switching upon each trial, as they are not aware if the forthcoming trial is a switch or repeat. In this respect it is safer, and a form of damage-limitation to switch rather than risk a repeat. However, with this tactic a resulting outcome is found; since repeat trials are treated as switches, performance differences between repeat and switch trials are minimal. Hence, there is a nominal switch cost on the basis of a substantial mixing cost.

A similar process is evident with the control participants, yet to a much smaller extent. Indeed, the difference in switch cost measures between articulatory suppression and reading aloud is approximately 20ms. On the basis of such minor differences it is likely that this is a consistent switch cost, and is indicative of a strong sequence maintenance ability. Yet this does not state that performance in both tasks is equal; during the reading aloud task performance is clearly facilitated by the relevant verbalisations – hence resulting in a smaller mixing cost value than with articulatory suppression. Although the differences between the tasks are relatively minor, the results nevertheless demonstrate improved task sequence maintenance, and improved overall performance, when using relevant verbal commands.

With the left-hemisphere participants the results do not provide as clear of a picture as to the dependency or it's impact. It may be logical to assume that the results are the effect of the processing dependency also, but due to the relatively large switch cost obtained during the reading aloud condition, this is somewhat clouded. Regardless of this large cost measure it remains substantially smaller than the connected mixing cost. Furthermore during the articulatory suppression condition, a negative switch cost is obtained, clearly demonstrating that the slowest responses were during the repeat trials. This most likely illustrates that switches were being performed on each individual trial, regardless if the trial was a switch or a repeat. The results obtained for this participant group are difficult to interpret, and only further complicated by the reversal in expected response outcomes (reading aloud slower than articulatory suppression). It is a reasonable assumption that the obtained results do follow a processing dependency theory, but that it is affected by additional factors most likely connected to the neurological issues outlined previously.

On the basis of the theories outlined here, in connection with the results obtained, a strong case is made for the assertion that mixing costs are the prominent measure within this study. Although there is some movement in the switch costs between tasks and groups, such fluctuations are caused by the movement of the repeat trials, and hence mixing costs upon which the switch costs are founded.

Examining the findings presented here demonstrates that there are many factors involved in goal-directed behaviours, particularly with respect to the tasks, but more crucially the participant groupings. It appears, albeit in the initial stages, that PD participants perform tasks using different tactics and techniques depending upon their lateralised affect of symptoms. Indeed, in some cases it is evident that using verbal commands (directing performance towards the correct tasks) improves task sequence maintenance and hence facilitates responses towards these. Where relevant verbal commands cannot be used the ability of the participants to maintain task sequences diminishes, and thus responses are performed in a different manner; performing a switch on each trial, regardless of whether this is necessary - right-hemisphere PD. With other PD participants (left-hemisphere PD) such tactics are not feasible as the theoretical cortical loops connecting the relevant areas of the brain are unable to perform correctly. Although the loop circuitry itself may be in good order, it cannot function fully as the basal ganglia is unable to take direct input as adequately as with other PD participants. Control participants also find benefits in using relevant verbal commands, but not to the same extent (comparatively as against irrelevant verbal commands) as the right-hemisphere PD participants. This is because the control participants do not require the same 'boosting' potential as provided by the cortical loop circuits; these participants have fully functioning basal ganglia, and hence have none of the difficulties experienced by the PD participants.

Although the preceding information is very much theoretical in formation and detail, it nevertheless promotes further investigation into this important field. It is granted that the information presented is very much in the initial stages, but it gives the impression that research into the cortical loop circuitry could provide much needed information in the palliative care of many PD patients. Although it is probable that much of the benefit would only be accessible to patients with specific and lateralised symptoms, it demonstrates that these patients may be able to improve their responses in daily life. It is important to state that the work conducted here is within a laboratory setting, and that this is not environmentally relatable to an everyday situation, yet if such benefits can be accounted for within such an environment, it is likely that with practice and comfortable surroundings the benefits may be even more substantial.

APPENDIX B

A VISIT TO PAUL BROCA'S RESIDENCE

Figure 21. : The outside of Paul Broca's house - Sainte-Foy-la-Grande.

Figure 22. : A plaque detailing that he lived in this building.

Figure 23. : Standing outside the building, ever the tourist.