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# Cognitive Changes Associated with Martial Arts Practice

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# Cognitive Changes Associated with Martial Arts Practice

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*Dedication*

To Charlie Johnstone, Maggie Steele, Isabel Callow, & Hugh Agnew

Some of you knew about this thesis, and some of you sadly didn't,
but I know you'd all be proud.

## Declaration

Yr wyf drwy hyn yn datgan mai canlyniad fy ymchwil fy hun yw'r thesis hwn, ac eithrio lle nodir yn wahanol. Caiff ffynonellau eraill eu cydnabod gan droednodiadau yn rhoi cyfeiriadau eglur. Nid yw sylwedd y gwaith hwn wedi cael ei dderbyn o'r blaen ar gyfer unrhyw radd, ac nid yw'n cael ei gyflwyno ar yr un pryd mewn ymgeisiaeth am unrhyw radd oni bai ei fod, fel y cytunwyd gan y Brifysgol, am gymwysterau deuol cymeradwy.

I hereby declare that this thesis is the results of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards.

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## Summary

The idea of being able to improve our cognitive functioning is one that has been increasing in popularity over the past decades. Martial Arts are an activity that has been heavily researched in this regard, in populations of children and older adults. However, there has been far less research in this area using populations of healthy, typical adults. This thesis aimed to fill this literature gap by comparing groups of experienced martial artists and groups of participants with no experience in the sport. The participant groups were compared on three validated and strong cognitive measures and paradigms – the Go/NoGo test in Chapter Two, the Attention Network Test in Chapter Three, and a Task Switching paradigm in Chapter Four. The thesis aimed to address research questions investigating potential differences in inhibitory control, attentional networks, and cognitive flexibility. Additionally, a fourth research question sought to understand whether any cognitive changes are associated with the length of time a person has been taking part in Martial Arts. Over the course of the following chapters, it is suggested that martial artists have a more efficient alert network representing greater vigilance, and a smaller mixing cost for specific incongruent trials again representing superior vigilance. Additionally, the martial artists also showed a greater sensation seeking score suggesting higher impulsivity, and a higher number of commission errors suggesting poor inhibitory control. This thesis therefore suggests that improved vigilance can be associated with Martial Arts practice, along with high impulsivity and poor inhibition.

# Chapter One:

# General Introduction

**1.1 Executive Functions**

Executive functions are an essential part of day to day life. They are the cognitive processes that allow us to merge our thoughts and actions together, in a way that enables us to achieve goals (Miller & Wallis, 2009). We use them to remember to take our packed lunch out of the fridge and put it into our work bag each morning, when we think about phoning the dentist to make an appointment and follow through with those plans, or to avoid spontaneously purchasing that cute puppy that we have seen but do not have the facilities to look after. These are clear examples of planning, memory, initiating actions, and inhibition.

Typically, executive functions have been defined as a collection of top down mental processes that engage when it is not possible for us to continue utilising automaticity (Diamond, 2013; Miller & Wallis, 2009). Indeed, Miller and Wallis (2009) suggested that the term executive control (sometimes referred to as cognitive control) refers to the ability to switch from this automatic behaviour to a more controlled way of responding. Therefore, when a person performs well on measures of executive function, they are said to have strong executive or cognitive control.

It is known that executive functions are something that can change over time and depending on a person's life experiences. This begins early, with the development of many of these functions taking the form of an inverted u-shape, as abilities improve throughout infancy and childhood, and then beginning to decline throughout the aging process (Kray, Eber, & Lindenberger, 2004). This pattern has been found within several core cognitive functions including inhibition, planning, and working memory (Belleville, Rouleau, & Van der Linden, 2006; Brown, Johnson, Sohl, & Dumas, 2015; Grafman & Litvan, 1999; Zook, Welsh, & Ewing, 2006).

Alongside an age-related decline in executive functioning, there are many other factors which are associated with executive dysfunction. These may be large events which lead to a sudden acquired deficit, or different factors which lead to a more subtle, gradual dysfunction. For example, strokes (Zinn, Bosworth, Hoenig, & Swartzwelder, 2007), Alzheimer's Disease (Lafleche & Albert, 1995), and traumatic brain injuries (Gioia & Isquith, 2004) may produce deficits in functioning that would not otherwise have been present. Lifestyle factors such as poor sleep (Wilckens, Woo, Kirk, Erickson, & Wheeler, 2014), substance use (Verdejo-García & Pérez-García, 2007), and sedentary behaviour (Falck, Davis, & Liu-Ambrose, 2017), on the other hand, may be more associated with a gradual decline in executive functioning.

### 1.2 Brain Training

Given the fragility of executive functions, over the past two decades there has been an increase in the popularity of interventions designed to either prevent the decline in these functions, restore lost function, or even produce improvements. Many of these interventions are computerised tests known as 'brain training games' (Owen et al., 2010). In 2007, the New York Times suggested that brain training is a multimillion dollar industry (Aamodt & Wang, 2007), and more recently this estimation has increased to being a multibillion dollar industry (Ahuja, 2019). This increase has been linked to the increasing commercialisation of 'brain training' as a concept, led by the release of 'Dr Kawashima's Brain Training' brain training game by Nintendo in 2005 (Simons et al., 2016). From these early beginnings, the industry has expanded, and now if you look through any app store, you will likely find a plethora of brain training applications and games. These games make bold claims within their tag lines and slogans, for example 'Peak' has the tagline 'Better games for smarter minds' and offers to help consumers 'level up your brain' (Peak, n.d.).

Lumosity, another brain training game, promises to help users 'improve memory, increase focus, and feel sharper' (Lumosity, n.d.). Following the rise in these games, research within cognitive sciences has increasingly focused on the potential training and improvement of our cognitive functions. The big question though, is does brain training really work? Can we improve our brain's executive functioning through training? Brain training can take the form of specific cognitive test training such as working memory training, or a more meditative form of training such as mindfulness or exercise. The rest of this chapter aims to further understand some of the activities purported to lead to cognitive improvements.

### 1.3 Working Memory Training

In an opinion piece, Tang and Posner (2014) discussed working memory training, such as that which uses an adaptive visual *N*-back task in an attempt to increase the number of items a person can hold within their working memory. From reviewing much of the literature, they posited an interesting criticism, that this training did indeed produce benefits in this task, and other similar tasks, but that this was not transferable to different tasks. This supported a previous argument by Shipstead, Redick, and Engle (2012) that research in this domain was not ready to make bold claims about the potential benefits of working memory training. In fact, Shipstead et al. (2012) listed several reasons as to why many of the assumptions made by working memory training research had not yet been demonstrated. This includes many studies not using a control condition, a lack of task that provides a clear measure of a specific aspect of working memory (many tasks used more generalised measures), and a lack of transfer to tasks that are untrained and not related to the task the participants were trained on. Redick et al. (2013) followed this up a year later and found that training on dual *N*-back and visual *N*-back tests produced improvements on these tests, but not on other measures such as multi-tasking or working memory capacity. Following this, they suggested that the idea of training producing benefits in the same or extremely similar tasks is reasonable, but that there is still a lack of evidence of any further transfer.

Interestingly, Redick et al. (2013) also commented that the file drawer problem within psychology may be hindering research investigating brain training. They suggested that research which does show the wider transfer of cognitive training is more likely to be published than that which does not show any effects or transfer. This then means that there may be a wealth of research on this topic that is not available to other researchers. It is just as important for us to know about the limits of brain training and what it cannot do, as it is to know what it can do.

### 1.4 Mindfulness and Meditation

Alongside these computerised cognitive tasks that are advertised as brain training, mindfulness, meditation, and aerobic exercise are now also being promoted as an intervention which could improve our executive functioning. Tang, Hölzel, and Posner (2015) explained that mindful meditation may be able to provide benefits in several core aspects of executive functioning, such as attention, emotion regulation, and self-awareness. This is already a marked difference from the traditional brain training of practicing cognitive tasks which often only show benefits on one specific function. Posner, Rothbart, and Tang (2015) later agreed that these activities such as mindfulness, meditation, and exercise may have more general and broad effects than the specific direct effects often seen in computerised brain training.

Tang, Yang, Leve, and Harold (2012) reported that mindfulness-based training often teaches the participant relaxation and breathing techniques, as well as body and mind awareness. They noted that these techniques aim to help the person develop an understanding of the connection between their body and their mind, which allows them to reach a clear level of focus. Tang et al. (2012) suggested that this clarity may be caused by increased activation of the prefrontal cortex as a result of the shift in brain state brought on by the mindfulness techniques. Interestingly, many aspects of executive function, including attentional control, self-monitoring, and cognitive flexibility, have been associated with activation in the prefrontal cortex in neuroimaging studies (Roth, Randolph, Koven, & Isquith, 2006), thus giving further support to this theory.

Luu and Hall (2017) investigated the effects of hatha yoga and mindfulness on executive functions by giving participants a Stroop task as a measure of inhibitory control. Each participant had at least 4 months to 5 years of experience in hatha yoga and were asked to complete three conditions with a week in between each. In one condition they did 25 minutes of hatha yoga, in another they did 25 minutes of mindfulness meditation, and in the control condition the participants simply read yoga magazines. After each activity they did the Stroop task twice, once after 5 minutes and again after 10 minutes. They found that 25 minutes of either hatha yoga or mindfulness meditation significantly improved performance on the Stroop task when it was done 10 minutes after the session. Whilst this improved performance did not significantly differ between the yoga and the meditation, they both produced significant benefits in comparison to the control condition. This supports the findings from a review into the research on mindfulness meditation and executive functioning (Gallant, 2016), which suggested that the most common cognitive function to see a benefit from mindfulness is inhibition. Gallant (2016) suggested that this is due to the core component of mindfulness practice being training to inhibit distractions and shift attention back to the present moment.

A later review discussed how some of the research in this field has been conflicting, with some studies showing benefits of meditation and others showing no benefits (Mak, Whittingham, Cunnington, & Boyd, 2018). They assessed 13 studies and found that only 5 of them reported significant cognitive benefits associated with meditation. However, upon further investigation they realised that the 5 studies which showed significant benefits had all used computerised cognitive tasks to measure executive functioning, whereas the other 8 studies had used pen and paper neuropsychological tests. Mak et al. (2018) noted that this may suggest that computerised cognitive tests may be better suited to detecting more subtle changes in functions. They suggested that the millisecond by millisecond differences given by computerised testing, may be a more valuable measurement in this type of research than the accuracy measure from neuropsychological pen and paper tests. This is not to say that these tests do not have a highly important role within psychology, but that they may not be sensitive enough for these specific purposes. This is an observation that would be interesting to follow up further.

### 1.5 Physical Activity and Exercise

Another factor that has been gaining more traction as a brain training activity is physical activity and exercise. As briefly noted earlier, a link between sedentary behaviour and poorer executive functioning has been reported although the magnitude of this effect is not clear (Falck, Davis, et al., 2017), and so it seems reasonable to suggest that more physically active behaviour may be associated with stronger cognition.

Hillman et al. (2009) used a modified flanker task along with academic achievement measures (to assess a more applied aspect of cognition) to investigate the effects of a 20-minute run on a treadmill compared to sitting quietly and resting in primary school aged children. They found an improvement in accuracy (but not reaction time) on the flanker task after the treadmill session, as well as better performance with regards to academic achievement. This is supported by Ellemberg and St-Louis-Deschênes (2010) who found differences in cognitive measures in children who did 30 minutes of active aerobic exercise compared to children who watched television. In this experiment children completed two tasks – one simple reaction time task, and a choice task in which the participant had to press one button if they saw a circle, and another button if they saw any other shape. The children in the exercise condition performed significantly faster after their aerobic exercise, than the children who watched television. This improvement was found in both the reaction time task and the choice task, which the authors suggest highlights that the exercise condition improved cognitive performance rather than just motor speed. Interestingly though, accuracy for both groups did not differ from baseline to post-test.

While the two previously mentioned studies have investigated the effects of exercise on executive functioning in children, there has also been some research within typical adult populations. It is important that several age ranges are studied, as children will still be developing and therefore may have more room for cognitive improvements, whereas adults are likely to be in their 'cognitive prime'.

In typical adults, Chang et al. (2011) were interested in the potential effects of exercise on planning, which appears to be an often overlooked aspect of executive function in this area of research. The Tower of London is a task typically used to assess planning ability. It involves a set of pegs and beads, with the participant being asked to move the beads from one peg to another, but following a specific set of rules (Krikorian, Bartok, & Gay, 1994). Chang et al. (2011) asked participants in the exercise condition to complete the Tower of London test after a 20-minute cycling activity, and participants in the control condition completed the test after 20 minutes of reading magazines about aerobic exercise. Here they found that participants from the exercise condition were able to complete the Tower of London test in significantly fewer moves than participants from the control condition, suggesting better planning ability. This is an interesting finding, as the Tower of London is a commonly used neuropsychological test and these authors used physical pegs and beads rather than a computerised version. Earlier we discussed how Mak et al. (2018) suggested that non-technology based neuropsychological tests may not be sensitive enough to detect changes in executive function in relation to mindfulness or meditation. This research by Chang et al. (2011) may suggest that this is not the case for exercise related changes, or that functions such as planning may be better suited to this style of test.

Coles and Tomporowski (2008) evaluated the effects of a 40-minute exercise session on a range of measures, including set-shifting, visual short-term memory, and a free recall task. The researchers decided to have two control conditions – one traditional control condition in which the participants sat quietly in a room for 40 minutes, and another in which they followed the same set up procedures as the exercise condition and sat on the equipment, but did not take part in any exercise. Here they found no differences between the control conditions and the exercise condition in the measures of set-shifting and visual short-term memory. However significant differences were found in the free recall task, in that after the exercise condition participants were better able to recall words from the beginning and end of the list after a delay, than in the control conditions. The authors noted that this suggests that participants were better able to maintain their level of recall following the exercise session, but not after the control conditions. They suggested that the exercise may not have led to a better memory performance, but instead may have helped to offset any decline in the consolidation of these memories.

The studies reviewed and discussed here suggest that there is evidence behind the theory that exercise may be able to produce small benefits in a variety of measures of executive functioning. Interestingly, much of the research into cognitive benefits of physical activity and exercise focuses on a single bout of exercise, rather than more sustained, long-term benefits of exercise.

## 1.6 Martial Arts and Children

Martial Arts are a particularly interesting form of exercise, as many types involve an element of meditation or focused breathing and attention, as well as aerobic exercise. As we have previously seen that exercise and meditation may both have some sort of impact on executive functioning, Martial Arts have been attracting the attention of researchers interested in improving cognition. Much of the research has focused on populations of school-aged children, with the intention of assessing how Martial Arts may affect cognitive functioning during their development. Lakes et al. (2013) suggested the benefit of this type of physical activity-based intervention in schools is that it can allow us to also tackle the issue of rising childhood obesity and related health conditions.

Lakes et al. (2013) conducted a Martial Arts intervention in a South Californian middle school. In this school, children typically had 5 40-minute Physical

Education (PE) classes per week. During the school year, half of the children had 2 of these classes replaced with a Taekwondo class taught by a trained Taekwondo master, and the other half continued with their usual PE routine. Parental ratings of attentional and behavioural control were collected pre- and post-intervention; however, measures of cognitive factors were only collected post-test for comparisons between-group, rather than within-subject. The cognitive measures came from the Hearts & Flowers test, which claims to assess attention, inhibitory control, working memory, and cognitive flexibility. This test involves the child responding to congruent stimuli in one block, incongruent stimuli in another block, and mixed stimuli in the final block. The authors reported greater accuracy in the congruent trials for the Taekwondo group, and better parent reported self-control in the same participant group. They suggested that this is evidence of improved executive function following a year of Taekwondo classes rather than typical PE classes. Interestingly, many of the children commented that they preferred their Taekwondo classes to the PE class, which suggests that the introduction of Martial Arts into schools may also lead to improved engagement with physical activity. It is disappointing that the researchers did not collect pre-intervention measures of cognitive functioning, as this would have allowed us to see the effect of the Taekwondo intervention within each participant, however it is possible that this was not done due to the logistical constraints of working around the school year.

More recently, Lo et al. (2019) recruited students with Judo experience from a high school in Hong Kong to assess cognitive differences in set-shifting. In their first experiment they recruited people aged 12-16 years old, with at least 4 years of Judo experience, and a group of healthy, age-matched controls who have no experience with Martial Arts. Their second experiment involved an intervention of Judo classes three times per week, for eight weeks, being given to participants who had never previously engaged with Martial Arts. In both experiments the participants were asked to complete a spatial task-switching test, designed to provide a measure of set-shifting ability. In the first experiment, participants from the experienced Judo group produced significantly fewer errors than those in the control group, reflecting a better performance. Similarly, in experiment two, participants from the Judo intervention improved performance on the test, and produced less errors in the post-intervention testing – the control group did not show this improvement, and were poorer on the test. Lo et al. (2019) proposed a theory for why Judo may be related to improved performance on a set-shifting task, by discussing how the sport trains people to anticipate changes in an uncertain and evolving environment. This training to always try to anticipate the next move and be prepared to change response may enhance the executive functions needed for efficient set-shifting. The authors made an interesting observation that their participants would have been people who were drawn to or willing to take part in a Judo intervention, and therefore this added motivation may have helped to enhance any cognitive benefits. This is a particularly interesting point that should perhaps be considered further in future research into the effects of Martial Arts on executive functioning, as it is likely to be a consistent source of potential bias due to only being able to recruit participants who already have an interest in this specific physical activity. It may be important to find out whether there are any specific personality factors that are often found in people who choose this kind of exercise, and whether they are related to cognitive functioning.

### 1.7 Martial Arts and Older Adults

Another population that has been heavily studied in regards to Martial Arts is older people. Martial Arts have been a popular choice for physical activity-based interventions in this population, as it encourages older adults to keep moving and socialising with other people. An adapted form of karate training has been piloted on a group of 50 year old men, in order to assess its potential use as a wellbeing intervention (Chateau-Degat, Papouin, Saint-Val, & Lopez, 2010). After doing three 90-minute sessions of karate per week for a year, the participants showed an improvement in some aspects of quality of life.

More recent research has begun to include measures of cognitive functioning as well as well-being when assessing the effectiveness of Martial Arts interventions in older adults. For example, Jansen and Dahmen-Zimmer (2012) investigated the effects of cognitive, motor, and karate training on a series of cognitive and psychological variables in older adults. Participants were split into three different intervention groups: 1) cognitive training which aimed to train memory performance through a variety of ordered tasks; 2) motor training which involved strength, stretching, and relaxation training tailored to each participant; or 3) karate training taught by a trained karate teacher. These interventions took place over 3-6 months. Participants completed measures of cognitive speed, working memory, and emotional well-being both pre- and post- intervention. Although there was an improvement in memory performance for participants in the karate group it was not significant. Additionally, there were no significant differences between the groups on any of the other cognitive variables. Despite this, the participants who completed the karate training showed a significant improvement on measures of emotional wellbeing and quality of life. The authors found the lack of difference in the cognitive variables surprising, but noted that the short duration of the interventions and the lack of true randomisation due to the nature of the population may have influenced this.

Witte, Kropf, Darius, Emmermacher, and Böckelmann (2016) built on previous research by increasing the number of participants, reducing the age variation, and increasing the length of the intervention. 200 participants aged 63-83 were divided up into three groups: either a karate or general fitness intervention group with 60-minute sessions twice a week for 10 months, or a control group who did not complete any sports intervention. Participants completed a pre-test, and two post-tests: one after 5 months, and another after an additional 5 months (i.e., 10 months after the pre-test). Measures included tests for mild cognitive impairment, motor reactivity, stress tolerance, and divided attention. After the first post-test at 5 months, there were some small but not-significant improvements for the karate group across all measures. Importantly, following another 5 months of karate training (equalling 10 months of the intervention), more significant differences were found between the karate group and the other two groups. The authors note that this may indicate that Martial Arts interventions in older adults may need a longer duration before benefits can be seen – perhaps due to starting the intervention from a lower baseline functioning compared to healthy, typical adults. It is interesting to consider this in relation to the Jansen and Dahmen-Zimmer (2012) paper, in which the authors noted that their 3-6 month intervention may not have been long enough to produce differences in a sample of older adults.

### 1.8 Thesis Aims and Research Questions

Much of the research into the effects of Martial Arts on executive function has used either school-aged children (Lakes et al., 2013; Lo et al., 2019) or older adult populations (Jansen & Dahmen-Zimmer, 2012; Witte et al., 2016) as their main participant sample. Other research has also investigated the effects of Martial Arts in populations with behavioural or health conditions (Kadri, Slimani, Bragazzi, Tod, &

Azaiez, 2019; Origua Rios, Marks, Estevan, & Barnett, 2018). While there has recently been a move towards studying cognitive improvements related to Martial Arts in typical, healthy adults (such as Douris et al., 2015), there is still a lack of research in this area using well-validated tests of cognitive functioning and adequate samples.

This thesis aims to address this gap in the literature by assessing three distinct cognitive paradigms that have previously been well-validated as providing strong measures of executive functioning: Go/NoGo, the Attention Network Test (ANT), and task switching. Using these paradigms, the thesis hopes to develop a wider understanding of cognitive changes associated with Martial Arts practice in healthy, typical adult populations. It is important to note here that this thesis does not aim to discuss whether Martial Arts is the best activity to improve cognition compared to other activities. Instead it aims to assess three specific elements of executive function – inhibition, attentional control, and cognitive flexibility – and whether there are Martial Arts related changes. A lot of the research discussion in this introductory chapter has utilised interventions (within mindfulness and Martial Arts) or singular bouts of a physical activity. However, we were interested in long-term, sustained benefits of Martial Arts practice which would not have been possible to investigate with only one session, and logistically a full intervention was not possible for this body of work. Therefore, the decision was made to follow the approach laid out in Luu and Hall (2017)'s hatha yoga research and Lo et al. (2019)'s Judo work, and focus on participants who already have experience in the activity of interest.

Chapter 2 of this thesis is the first empirical chapter, which uses a Go/NoGo paradigm to understand whether Martial Arts can improve inhibitory control. Chapter 3, the second empirical chapter, uses the ANT to explore attentional networks and how they may be influenced through Martial Arts practice. The final empirical chapter, Chapter 4, uses a task-switching to follow up results from Chapter 3, and investigate mixing and switch costs. Chapter 5 is a general discussion chapter which aims to further bring together the results from each of the empirical chapters and discuss what this means for the field. The core research questions for this thesis are as follows:

**Research Question 1:** Does Martial Arts practice influence inhibitory control?

**Research Question 2:** Does Martial Arts practice influence any of the attentional networks, and if so, which ones?

**Research Question 3:** Does Martial Arts practice influence our ability to task switch?

**Research Question 4:** Do any potential benefits alter with the length of time a person has been taking part in Martial Arts?

# Chapter Two:

# Inhibition and Impulsivity in Martial Artists and Non-Martial Artists

## Abstract

Inhibitory control has been described as one of the core executive functions required for efficient day to day functioning. It allows us to stop or slow down mental processes to avoid unnecessary or inappropriate responses. Poor inhibitory control is sometimes associated with high impulsivity, due to an inability to prevent certain responses or actions. Mindfulness practice has been suggested to lead to improvements in inhibition, and research on the inhibitory effects from exercise varies. Prior research into the effects of Martial Arts practice in older adults has suggested no differences in inhibitory control, but there is little research in typical adults. 36 martial artists and 36 non-martial artists took part in this experiment to further understand inhibitory control in this population. Participants completed a Go/NoGo task which involved either responding to or withholding a response to a stimulus, followed by impulsivity subscales measuring sensation seeking and premeditation. The martial artist participants showed poorer inhibitory control by producing more commission errors – responding when not required to – than non-martial artists. Additionally, martial artists showed higher scores on a sensation seeking scale described as a measure of impulsivity. Therefore, suggesting that Martial Arts practice may not be associated with improvements in inhibitory control, but in fact poorer inhibition, and higher impulsivity.

## Introduction

If we think about inhibition, we may think about being able to say no to 'just one more drink' at the pub or holding yourself back from that honest but potentially offensive response of 'no' when your friend asks whether you like their new haircut. This is an important part of daily life, and is important for a healthy and harmonious lifestyle. This type of inhibition may also be known as self-control. However, within cognitive psychology, cognitive inhibition has been defined as the slowing down or stopping of mental processes, either voluntarily or automatically (MacLeod, 2007). Inhibition is often described as one of the core executive functions, and is an important element which works with other functions such as attention and memory (Bari & Robbins, 2013; Logue & Gould, 2014). If we can effectively inhibit inappropriate or unwanted responses or behaviours, we are said to have high inhibitory control. If we were not able to do this, we would have low inhibitory control. It has also been suggested that poor inhibitory control may be related to high impulsivity. Bari and Robbins (2013) noted that a person without adequate inhibitory control may find it difficult to resist or inhibit any inappropriate impulses.

This chapter aims to understand whether there may be differences in cognitive inhibition and impulsivity in martial artists compared to non-martial artists.

### Factors influencing inhibition

There are several factors which may influence inhibition. Age, for example, has often been discussed as a factor which may have a large influence. In typical human development, inhibition develops with age, with adults possessing greater inhibitory control than children (Moilanen, Shaw, Dishion, Gardner, & Wilson, 2010). Upon older adulthood, however, this ability declines and therefore as people reach older age, their inhibitory capabilities reduce (Maldonado, Orr, Goen, &

Bernard, 2020; West & Alain, 2000). Due to the importance of inhibitory control, and the wide range of factors that can reduce its effectiveness, inhibition has been researched in terms of training and whether there are ways for us to improve its effectiveness.

A review paper found reliable improvements in inhibitory control related to mindfulness meditation practice (Gallant, 2016). Indeed, in considering research assessing inhibition, updating, and shifting, they suggested the greatest and most reliable improvements were found in inhibition research. This suggestion is further supported by more recent research. Pozuelos, Mead, Rueda, and Malinowski (2019) asked adults to complete a Go/NoGo task before and after undergoing a three-week mindful breath awareness training course. The Go/NoGo task is often used as a measure of inhibition, due to its requirement for participants to respond to certain stimuli but not others. The frequency of the 'Go' stimuli is often changed throughout the task, altering the predictability of the task. When these trials are more frequent, it can become harder for the participants to inhibit their responses on a 'NoGo' trial (i.e., a trial in which they should not respond). Thus, the Go/NoGo task can be a reliable measure of inhibition. After a 3 week mindfulness practice course, Pozuelos et al. (2019) reported a decrease in impulsive responding and a trend which, although not significant, suggested an increase in inhibitory control. Additionally, the authors noted some of their effects were stronger the more the participants had practiced mindfulness, perhaps suggesting a cumulative effective of mindfulness practice on inhibition and impulsivity.

Peruyero, Zapata, Pastor, and Cervelló (2017) looked at how exercise may influence inhibitory control, by comparing the performance of adolescents on a Stroop Test following light exercise, vigorous exercise, and sessions containing no exercise. Here they found that both exercise conditions provided improvement in inhibition compared to the no exercise condition, but also that inhibitory control was stronger following the vigorous exercise session compared to the light exercise session. The authors noted that this may suggest that intensity may be important when considering exercise-induced inhibitory benefits, as long as the intensity is not so high it leads to cognitive fatigue. Interestingly, however, Gejl et al. (2018) analysed performance on a modified flanker test in adolescents following different exercise intensities, and found that exercise only had general, rather than specific, cognitive benefits. This research did not find any evidence of specific benefits to inhibitory control, regardless of the intensity of the exercise, leading to uncertainty about these effects of exercise intensity on inhibition.

Previously, Wang et al. (2013) has explained sports related inhibitory differences by discussing how there may be two key types of sport – open skill (or open loop) and closed skill (or closed loop). Open skill sports require athletes to be highly reactive and responsive, and able to perform in unpredictable situations, whereas closed skill sports have a more consistent and predictable environment. Therefore open skill sports naturally require a higher level of inhibition to allow for the quick changing actions and thinking. Wang et al. (2013) supported this with findings of improved inhibitory control in participants from open skill sports compared to closed skill sports. Intriguingly, they found that these differences were specific to inhibitory control, and found no differences in impulsivity between the groups, perhaps suggesting a dissociation between the two concepts that are often linked. This idea of different types of sport having different associations with inhibitory control may explain some of the discrepancies in research assessing exercise and inhibition.

**Martial Arts and inhibition**

Martial Arts has previously been described as an open skill sport (Arvinen-Barrow, Weigand, Thomas, Hemmings, & Walley, 2007), with Martial Arts training typically involving unpredictable or rapidly changing situations and expectations. This would suggest that Martial Arts may be related to higher inhibitory control, however research assessing the impact of Martial Arts on inhibition and impulsivity is varied. Much of the research comes from specific populations such as children with Autism Spectrum Disorder (such as Phung & Goldberg, 2019) or from the field of education in relation to academic achievement (such as Gagne & Nwadinobi, 2018). A recent study by Gerritsen, Lafeber, van den Beukel, and Band (2020) gave a Tai Chi intervention to older adults. Amongst other cognitive measures, the participants completed a stop-signal task designed to give measures of inhibition. The results found no significant differences in inhibition-based measures between the Tai Chi group and the control group. This would suggest that there are no inhibitory differences driven by Martial Arts practice, but again this research is not using populations of typical adults.

There is, however, more research about Martial Arts when self-control is considered rather than inhibition. Some researchers use the terms ‘self-control’ and ‘inhibition’ interchangeably, however Saunders, Milyavskaya, Etz, Randles, and Inzlicht (2018) suggest that self-reported measures of self-control do not correlate with cognitive measures of inhibition. This means that while previous research may suggest links between Martial Arts and improved self-control (Saunders et al., 2018; Twemlow et al., 2008), it is not clear whether there are cognitive inhibition benefits related to Martial Arts practice.

## Aims & Hypotheses

This chapter aims to further develop the research investigating inhibitory control and impulsivity in relation to Martial Arts experience. By using the Go/NoGo task, a well validated cognitive measure of inhibition, and impulsivity subscales, the chapter aims to understand whether Martial Arts practice is linked with increased inhibition or reduced impulsivity. Measures of both of these constructs were chosen due to their linked nature – with impulsivity often being seen as one of the outcomes of poor inhibition.

Experiment 1 consisted of a pilot study which aimed to understand any relationships between demographic variables and the measures of inhibition and impulsivity, allowing for later between-group experiments to be run with fewer confounding variables. Experiment 2, then used the findings of Experiment 1 to match participants with and without Martial Arts experience in order to carefully assess the influence of Martial Arts training on inhibition and impulsivity.

In Experiment 2 we hypothesised that there would be differences in inhibitory control and impulsivity between martial artists and non-martial artists due to previous literature regarding mindfulness and exercise in typical adults. We also anticipated any effects to be related to the number of years of Martial Arts practice, similar to the results found in mindfulness research.

## Experiment 1

## Method

### Participants

90 participants were recruited through word of mouth and Bangor University's SONA participant panel. Participants recruited through SONA were

reimbursed through course credits, and those recruited through word of mouth were entered into a prize draw. All participants reported being neurotypical and having normal or corrected to normal vision. Please see Table 1 for participant demographics. The information requested regarding the demographics of the participants was chosen based on factors that may influence either ability to take part in physical activity factors previously associated with varying executive functioning. Ethical approval was granted by the Bangor University Ethics and Governance Committee (Ethics Approval #2018-16265).

Table 1. *Descriptive data for key participant demographics. Values represent mean averages, +/- standard deviation, or frequencies.*

| | |
|---|---|
| Age | 20.19 +/- 2.87 |
| Body Mass Index | 23.24 +/- 5.11 |
| Alcohol (units per week) | 7.91 +/- 9.84 |
| Smokers | 12 |
| On medication | 21 |
| On a special diet | 16 |
| Health condition | 19 |

Note. ‘Health condition’ encompasses a variety of physical and mental health conditions that participants reported.

## Questionnaires

Two subscales from the Urgency, Premeditation, Perseverance, and Sensation Seeking (UPPS) Scale (Whiteside & Lynam, 2001) were used to assess impulsivity. This scale was developed to provide a measure of the four key dimensions of human impulsivity: urgency, lack of premeditation, lack of perseverance, and sensation seeking. Only two subscales (premeditation and sensation seeking) were used in this experiment to streamline the experimental process. Responses to both subscales were requested through 6-point Likert scales (0 = Do not wish to answer; 1 =

Strongly disagree; 2 = Disagree; 3 = Neither agree or disagree; 4 = Agree; 5 = Strongly agree).

**Premeditation.** The premeditation subscale consists of 11 items (see Table 2), and assesses a lack of premeditation. Whiteside and Lynam (2001) stated that a high score on this scale suggests a lack of premeditation. This lack of premeditation would reflect an impulsive personality, and people acting without putting much thought into their actions. A low score on the scale would suggest a high level of premeditation, and therefore more thoughtful actions.

Table 2. *Items from Premeditation subscale (Whiteside & Lynam, 2001)*

| | |
|---|---|
| 1. | I have a reserved and cautious attitude toward life. |
| 2. | My thinking is usually careful and purposeful. |
| 3. | I am not one of those people who blurt out things without thinking. |
| 4. | I like to stop and think things over before I do them. |
| 5. | I don’t like to start a project until I know exactly how to proceed. |
| 6. | I tend to value and follow a rational, “sensible” approach to things. |
| 7. | I usually make up my mind through careful reasoning. |
| 8. | I am a cautious person. |
| 9. | Before I get into a new situation I like to find out what to expect from it. |
| 10. | I usually think carefully before doing anything. |
| 11. | Before making up my mind, I consider all the advantages and disadvantages. |

**Sensation Seeking.** 12 items make up the sensation seeking scale (see Table 3). A person high in sensation seeking would be more likely to take large risks for new or exciting experiences (Whiteside & Lynam, 2001).

Table 3. *Items from Sensation Seeking subscale (Whiteside & Lynam, 2001)*

| | |
|---|---|
| 1. | I generally seek new and exciting experiences and sensations. |
| 2. | I'll try anything once. |
| 3. | I like sports and games in which you have to choose your next move very quickly. |
| 4. | I would enjoy water skiing. |
| 5. | I quite enjoy taking risks. |
| 6. | I would enjoy parachute jumping. |
| 7. | I welcome new and exciting experiences and sensations, even if they are a little frightening and unconventional. |
| 8. | I would like to learn to fly an airplane. |
| 9. | I sometimes like doing things that are a bit frightening. |
| 10. | I would enjoy the sensation of skiing very fast down a high mountain slope. |
| 11. | I would like to go scuba diving. |
| 12. | I would enjoy fast driving. |

**Go/NoGo Task**

A Go/NoGo task was used to provide cognitive measures of inhibition. The stimuli were an oval shape, and was presented in either green (representing a Go trial) or red (a NoGo trial). See Figure 1. A Go trial required a participant response, whereas a NoGo trial required the participants to withhold their response.

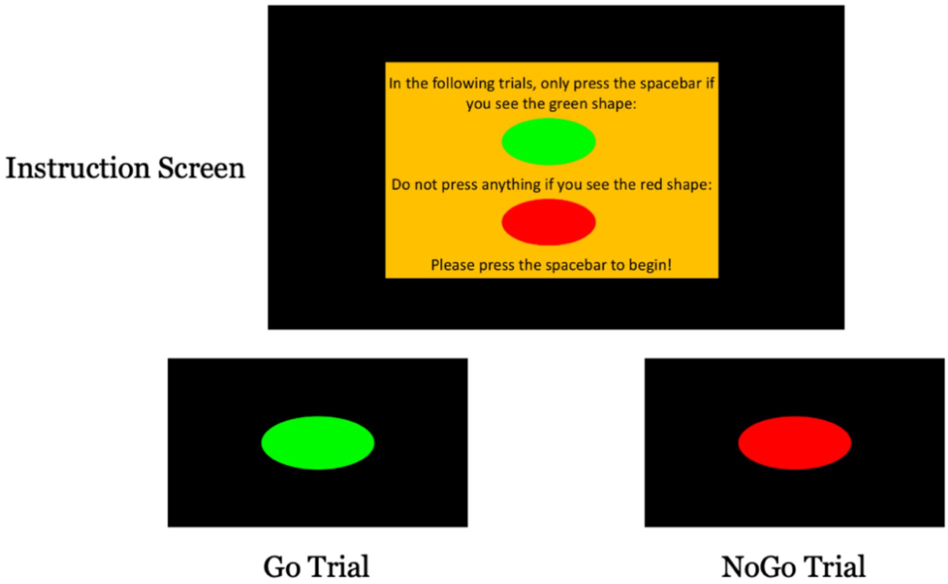


*Figure 1*. Diagram showing instruction screen and stimuli displayed for Go and NoGo trials.

The stimuli were presented on a black background for 2000ms or until a response was recorded. A black screen then followed for 500ms until the next trial began. The task consisted of 3 blocks, each containing 80 trials, with the proportion of Go and NoGo trials varying to alert the predictability. Block 1 was 50% Go trials and 50% NoGo trials. The second block had less Go trials (20%) and more NoGo trials (80%). The final block was 80% Go trials and 20% NoGo trials. All participants did all three blocks. This totalled 240 trials and participants were able to take a self-paced break halfway through each block, and again between each block.

**Procedure**

The questionnaire and the Go/NoGo task were both completed through PsyToolKit (Stoet, 2010, 2017). Participants received a web link to the experiment and were able to complete it at a time and place convenient for them. All participants completed the questionnaire portion of the experiment first, which started with a demographics questionnaire and then moved onto the UPPS subscales for premeditation and sensation seeking. Following the questionnaires, the participants were presented with the instructions for the Go/NoGo task. They were asked to press the space bar on their computer keyboard when they saw a green oval, and to avoid pressing the button when they saw the red oval. Participants received an error feedback message on screen immediately following the trial if they responded incorrectly – i.e., pressed the space bar on a NoGo trial or did not respond to a Go trial.

## Data analysis

**Questionnaire variables.** The sensation seeking and premeditation subscales were calculated independently from each other. They were standardised so that each participant received an overall score between 0 and 5. An overall score of 0 on either subscale would indicate that the participant did not respond to any item on the subscale. On the sensation seeking scale, a score of 5 would represent a high level of sensation seeking. A score of 5 on the premeditation scale indicates a high *lack* of premeditation, meaning that a high score here represents more impulsivity.

**Go/NoGo.** Analysis of a Go/NoGo task typically separates out correct and incorrect trials. However, both correct and incorrect trials can be based on an overt response depending on whether the trial is a 'Go' trial or a 'NoGo' trial. For example, an overt response on a Go trial would be correct, but it would be incorrect for a NoGo trial. Therefore, wherever there is a response, average reaction times were calculated and sorted into correct response reaction times, and incorrect response reaction times. When there was no response made, the proportion of error trials compared to the number of trials of that type in the block were calculated. These were calculated per block: 20% which refers to the block that contains 20% Go trials and 80% NoGo; 50% which contained an equal number of Go and NoGo trials; and 80% which was the block that contained 80% Go trials and 20% NoGo trials. Overall commission errors (pressing the space bar when not required) and omission errors (failing to press the space bar when required) were also calculated.

We calculated the proportion of commission errors by computing the total number of errors in the NoGo trials for each block (20%, 50%, 80%) for each participant and then dividing it by the total number of Go trials within that block. As the commission error is based on an actual response, these reaction times were also assessed. Omission errors were calculated by computing the unanswered number of trials in the Go conditions relative to the overall number of trials within each block.

A series of bivariate Pearson's correlations were then run to investigate any relationships between key demographic variables and the experimental variables.

## Results

Key significant findings from the Pearson's correlations can be found in Table 4. These are the significant correlations between the demographic variables and the experimental variables from the questionnaire and Go/NoGo task.

Age was significantly correlated with error RT for NoGo trials in the 80% block, $r(65) = .325$, $p = .008$, and proportional errors on NoGo trials in the 50% block, $r(89) = -.247$, $p = .020$. The self-reported number of alcohol units drunk per week was significantly correlated with scores on the sensation seeking scale, $r(47) = .334$, $p = .022$. Significant correlations were also found between age and Body Mass Index (BMI), $r(76) = .321$, $p = .005$, and between BMI and alcohol units per week, $r(41) = .474$, $p = .002$.

Table 4. *Pearson correlations between significant demographic variables and experimental variables.*

| | Age | BMI | Alcohol Units | Sensation Seeking | Error RT for NoGo (80% block) | NoGo Proportional Errors (50% block) |
|---|---|---|---|---|---|---|
| Age | - | - | - | - | - | - |
| Body Mass Index | .321** | - | - | - | - | - |
| Alcohol Units | -.016 | .474** | - | - | - | - |
| Sensation Seeking | -.082 | -.033 | .334* | - | - | - |
| Error RT for NoGo (80% block) | .325** | -.043 | .036 | -.198 | - | - |
| NoGo Proportional Errors (50% block) | -.247* | -.015 | .011 | .125 | -.169 | - |

** Correlation is significant at < .01 * Correlation is significant at < .05

## Discussion

Experiment 1 concluded that the age of the participants and the number of alcohol units drunk per week may be associated with the some of the experimental variables measured in this chapter. BMI does not seem to be directly associated with the variables of interest but are associated with age and alcohol units. Therefore, for Experiment 2, martial artist and non-martial artist participants will be matched on age, alcohol consumption per week, and BMI.

## Experiment 2

## Method

### Participants

72 participants (36 martial artists, and 36 non-martial artists) were recruited for Experiment 2. An opportunistic sample was recruited through Bangor University's SONA panel and word of mouth, as in Experiment 1. It was hoped to

recruit martial artists with at least two years of experience, however due to recruitment difficulties, this was expanded to include participants with at least one year of experience. The participants' years of experience ranged between 1 year and 27 years. Participants within the non-martial arts group reported taking part in physical activities such as going to the gym and team sports, ensuring they had a similar level of physical fitness as the martial arts participants.

Table 5. *Participant demographics for both participant groups*

| | **Martial Artists** | **Non-Martial Artists** | ***p*** |
|---|---|---|---|
| *N* (Male) | 36 (17) | 36 (2) | - |
| Age | 22.83 ± 5.98 | 21.44 ± 4.94 | .287 |
| BMI | 23.91 ± 3.60 | 23.99 ± 5.22 | .939 |
| Alcohol (units per week) | 6.15 ± 6.78 | 5.52 ± 5.10 | .767 |
| Smokers | 2 | 3 | - |
| Health Condition | 6 | 13 | - |

Values represent mean averages, ± standard deviation, or frequencies.

The Martial Arts group consisted of participants with experience in the following styles: Brazilian Jiu-Jitsu (6), Jiu-Jitsu (5), Karate (5), Aikido (4), Taekwondo (4), Judo (4), Mixed Martial Arts (2), Muay Thai (2), Other/Non-Specific (2), Kendo (1), and Boxing (1).

**Design and procedure**

The design and procedure for Experiment 2 was the same as that described for Experiment 1.

**Data analysis**

Data analysis procedures followed that of Experiment 1, with the addition of a series of ANOVAs to see differences across Go-proportion blocks (20%, 50%, 80%) for each Martial Arts group (Martial Artist, non-Martial Artists). Whenever there was a significant effect of the Go-proportion block, orthogonal polynomial contrasts were used in order to assess any trends in differences in performance across the blocks.

# Results

## Questionnaires

Analysis compared scores on the sensation seeking and premeditation scales between the two participants groups. It was found that Martial Artists scored significantly higher than non-Martial Artists on sensation seeking ($t(70)=2.56$, $p=.012$). No significant differences were found on the premeditation scale. Each participant received a score between 0 and 5 for each scale. These results can be seen in Figure 2. On the sensation seeking scale, a higher score represents more sensation seeking, whereas a high score on the premeditation scale represents a lack of premeditation, and therefore more impulsivity.

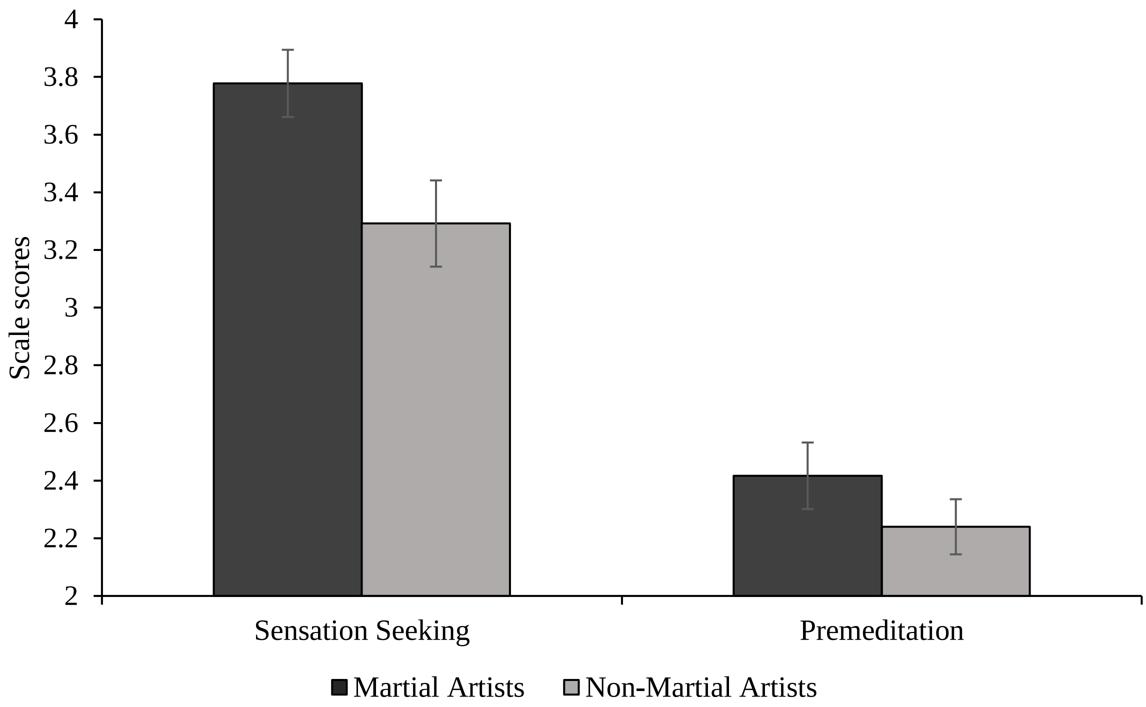


*Figure 2*. Bar chart showing scores on Sensation Seeking and Premeditation scales for Martial Artist and Non-Martial Artist participant groups.

## Correct Go trials x Martial Arts

For Go trials we calculated the average reaction times per block (20%, 50%, 80%) and per participant group (see Table 6).

Table 6. *Mean reaction times (in ms) for correct responses to Go trials in the three proportional blocks. Values in parentheses represents standard error.*

| | 20% | 50% | 80% |
|---|---|---|---|
| Martial Artist | 427<br>(12.18) | 383<br>(10.06) | 352<br>(8.11) |
| Non-Martial Artist | 439<br>(12.18) | 396<br>(10.06) | 365<br>(8.11) |

Results demonstrated significant differences across blocks [$F(2,140)=79.39$, $p<.001$, $\eta_p^2=.531$], with the expected linear trend where responses become faster as the proportion of Go trials increases [$F(1,70)=132.86$, $p<.001$, $\eta_p^2=.655$]. No significant differences were found between groups ($F<1$) or in the interaction ($F<1$).

## Commission errors x Martial Arts

For the incorrect trials we first analysed the proportion of commission errors, i.e., responding when not required to. The descriptive statistics for these can be found in Table 7.

Table 7. *Proportion of commission errors in the three blocks. Values in parentheses represents standard error.*

| | 20% | 50% | 80% |
|---|---|---|---|
| Martial Artist | .011<br>(.003) | .022<br>(.004) | .134<br>(.018) |
| Non-Martial Artist | .005<br>(.003) | .010<br>(.004) | .085<br>(.018) |

Results showed significant differences across the blocks [$F(2,140)=63.52$, $p<.001$, $\eta_p^2=.476$]. This time, there was a trend towards a significant interaction with the Martial Arts groups [$F(2,140)=2.66$, $p=.073$, $\eta_p^2=.037$], this interaction seemed to be attributed to a change in the linear slope between the groups, although this effect did not reach significance [$F(1,70)=2.93$, $p=.092$, $\eta_p^2=.04$]. When the group differences were tested block by block, it did not reach significance for the trials in the 20% block ($p=.125$), but then became significant for the 50% block ($t(70)=2.22$, $p=.029$) and neared significance for the 80% block ($t(70)=1.89$, $p=.064$).

The analysis of the proportion of errors, and subsequently the RT analysis, was based on data from 9 participants in the Martial Arts group and 5 in the non-Martial Arts group since the remaining participants did not produce any of these errors. Please see Table 8 for the descriptive statistics for this RT analysis. Results revealed significant differences across the blocks [$F(2,24)=4.97$, $p=.016$, $\eta_p^2=.293$] due to a linear trend in decreasing response times as the proportion of Go trials increases [$F(1,12)=8.142$, $p=.015$, $\eta_p^2=.404$]. There were no significant differences between the groups ($F<1$) nor in the interaction between the groups and the blocks ($F<1$).

Table 8. *Commission error reaction times for the three proportional blocks. Values in parentheses represents standard error.*

| | 20% | 50% | 80% |
|---|---|---|---|
| Martial Artist | 745.57<br>(167.95) | 418.52<br>(77.17) | 296.04<br>(18.99) |
| Non-Martial Artist | 587<br>(225.32) | 373.40<br>(103.53) | 257.40<br>(25.47) |

**Omission errors x Martial Arts**

Incorrect trials that were omission errors, meaning there was no response from the participant when a response was required, were then analysed. The analysis of these omission errors did not reveal a significant effect across the blocks ($F<1$), between the groups ($F<1$), or the interaction ($F<1$).

**Year of Martial Arts experience**

A series of correlations were run on any experimental variable that produced a significant between-group difference, and a variable measuring the number of years of Martial Arts experience from each participant. No significant relationships were found between these variables and years of Martial Arts experience.

## Discussion

In this chapter we aimed to assess differences in inhibitory control in martial artists and non-martial artists. The experiment used the Go/NoGo test to gain measures of inhibitory control, and questionnaire scales to measure impulsivity which has previously been linked to poor inhibition. No significant differences were found between the two participant groups on overall reaction times for Go trials or commission errors, or in the number of omission errors. Additionally, no significant differences were found in the premeditation scale. Martial artists and non-martial artists did significantly differ on sensation seeking and the number of commission errors made in the 50% block. These two variables were not correlated with years of experience. The hypothesis suggesting differences in martial artists and non-martial artists on the experimental variables was partially supported, and the hypothesis suggesting a relationship with years of Martial Arts experience was rejected.

Despite a variety of measures of inhibition, the current experiment only found group differences in commission errors in the 50% block. This means that in a block of 50% Go trials and 50% NoGo trials, the martial artists made more commission errors (responding when a response was not required) than non-martial artists. This suggests poorer inhibitory control, as the participants were not able to withhold a response on the NoGo trials. That this effect was found in the 50% block is particularly striking, as it is more likely to be expected in the 80% block where most trials require a response, making it then harder to withhold a response. This would suggest that martial artists are performing worse than the non-martial artists, and finding it more difficult to withhold responses. Interestingly, the same pattern of martial artists committing more commission errors follows in the 80% block, although this group difference did not reach significance. As poor inhibitory control has been linked with high impulsivity, it would therefore be reasonable to assume that participants with poorer measures of inhibition would also have higher scores on the impulsivity scales.

The current study found a significant difference in sensation seeking between martial artists and non-martial artists, with martial artists having a higher score. Taken with the poor inhibitory control displayed through the commission errors, this makes sense that the martial artists displayed high scores on a measure of impulsivity. Sensation seeking has been defined as the search for novel sensations and experiences, and a willingness to take risks in order to attain those experiences (Zuckerman, 1994), and is therefore seen as a sign of impulsivity. Gomà-i-Freixanet, Martha, and Muro (2012) described Martial Arts as a medium risk sport due to its risk of physical injury, and people who do karate have previously been described as being moderately sensation seeking (Zuckerman & Aluja, 2015). It is therefore reasonable for there to be differences in this measure between martial artists and non-martial artists. However, due to the cross-sectional nature of this research we cannot assume that this is a causal relationship. It is likely that people who are high in sensation seeking are more naturally drawn to a sport such as Martial Arts due to the potential risk, but further research with a different research design would be required to investigate this further. It is also not clear whether this would reflect higher impulsivity in the martial artists compared to the non-martial artists, or whether this variable is measuring another construct rather than impulsivity. The Martial Arts participants for the current study had all been taking part in the sport for at least a year, and participants reported attending training sessions multiple times per week. This precise and organised behaviour does not seem to match the definition of impulsivity – a tendency to act without much adequate thought (DeYoung & Rueter, 2010). A highly impulsive person may not be able to keep up with the dedicated training schedule that comes with martial arts practice. It should also be noted that there was no correlation between scores in sensation seeking and years of Martial Arts experience, perhaps suggesting that the observed differences in sensation seeking may be present in the participant before they started Martial Arts, rather than having any relationship with the martial art itself.

The analysis of errors posed a challenge in these experiments. Commission errors – participants pressing the response key when a response was not required – allowed for analysis of reaction times (i.e., how quickly the participant responded to NoGo stimuli) and the proportion of error trials for each block. Omission errors, on the other hand, were those in which no response was made when there should have been a response. This meant that if a Go trial was presented for 2000ms and there was no response, it was recorded as an error. It does not tell us why the error was made. Due to the online nature of the experiment, it is not possible to confirm that all of the omission errors were indeed legitimate errors or due to distraction in the participant's environment leading to the trial timing out. As well as this, errors (either commission or omission) were not common in either participant group, and many participants did not make any errors throughout the experiment. This means that the significant finding between groups in the number of commission errors made in the 50% block should be interpreted with caution. Despite the need for caution, the results from this study do suggest that martial artists may have poorer inhibitory control and greater levels of impulsivity. This needs further investigation which would be able to tell us if these results are reproducible, and perhaps whether these results come from Martial Arts practice or are natural to people who may be more drawn to the sport.

Due to previous research in inhibition showing cumulative effects of mindfulness practice (Pozuelos et al., 2019), a similar trend was anticipated in the current experiment with martial artists. Instead there were no correlations between years of Martial Arts experience and the variables with significant group differences. For sensation seeking, this likely suggests a stable personality factor rather than a factor changeable or trainable through Martial Arts. The lack of correlation for years of experience with number of commission errors is more surprising, as this is the variable most similar to the one discussed by Pozuelos et al. (2019).

This chapter aimed to understand potential links between inhibition, impulsivity, and Martial Arts practice. Findings from a Go/NoGo task suggested poorer inhibitory control in martial artists due to a larger proportion of commission errors, however this should be interpreted with caution due to only a small number of errors being made by participants. Martial artists also displayed higher scores on sensation seeking compared to non-martial artists, although it is not clear whether this variable truly represents impulsivity. This chapter provides evidence to suggest that inhibition is not a function that can be trained or improved by Martial Arts practice. As inhibition has been described as a core component of cognitive control, this chapter provides an important introduction into cognitive changes associated with Martial Arts practice.

# Chapter Three: The Effects of Martial Arts Training on Attentional Networks in Typical Adults

This chapter has been adapted from the paper published as:

Johnstone, A., & Marí-Beffa, P. (2018). The effects of Martial Arts training on attentional networks in typical adults. *Frontiers in Psychology*, *9*, 80.

## Abstract

There is substantial evidence that training in Martial Arts produces improvements in cognitive function in children and older adults; but there is little published work with typical healthy adults. Here we studied the impact of extensive training in Martial Arts on cognitive control in adults. To do so, we used the Attention Network Test (ANT) to test two different groups of participants: with at least two years of Martial Arts experience, and with no experience with the sport. Participants were screened from a wider sample of over 500 participants who volunteered to participate. 48 participants were selected: 21 in the Martial Arts group (mean age = 19.68) and 27 in the Non-Martial Arts group (mean age = 19.63). The two groups were matched on a number of demographic variables that included Age and BMI, following the results of a pilot study where these factors were found to significantly impact the ANT measures. An effect of Martial Arts experience was found on the Alert network, but not the Orienting or Executive ones. More specifically, Martial Artists showed improved performance when alert had to be sustained endogenously, performing more like the control group when an exogenous cue was provided. This result was confirmed by a negative correlation between number of years of Martial Arts experience and the costs due to the lack of an exogenous cue suggesting that the longer a person takes part in the sport, the better their endogenous alert is. Results are interpreted in the context of the impact of training a particular attentional state in specific neurocognitive pathways.

## Introduction

Being able to attentionally focus on a task, and therefore avoid distraction, is fundamental to achieving our goals. Despite its central role in human adaptation to life, it is one of the most vulnerable cognitive functions. This is evidenced by the level of research showing the number of variables that deficits in attention can be attributed to, such as genetics (Durston, Mulder, Casey, Ziermans, & van Engeland, 2006), mental illness (Clark, Iversen, & Goodwin, 2002), and traumatic brain injury (Shah et al., 2017), among others. Age has perhaps the biggest influence on attentional control with a large amount of research discussing the decline in this function in older adults (Carriere, Cheyne, Solman, & Smilek, 2010; Deary et al., 2009; Dorbath, Hasselhorn, & Titz, 2011; Jennings, Dagenbach, Engle, & Funke, 2007; Kray et al., 2004; Milham et al., 2002). Deterioration of attentional control is variable but generally progressive, establishing it as the best predictor of cognitive dysfunction in older people. In neural terms, attentional control is achieved by the coordinated activation of a number of attentional networks with various specialities depending on the type of control required, although not all of these networks are affected by age in the same manner (Jennings et al., 2007).

Compared to how easily attentional control seemingly declines, little is known about whether we can enhance this function, and if so, how. In this chapter, we evaluate the impact of Martial Arts experience on three different attentional networks: Alert, Orienting, and Executive. These networks have been neuroanatomically validated and reported as being largely independent of one another (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The results provided in this chapter are important in aiding understanding of the impact of experience on these networks, whilst also highlighting potential intervention strategies.

**Attentional Control in Martial Arts**

Tang and Posner (2009) suggested that there are two different ways to improve attentional control: Attention Training (AT, also called Network Training; Voelker et al., 2017) and Attention State Training (AST). AT comes from Western cultures and is mostly based on specific task practice; over the past decade it has become popularised and marketed as 'brain training' games (Bavelier & Davidson, 2013; Boot, Kramer, Simons, Fabiani, & Gratton, 2008). This means that much research into AT focuses on training participants on a certain task to improve a specific cognitive skill, yet these improvements often are not transferable to tasks measuring other skills (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). For example, training at an attentional task will only improve the skills required for attentional tasks similar in nature (Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009). Despite this, improvements are often found in this type of AT research. Participants given training in playing an action video game were shown to present an increase in visual attention, in comparison to those given training in playing Tetris (Green & Bavelier, 2003). This is possibly due to the need to stay vigilant whilst also scanning the screen for targets or enemies during this type of game. In addition to the improvement not being transferable, this improvement seems to be short-term, rather than the long-term improvement researchers are striving for (Tang & Posner, 2009).

On the other hand, AST is based on Eastern cultures and aims to improve attention through a change in state of mind and body, also claiming to provide a better transference to other tasks not specifically trained by the activity (Tang & Posner, 2009). Activities suggested by Tang and Posner (2009) to involve AST include yoga, mindfulness, meditation, and Martial Arts. Gothe, Pontifex, Hillman, and McAuley (2013) used healthy, adult participants to investigate the effects of yoga on cognitive control. Participants were asked to visit the laboratory on three occasions to complete some computerised behavioural tasks after a different activity on each day: (1) a 20-minute yoga session; (2) a 20-minute exercise routine on a treadmill; (3) no activity in order to collect baseline data. The order of the three activities was randomised. A flanker task and an n-back task were used to provide measures of attentional control, and results indicated that the yoga session provided an improvement across both of these tasks. Interestingly, these benefits were not seen after the aerobic exercise condition, perhaps suggesting that the exercise element of yoga is not the sole force behind the effects. Similarly, Moore and Malinowski (2009) found a correlation between mindfulness experience and improved performance in attention and response inhibition tasks. However, unlike the Gothe et al. (2013) experiment, this was a cross-sectional design using the amount of mindfulness experience as a variable rather than results after a single session.

Martial Arts includes similar aspects to mindfulness and yoga through careful breathing and elements of meditation, and could potentially produce similar improvements in attentional control, although much of the research with Martial Arts has been conducted with school aged children (Diamond & Lee, 2011). For example, during an academic year, an average of three sessions of Taekwondo per week showed improvements in working memory and attention, as well as parentally-reported benefits in concentration and behavioural inhibition (Lakes et al., 2013). Additionally, a recent large-scale review of 84 studies conducted by Diamond and Ling (2016) found that Martial Arts, mindfulness, and Montessori Teaching produced the widest range of benefits in executive control tasks in children when compared with other interventions such as team sports, aerobic exercises, board games, or adaptations to the school curriculum. This review also raised an important point, noting that the greatest benefits were found in the children with the lowest starting scores in cognitive tests, and those from lower socio-economic backgrounds. This observation indicates that the greatest benefits from this type of intervention should be observed in those who display poor cognitive control and that neurotypical populations composed of developed young adults may already be at a ceiling in their attentional performance. Indeed, reports of improved cognitive abilities in younger adults are rare. Most of the benefits have been found in the sensorimotor system, involving corticospinal excitability due to long term training in Karate (Moscatelli, Messina, Valenzano, Petito, et al., 2016), or in the excitability of the motor cortex in Taekwondo athletes (Moscatelli, Valenzano, et al., 2016). Interestingly, some of these pathways coexist with more cognitive networks, such as attentional networks (as reviewed further on), raising the possibility of successfully finding changes in cognition with neurotypical adults despite the lack of previous reports.

Conversely, one would expect some improvements in older adults due to the evidence suggesting an age-related decline in cognitive control. Kray et al. (2004) suggested that if cognitive control was plotted on a graph along the lifespan, then it would take the shape of an inverted ‘U’, with performance improving as a person ages, remaining relatively stable during early adulthood, and then declining again as a person grows older. Studies using older populations to investigate the effects of Martial Arts on attentional control remain elusive, possibly due to the physical demands the sport requires, however that is not to say that this type of research is impossible. Jansen and Dahmen-Zimmer (2012) recruited participants aged 67-93 to compare the effects of Karate training in comparison to general physical exercise training, and cognitive training. This training took place over 20 sessions over 3-6 months, yet despite an increase in well-being reported by those in the Karate training group, there were no significant effects on cognitive speed or working memory across any of the groups.

However, it is important to note that outside laboratories, Martial Artists usually measure their differences in training in terms of years, rather than weeks or months, so it is conceivable that short interventions would not achieve the state of mind characteristic of the discipline. As mentioned in the general introduction, Witte, Kropf, Darius, Emmermacher, and Böckelmann (2015) built on previous research and studied three different groups of participants, with an age range of 63-83. They compared a group training in Karate, with another training in fitness and with a passive control group that did not complete any sports intervention. The results showed that the Karate group displayed small improvements in each of the four tasks performed. In a test of divided attention, for example, this improvement was not quite significant ($p$ = .063) after 5 months but, after another 5 months of extra training, the level of improvement further increased, reaching more reliable effects ($p$ = .002). These results clearly suggest that, at least in adults, potential benefits may need a longer time of training to emerge than those normally used in pre-post intervention studies.

To sum up, much of the research into the effects of Martial Arts on attentional and cognitive control has used either school-aged children or older adults. There appears to be a lack research focusing on healthy, neurotypical, adult participants. This population seems to need longer periods of training to show any improvement in other transference tasks, and this is the gap that we aim to fill with our current research.

## The Attention Network Test

A limitation of comparing much of the previous research is the wide range of measures used to assess attentional control, potentially leading to inconsistency across studies. One way to reduce this problem is to avoid using general measures (such as academic results or IQ) that result in difficulties isolating the core mechanisms behind the benefits. The problem could also be countered by using tasks which have been validated as measuring specific functions that have been localised to neuroanatomical locations.

Petersen and Posner (2012) discussed recent literature in attentional control and confirmed the existence of three core networks of attention in the human brain: Alert, Orienting, and Executive (Posner & Petersen, 1990). They suggested that these networks are independent of each other, each having distinct neuroanatomical structures, and responsible for a different aspect of attention. The alert index is related to optimal vigilance, Orienting has associations with the spatial location of targets, and executive has been linked with conflict resolution. Measures of these indexes can be collected using the Attention Network Test (ANT; Fan et al., 2002), which utilises a modified flanker task with 4 cue types to produce various trial types. The Alert index gives a measure of how well a person is able to respond to targets appearing at unpredictable intervals (uncued) compared to a predictable one (time cued). The Orienting index assesses how well participants can orient to a target that appears in an unpredictable location (uncued) compared to a certain one (spatially cued). Finally, the executive index evaluates how well participants can resolve response conflict in a flanker task, where distractors evoke the same response as the target (congruent) or the opposite one (incongruent). Behaviourally, all these three indexes are interpreted as costs, where large differences in RTs or accuracy reflect poor control (Fan et al., 2002; Jennings et al., 2007; Petersen & Posner, 2012).

Functional magnetic resonance imaging (fMRI) has been used to assess the neural activity related to the three attentional networks measured by the ANT. It has been suggested that these three networks are independent of each other, and while there is some overlap, the functional response for each network has a distinct anatomical location (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). The Alert index seems to involve norepinephrine circuits connecting the *locus coeruleus* with the right frontal and parietal cortices. The Orienting index is mostly driven by acetylcholine areas engaging the superior parietal cortex, temporoparietal junction frontal eye fields and superior colliculus. Finally, the Executive network activates dopamine based areas including the anterior cingulate, lateral and ventral prefrontal cortices, and the basal ganglia. When a particular sensory event is presented, it is believed that the coordinated activation of these three networks makes it possible to react to them with fast and accurate responses.

Training in Martial Arts is a wide-reaching experience involving not only a great level of motor training but also a mental state of concentration and reactivity to targets with a strong social context. Because of this, it is difficult to confidently predict where the improvements, if any, should be observed. There are, however, different aspects of the training that could impact directly these indexes. For example, during sparring, martial artists need to continuously scan the body of the opponent for an opening where they can score. As this may happen at any particular time, training in sparring may transfer to other tests involving target detection at random intervals, as measured by the Alert index. In addition to scoring, the Martial Artist needs to avoid and block any incoming hit from the opponent. This requires not only good timing (also linked to the alert system) but enhanced spatial orienting to the exact location where the hit comes from. Following the example of sparring, Martial Artists also throw feigned punches and kicks to distract the opponent's attention in order to score with an unexpected move. Not reacting to these in order to better respond to the real ones should require response conflict control of the type measured by the Executive index. Of course, it is not just sparring that is involved in Martial Arts training. Equally, these aspects are not exclusive of Martial Arts and can be shared with many other activities such as tennis, fencing, dancing, etc. But they at least represent a context of repetitive training on specific skills that are comparable to those used in AT studies, such as brain training. With the added element of concentration, meditation, and discipline (as is typical in AST research), it provides a promising strategy for training in attentional control.

In this chapter we discuss two experiments. We were aware that due to the nature of our participant groups – Martial Artists with at least 2 years of experience, and people with no previous experience of Martial Arts – we would not be able to randomly assign participants to a condition, and therefore we wanted to ensure that demographic differences between the participants did not confound the outcome. Experiment 1 in this chapter is a pilot study which aimed to detect these potential confounds in relation to the attentional networks, the results of which then informed recruitment of Experiment 2.

## Experiment 1

## Method

### Participants

41 participants were recruited from Bangor University's SONA participant panel system. Key characteristics of these participants can be found in Table 9.

Participants were reimbursed for their time with course credits. All participants were neurotypical, had normal or corrected to normal vision, and normal hearing. This study gained approval from the Bangor University Ethics and Governance Committee (Ethics Approval #2015-15553). As a condition of this approval, all participants provided fully informed consent prior to taking part.

Table 9. *Descriptive data for key participant demographics. Values represent mean averages, +/- standard deviation, or frequencies.*

| | |
|---|---|
| Age | 22.22 +/- 6.40 |
| BMI | 22.35 +/- 2.82 |
| Alcohol (units per week) | 3.68 +/- 5.48 |
| Other activities (hours per week) | 5.61 +/- 3.76 |
| Smokers | 3 |
| On medication | 3 |
| On a special diet | 5 |
| Health condition | 6 |

**Stimuli and apparatus**

This experiment was presented using EPrime 2.0 (Psychology Software Tools; PST). Responses were recorded using a QWERTY keyboard, with the ‘C’ and ‘M’ keys as the response keys. Target stimuli consisted of a row of five black arrows on a white background, facing to either the left or right side of the screen; each arrow subtended 0.53° of a visual angle, with a gap of 0.09°. The complete series of arrows subtended 2.73°. Participants were required to press the left key (C) or the right key (M) in response to the direction of the central arrow. This could be in either a congruent position (facing the same way) to the other arrows, or in an incongruent one (facing the opposite way). These were displayed either 0.71° of a visual angle above or below a fixation cross in the centre of the screen (see Figure 3).

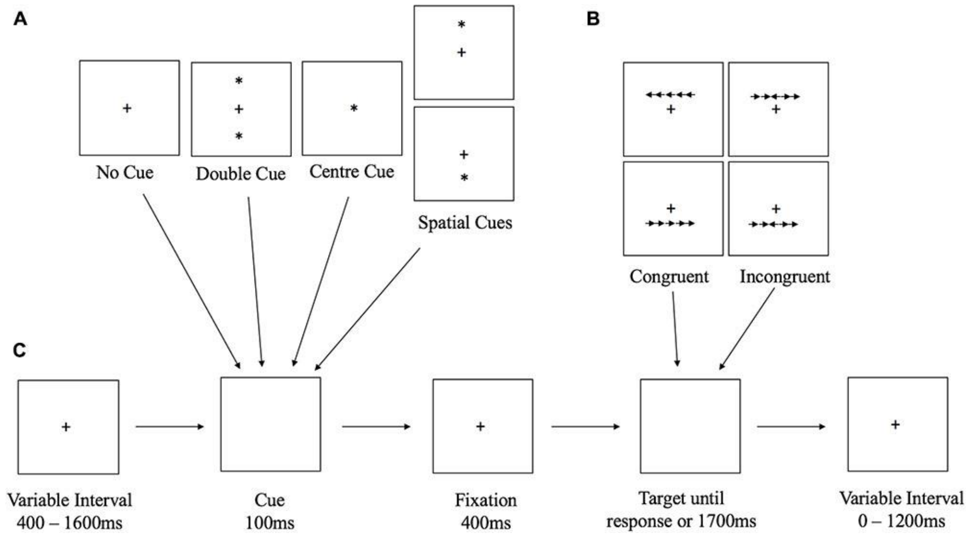


*Figure 3*. Diagram showing a) all possible cue types, b) the target types, and c) trial timings and procedure.

The target stimulus was preceded by one of four cue configurations (Figure 3): no cue, centre cue, double cue, and spatial cue. Each cue was made up of a black asterisk the same size as the fixation cross (0.44° of a visual angle tall; 0.44° wide) and appeared for 100ms before the target (Figure 3). During the no cue condition, an asterisk did not appear, instead, the fixation cross remained on screen. For the centre cue conditions, the asterisk simply replaced the fixation cross. Double cue conditions consisted of an asterisk appearing both above and below the fixation cross. Finally, during spatial cue conditions, the asterisk appeared either above or below the fixation cross, and always provided a true indication of the location in which the target would appear.

Each trial began with a fixation cross presented during variable intervals (400-1600ms) and ended with another fixation cross appearing just after the response to the target also with a variable duration to make the total interval time 1600ms per trial. After the first interval, the cue appeared on screen for 100ms, followed by another fixation cross for a fixed duration of 400ms. The target then appeared and remained on screen until the participant responded, or until 1700ms had passed. Responses exceeding this limit were recorded as errors.

**Procedure**

Upon arrival in the laboratory, participants were provided with information about the experiment, given the opportunity to ask questions, and provided with a consent form. After receiving fully informed consent, participants were presented with the demographics questionnaire, before being asked to complete the ANT by responding to the direction of a central arrow as described earlier.

A practice block of 24 trials was presented to participants, followed by a verbal check that the participant understood the instructions and the opportunity to ask any new questions to the researcher. No accuracy feedback provided on these practice trials. Once completed, participants moved onto the experimental block of 128 trials, before having a short break of approximately 1-2 minutes, which was then followed by another 128 trials. Again, no feedback was provided.

**Data analysis**

All data were pre-processed within EPrime 2.0 (PST), before being moved over to SPSS v.22. Trials with a response time exceeding 1000ms were removed, as were those where the participant had responded incorrectly. The three indexes, Alert, Orienting, and Executive, were then created using the calculations described by Fan et al. (2002). They represent mean cost indexes (i.e., a large score represents a less efficient network).

A series of bivariate Pearson's correlations were conducted to assess any relationships between the demographic variables and the attentional indexes, which could then inform participant recruitment for Experiment 2.

## Results

Following a series of Pearson's correlations on all the demographic variables and the attentional indexes coming from the ANT, the core significant correlations are reported below in Table 10.

Table 10. *Pearson correlations between key demographic variables and attentional networks*

| | Alert | Orienting | Executive | Age | BMI | Other Activities |
|---|---|---|---|---|---|---|
| Alert | . | - | - | - | - | - |
| Orienting | .009 | . | - | - | - | - |
| Executive | -.392* | .244 | . | - | - | - |
| Age | -.104 | -.323* | -.209 | . | - | - |
| BMI | .398* | .150 | .001 | -.009 | . | - |
| Other Activities | .209 | .081 | .105 | -.343* | .087 | . |

*. Correlation is significant at the .05 level (2-tailed)

A significant positive correlation was found between the Alert network and a person's BMI, $r(34)=.389$, $p=.019$, with the Alert index increasing with a rise in BMI. The Orienting network, on the other hand, was significantly correlated with age, $r(39)=-.323$, $p=.039$, with a smaller Orienting index being associated with older age. Another correlation of interest was found between the number of hours of other activities reported by participants and the age of participants, $r(39)=-.343$, $p=.028$, with more hours of non-Martial Arts related activities being reported by younger participants.

## Discussion

From the analysis conducted within this pilot study, it is clear that some demographic factors are associated with the attentional networks we plan to investigate in Experiment 2. In this exploratory pilot study, we have found significant correlations between the Alert index and BMI, and the Orienting index and age. As

Experiment 2 intends to assess differences in attentional networks between those with Martial Arts experience and those without, it is important for us to understand which demographic factors can have an impact these results. Due to this, when we recruited participants for this follow up study, we ensureed that the two groups of participants were matched as closely as possible on these two variables.

## Experiment 2

The aim of Experiment 2 was to assess the performance of Martial Artists and Non-Martial Artists on the three indexes of attention, as measured by the ANT. We hypothesised that smaller indexes, reflecting improved performance, would be observed in the Martial Arts group in comparison to Non-Martial Artists.

## Method

### Participants and screening procedure

Using G*Power 3.0.10, an a priori calculation of optimal sample size was calculated based on parameters taken from the pilot study. When using stringent criteria such as a correlation of 0.6 between measures, a desired power of 0.95, and an alpha level set to 0.05, it was estimated that a minimum sample size of 30 participants would be needed to reach an effect size of 0.25 from the required 2x2x2 ANOVA (see Design section). This would result in 15 participants in each of the two participant groups.

A screening questionnaire was introduced and distributed online to over 500 new people including Bangor University undergraduates and non-students from the local community. These responses then made up a participant pool which was used to create two experimental groups matched on the aforementioned variables: one group with no Martial Arts experience ($n$ = 27, 5 males), and the second with those who had undertaken Martial Arts practice during the last two years ($n$ = 21, 6 males). The Martial Arts group was made up of participants with experience in Karate (5), Taekwondo (3), Kickboxing (3), Jujitsu (3), Tai Chi (2), Judo (2), Thai Boxing (2), and Kung Fu (1). This sample exceeded the minimum sample size estimated by the power calculation. The participants from these groups were invited to participate in the ANT phase. The Non-Martial Arts group reported taking part in activities such as going to the gym, playing team sports, and mountain walking – this ensured that all participants engaged in some active activities to avoid participant groupings based on active or sedentary lifestyles.

As in Experiment 1, participants from Bangor University were reimbursed for their time with course credits, and those from the community were given a monetary token of £6. All participants were neurotypical, had normal or corrected to normal vision, and normal hearing. This study gained approval from the Bangor University Ethics and Governance Committee (Ethics Approval #2015-15553). As a condition of this approval, all participants provided fully informed consent prior to taking part. Information regarding the demographics of the selected participants can be found in Table 11.

Table 11. *Descriptive data for key participant demographics. Values represent mean averages, +/- standard deviation, or frequencies. p values show exact probability values. N represents number of participants with the number of males in parentheses.*

| | Martial Artists | Non-Martial Artists | *p* |
|---|---|---|---|
| N (male) | 21 (6) | 27 (5) | - |
| Age | 19.68 +/- 1.95 | 19.63 +/- 1.11 | .905 |
| BMI | 22.50 +/- 4.08 | 22.55 +/- 1.91 | .961 |
| Alcohol (units per week) | 3.47 +/- 5.26 | 4.59 +/- 5.98 | .515 |
| Other activities (hours per week) | 4.11 +/- 3.93 | 3.93 +/- 2.73 | .856 |
| Smokers | 3 | 0 | - |
| On medication | 1 | 3 | - |
| On a special diet | 2 | 4 | - |
| Health condition | 3 | 3 | - |

**Design and procedure**

The study took a 2 (participant group) x2 (trial type) x2 design (target congruency - executive) design. For the Alert index this would look like 2 (Martial Arts vs Non-Martial Arts) x2 (no cue vs double cue) x2 (congruent target vs incongruent target). Whereas for Orienting it would take the form of 2 (Martial Arts vs Non-Martial Arts) x2 (centre cue vs spatial cues) x2 (congruent target vs incongruent target). The Alert and Orienting networks come from cue manipulations, and are independent due to them using different trial types in their calculations, however the Executive network comes from a target manipulation and is therefore not independent of the Alert and Orienting networks. As a result, we will analyse this as an interaction.

The procedure for the experiment then followed that of the pilot which is described above under Experiment 1.

**Data analysis**

All data was pre-processed within EPrime 2.0 (PST). Incorrect trials were removed from the analysis, as were those with a response time greater than 1000ms. Once the filtering in EPrime was complete, the data was moved over to SPSS v.22 for statistical analysis, and split into the two participant groups based on the criteria mentioned above for Martial Arts experience. The significance level was set at $p \leq .05$. Descriptive statistics are presented as mean averages, +/- standard deviation for continuous variables, and frequencies for categorical variables (see Table 3). Differences between the groups were estimated using independent samples t-tests, whilst differences in frequencies were assessed using chi square. As described in Experiment 1, the three indexes of attentional control (Alert, Orienting, and Executive) were calculated using the procedures developed by Fan et al. (2002). These are expressed as mean cost indexes. Mean RT averages per participant, per condition were analysed through three different general linear models (see Table 4). Effect sizes for these effects are estimated through partial eta squared. When Martial Arts group differences were found, correlations were conducted with years of experience using the Pearson's coefficient.

## Results

Data were separately analysed for each of the attentional indexes.

**Executive**

When the Executive index was analysed, we found an overall increase of 36ms for incongruent trials compared to congruent ones [$F(1,46)=1013.92$; $p<.001$; $\eta_p^2$ =

.1]. This effect was almost identical for the Martial Arts group (36ms) compared to the Non-Martial Arts one (35ms, F<1) (see Figure 4).

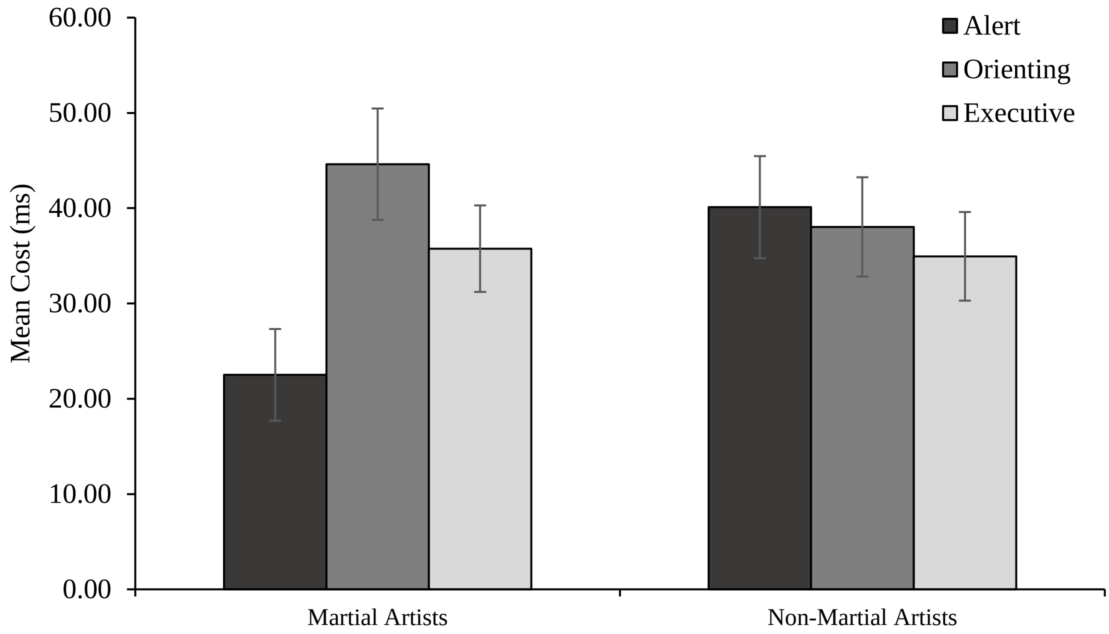


*Figure 4.* Graph depicting the mean cost for each of the three attentional network, for both participant groups. Error bars represent Standard Error. Asterisk denotes p < .05.

Table 12. *F values, probability values (p) and effect sizes ($\eta^2_p$), for all conducted general linear models.*

| | | F | *p* | $\eta^2_p$ |
|---|---|---|---|---|
| **Executive** | | | | |
| | Executive | 113.92 | .00*** | .71 |
| | Group | 1.34 | .25 | .03 |
| | Executive x Group | 0.02 | .90 | .00 |
| **Executive vs Alert** | | | | |
| | Executive | 52.60 | .00*** | .53 |
| | Group | 1.05 | .31 | .02 |
| | Alert | 71.30 | .00*** | .61 |
| | Alert x Group | 5.64 | .02** | .11 |
| | Executive x Group | 0.27 | .61 | .01 |
| | Alert x Executive | 4.18 | .05* | .09 |
| | 3-way interaction | 0.34 | .57 | .01 |
| **Executive vs Orienting** | | | | |
| | Executive | 160.93 | .00*** | .78 |
| | Group | 1.58 | .22 | .03 |
| | Orienting | 111.14 | .00*** | .71 |
| | Orienting x Group | 0.71 | .41 | .02 |
| | Executive x Group | 0.26 | .61 | .01 |
| | Orienting x Executive | 10.52 | .00** | .19 |
| | 3-way interaction | 3.09 | .09 | .06 |

*p ≤ .05; ** p ≤ .01; *** p ≤ .001

## Executive vs Alert

Mean RTs per participant per condition were submitted to a Mixed Factor Analysis of Variance (ANOVA) with the Martial/Non-Martial Arts variable as a grouping factor and the Type of Cue (Double Cue, No Cue) and Congruency (Congruent, Incongruent) as repeated measures. Results indicated no overall differences in RTs across the groups ($p$=.31). Responses to targets preceded by the double cue were 32ms faster than those without a cue as would be expected as a measure of Alert. More importantly, this benefit from the double cue was 18ms smaller in the Martial Arts group compared to the Non-Martial Arts group [$F(1,46)=5.64$; $p=.022$; $\eta_p^2 = .642$]. Although group differences did not reach significance in any of the conditions, Non-Martial Artists were found to be 24ms slower than the Martial Artists when no cue was presented, while both groups seemed more similar with the double cue (see Figure 5). Congruent trials were overall 32ms faster than incongruent ones [$F(1,46)=52.59$; $p<.001$; $\eta_p^2 = .1$] , but this effect did not change with the group ($F<1$). Interestingly, the executive congruency effects were more evident in the double cue trials (38ms) than with no cue (27ms) [$F(1,46)=4.18$; $p=.047$; $\eta_p^2 = .516$]; but this was found in general for all participants and did not change across the groups ($p$=.57).

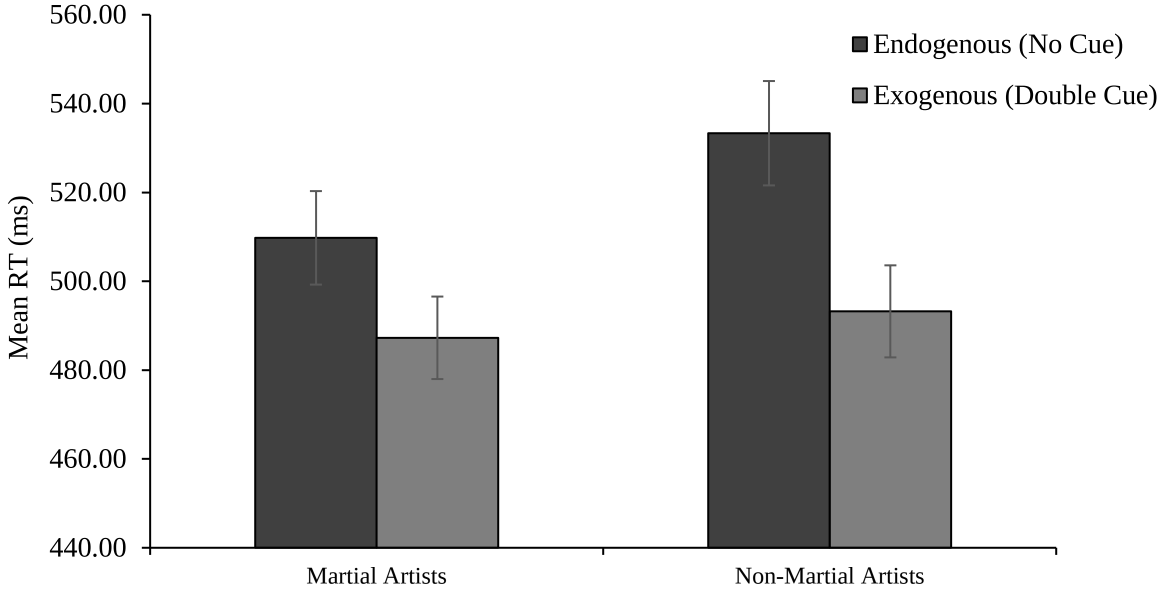


*Figure 5*. Graph depicting the mean RT for the trial types that make up the Alert index, no cue trials and double cue trials. Mean RTs are displayed for both participant groups. Error bars represent Standard Error. Asterisk denotes p < .05.

## Executive vs Orienting

Mean RTs per participant per condition were also submitted to a Mixed Factor Analysis of Variance (ANOVA) with the Martial/Non-Martial Arts variable as a grouping factor and the Type of Cue (Spatial, Center Cue) and Congruency (Congruent, Incongruent) as repeated measures. As before, no overall differences were found between the Martial Arts and the Non-Martial Arts groups ($p$=.22). Congruent trials were found to be 38ms faster than the incongruent ones [$F$(1,46)=160.93; $p$<.0001; $\eta_p^2$ =1]. Also, spatial cues produced responses that were 41ms faster than the single central cue [$F$(1,46)=111.14; $p$<.0001; $\eta_p^2$ =1]. Interestingly, the congruency effects changed depending on the type of spatial cueing [$F$(1,46)=10.52; $p$=.002; $\eta_p^2$ =.89], with a flanker congruency effect of 47ms in the centre cue condition congruent trials that was reduced to 29ms with the spatial cue. No group differences were found.

**Attentional Networks Correlations**

We analysed whether there were any interactions across attentional networks by calculating the correlations across the three indexes. Results demonstrated a marginally significant correlation between the Alert and Executive indexes only (r=-.262; *p*=.072).

A correlation was also done on the three indexes of attention and the number of years of Martial Arts practice. No significant correlation between Orienting and number of years was found, r=.121, n=46, *p*=.421, nor between Executive and number of years, *r*=.039, n=46, *p*=.798. However, a correlation nearing significance was found between the Alert index and the number of years of practice, *r*=-.274, n=46, *p*=.065.

**Accuracy**

Finally, a series of analyses were run on the accuracy of responses to each trial type. For each participant, a percentage (%) accuracy score was calculated for each type of trial (cue type and congruency type), and these were then compared between groups. There were no significant differences between the two participant groups for any trial type for the ANT, suggesting that all trials were equally as difficult. Less than 16% of overall responses were recorded as errors.

## Discussion

In this chapter, we provide evidence that training in Martial Arts is associated with an improved Alert attentional network. This appears to be a specific benefit that boosts endogenous preparation for uncertain targets, as suggested by the increased benefits in the uncued conditions in comparison to a lack of improvement in the cued conditions. This means that when an upcoming target had no cue, the Martial Artists performed at a higher level, however when the target had a reliable cue, these group differences disappeared. Importantly, the Alert benefits observed in the MA group was further supported by the negative correlation found between the Alert index and the number of years of training.

The use of ANT allows us to speculate on the nature of these benefits, as explained in the introduction. Previous research with this task using neuroimaging techniques found that the Alert index is linked to the activation of a norepinephrine based network connecting the *locus coeruleus* with the right frontal and parietal cortices, as well as the Anterior Cingulate Cortex (ACC) and Orbitofrontal Cortex (OFC; Nieuwenhuis, Aston-Jones, & Cohen, 2005; Petersen & Posner, 2012; Raz & Buhle, 2006). The *locus coeruleus* is a nucleus in the brainstem in charge of producing norepinephrine, which has an excitatory effect on the rest of the brain, resulting in an increased level of arousal. As a result of this activation, different parts of the brain involved in perceptual and motor processing get primed to enable faster responses to stimuli (Moscatelli et al., 2016a; Moscatelli et al., 2016b; Monda et al., 2017).

It is not yet clear which aspect of Martial Arts training may be driving the effect on the alert index, or indeed where the effect is coming from. Further work using neuroimaging techniques may allow us to gain an insight into these details. For example, Fan and Posner (2004) suggested the use of diffusion tensor imaging (DTI) to look at the attentional networks' functional connectivity; by understanding how these circuits work in a typical group of participants, we could then begin to investigate whether Martial Arts experience has any effect, which would then be able to show us where the effect on alert is observed at a neural level. Of course, it is conceivable that Martial Artists who trained for years on fast reactions to stimuli may have modelled their brains to lower the activation threshold of areas involved in perceptual processing and motor control (Moscatelli, Valenzano, et al., 2016). However, we would expect this influence to appear across all conditions, for both predictable and unpredictable targets, simply inducing faster reaction times, rather than any exclusive benefits. This idea is not supported by the results which suggested no significant differences in overall RTs in the Martial Arts group in comparison to the Non-Martial Arts controls.

An interesting aspect of our results is that the strongest benefits seem to appear more specifically in the unpredictable condition. Somehow, our Martial Artists seem to be more capable of inducing these increases in arousal to improve sensorimotor processing endogenously without the aid of external cues. Indeed, there is evidence that endogenous time allocation of attention to the particular moment when a target appears improves identification of masked targets that otherwise would have been unconsciously processed (Naccache, Blandin, & Dehaene, 2002). More importantly, they also found that identifications were better for targets closer to the expected time frame than for more distant ones in time. When this is considered in relation to our findings, it raises the possibility that Martial Artists may endogenously hold the level of vigilance for longer periods of time reaching the unpredictable target in a more efficient way than controls.

This interpretation is supported by recent findings of increased excitability of the corticospinal motor system in Karate athletes (Monda et al., 2017; Moscatelli, Messina, Valenzano, Monda, et al., 2016; Moscatelli, Messina, Valenzano, Petito, et al., 2016). In this study, the authors found that this greater excitability from the Karate group was evidenced in faster reaction times to targets appearing in variable intervals (as is standard in the Reaction Time [RTI] test from the Cambridge Neuropsychological Test Automated Battery [CANTAB®]). Related findings from this team have also found excitability of the motor cortex in Taekwondo athletes (Moscatelli, Valenzano, et al., 2016), suggesting that this effect may be found in other types of Martial Arts. In the current study, when the target appeared in a predictable interval, no group differences were found. Our Martial Arts group were faster than the Non-Martial Arts group only with unpredictable targets, thereby supporting Moscatelli et al.'s findings. Interestingly this RTI task was also described as a vigilance task. Our results can be seen as a step forward, further suggesting that the excitability of this corticospinal motor system may be linked to the more efficient activity in the Alert network due to Martial Arts practice.

Although previous research seems to assume that the three attentional networks studied here are largely independent, there is some evidence of influences across them. For example, spatial orienting seems to have a fundamental role in the activation of competing responses during a flanker task in what it would seem like a modulation of the Orienting network over the Executive one (Vivas & Fuentes, 2001). Also, when testing neglect patients, increased Alert can be used to improve target detection in the hemifield contralateral to the site of the lesion (Robertson, Tegnér, Tham, Lo, & Nimmo-Smith, 1995), demonstrating an influence of the Alert network over the Orienting one. In our data, we did not find any correlation between Alert and Orienting, neither Orienting with Executive. However, we did find an interaction between Alert and Executive, since greater congruency effects were found in the predictable condition. Further support may come from studies finding that increases in norepinephrine improve executive response selection (Chamberlain et al., 2006). This also fits well with results described earlier in which response congruency effects were only found at the spatially cued location (Vivas & Fuentes, 2001). Basically, the executive resolution of conflict elicit by incongruent flankers requires first the selection of the target, both spatially and temporally. Although this is an interesting aspect of the data, it nevertheless did not change with the group, not being affected by training in Martial Arts.

The benefits of MA training in our study seem to be exclusive to the Alert system, mostly with regards to endogenous alert. Importantly, this improvement increases with years of practice extending up to 18 years. These results are important because it highlights the potential difficulties of getting significant results from studies of using randomised groups with a training intervention of only a few months. Nevertheless, one of the biggest disadvantages of using cross-sectional samples is the lack of control of group variables. In order to improve the control over the current study, participants were carefully matched on various variables. To find two homogeneous participant groups, demographic information for over 500 people was collected and then filtered based on age, BMI, lifestyle, and health factors such as smoking status, and level of education. To avoid ending up with an active participant group and a passive participant group, we ensured that control participants were only recruited if they reported taking part in several hours of activity per week. The activities reported included gym time, football, and basketball among others, suggesting that the control participants were just as active as the Martial Artists. We believe that this is an important variable to use with regards to matching the groups to ensure a similar level of fitness due to previous research suggesting a link between fitness and cognitive control. Our estimation, however, has been based on a non-validated self-report measure so should be considered with caution. In any case, the descriptive data showed no significant differences in terms of hours of participating in other activities per week between the two groups. Despite this, future research may benefit from the assessment of data from wearable activity monitors in order to gain a more objective measure of general activity.

A further consideration comes from the heterogeneity of participants in the Martial Arts group, specifically in relation to the styles of Martial Arts. In the current chapter, different styles of Martial Arts with variations in both training and philosophy are used. This was done under the assumption that all of them would contain elements of physical and mental training in line with Tang and Posner (2009) AST classification, found to cause improvements in executive control (Gothe et al., 2013; Moore & Malinowski, 2009). However, Weiser, Kutz, Kutz, and Weiser (1995) suggested that Martial Arts exist on a continuum with more meditative styles on one end, and more combative styles on the other. This suggests that it may be important to consider potential differences in style in various forms of Martial Arts. Further research intends to assess these possible differences, in the hope that it could lead to a greater understanding of the underlying drivers behind the cognitive improvements associated with Martial Arts.

The current research suggests that the alert network of attention differs between people with Martial Arts experience and those without this experience. Whilst this effect was only found in one of the three known attentional networks, it supports previous work which suggests changes in control as a result of taking part in Martial Arts, whilst also extending the research field into populations of neurotypical adults. Further research should seek to replicate this finding, and discover the underlying reasons for the effect solely appearing in the Alert network and not Orienting or Executive. This may help improve our understanding of how activity in different attentional networks can be 'trainable' or able to be improved through Martial Arts.

# Chapter Four:

# The Influence of Martial Arts Experience on Task Switching

## Abstract

Martial Arts can be considered both a sport and a therapy, combining physical exercise with intense periods of concentration (similar to meditation). Previous research suggests that both exercise and meditation can lead to improvements in executive functions (i.e., cognitive flexibility) in adult participants. Results from our lab have previously suggested that martial artists show improvements in the alerting attentional network – a measure of vigilance. The current research aims to investigate the impact of Martial Arts training on a task-switching protocol to measure both vigilance and cognitive flexibility in typical adults. Here we recruited adult martial artists with at least two years of experience, and control participants with no experience. Participants had to respond to either the shape or the colour of a figure in pure and mixed blocks to provide measures of mixing costs (sustained vigilance) and switching costs (cognitive flexibility). Results demonstrated martial artists did not differ from controls in the pure block, but displayed improved performance in the mixed block, revealing an improvement in mixing costs (vigilance). These benefits in vigilance mirror those previously found in attentional tasks, providing convergent evidence on the impact of Martial Arts training on vigilance.

## Introduction

In the previous chapter we discussed how experience of Martial Arts practice appears to be associated with increased vigilance. This finding came through the use of the Attention Network Test (ANT; Fan et al., 2002), which suggested that participants with at least two years of Martial Arts experience showed a more efficient alert network (i.e., less of a detrimental effect of having no cue versus having a cue) than participants with no Martial Arts experience. We wanted to follow up this finding and assess its robustness when using a different measure of vigilance.

We were also interested in cognitive flexibility, as this is a core executive function which has an important role in some of the other functions discussed in this thesis – i.e., inhibition (Go/NoGo chapter) and various indexes of attention (Attention chapter). Cognitive flexibility has often been defined as the ability to assess a situation and appropriately adapt the cognitive strategies and processes according to the new situation or environment (Dajani & Uddin, 2015). Indeed, Martin and Rubin (1995) suggested that throughout day to day life, people have to make choices about their behaviour and how to respond to situations. They go on to further suggest that cognitive flexibility is the state of willingness we need to adapt our behaviours and choose the most effective response. This is an important function in everyday life; it allows us to multi-task, problem solve, and even work multi-lingually (Ionescu, 2012). It also allows us to ‘adapt and overcome’ when situations do not work out as first planned. Without cognitive flexibility we would not be able to move on past life’s obstacles. For example, a person finding it difficult to begin the search for a new job following redundancy, or older people sticking to a set routine without engaging in new activities, or children sticking only with one colour of vegetable without trying others. Small examples perhaps, but those which can have a longer-term impact on a person's life.

Some previous experiments have used a combination of two different tasks to create a measure of cognitive flexibility – for example, Masley, Roetzheim, and Gualtieri (2009) used an amalgamation of scores from a shifting attention test and a Stroop test to create their measure of cognitive flexibility. Dajani and Uddin (2015) suggested that research such as this would have been stronger if the key measure was not a combination of two different tasks, but instead one singular paradigm which has been well-used and validated for measuring cognitive flexibility. They suggested task-switching which has been described as a form of 'high level' cognitive flexibility. Due to its common use as a measure of cognitive flexibility, as well as its associations with vigilance (please see 'mixing costs and vigilance'), it was decided to use a task-switching paradigm for the current experiment.

**Task-switching**

Whilst there are several different iterations of task-switching paradigms, one of the most common is the alternating runs paradigm (Rogers & Monsell, 1995). In this paradigm there are two types of block, a pure block and a mixed block. In the pure block participants are asked to complete one task, either task A or task B, for the whole block. For example, a pure block could look like 'AAAAAA'. This is often followed by a pure block of the other task, such as 'BBBBBB'. In the mixed block, however, the tasks are often presented as 'AABBAA' which produces two types of trial, repeat trials and switch trials. Repeat trials consist of the same task appearing twice consecutively, whereas the switch trials occur when the task switches such as the 'AB' portion of the block.

This way of presenting trials in the alternating runs version of the task, adds an element of predictability. This allows the participant to recognise the predictable pattern, and hold it within their working memory to allow preparation for the upcoming trial (Dreisbach, Haider, & Kluwe, 2002; Ruthruff, Remington, & Johnston, 2001). If the participant has an efficient working memory, this can allow for faster and more efficient responses. Marí-Beffa and Kirkham (2014) use a tennis analogy to further explain this. Tennis players typically return to the centre of the court after playing their shot, because the location of the return ball will be unpredictable. This means that regardless of which side the return ball arrives, the player is in the best location to respond – think of this as moving back to respond to a switch cost. However, if the return ball is predictable, and the player knows that the ball will return to the same side of the court, they will stay where they are for the most efficient response. This is analogous to the predictable trials in the alternating runs paradigm – participants can recognise the pattern and hold it within their working memory, to ensure they are making the most efficient responses, rather than always 'returning to the centre of the court'.

Due to its predictable nature and the participant needing to keep track of where they are in the pattern, the alternating runs paradigm is believed to have greater working memory demands than other task-switching paradigms (Kamijo & Takeda, 2010). Because of this, many researchers include some form of cue which acts as a signal to the participant and reminds them of their place in the pattern. If no cues are present, this means that participants have to be able to keep track of which trials they have previously completed, as well as how the present trial fits into the pattern. This level of vigilance is not sustainable forever, and therefore it is likely that participants will lose track of the pattern at some point, and so the cues guarantees that they can get back on track – although, in this case, we would expect their response to be similar to that of a switch trial even if it is technically a repeat trial.

The task switching paradigm provides two measures, one of switch costs and one of mixing costs (Monsell, 2003). For both of these measures, a larger cost represents poorer cognitive flexibility and concentration.

**Mixing costs and vigilance**

It has previously been suggested that continuous repetition of a task in which the rules often change is more effortful than continuously completing one single task with no changes, as the first situation requires the participant to be able to maintain two sets of rules and processes throughout (Marí-Beffa & Kirkham, 2014). By comparing the outcome of two situations like this, we gain a measure known as 'mixing costs' which are the costs associated with mixing different tasks or rules. This means that mixing costs are calculated by comparing outcomes from trials in the pure block to repetition trials in the mixed block.

Traditionally, there have been differences in the way mixing costs have been calculated and assessed, with Kamijo and Takeda (2010) noting that many researchers calculate mixing costs by comparing all pure trials with all of those from the mixed block – therefore combining repeat and switch trials. As they suggest, this means the mixing cost measure can be contaminated by switch trials which are also assessed separately through switch costs. Therefore, calculating the mixing cost by comparing trials from the pure block to repeat trials from the mixed block, it avoids this contamination, and provides us with a separate, distinct measure.

Whilst mixing costs has typically been used as a measure of cognitive flexibility alongside switching costs, it has more recently also been described as a measure of vigilance by (Marí-Beffa & Kirkham, 2014). They suggested that when a person is simply repeating a task with no switches, they require a very low level of vigilance to be able to maintain their performance, as responding becomes almost automatic. However, when the possibility of switches arises, the person needs to become more vigilant in order to prepare and appropriately respond.

Previous research has begun to assess whether regular exercise and physical activity can improve task-switching abilities. Kamijo and Takeda (2010) recruited participants with active or sedentary lifestyles, and gave them an alternating runs task-switching paradigm. They found a smaller mixing cost for their physically active group compared to their sedentary participants. Interestingly, they only found this result in one of the two tasks that participants were asked to complete. They suggested that this task was more difficult than the other, and therefore demanded greater cognitive control and working memory. Due to this, they proposed that physical activity may influence working memory capacity, which, in turn, then also affects the mixing costs.

**Switching costs and cognitive flexibility**

From an experimental cognitive psychology perspective, switch costs from task switching can tell us about a person's cognitive flexibility. Switch costs are the costs in performance associated with switching between sequential tasks and come from comparing the switch and repeat trials from the mixed block (Marí-Beffa & Kirkham, 2014). This cost comes from the amount of time taken to disengage with the processes needed to deal with the first trial, processing the new trial, and then engaging the new rules and processes needed to respond. As discussed by Marí-Beffa and Kirkham (2014), this is only the case for switch trials, as when the trial is repeated, the participant does not need to change their approach to be able to respond, as they simply need to maintain the rule.

As noted earlier, Kamijo and Takeda (2010) utilised a task-switching paradigm with participants of active and sedentary lifestyles. Alongside the effect on mixing costs, they also found an effect in switch costs, with participants with active lifestyles showing a smaller switch cost than that of those with a sedentary lifestyle. Interestingly though, these findings were only found in their behavioural measures of the switch cost, and not their electrophysiological measures. The authors stated that the reasons for this were unclear, and therefore more research is needed to fully understand the link behind physical exercise and switch costs.

Masley et al. (2009) recruited participants for an experiment investigating the effects of aerobic exercise on a series of cognitive measures. Participants were asked to complete the CNS Vital Signs neurocognitive battery, which provided measures of memory, attention, information processing speed, and cognitive flexibility. They found an increase in cognitive flexibility which was proportional to the level of aerobic exercise completed by the participants – i.e., moderate or intense. This research, along with that of Kamijo and Takeda (2010), suggests that there may be exercise induced benefits in cognitive flexibility.

**Aim and hypotheses**

Experiment 1 of this chapter is a pilot study which aimed to uncover potential confounding demographic variables which could affect the main experimental variables of mixing costs and switch costs. Experiment 2 then aimed to investigate the effects of Martial Arts training on vigilance and cognitive flexibility with matched participant groups.

Within Experiment 2, we hypothesised that differences would be most prevalent in mixing costs due to its relationship with vigilance which Chapter Three showed to be affected by Martial Arts practice. If this is the case, then it is expected that this would be correlated with years of experience in Martial Arts, as was the case in Chapter Three. It is also possible that there will be differences in switch costs between the two groups, due to previous research reporting evidence of changes in cognitive flexibility related to exercise.

## Experiment 1

## Method

### Participants

40 participants were recruited from Bangor University's SONA participant panel system, the demographics of which can be found in Table 13. These were naïve participants that had not taken part in any other study presented in this thesis. Participants were reimbursed for their time with course credits. These participants were neurotypical, had normal or corrected to normal vision, and normal hearing. Ethical approval was granted by the Bangor University Ethics and Governance Committee (Ethics Approval #2015-15553).

Table 13. *Descriptive data for key participant demographics. Values represent mean averages, +/- standard deviation, or frequencies.*

| | |
|---|---|
| Age | 22.32 +/- 6.44 |
| BMI | 22.45 +/- 2.80 |
| Alcohol (units per week) | 3.31 +/- 5.02 |
| Other activities (hours per week) | 5.57 +/- 3.80 |
| Smokers | 3 |
| On medication | 3 |
| On a special diet | 5 |
| Health condition | 6 |

**Stimuli**

Stimuli were presented on screen through EPrime 2.0 [Psychology Software Tools (PST)]. Stimuli consisted of either a square or a circle, presented in blue or red, on a white background. Before these figures appeared, a cue of 'COLOUR' or 'SHAPE' was presented in black text for 500ms, and then a 250ms blank screen interval. Following this, the target stimulus appeared for 1000ms or until the participant responded, before a 250ms blank screen interval finished the trial.

These target stimuli could appear as either congruent or incongruent, depending on the cue shown. Blue stimuli and square stimuli required a press of the 'F' key as a response, whereas red or circular stimuli required a 'J' keypress. This means that a blue square (or red circle) would elicit the same response, regardless of whether the participant was asked to respond to the shape or colour of the figure, making it a congruent stimulus. A blue circle (or red square), on the other hand, would be an incongruent stimulus as the required response would depend on the given cue.

## Design

This study utilised a cued version of the alternating runs task-switching paradigm, which consisted of three blocks (two pure task blocks, and one mixed task block; see Figure 6). All participants completed all three blocks.

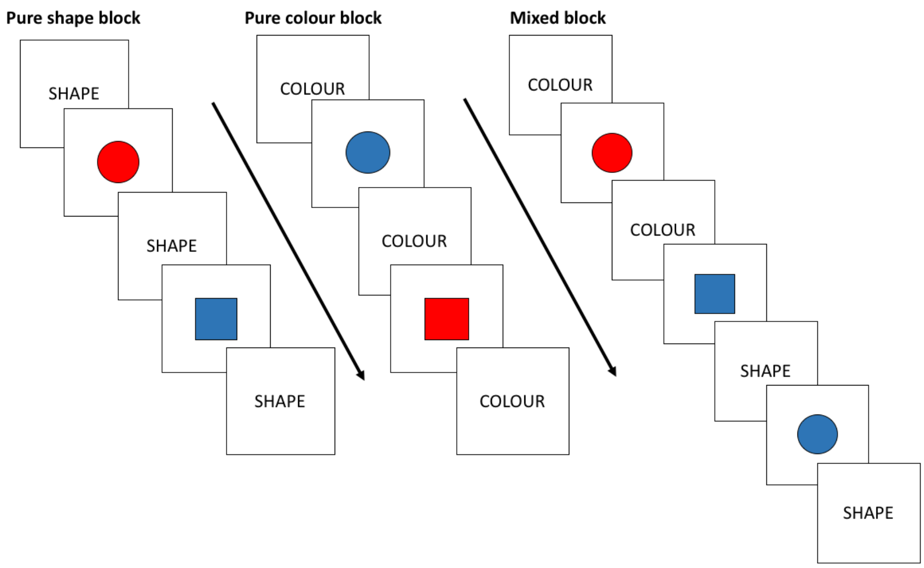


*Figure 6*. Diagram showing structure of the blocks used in this experiment.

**Pure Blocks.** There were two pure blocks, each consisting of a different task, colour and shape. In one block participants were asked to respond to the colour of the presented figure (i.e., CCCCCC for all trials in the block), and in the other block they responded to the shape of the figure (SSSSSS for all trials in this block). These trials will be referred to as 'pure trials' from this point onwards. The order of these blocks was counterbalanced, to ensure that half of the participants completed the colour block first, and half completed the shape block first. This was done to account for any potential contamination effects in the second pure block.

**Mixed Block.** The final block for all participants was the mixed block, which comprised of two alternating trial types. Half of the trials in this block consisted of the participant responding to the colour, or shape for the other half (i.e., CCSSCC). This structure allows us to assess repeat trials and switch trials, (please see Figure 7).

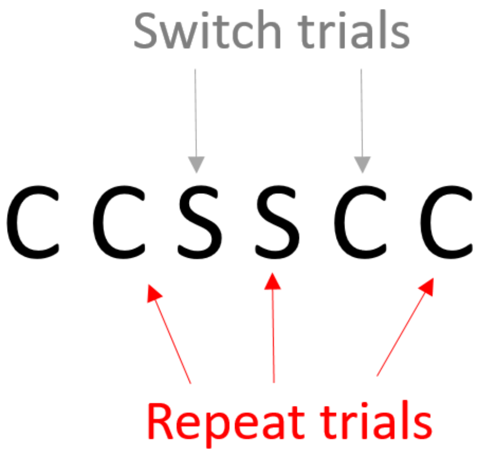


*Figure 7.* Pictorial representation of order of six trials in the mixed block. 'C' represents a colour trial, while 'S' represents a shape trial.

**Procedure**

Participants were provided with a consent form, and then asked to complete a demographics questionnaire before partaking in the computer-based task-switching experiment. Before beginning, participants were reminded of the importance of reading the instructions for each block due to the changing instructions throughout the task. They were asked to press the 'F' button on a computer keyboard if their response was either 'blue' or 'square', or the 'J' key if their response was 'red' or 'circle'. The two pure blocks contained 144 trials each, and the mixed block consisted of 288 trials (please see Figure 6 for block structure). There were an equal number of congruent and incongruent trials. Participants were not given feedback on their responses throughout the task.

**Data analysis**

Data were pre-processed in EPrime 2.0 to allow for the removal of incorrect trials, and any trials with a RT of under 200ms. This provided an average mean RT for pure, repeat, and switch trials, which were used in the calculations for the mixing costs and switch costs, as described by Kirkham, Breeze, and Mari-Beffa (2012). RT for repeat trials during the pure block were subtracted from RT for the repeat trials from the mixed block to produce the mixing costs. For switch costs, it was calculated as RT for switch trials minus RT for repeat trials from the mixed block.

As in Experiment 1 of Chapters 2 and 3, we ran a series of bivariate Pearson's correlations to investigate relationships between demographic variables and our experimental variables (mixing and switch costs).

## Results

Significant results from the Pearson's correlations on the demographic variables and the experimental variables can be found in Table 14 below.

Table 14. *Pearson correlations between key demographic variables and mixing costs and switch costs.*

| | Mixing Cost | Switch Cost | Age | BMI | Alcohol Units | Other Activities |
|---|---|---|---|---|---|---|
| Mixing Cost | - | - | - | - | - | - |
| Switch Cost | .161 | - | - | - | - | - |
| Age | -.067 | -.369* | - | - | - | - |
| BMI | -.296 | -.164 | -.032 | - | - | - |
| Alcohol Units | -.004 | -.047 | .355* | .065 | - | - |
| Other Activities | .107 | .163 | -.340* | .102 | -.229 | - |

*. Correlation is significant at the .05 level (2-tailed)

Age was significantly correlated with switch costs, $r(40)=-.369$, $p=.019$. BMI showed a relationship with mixing costs, although not significantly so, $r(35)=-.296$, $p=.084$. There were also several other correlations between the demographic variables. A significant positive correlation was found between age and units of alcohol per week, $r(39)=.355$, $p=.026$, whilst a significant negative correlation was found between age and hours of reported other activities per week, $r(40)=-.340$, $p=.032$.

## Discussion

From this pilot study we concluded that the age of the participants is significantly associated with their switch costs, and that their BMI may be related to their mixing costs. These findings will help to inform participant group matching in Experiment 2, where mixing costs and switch costs are assessed between two participant groups. It is particularly striking that age and BMI are two variables that may be associated with our cognitive measures, as these are two of the demographics variables we controlled for in Chapters 2 and 3. This led to the decision to match our martial artist and non-martial artist participant groups on these two demographic variables, in an attempt to avoid confounding effects.

## Experiment 2

Following the pilot study in which key demographic factors were identified, the aim of Experiment 2 was to investigate the effects of Martial Arts practice on mixing costs and switch costs.

## Method

### Participants

To calculate the optimal sample size, we used G*Power 3.1.9.4 using parameters taken from the pilot study. Using the following stringent criteria, it was calculated that 18 participants in each of the two participant groups would be needed, leading to a total of 36 participants: a correlation of 0.6 between measures, a desired power of 0.95, and an alpha level set to 0.05, to reach an effect size of 0.25 from the required mixed factorial ANOVA.

A screening questionnaire which assessed Martial Arts experience as well as a range of other demographic factors, was distributed to Bangor University students and non-students from the local community. Responses to this questionnaire were then used to recruit participants for the experimental phase of the study, leading to a total of 84 participants, 41 in the Martial Arts group, and 43 in the Non-Martial Arts group. These participant groups were matched on the key demographic variables identified in Experiment 1. See Table 15 for demographics information for both groups.

Table 15. *Participant demographics for both participant groups*

| | **Martial Artists** | **Non-Martial Artists** | ***p*** |
|---|---|---|---|
| *N* (Male) | 41 (18) | 43 (11) | - |
| Age | 23.51 ± 5.82 | 22.19 ± 4.19 | .236 |
| BMI | 23.27 ± 3.35 | 23.86 ± 3.23 | .445 |
| Alcohol (units per week) | 3.70 ± 5.47 | 3.15 ± 4.75 | .627 |
| Smokers | 5 | 3 | - |
| Health Condition | 4 | 3 | - |

Values represent mean averages, ± standard deviation, or frequencies.

The Martial Arts group was made up of participants with experience in the following styles: Multiple (12), Karate (9), Taekwondo (5), Judo (4), Kickboxing (4), Jiu-Jitsu (4), Boxing (2), and Aikido (1).

## Design and procedure

The task design and procedure were identical to that described for Experiment 1.

**Data analysis**

Again, data were pre-processed in EPrime 2.0 with the same filtering criteria. This provided an average mean RT for pure, repeat, and switch trials, as well as congruent and incongruent trials, for each participant. This meant that each participant had data from six trial types – pure congruent trials, pure incongruent trials, repeat congruent trials, repeat incongruent trials, switch congruent trials, and switch incongruent trials. We calculated global mixing and switch costs (incorporating congruent and incongruent trials) and costs based on congruency. Finally, effect sizes were estimated using partial eta squared, and any correlations were completed using Pearson's correlations.

## Results

We first analysed all of the data as part of a global ANOVA (2x3x2) including participant group (martial artists and non-martial artist; 2) as between group factor, and switching condition as repeated measures (pure, repeat, switch; 3), and congruency as another repeated measures (congruent, incongruent; 2). Please see Table 16 for descriptive statistics. These main results demonstrated that overall martial artists were 42ms faster than non-martial artists, $F(1,82)=4.32$, $p=.041$, $\eta_p^2=.050$.

There was a main effect of switch condition, $F(2,164)=46.15$, $p<.001$, $\eta_p^2=.36$, where pure repeat trials were 38ms faster than mixed repeat trials (the mixing cost; $t(83)=4.15$, $p<.001$). The switch trials were 47ms slower than the repeat trials (switching cost; $t(83)=7.72$, $p<.001$). There was also a main effect of congruency, $F(1,82)=11.95$, $p=.001$, $\eta_p^2=.127$, where congruent trials were 14ms faster than incongruent trials. The switching variable condition changed depending on the congruency, $F(2,164)=8.45$, $p<.001$, $\eta_p^2=.093$, with greater differences observed in the incongruent compared to the congruent condition. More importantly, the change of switching conditions as a function of congruency was different across the two groups $F(2,164)=4.09$, $p=.018$, $\eta_p^2=.048$.

Table 16. *Mean reaction times (in ms) for each trial type, plus mixing cost and switch cost for the two participant groups*

| | | Pure | Repeat | Switch | Mixing cost | Switch cost |
|---|---|---|---|---|---|---|
| Martial Artist | Congruent | 458 (14.90) | 477 (15.35) | 521 (18.07) | 19 (0.45) | 44 (2.72) |
| | Incongruent | 465 (15.90) | 489 (17.39) | 538 (17.92) | 24 (1.49) | 49 (0.53) |
| Non-Martial Artist | Congruent | 486 (14.55) | 524 (15.00) | 563 (17.64) | 38 (0.45) | 39 (0.53) |
| | Incongruent | 475 (15.53) | 547 (16.98) | 602 (17.50) | 72 (1.45) | 55 (0.52) |

We followed this interaction by analysing mixing costs and switching costs separately.

**Mixing costs**

The data were then submitted to a 2x2x2 mixed ANOVA (Martial Arts group – martial artist, non-martial artist; mixing cost – pure repeat and mixed repeat; congruency – congruent and incongruent). This result confirmed that martial artists were 36ms faster than non-martial artists overall ($F(1,82)=3.47$, $p=.066$, $\eta_p^2=.041$), although this was not quite significantly so.

In addition, results also confirmed previous findings that the mixing cost was significantly greater (reflecting poorer flexibility) in the incongruent condition than the congruent condition ($F(1,82)=7.32$, $p=.008$, $\eta_p^2=.082$). There was a 48ms mixing cost in the incongruent condition that went down to 29ms in the congruent trials. More importantly, this change of mixing cost with congruency was different across martial artist groups ($F(1,82)=4.20$, $p=.044$, $\eta_p^2 = .049$). The increase of mixing costs for incongruent trials was only observed in the non-martial artist group ($F(1,42)=9.93$, $p=.003$, $\eta_p^2 = .191$, while no interaction was found with the martial artists ($F<1$). Non-martial artists demonstrated a 48ms increased mixing cost in incongruent trials compared to martial artists, while they did not differ to martial artists in the congruent trials (see Figure 8).

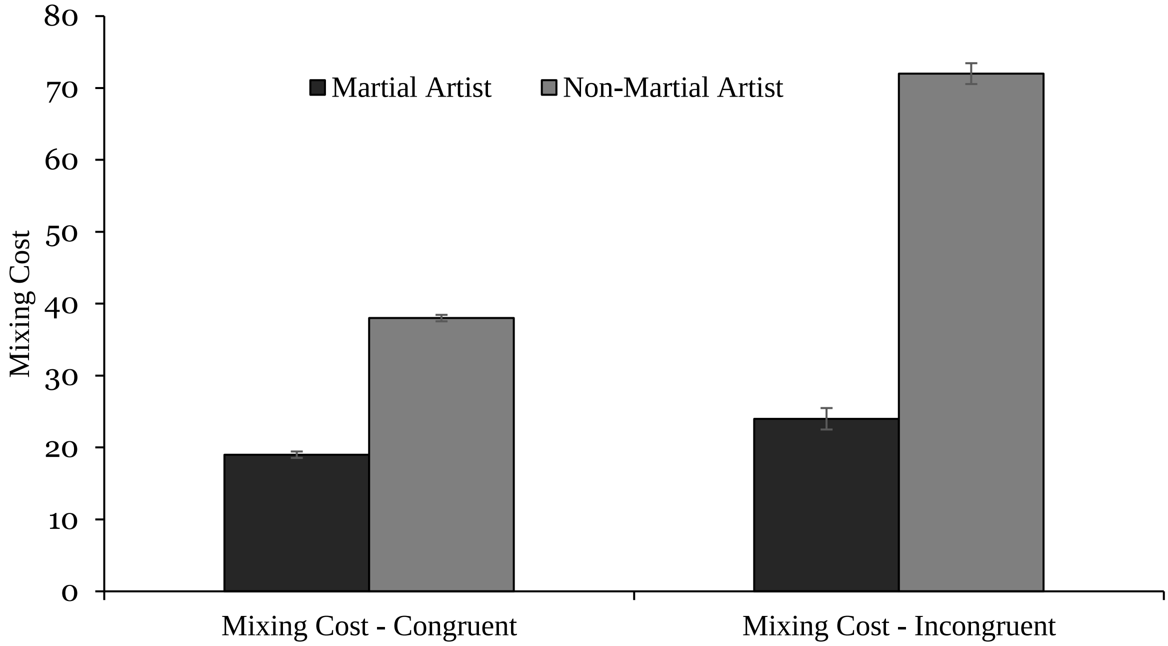


*Figure 8*. Graph depicting the congruent and incongruent mixing cost, for both participant groups. Error bars represent Standard Error.

Further follow up tests demonstrated no significant differences in the pure repeat conditions, while the only between group differences were observed in the mixed repeat conditions (congruent trials: $t(82)=2.2$, $p=.03$, incongruent trials: $t(82)=2.40$, $p=.019$). Importantly, RTs in the incongruent repeat condition significantly correlated with years of MA experience, $r(81)=-.245$, $p=.027$, and approached significance in the congruent repeat condition, r(81)=-.2, $p$=.074. A correlation was also found between mixing cost in the incongruent trials and MA years was found to be nearing significance , r(81)=-.21, $p$=.066.

**Switch cost**

We analysed the switching costs through a 2x2x2 ANOVA (Martial Arts group – martial artist, non-martial artist; switch cost – switch and mixed repeat; congruency – congruent and incongruent). For this analysis we exclusively considered trials from the mixed block (switch trials and mixed repeat trials). The results demonstrated that martial artists were 53ms faster than non-martial artists overall, $F(1,84)=5.48$, $p=.022$, $\eta_p^2 = .063$. In addition, congruency effects in the martial artists groups were significantly smaller (14ms) than in the non-Martial Arts group (32ms), $F(1,82)=4.45$, $p=.038$, $\eta_p^2 =.051$, see Figure 9.

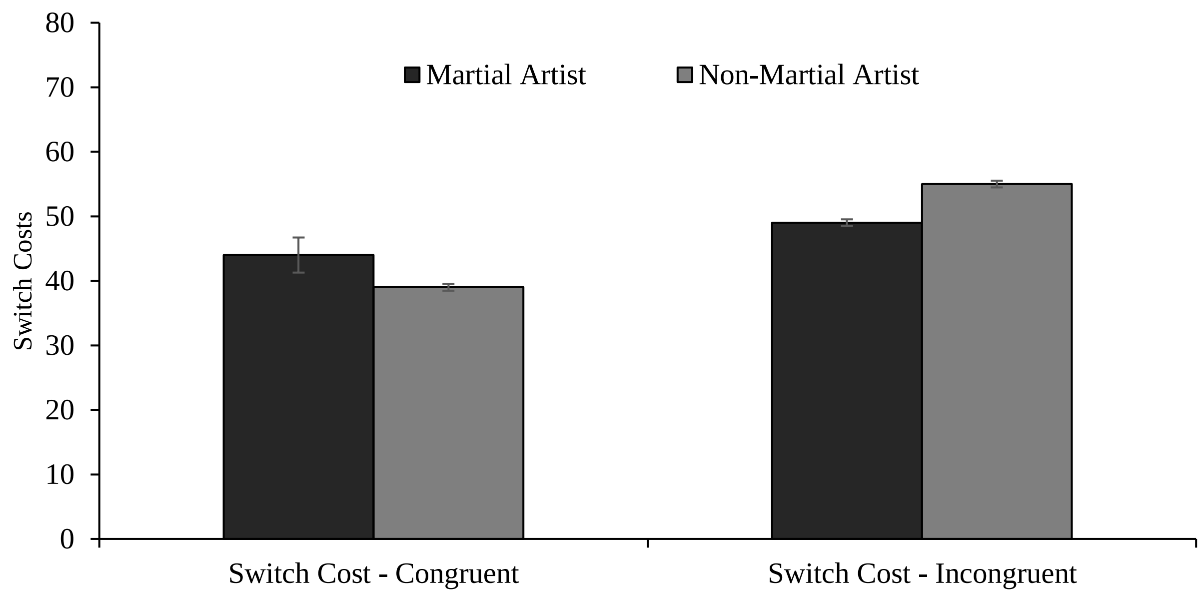


*Figure 9*. Graph depicting the congruent and incongruent switch cost, for both participant groups. Error bars represent Standard Error.

## Discussion

As predicted, these results suggest a difference in mixing cost associated with Martial Arts practice, with participants from the Martial Arts group performing at a similar level to controls in the pure block, but at a more improved level in the mixed block. Perhaps surprisingly there was no significant difference between the two groups with regards to switch costs.

The finding that martial artists did not differ from controls when considering congruent mixing costs, but performed significantly better than controls for incongruent mixing costs is interesting. This suggests that the martial artists are less affected by changes in congruency than the non-Martial Arts participants who exhibited a larger mixing cost in the incongruent trials. It is important to remember that a larger cost reflects poorer concentration. We believe this result reflects poorer vigilance from the non-martial artists, and therefore greater vigilance from the martial artists, as the martial artists perform at a similar level regardless of the congruency. This means that the martial artists could still execute an efficient response regardless of whether the stimulus was congruent or incongruent, whereas the non-martial artists were less efficient with incongruent stimuli.

Another possible interpretation of this result is related to working memory demands. The incongruent mixing costs are the element of our paradigm that has the heaviest working memory demand – first, participants have to remember where they are in the pattern of trials to help them predict which trial type will appear next, second, they need to hold the cue in mind, and finally they have to remember the response rules for the different stimuli types to ensure they provide an accurate response. This leads to a heavier working memory demand than any other condition. As discussed in the introduction, Kamijo and Takeda (2010) found physical activity related differences in mixing costs dependent on the working memory demands of their two tasks. Despite our tasks being different to the tasks used by Kamijo and Takeda, it is interesting to see this same pattern of results in which there appears to be clear differences between exercise-related participant groups in conditions with the highest working memory demand.

These results are particularly interesting when we consider that some previous research has noted that high working memory demand is often associated with *decreased* vigilance (Caggiano & Parasuraman, 2004; Helton & Russell, 2011). However, this research has often been done with typical populations rather than populations with increased vigilance. We know from Chapter Three that martial artists have a higher level of vigilance than non-martial artists, and therefore it may be that they still have an increased level of vigilance even with a small decrease due to the working memory demands. Therefore, it may be that the non-martial artists are more heavily affected by a decrease in vigilance caused by the working memory demands of the incongruent mixing costs. It is currently unclear if this is the case, and therefore future research considering the effects of Martial Arts experience on task switching may wish to include a measure of working memory capacity.

One way that we could get further clarification on whether these results are being driven by an increase in vigilance, would be to test participants on a random version of a task-switching paradigm (i.e., not a predictable pattern of trials) as well as an alternating runs version. As discussed in this chapter's introduction, the alternating runs paradigm involves an element of predictability for participants, which allows us to assess vigilance. If martial artists are performing at a greater level because of increased vigilance, we would only expect to see this greater performance in the alternating runs version of the task, and not the random version. Interestingly, Koch (2005) discussed how the predictability of the alternating runs paradigm is only beneficial if participants can hold the pattern in their working memory. They ran an experiment  in which the predictability of the trials was manipulated, and they found that removing the predictability had a large impact on mixing costs due to the index's reliance on repeat trials. Koch noted that due to the lack of predictability, participants were not receiving as much of a benefit from the repeat trials and were instead treating all the trials as potential switch trials.

The results from this chapter support previous findings in Chapter Three that Martial Arts practice is associated with increased levels of vigilance. Given the differences in tasks across the two chapters (the Attention Network Task in Chapter Three, and task-switching here in Chapter Four), the fact that these previous findings have been replicated within different participants increases the robustness of the results. Indeed, despite not reaching the threshold for significance, the correlation between mixing costs (measuring vigilance) and years of Martial Arts experience, closely resembles that of the correlation that we previously found between the alert attentional network (also representing vigilance) and years of experience. While neither of these correlations reached significance, they both showed a trend towards significance, highlighting an interesting potential avenue for further study, especially with a larger *n* study featuring a wider range of years of experience.

With regards to switch costs, there was no significant difference between the martial artists and non-martial artists. This was surprising due to previous research suggesting a relationship between physical activity and cognitive flexibility. However, we should consider that the Kamijo and Takeda (2010) research on active vs sedentary populations stated that there may be more to uncover about a relationship between switch costs and physical activity, as their findings were only present in their behavioural results and not their electrophysiological data. It is also difficult to know whether we can compare a group of 'physically active' participants to our sample of martial artists, as we do not know the ways in which the participants from Kamijo and Takeda (2010) kept active – for example, whether it was one type of activity, or several different methods.

This chapter aimed to extend the findings from Chapter Three, by further examining the effect of Martial Arts practice on vigilance, whilst also additionally assessing cognitive flexibility. The results showed a smaller mixing cost in incongruent conditions for martial artists in comparison to non-martial artists, which we believe reflects an increased vigilance. We also found no significant difference in switch costs between martial artists and non-martial artists, suggesting that martial artists may not benefit from an increase in cognitive flexibility. We believe these results are important for informing research on which aspects of cognition may be able to be improved through Martial Arts practice.

# Chapter Five:

# General Discussion

This thesis aimed to further understand cognitive changes associated with Martial Arts practice in healthy, typical adults, therefore filling an important gap in the field and extending the previous research. Across three empirical chapters, the thesis intended to address the following research questions:

**Research Question 1:** Does Martial Arts practice influence inhibitory control?

**Research Question 2:** Does Martial Arts practice influence any of the attentional networks, and if so, which ones?

**Research Question 3:** Does Martial Arts practice influence our ability to task switch?

**Research Question 4:** Do any potential benefits alter with the length of time a person has been taking part in Martial Arts?

This chapter will address these questions, the strengths and limitations of the approach taken, and future directions for research in this field.

## 5.1 Does Martial Arts practice influence inhibitory control?

Previous research has suggested that inhibition is the executive function most susceptible to mindfulness-based improvements (Gallant, 2016). As many types of Martial Arts contain similar meditative aspects to mindfulness, it was anticipated that this would be the function most likely to be improved by Martial Arts practice. In Chapter Two we used a Go/NoGo paradigm to provide a measure of inhibition. Measures of impulsivity were also collected and analysed due to its relation to poor inhibitory control (Bari & Robbins, 2013).

In Experiment 2 of Chapter Two we compared a group of experienced martial artists to participants with no experience in the sport, following a pilot experiment. From the measures that came from the Go/NoGo task, there were no significant differences between the groups on overall reaction times or the number of omission errors (i.e., not responding when a response should have been made). This would have suggested that there are no differences in inhibitory control between martial artists and non-martial artists, however there *was* a significant difference between the number of commission errors (i.e., responding when no response was required) but only in the block with 50% Go trials and 50% NoGo trials. Interestingly, in this block martial artists made *more* commission errors than the non-martial artists did, suggesting poorer inhibitory control in the martial artists. However, there were only a small number of this type of error made by each participant group, meaning this result should be interpreted with caution.

Interestingly, some martial artists train in a way that leads to reduced controlled thinking, and greater automaticity in times of high cognitive demand (Anshel & Payne, 2006). If we think about this in the context of sparring, it makes sense – when a martial artist is in a sparring match, carefully considering every response and movement wastes precious time, whereas when they have trained to respond more automatically, they are able to respond with greater speed. In this context, the benefit of automaticity over controlled responses could be the avoidance of receiving a punch. Sometimes, however, this may lead to the martial artist 'jumping the gun' and responding automatically in a situation where a moment's thought would have led to a different response. This may be the reason behind the increased number of commission errors by the martial artist participants – they may have been in the 'go' mindset and relying on automated responses, therefore producing a commission error through an automatic response when a NoGo trial appeared.

From the impulsivity measures, a significant difference between the groups was found in sensation seeking but not premeditation. Zuckerman (1994) defined sensation seeking as being willing to take risks to attain novel sensations or experiences, resulting in it being a sign of impulsivity. Martial Arts are sports that carries the risk of injury if not professionally trained, and therefore it makes sense that martial artists would be willing to take this risk – potentially reflected in this higher sensation seeking score.

This Chapter suggested that reaction times on a Go/NoGo paradigm and the number of omission errors are not related to Martial Arts practice, but that there may be a relationship with commission errors. This may reflect a difference in impulsivity more than a difference in inhibitory control, which would be supported by the group difference in sensation seeking scores.

## 5.2 Does Martial Arts practice influence any of the attentional networks, and if so, which ones?

Moving away from inhibitory control, Chapter Three assessed attentional networks. Previously, Tang and Posner (2009) have explained that attention can be improved in two different ways – Attention Training (AT) and Attention State Training (AST). The second type of training, AST, has been described as driven by Eastern cultures and ideas, and aims to improve attention through changes in the state of the mind and body. Martial Arts has been described as a type of AST (Tang & Posner, 2009).

In Chapter Three, a group of martial artists and non-martial artists completed the Attention Network Test (ANT) which provided measures of the efficiency of three attentional networks. In the Orienting and Executive networks, no significant differences were found between martial artists and non-martial artists. Differences were, however, found in the Alert index which has been reported to reflect vigilance (Petersen & Posner, 2012; Posner & Petersen, 1990). The Alert index is calculated from the difference in reaction times from trials that had a warning cue and trials that did not have this cue. Martial artists had a smaller Alert index, reflecting a more efficient Alert network. Investigating this effect further by analysing the components that make up the Alert index, participants from both groups performed similarly when provided with a cue, but the martial artists exhibited faster reaction times than non-martial artists when not given a cue. This suggests that the martial artists can better prepare endogenously for uncertain targets than non-martial artists can.

These findings support that of Sanabria et al. (2019) who found differences in vigilance based on sports type. They suggested that externally-paced sports were associated with better vigilance than self-paced sports. Here externally-paced sports were defined as those which require quick flexibility and adaption to an unpredictable environment. Several of the participants from the externally-paced sports participant group were martial artists – along with football, basketball, and tennis. Although the authors did acknowledge that there may be a selection bias, in that there may be individual difference related biases in the choice of sport each participant was interested in.

This Chapter suggested differences in attentional networks between people with and without Martial Arts experience. Here the martial artists showed greater vigilance, driven by a better performance when reliance on endogenous attention was required.

### 5.3 Does Martial Arts practice influence our ability to task switch?

Chapter Four intended to further the findings from Chapter Three by providing another measure of vigilance, whilst also allowing for investigations into cognitive flexibility. This was done using the task-switching paradigm which is a well validated measure which provides indexes of mixing costs (representing vigilance) and switch costs (cognitive flexibility).

In Chapter Four, participants were again split into groups based on their Martial Arts background, and then completed a task-switching paradigm. No differences between the groups were found in switch costs – the cost associated with switching between tasks with different rules. Interestingly, when the mixing cost (the cost associated with mixing different tasks or rules) was calculated using only congruent trials and again with only incongruent trials, differences were found between the groups on the incongruent trial mixing cost. This suggests that the non-martial artists were more affected by congruency changes, as they exhibited a larger mixing cost in the incongruent trials that the martial artists. Note that a larger cost reflects poorer concentration. Martial artists performed similarly whether the trials were congruent or incongruent, whereas the non-martial artists performed much worse when the trials were incongruent.

This finding may reflect a greater working memory demand as the incongruent mixing costs required the heaviest demand on working memory than any other trial type. This is because the participants had to keep the cue in mind whilst also remembering the correct response for each cue, whereas on congruent trials the response was the same regardless of the cue. However, these experiments did not include a measure of working memory and therefore it is difficult to promote this theory with any certainty.

An alternative theory comes from the idea that martial artists typically prepare mental plans as a cognitive strategy during training and competitions (Anshel & Payne, 2006). This involves acknowledging that preferred responses and actions may not always be the accurate reaction, and therefore they need to plan several back-up responses. This allows for another plan to be quickly implemented when a challenge arises, meaning that performance can be maintained. Having another planned response ready and waiting to go could explain why the martial artists were less affected by congruency in the mixing costs.

This chapter has suggested differences in performance on a task-switching paradigm between martial artists and non-martial artists. Differences between the groups on incongruent mixing costs supports previous findings in Chapter Three with regards to better vigilance in martial artists. With switch costs there were no significant differences, suggesting a lack of difference in cognitive flexibility between martial artists and non-martial artists.

## 5.4 Do any potential benefits alter with the length of time a person has been taking part in Martial Arts?

The final research question aimed to further understand longer term benefits of Martial Arts practice. Prior research investigating mindfulness has suggested cumulative effects, with more benefits appearing as the participant has completed more practice (Pozuelos et al., 2019). Due to this it was decided that variables with significant differences between the two participant groups would be submitted to a correlation with a variable measuring the years of Martial Arts experience the participant had. This variable did not significantly correlate with any variables in the Go/NoGo experiment discussed in Chapter Two. This is perhaps the most surprising, as the findings discussed by Pozuelos et al. (2019) were found when assessing inhibition and impulsivity in people who practice mindfulness, and therefore it was anticipated that a similar effect would also be seen in populations of martial artists due to its similarities. With regards to indexes of attentional networks (Chapter Three), the alert index showed a correlation that neared significance with years of Martial Arts experience. In Chapter Four, a similar pattern nearing significance was found with mixing costs in incongruent trials from the task switching paradigm. Interesting, reaction times from incongruent repeat trials from this experiment were significantly correlated with years of Martial Arts practice. These findings show that the idea of cumulative benefits of Martial Arts practice may not be clear. One interpretation of this is that typical adults are often seen to be at the peak of their cognitive functioning, and therefore it may be that they see an improvement from Martial Arts practice relatively quickly and therefore there is not enough differentiation to be picked up in a correlation or that it simply helps them maintain their natural cognitive state.

Therefore, there are no straightforward answers to whether long-term Martial Arts practice leads to greater improvements than short-term practice. The only significant correlation with years of Martial Arts experience came from a small, specific element of the task switching paradigm (reaction times from incongruent repeat trials) rather than a more general complete index of cognitive control.

## 5.5 Thesis approach

The experiments discussed in this thesis took a cross-sectional approach to studying cognitive changes associated with Martial Arts practice for various reasons.

Much of the previous research in this area using child or older adult populations recruited naïve participants with no prior Martial Arts training (Chateau-Degat et al., 2010; Jansen & Dahmen-Zimmer, 2012; Witte et al., 2016), and then provided participants with a short-term Martial Arts intervention. This approach has its benefits, however it would not enable us to address research question 4 (*do any potential benefits alter with the length of time a person has been taking part in Martial Arts?*) beyond the short-term period of the intervention. A longer-term randomised control experiment would have allowed for analysis of this research question, whilst still giving the benefit of Martial Arts naïve participants. Similarly, a longitudinal experiment following participants who chose to begin training in Martial Arts over a period of several years could have had the same benefits. However due to the time constraints associated with doctoral research, it was decided that a cross-sectional approach would best allow for analysing changes in cognition in relation to Martial Arts practice, whilst also allowing for investigations into longer term, sustained effects of the sport. This approach has also been taken in similar research investigating factors that may influence cognitive functioning (Clare et al., 2017; Falck, Landry, et al., 2017; Moore & Malinowski, 2009).

For the Martial Arts participant groups in the experiments, it was decided to recruit participants with at least one year of experience in the sport to ensure the participants were committed to their training. This did, however, cause difficulties in the recruitment process. There are a limited number of Martial Arts clubs within the local area of Bangor University, and the potential participant pool was further limited by the experience requirement. To ensure that sample sizes would be sufficient, it was therefore decided to accept participants from any type of Martial

Arts, rather than restricting participation to one specific style. This issue is discussed further in the 'Future Directions' section of this chapter.

To mitigate the weaknesses associated with cross-sectional research, it was decided that each experiment would take a two-pronged approach. First, each experimental paradigm was tested on a sample of university students in order to assess any correlations between the experimental measures and the core demographic variables (i.e., age, BMI, alcohol consumption). This allowed for careful matching of participants in the Martial Arts and non-Martial Arts groups, to ensure that any differences found in the experimental variables were likely due to the Martial Arts practice.

Throughout each experiment age correlated with various indices of cognitive control – e.g., commission errors in Chapter One, the orienting network in Chapter Two, and switch costs in Chapter Three. This was to be expected as there is a wealth of previous research suggesting age-related changes in cognitive functioning (Belleville et al., 2006; Brown et al., 2015; Grafman & Litvan, 1999; Zook et al., 2006). This led to the decision to match participants on age in each experiment.

BMI was correlated with other variables in Chapters Two (age and alcohol consumption) and Three (alert index). A similar pattern was uncovered between switch costs and BMI in Chapter Four, however this was not significant. Despite this, the decision was made to match participants on BMI throughout each of the experiments to maintain consistency throughout this thesis and to allow for closer comparisons – particularly between Chapters Three and Four. Previously, research has suggested associations between BMI and cognitive performance – with high BMI being associated with a greater cognitive decline than a lower (but still healthy) BMI (Cournot et al., 2006; Gunstad et al., 2007).

## 5.6 Future Directions

Whilst the experiments presented in this thesis work towards filling a gap in the literature, by providing a deeper insight in Martial Arts related changes in cognition in typical adults, there are still questions to be answered.

Firstly, due to recruitment difficulties we worked with participants who reported experience in any form of Martial Arts practice. This meant participants came with experience from Karate, Judo, Taekwondo, Tai Chi, among others, rather than one specific style. They all involve elements of mental and physical training, consistent with elements typically found in Attention State Training which is thought to train participants in a state of mind conducive to cognitive improvement (Tang & Posner, 2009). However, Weiser, Kutz, Kutz, and Weiser (1995) noted that there are differences in Martial Arts styles too, with one end of the continuum placing more emphasis on meditation, and the other end focusing more on combativeness and competition. Therefore, it may be interesting for future research to assess specific Martial Arts styles – if possible. If this proves difficult, then having groups of Martial Arts styles from each end of the continuum would also be an interesting alternative. This could lead to further important developments and insights into understanding cognitive changes associated with specific styles of Martial Arts practice. It may be that different styles may produce benefits in different cognitive function, and this is important to know. This would allow specific Martial Arts styles to be utilised for interventions for the specific function.

Secondly, many executive functions are associated with other functions, and therefore cognitive tasks may inadvertently measure more than one function. For example, in Chapter Four it is noted that differences in incongruent mixing costs may be driven by differences in working memory as well as vigilance. All of the tasks used throughout this thesis involve the participant holding a set of responses in their mind that differ depending on what they are being asked in that trial. A person with poorer working memory may struggle with these tasks, regardless of their level of inhibition, attentional control, or cognitive flexibility. Future research may wish to include measures of working memory to get a baseline level from each group, and then assess whether these are correlated with task performance. Alternatively, the use of a neurocognitive battery to assess a wide variety of cognitive functions between martial artists and non-martial artists may provide further insight into which functions may be malleable, which would then drive additional research to those specific functions.

Thirdly, we wanted to understand the potential cumulative effects of Martial Arts practice. In the experiments presented in this thesis, we found inconsistent trends when using years of Martial Arts experience as the key variable. We believe that this requires further exploration, perhaps considering the years of experience and the level of expertise (for example, belt colour) as two separate variables of interest. This would allow for a more in-depth assessment of which component is most important when considering cumulative benefits. Once the most valid measure for these benefits has been determined, it would allow for further research to investigate whether different styles of Martial Arts have differing patterns of cumulative effects.

Finally, other lines of enquiry were opened but had to be discontinued due to various logistical and resource constraints. For example, a protocol was created in order to assess electrophysiological correlates of a single bout of Martial Arts in experienced participants. This would have involved participants completing two cognitive tasks whilst electrophysiological measures were recorded, then taking part in a 30-minute Martial Arts session, followed by the tasks being completed and the measures being recorded again. Participants would be asked to complete the same protocol on a second occasion, but with a 30-minute control task instead of the active session. With more time and resources, this research plan could be re-started, allowing for an additional in-depth investigation into cognitive changes associated with Martial Arts practice. This would have provided insight into transient changes, alongside the sustained benefits discussed throughout this thesis.

## 5.7 Contribution of Thesis

Whilst this thesis has added to the empirical literature surrounding Martial Arts and cognitive control, it is also important to consider the wider implications of this work. Similar work in children has led to interventions being designed based on principles of Martial Arts training, with the aim of improving behaviour, self-control, and academic achievement (Lakes et al., 2013). Additionally, Martial Arts research in older adults has led to interventions using activities such as Tai Chi to improve balance, motor coordination, and social well-being (Witte et al., 2016). These are valuable contributions and show how we may be able to use the findings from the current research.

For example, as we have found that long-term Martial Arts practice is associated with increased vigilance, an intervention could be developed to work with people with naturally poor vigilance. A recent review paper noted that chewing gum, pharmaceutical drugs, caffeine, and even specific fragrances, have all been associated with improving vigilance (Al-Shargie et al., 2019). These may be great options for some people who wish to improve their vigilance, however some people may prefer a method that involves being active or developing a further social network. Developing a Martial Arts based intervention for people with vigilance or attentional deficits may allow for an intervention that is attractive or beneficial to people who previously were not interested in the available options. Once further research has been conducted to understand other cognitive changes related to Martial Arts practice, these interventions could then be expanded on further. By creating different styles of intervention, we can provide people with a range of potential options so that they can find something best suited to their lifestyle and needs.

Additionally, we have found cognitive benefits of Martial Arts in a typical, healthy adult population. Diamond and Ling (2016) discussed how cognitive interventions typically find greatest benefits in populations that may naturally have poorer cognitive control – for example, younger children who are still developing, or older adults who are experiencing cognitive decline. On the other hand, typical healthy adults are more likely to be closer to their optimal cognitive performance, and therefore there is less room for improvement before they reach their ceiling or peak. This makes it all the more remarkable that Martial Arts related cognitive changes were uncovered in the empirical work presented within this thesis. If changes can be found within an optimally functioning population, it leads us to wonder how Martial Arts may be able to help people with a poorer baseline level of cognitive control.

## 5.8 Concluding Comments

This thesis has aimed to fill an important gap in the field of Martial Arts related cognitive changes. Much of the previous research has focused on child or older adult populations, with little focus on healthy, typical adults. The findings were mixed, with more efficient alert networks and smaller mixing costs in incongruent trials found in martial artists, but also more commission errors and higher sensation seeking. This would suggest a higher level of vigilance in martial artists, but not inhibitory control or impulsivity. Additionally, there were no differences in cognitive flexibility from the switch costs between martial artists and non-martial artists. These are all important findings, which greatly add to the existing literature, whilst also providing further room for future research to continue this line of enquiry.

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