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Does high state anxiety exacerbate distractor interference?

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RUNNING HEAD: State anxiety and distractor effects

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Abstract

Attentional Control Theory states that anxiety can cause attention to be allocated to irrelevant sources of information by hindering the ability to control attention and focus on the information that matters. In a separate line of inquiry, action-centred views of attention state that non-target distractors involuntarily activate response codes that may cause interference with target-directed movements (*distractor interference effect*). Due to the proposed negative effects of anxiety on attentional control, we examined whether anxiety could also modulate distractor interference. Participants executed target-directed aiming movements to one of three targets with the potential of a distractor being presented at near or far locations. Distractors were presented at different times with respect to the target presentation in order to explore the excitatory (0, -100 ms) and inhibitory (-850 ms) processing of the distractor. As a broad indication of the effect of anxiety, the analysis of no distractor trials indicated a lower proportion of time and displacement to reach peak velocity under high compared to low anxiety conditions. Meanwhile, the typical excitatory influence of the distractors located near, compared to far, at a short distractor-onset asynchrony was found in movement time and overall response time. However, this distractor excitation was even greater under high compared to low anxiety in the reaction time component of the response. These findings broadly implicate the attentional control perspective, but they further indicate an influence of anxiety on the excitation rather than inhibition of responses.

Keywords: stress; distraction; attentional control theory; excitation; inhibition

1. Introduction

One shared interest of clinical, sport and experimental psychologists is how state anxiety (i.e., anxiety pertaining to a perceived threat within a particular pressured situation) impacts cognitive and sensorimotor performance (for a review, see Eysenck & Wilson, 2016; Nieuwenhuys & Oudejans, 2012). It has been frequently found that perceived threat due to competitive pressure can negatively affect performance compared to low pressure conditions (e.g., Harris, Eysenck, Vine & Wilson, 2019). However, this decrement in performance may not always materialise; indeed, it may even be possible for performers to excel under such circumstances (e.g., Jones & Swain, 1995; Otten, 2009). The present study attempts to shed more light on the mechanisms underlying potential changes in performance under different levels of state anxiety.

One heavily cited theoretical framework adapted to explain the complex relationship between state anxiety and performance is the Attentional Control Theory (Eysenck et al., 2007; Eysenck & Calvo, 1992; Derakshan & Eysenck, 2009). Here, it is suggested that anxiety causes attentional resources to become compromised by seeking out the sources of worry. This process unfolds following an imbalance between bottom-up/stimulus-driven attention and top-down/goal-directed attention (Corbetta & Shulman, 2002), as working memory processes that have been developed to inhibit task-irrelevant stimuli become impaired (Miyake et al., 2000). In turn, the performer must compensate by issuing 'auxiliary resources' (more recently attributed to self-control; Englert & Bertrams, 2012; 2015), which may maintain overall performance effectiveness, but at the expense of performance efficiency.

Recent empirical efforts have shed light upon this issue by manipulating anxiety during discrete and elementary target-directed movements (Allsop, Lawrence, Gray, & Khan, 2016; Goddard & Roberts, 2020; Lawrence, Hardy, & Khan, 2013; Roberts, Wilson, Skultety, & Lyons, 2018). In these studies, performers aim toward a target as quickly and accurately as possible using their upper-limb and the researchers analyse the spatio-temporal characteristics of the movements to examine the precise influence of anxiety on the planning and control of movement. Of interest, the characteristics of the initial ballistic phase of the reach that covers most of the required amplitude (e.g., before peak velocity) can be attributed to pre-response programming, while the later slowed portion of the movement (e.g., after peak velocity) is related to the utilisation of sensory feedback (e.g., vision) for the correction of errors (Elliott et al., 2017; Woodworth, 1899; see also, Vine, Lee, Moore & Wilson, 2013). Within the context of the Attentional Control Theory, it is suggested that anxiety could primarily influence the pre-response programming phase by negatively affecting the attention that is required to initially parameterize a target response (Lawrence, Khan, & Hardy, 2013). Meanwhile, anxiety is less likely to influence the control phase because this late process unfolds relatively automatically with limited conscious attention (see Cressman, Franks, Enns, & Chua, 2006; Goodale, Pélisson, & Prablanc, 1986; Proteau, Roujoula, & Messier, 2009).

To explore this logic, researchers have predominantly exploited the measure of spatial variability – within-participant standard deviation of limb position at different points along the trajectory (for a review, see Khan et al., 2006). Typically, it is shown that there is an increase in the variability during the initial phase of the movement followed by a decrease in variability toward and at the end of the movement. It is reasoned that the degree of precision during the initial phase indexes the accuracy and consistency of programming, while the magnitude of decline toward the end of the movement indicates an influence of online error detection and control processes that ensure endpoint accuracy. The initial findings indicated that there was a negative influence of anxiety within online control because of a larger amount of spatial variability at the end of the movement during high compared to low anxiety

(Lawrence et al., 2013). However, subsequent findings have also indicated a positive influence of anxiety within programming because of an inversely lower amount of spatial variability within the initial phase of movement (i.e., peak deceleration) during high compared to low anxiety (Allsop et al, 2016; Roberts et al., 2018). This pattern of results has been explained as state anxiety generating enhanced precision within the initial programming to partially off-set the negative effect in late online control (Allsop et al., 2016; see also, Causer, Hayes, Hooper, & Bennett, 2017; Mottet, van Dokkum, Froger, Gouïach, & Laffont, 2017; Welsh, Higgins, & Elliott, 2007). Alternatively, it has been speculated that it is due to a reallocation of attentional resources toward the initial programming, which may inadvertently negate the need for online control (Roberts et al., 2018).

While these empirical accounts allude to the general influence of anxiety on basic sensorimotor processes, they have typically involved a single task imperative under minimal constraints – participants execute multiple aiming trials to a single pre-determined target and amplitude. Consequently, it may be argued that there has been comparatively limited scope to explore the influence of anxiety on the specific attentional control processes that are more closely related to our often cluttered environments (e.g., manufacturing production lines, surgical workstations, team sports). Thus, the present study attempts to examine the influence of anxiety on attentional control processes by incorporating a selective aiming task where there are multiple potential targets and distractors (i.e., competing non-target).

In previous studies of selective aiming movements, participants execute rapid aiming toward targets whilst in the presence of distractors. The target and distractor locations are not known prior to the beginning of the response (Ambron, Della Sala, & McIntosh, 2012; Tipper, Lortie, & Bayliss, 1992; Welsh & Elliott, 2004; 2005; Bloesch, Davoli, & Abrams, 2013). Consequently, the participants must actively select and execute a movement toward a target while inhibiting any movement toward the distractor. The findings have typically shown slower responses toward a target when it is coincidentally presented with a distractor as opposed to being presented on its own. Furthermore, the magnitude of the interference is heightened for a distractor that is presented nearer to the starting position than the target – something referred as the proximity-to-hand effect (Meegan & Tipper, 1998; for review, see Welsh & Weeks, 2010). This asymmetric pattern of interference has been attributed to the efficiency of involuntary priming of a response toward the target relative to a distractor (for an example with manipulating target sizes, see Welsh & Zbinden, 2009). To elucidate, based on the notion that action and attention systems are tightly coupled (Rizzollatti, Riggio, & Sheliga, 1994; see also, Hommel, Müsseler, Aschersleban, & Prinz, 2001), any target or distractor stimulus that captures attention will activate/excite a response code that is designed to enable the performer to physically interact with the respective stimulus. The amount of interference caused by a particular distractor is contingent upon the efficiency of response activation that is elicited by the target and distractor, as well as the proficiency of subsequent inhibition toward the distractor (Welsh & Elliott, 2004). Thus, a distractor that is located nearer to the start position than the target may elicit greater interference because the response code for the distractor is more efficiently excited when it is located at a shorter amplitude (Fitts & Peterson, 1964), which requires significant time and effort to inhibit. Alternatively, a distractor that is farther from the start position than the target generates limited interference because the response code for the distractor is less efficiently excited when it is located at a longer amplitude, which requires less time and effort to inhibit.

In addition to the influence of distractor location on the excitation of competing responses and subsequent interference, it is also important to consider the time-course of distractor presentation relative to target presentation. Indeed, the presentation of distractors shortly in advance of (e.g., -100 ms distractor-onset asynchrony) or simultaneous to (e.g., 0 ms distractor-onset asynchrony) the target can cause movement trajectories to be contaminated by characteristics of the distractor (e.g., shorter displacement at peak velocity following "near" distractors; longer displacement at peak velocity following "far" distractors) (Welsh & Elliott, 2004; see also, Song & Nakayama, 2009). Alternatively, the presentation of distractors even further in advance of the target (e.g., -850 ms distractor-onset asynchrony) can cause the inverse pattern of results, where performers seem to veer away or avoid the distractor (e.g., longer displacement at peak velocity following "near" distractors; shorter displacement at peak velocity following "far" distractors) (see also Howard & Tipper, 1997; Neyedli & Welsh 2012). The deviation towards or away from the distractor location is suggested to manifest from the excitation or inhibition of the response codes to the distractor, respectively. This logic can be related to previous findings from the classic attentional-cueing paradigm, where shorter cue-onset asynchronies (<300 ms) generate excitation effects, while longer ones generate inhibition effects (>300 ms) (Posner & Cohen 1984; for examples, see Hansen, McAuliffe, Goldfarb, & Carré, 2017; McAuliffe, Hansen, McAuliffe, Goldfarb, & Carré, 2013; Neyedli & Welsh, 2012).

Taken together, it is possible that the attentional control processes that are influenced by anxiety (Eysenck et al., 2007) may also coincide with the selective processes underlying distractor interference. Specifically, the failure in working memory to inhibit task-irrelevant stimuli following feelings of anxiety may manifest in an enhanced excitation and/or reduced inhibition of responses to distractors. Hence, the present study adapted the selective aiming paradigm, where distractors were located either near or far with respect to the starting position and target (see Figure 1). In addition, the distractors were presented at different times with respect to target onset to assess the time course of the excitation (0, -100 ms) and inhibition (-850 ms) of responses to distractors (e.g., Welsh & Elliott, 2004; Welsh, Neyedli, & Tremblay, 2013).

Broadly speaking, it was predicted that there would be a greater difference in the response times and trajectories between the distractor locations under high compared to low anxiety. The direction of these distractor effects would be contingent upon a combination of enhanced excitation and reduced inhibition – more readily primed responses that take longer to inhibit. Specifically, if state anxiety enhances the processing of the distractor due to less efficient selective processes, then high anxiety would decrease the time to initiate responses toward the near as opposed to far distractor at the shorter distractor-onset asynchronies. Likewise, the trajectories may reflect a greater veering towards the distractor locations at the shorter distractor-onset asynchronies. On the other hand, if state anxiety negates inhibition, then high anxiety would increase the time to initiate responses toward the near as opposed to far distractors at the long distractor-onset asynchrony. In this regard, there may also be a decrease in the extent to which the trajectories veer away from the distractor locations at the long distractor-onset asynchronies. Additionally, we also examined the no distractor trials that were similar to previous studies (e.g., Allsop et al., 2016; Lawrence et al., 2013; Roberts et al., 2018) in order to corroborate the original findings and advance the theoretical framework surrounding the anxiety-performance relation.

2. Method

2.1. Participants

Twenty-four participants volunteered for the study (self-declared 21 right- and 3 left-handed; 17 male and 7 female; age range = 18-21 years). Participants had normal or corrected-to-normal vision and were free from any neurological or anxiety-related disorders. The study was approved by the local ethics board, and designed and conducted in accordance with the Declaration of Helsinki (1964).

2.2. Apparatus and Task

Visual stimuli were presented on a standard LCD monitor (spatial resolution = 1280 x 800 pixels; temporal resolution = 60 Hz). Dominant upper-limb movements were recorded via a digitizing graphics tablet (Calcomp Drawing Board VI – spatial resolution = 1000 lines per inch; temporal resolution = 125 Hz). Stimuli and data acquisition were controlled by a custom-written Matlab program (2018b) (The Mathworks Inc., Natick, MA) running Psychtoolbox (version 3.0.11) (Pelli, 1997) (https://osf.io/nb7af).

The task involved participants executing a single reach toward one of three possible targets as quickly and accurately as possible by sliding a stylus-tip across the tablet surface using their dominant limb. The targets were each separated by 10 cm (10, 20, and 30 cm) along the medio-lateral axis (left-to-right), and initially presented as unfilled black squares (2-cm target-width, 1 pixel line-width (~0.35 mm)) on a white background. The movements of the stylus on the digitizer were translated (one-to-one mapping) to the monitor as a small black square (0.5-cm width). Participants commenced a trial by initially fixating on the black cross-hair (1-cm line-amplitude) that was presented at the middle location until one of the targets was highlighted. This experimental control was designed to ensure that the same location of gaze was occupied for each trial across individual participants, whilst attributing an equal extent of eye movements when localising the far left or right targets (for similar procedures, see Ray, Weeks, & Welsh, 2014).

To commence a trial, participants had to locate their limb over the home position (red; 1-cm width) and press the stylus button using their index finger. Following a random foreperiod (800-2300 ms), one of the squares would change green to indicate the target location for the trial. On trials on which a distractor was present, another location would turn yellow. Participants were instructed to ignore the yellow stimulus if it presented itself and move only to the green-highlighted target. The stylus button was re-pressed once participants had ended their movement to cue their progress to the next trial.

2.3. Procedure

Figure 1 indicates the trial events for each distractor condition. The trials where the yellow highlight appeared represented a distractor. The time-course of the distractor-onset was manipulated so that it appeared before (-850, -100 ms) or on (0 ms) target presentation (see Figure 1). Each combination of target, distractor location and distractor-onset asynchrony were randomly presented for an equal number of trials using a randomisation procedure without replacement (courtesy of a random number generator function within Matlab).

In advance of the movement trials, participants were provided with instructions that were designed to manipulate state anxiety. In the high anxiety condition, participants were informed that their performance was to be compared with their peers to form a standing/league table that would be posted in front of the class. This competition was scored based on an index of both speed and accuracy (i.e., too slow and/or inaccurate would render a poor performance). Furthermore, participants were led to believe that the experimenter was additionally evaluating their performance courtesy of a digital recording for post-study video-analysis (for similar procedures, see Masters, 1992; Lawrence et al., 2013). Alternatively, the low anxiety condition involved instructions that the data being generated were designed to purely contribute to the research database, and inform the researchers of the present protocol's merits for potential future work within the lab.

An initial 21 trials of practice were issued including one attempt at each possible combination of target, distractor location and distractor-onset asynchrony. The high or low anxiety instructions were then issued prior to each one of the two possible blocks of trials, which were ordered in a counter-balanced fashion. Each of the two blocks comprised of 105 trials, including 5 trials per target-distractor combination. Consequently, there was a total of 210 trials (i.e., 21 trial types x 5 repetitions x 2 anxiety blocks). Breaks were offered around halfway into each block (53 trials), while there was a mandatory five-minute break between the first and second block of trials. Participants were also instructed to break from the routine if ever they deemed necessary.

[Insert Figure 1 about here]

2.4. Data Management and Analysis

In line with principles of open science, the individual participant data for each of the following measures can be found on the Open Science Framework (https://osf.io/vfazh) To examine the anxiety manipulation, participants completed the Mental Readiness Form-3 (MRF-3; Krane, 1994), which required a rating from 1-11 regarding how worried (cognitive sub-scale; (1) not worried – (11) worried), tense (somatic sub-scale; (1) not tense – (11) tense) and confident (confidence sub-scale; (1) confident – (11) not confident) they felt going into the upcoming motor task. The sum of these three sub-scales was calculated to arrive at a single score (Goddard & Roberts, 2020; Lawrence, Gottwald, Khan, & Kramer, 2012). The form was issued both before the first (trial 1) and second half (trial 54) of each block of trials, which generated two sets of ratings for both the low- and high-anxiety conditions.

Cartesian coordinates of the stylus tip were stored and processed within Matlab. The data were initially filtered using a second-order, dual-pass Butterworth filter with a low pass cut-off frequency of 8 Hz. Instantaneous velocity within the primary movement direction (x-axis) was obtained using the three-point central difference method. Movement onset was marked at the first point where velocity reached >20 mm/s in the primary movement direction, while movement offset was marked at the first moment that velocity reached <10mm/s and > –10mms/s in the primary movement direction.

Dependent variables comprised a series of temporal and spatial measures. For the temporal measures, we first calculated reaction time (time difference between target onset and movement onset) and movement time (time difference between movement onset and movement offset). These measures were combined in order to derive the total/response time. Furthermore, we calculated the absolute time to (time difference between movement onset and the moment of peak velocity) and after (time difference between the moment of peak velocity and movement offset) peak velocity. Time to peak velocity was also expressed as a proportion of the entire movement (i.e., time to peak velocity divided by the movement time and multiplied by 100). For the spatial measures, we first calculated constant error, which pertained to the signed difference between the location of movement endpoint and target centre (i.e., negative and positive values were synonymous with undershooting and overshooting, respectively) in each of the primary (x-axis) and secondary (y-axis) directions. Furthermore, we calculated the participant mean displacement (i.e., cumulative sum of the location differences across each of the digitized samples) at peak velocity, as well as spatial variability at peak velocity and movement end (trial-by-trial within-participant standard deviation of position). Spatial variability is frequently adapted for the inference of programming and control as increases in variability upon reaching early peak velocity may be overturned and subsequently reduced by utilising sensory feedback to adjust the movement (see Khan et al., 2006). Consequently, any differences between conditions for the spatial variability at peak velocity may represent the precision of the movement parameterization during the programming phase. Alternatively, any differences for spatial variability at movement end may represent the utilisation of sensory feedback during the control phase.

Because the middle target assumed an equal distribution of distractors appearing near and far, we only examined trials with movement directed at the middle target (35 trials) (for similar procedures, see Tipper et al., 1992). Specific sets of measures were analysed according to the hypothesized direction of effects. That is, to corroborate the previous evidence of changes in characteristics of target-directed aiming under low and high anxiety conditions (Allsop et al., 2016; Lawrence et al., 2013; Roberts et al., 2018), we analysed a combination of reaction time, movement time, absolute time to and after peak velocity, proportional time to peak velocity, constant error and displacement (distance travelled) at peak velocity for the no distractor trials. These measures were analysed using a paired-sample t-test, or the Wilcoxon signed-rank test if the data were deemed to be non-normally distributed. For the analysis of spatial variability, we used a two-way repeated-measures ANOVA featuring factors of kinematic landmark (peak velocity, movement end) and anxiety (low, high).

To examine the distractor effects under different levels of anxiety, we derived total/response time, reaction time, movement time, and displacement at peak velocity. Indeed, these measures collectively capture time that is needed to prepare and execute movements in order to eventually override distractor interference and land on a set target location (Tipper et al., 1992), along with any the veering that unfolds within the early portions of the trajectory (Welsh & Elliott, 2004; see also, Welsh, Elliott, & Weeks, 1999; Welsh & Weeks, 2010). Any trials where participants prematurely initiated a reach toward the distractor prior to the appearance of the target (i.e., as indicated by <0 ms reaction time e.g., a false start), or landed closer to the distractor (>5 cm away from the target) were removed prior to the analysis (4.29% trials). Participants' mean score for the no distractor condition was subtracted from the means of the distractor conditions (i.e., negative (positive) values assume a shorter (longer) movement in time and space for the distractor compared to no distractor) to derive a difference score, which reflected the direction and magnitude of any distractor effects. The analysis involved a repeated-measures ANOVA including factors of anxiety (low, high), distractor-onset asynchrony (0, -100, -850 ms) and location (near, far). Potential violations in the assumption of Sphericity were corrected using the Huynh-Feldt adjustment when epsilon was >.75, and the Greenhouse-Geisser adjustment if otherwise (original Sphericity assumed degrees-of-freedom were nonetheless reported). Individual mean differences were decomposed using the Tukey HSD post hoc procedure, and effect sizes were indicated using partial eta-squared (η^2). Significance was declared at $p < .05$.

3. Results

3.1. Anxiety manipulation check

On review of the MRF-3 scores, it seems there was a large degree of variability in responses to low (block 1+2 $M = 8.02$, $SE = .88$) and high anxiety (block 1+2 $M = 8.98$, $SE = .98$) instructions. Because our focus was primarily related to responses under high compared to low anxiety, we isolated individuals that positively reported greater ratings under the high compared to low anxiety instructions (14/24 participants; 5 participants receiving the low anxiety condition first; 9 participants receiving the high anxiety condition first). Prior to reaching this sample and formally undertaking an inferential statistical analysis, we conducted a power analysis using G*Power software (version 3.1.9.4; see Faul, Erdfelder, Lang, & Buchner, 2007). Input parameters included $\alpha = .05$, $1-\beta = .80$, and $f = .25$ (medium) (adapted from the endpoint variability findings of similar previous studies; Lawrence et al., 2013; Roberts et al., 2018), which generated a minimum requirement of 13 participants. Thus, the select sample was sufficient for further analysis.

Anxiety ratings were analysed using a two-way repeated-measures ANOVA with factors of anxiety (low, high) and time (before, halfway). Naturally, there was a significant main effect of anxiety, $F(1, 13) = 20.32$, $p < .01$, *partial* $\eta^2 = .61$, although there was no significant main effect of time, $F(1, 13) = 2.73$, $p > .05$, *partial* $\eta^2 = .17$, nor a significant anxiety x time interaction, $F(1, 13) < 1$, *partial* $\eta^2 = .01$. Thus, it appears participants were more anxious under the high ($M = 10.68$, $SE = 1.28$) compared to low ($M = 7.86$, $SE = 1.04$) anxiety condition, and this did not appear to change as the trial blocks proceeded.

3.2. Does anxiety generally influence standard target-directed aiming (no distractors)?

Mean values for movements in the no distractor condition under the low and high anxiety conditions are shown in Table 1. There were no significant differences for reaction time, $t(13) = .13$, $p > .05$, movement time, $t(13) = .02$, $p > .05$, constant error-primary axis, $t(13) = 1.14$, $p > .05$, constant error-secondary axis, $t(13) = .76$, $p > .05$, and time after peak velocity, $t(13) = .96$, $p > .05$. However, the difference for the time to peak velocity approached conventional levels of significance, $t(13) = 2.02$, $p = .065$, which was corroborated by a significantly larger proportion of time to reach peak velocity for the low compared to high anxiety condition, $t(13) = 3.06$, $p < .01$. Additionally, there was a significantly larger displacement (distance travelled) at peak velocity for the low compared to high anxiety condition, $t(13) = 2.57$, $p < .05$. Meanwhile, the analysis of spatial variability revealed a significant main effect of kinematic landmark, $F(1, 13) = 30.54$, $p < .001$, *partial* $\eta^2 = .70$, although no significant main effect of anxiety, $F(1, 13) < 1$, *partial* $\eta^2 = .03$, nor a significant kinematic landmark x anxiety interaction, $F(1, 13) < 1$, *partial* $\eta^2 = .03$ (low: peak velocity $M = 17.42$, $SE = 1.83$; movement end $M = 7.25$, $SE = 1.13$; high: peak velocity $M = 15.44$, $SE = 2.23$; movement end $M = 7.35$, $SE = .79$).

[Insert Table 1 about here]

3.3. Does anxiety influence excitation at short distractor-onset asynchronies, or inhibition at long distractor-onset asynchronies?

Recall that the following statistical effects involve measures that were normalized with respect to the no distractor trials toward the middle target. For the sake of brevity, only the statistical effects that were significant, or featured the factor of anxiety will be reported.

For total time, there was a significant main effect of distractor-onset asynchrony, $F(2, 26) = 7.99$, $p < .01$, *partial* $\eta^2 = .38$, which indicated a significantly larger decline in total time for -100 ms compared to 0 ms (see Figure 2a). In addition, there was a significant distractor-onset asynchrony x location interaction, $F(2, 26) = 4.83$, $p < .05$, *partial* $\eta^2 = .27$, which indicated a significantly reduced time to completion for the distractor presented near compared to far at the 0 and -100 ms distractor-onset asynchrony. There were no significant main or interaction effects featuring the factor of anxiety (anxiety x location: $F(1, 13) = 1.46$, $p > .05$, *partial* $\eta^2 = .10$; remaining statistical effects: *Fs* < 1).

These findings were corroborated by the movement time analysis as there was also a significant distractor-onset asynchrony x location interaction, $F(2, 26) = 4.29$, $p < .05$, *partial* $\eta^2 = .25$. There were no significant main or interaction effects featuring the factor of anxiety (*Fs* < 1). For reaction time there was a significant main effect of distractor-onset asynchrony, $F(2, 26) = 28.29$, $p < .005$, *partial* $\eta^2 = .69$, and location, $F(1, 13) = 6.21$, $p < .05$, *partial* $\eta^2 = .32$, and a significant anxiety x location interaction, $F(1, 13) = 6.00$, $p < .05$, *partial* $\eta^2 = .32$. These effects were superseded by a significant anxiety x distractor-onset asynchrony x location interaction, $F(1, 13) = 4.40$, $p < .05$, *partial* $\eta^2 = .25$, which indicated a shorter time to initiate responses for distractors presented near compared far at the -100 ms distractor-onset asynchrony under high anxiety (see Figure 2b).

Finally, the displacement at peak velocity revealed a trend toward significance for the main effect of anxiety, $F(1, 13) = 3.63$, $p = .079$, *partial* $\eta^2 = .22$, which indicated a reduction in amplitude displacement for low (*M* = -3.26 mm; *SE* = 2.48) compared to high anxiety (*M* = 2.47 mm; *SE* = 2.19). There were no other statistically significant effects featuring the factor of anxiety (anxiety x distractor-onset asynchrony x location: $F(2, 26) = 1.60$, $p < .05$, *partial* $\eta^2 = .11$; remaining statistical effects: *Fs* < 1).

[Insert Figure 2 about here]

4. Discussion

The anxiety-performance relation has been widely explained by the Attentional Control Theory (Eysenck et al., 2007; Eysenck & Wilson, 2016), which states that anxiety compromises attentional resources by hindering working memory processes for the inhibition of task-irrelevant stimuli (Miyake et al., 2000). Consequently, there is an up-regulation in bottom-up/stimulus-driven attention, and a down-regulation of top-down/goal-directed attention (Corbetta & Shulman, 2002). The present study introduced a potentially compromising selective aiming task, where participants aimed to one of three possible targets in the presence of a near- or far-located distractor at short or long onset asynchronies, which was designed to examine processes of distractor excitation and inhibition (Howard & Tipper, 1997; Tipper et al., 1992; Welsh & Elliott, 2004; Welsh et al., 2013; see also, Posner & Cohen, 1984). The findings indicated that when aiming to targets with no distractors present, anxiety caused the aiming movements to reach a shorter point in time and space at peak velocity. Meanwhile, a distractor effect was captured by the shorter overall response and movement time following the short distractor-onset asynchronies (0, -100 ms). This effect of the distractor emerged mostly when the distractor was located nearer as opposed to farther from the start position than the target. This effect was even greater under high compared to low anxiety for the reaction time component of the response. From herein, the discussion will adopt a similar structure to the *Results*, where we separately address the standard aiming findings that are more closely related to previous studies, as well as the novel insights on the potential for anxiety to influence distractor effects.

4.1. Standard target-directed aiming without distractors

The results of aiming movements executed when only the target was present (no distractor trials) showed that there was a decrease in the proportion of time to peak velocity in the high compared to low anxiety condition. Interestingly, there were no substantive differences in the absolute time to complete the movements between the high and low anxiety conditions. Consequently, it appears performers spent less time within the trajectory based on the initial pre-programming of a response (offline planning), and more time for "homing-in" on the target (online control) (Elliott et al., 2017). As a result, performers were able to uphold their endpoint accuracy and precision (see constant error and spatial variability findings). Based on previous findings that anxiety negatively impacts online control (Lawrence et al., 2013), it is possible that the extended time for "homing-in" enabled a sufficient delay to accumulate sensory feedback and incorporate it into the movement. This logic can be related to suggestions that the anticipated negative impact of anxiety toward online control can cause performers to compensate for it by altering their approach to the movement (Allsop et al., 2016; Cassell, Beattie, & Lawrence, 2017; Goddard & Roberts, 2020; Roberts et al., 2018). In a similar vein, individuals with sensorimotor difficulties tend to extend the proportion of time after peak velocity, and in so doing, the time that is required to use online sensory feedback and reach the intended target (e.g., Down syndrome: Elliott, Welsh, Lyons, Hansen, & Wu, 2006; stroke patients: Mottet et al., 2017; older adults: Shimoda, Lee, Kodama, Kakei, & Masakado, 2017; ocular disorders: Timmis & Pardhan, 2012).

Additionally, there was a shorter displacement to peak velocity for the high compared to low anxiety, which could indicate a safer approach to the target. This approach reflects the optimization of the speed-accuracy trade-off, where performers tend to conserve the time and energy required for controlling the movement (Elliott, Hansen, Mendoza, & Tremblay, 2004). It is suggested that the tendency for performers to undershoot reflects an attempt to avoid an overshoot error, and with it, the time and energy for overcoming inertia and reversing the limb to the target. Nevertheless, this finding would appear to conflict with previous evidence of aiming to a single target, where there appeared an inversely longer reach and more frequent overshooting under high compared to low anxiety (Roberts et al., 2018). These different outcomes may manifest from the subtle variations in the sensorimotor environments that are adopted across studies. For example, the present video-based, two-dimensional aiming environment may require some degree of delayed translation between the motor efferent and visual afferent signals (e.g., Lyons, Elliott, Ricker, Weeks, & Chua, 1999), whilst the elementary three-dimensional approach featuring a real-life target can be more heavily influenced by the initial pre-programming. Likewise, the potential number of targets may have influenced the outcome as the present study, which involved a comparatively complex scenario of three potential targets. Indeed, similar discrepancies have been identified within the literature where some have isolated the negative effects of anxiety to the late online control phase (as indicated by an enhanced variability toward the end of movement; Lawrence et al., 2013), while others have scarcely reflected this finding (Allsop et al., 2016; Roberts et al., 2018). It is of interest to further explore this seeming disparity between studies, including the task constraints, participant characteristics and nature of the evaluative stressor.

4.2. Distractor effects

The distractor effects of the present study featured a shorter reaction time following the presentation of the near as opposed to the far distractor at the -100 ms distractor-onset asynchrony when under high, but not low, anxiety. This asymmetric pattern under high anxiety may be explained by the more rapid or efficient excitation of response codes that are specific to distractors located nearer to the start position than the target (Tipper et al., 1992; see also, Welsh & Weeks, 2010). Likewise, the nature of the distractor-onset asynchrony, where there was a short time period that immediately preceded the presentation of the target, would suggest that this effect was most likely related to the magnitude of pre-response activity rather than inhibition *per se* (Welsh & Elliott, 2004). Meanwhile, the failure of anxiety levels to discriminate distractor effects at the much earlier -850 distractor-onset asynchrony, as well as for the measure of movement time, would suggest that any prior excitation under high anxiety was eventually overturned. That is, when the time to process the distractor was extended then it may have allowed any of the initial excess pre-response activity under high anxiety to become inhibited and/or the normal pre-response activity under low anxiety to catch-up. Indeed, the complete absence of any distractor effects for the mean displacement at peak velocity may even suggest that these effects can become completely nullified by the time the limb reaches the very early portions of the trajectory (proportion of time to peak velocity: *grand M* = 37.06%; displacement at peak velocity: *grand M* = 92.34 mm) (for a similar discussion on the temporal aspects of distractor interference, see Welsh & Elliott, 2004; Welsh et al., 1999).

The proposed influence of anxiety within the reaction time interval would appear to correspond with the tenets of the Attentional Control Theory (Eysenck et al., 2007). That is, state anxiety can cause performers to become pre-occupied with other irrelevant sources of information, which require more effort to inhibit and take control of attention (Eysenck et al., 2007). While initial performance outcomes may be upheld under such circumstances, it has been shown that the eventual losses in auxiliary self-control resources (ego-depletion; synonymous with mental effort) may cause performance to decline (e.g., Englert & Bertrams, 2015). In the context of the present study, the high anxiety condition may have caused performers to involuntarily allocate more attention toward the distractor, which inadvertently generated greater excitation. As a result, it would have been more taxing for the inhibition of the unfolding response, which was essential to avoid the distractor and reach the required target. Presumably, the trials where there was an extended time between the presentation of the distractor relative to the target (-850 ms) allowed sufficient time for inhibition to unfold and overturn any of the pre-response activity.

4.3. Conclusion and Future Directions

To this end, it is important to recognise the potentially small sample size of the present study. This limitation was in part due to the selection of only those participants that positively indicated increased anxiety, which may also raise questions regarding the generalizability or external validity of the current findings. These particular participants tended to receive the high anxiety condition first, which would suggest that the anxiety manipulation was less efficacious when implemented later on within the protocol (for a similar discussion on the effect of order, see Allsop et al., 2017; Lawrence et al., 2013).

Nevertheless, from the individuals that did experience anxiety, we showed that during standard target-directed movement (no distractor trials), there was a shorter time and displacement to reach peak velocity. In line with contemporary views on sensorimotor control (Elliott et al., 2017), the current findings reflect a strategic attempt to optimize the utilisation of feedback and energy-expenditure, respectively. In addition, there was an enhanced early excitation toward non-target distractors under high compared to low anxiety, which could potentially highlight an enhanced susceptibility to distraction (Eysenck et al., 2007).

It is of interest for future research to more closely examine how anxiety influences the time-course of these distractor effects (e.g., 100-600 ms across 5 cue-onset intervals; Welsh et al., 2013), as well the required resources for their successful inhibition. In light of the contribution of working memory processes toward inhibition (Miyake et al., 2000), and the self-control resources that help combat distraction (Englert & Bertrams, 2015), it is possible that future training interventions may prevent unfavourable excitation following anxiety (e.g., Ducrocq, Wilson, Vine, & Derakshan, 2016; Ducrocq, Wilson, Smith, & Derakshan, 2017).

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Declaration of interest: none

Figure captions

Figure 1. Illustration of the time-course of movement trial events. Each trial commenced with a cross-hair located at centre to cue fixation. There were three potential targets, which after a random foreperiod (800-2300 ms) would become highlighted. No distractor condition featured only a single *green* highlight to indicate the target location (top panel). Distractor conditions additionally featured a *yellow* highlight that appeared prior to (-100/-850 ms; middle panel) or at the same time as the target presentation (0 ms; lower panel). For the colour illustration, please see the online version.

Figure 2. Mean total time (A) and reaction time (B) relative to the no distractor/control condition (zero representing no distractor interference). Error bars represent standard errors.

Table 1. Mean (±SE) values for measures of target-directed performance as a function of anxiety. (*) indicates a significant difference ($p < .05$)

Measure	**Low**	**High**
Reaction time (ms)	409.21 (10.43)	410.58 (9.11)
Movement time (ms)	574.74 (26.46)	575.06 (29.32)
Time to peak velocity (ms)	213.72 (9.99)	200.95 (10.89)
Time after peak velocity (ms)	361.02 (20.81)	374.11 (21.65)
Proportion of time to peak velocity (%) *	38.39 (1.35)	36.00 (1.25)
Constant error-primary axis (mm)	.96 (1.58)	-1.77 (1.34)
Constant error-secondary axis (mm)	1.36 (.61)	.98 (.53)
Displacement at peak velocity (mm) *	96.44 (3.11)	89.04 (3.73)