

BIROn - Birkbeck Institutional Research Online

Ducrocq, Emmanuel and Wilson, M. and Vine, S. and Derakhshan, Nazanin (2016) Training attentional control improves cognitive and motor task performance. *Journal of Sport and Exercise Psychology* 38 (5), pp. 521-533. ISSN 0895-2779.

Downloaded from: <https://eprints.bbk.ac.uk/id/eprint/18817/>

Usage Guidelines:

Please refer to usage guidelines at <https://eprints.bbk.ac.uk/policies.html>

or alternatively

contact lib-eprints@bbk.ac.uk.

Training attentional control improves cognitive and motor task performance

Submitted on 19/09/2016

Training attentional control improves cognitive and motor task performance

Emmanuel Ducrocq¹, Mark Wilson², Sam Vine², & Nazanin Derakshan¹

¹ *Department of Psychological Sciences, Birkbeck University of London, UK*

² *Department of Sport and Health Sciences, University of Exeter, UK*

Address for correspondence:

Emmanuel Ducrocq or Nazanin Derakshan,

Department of Psychological Sciences

Birkbeck University of London, London, UK.

Email: manu.ducrocq@gmail.com, n.derakhshan@bbk.ac.uk

ABSTRACT

Attentional control is a necessary function for the regulation of goal-directed behavior. In three experiments we investigated whether training inhibitory control using a visual search task could improve task specific measures of attentional control and performance. In experiment 1 results revealed that training elicited a near-transfer effect; improving performance on a cognitive (antisaccade) task assessing inhibitory control. In Experiment 2 an initial far-transfer effect of training was observed on an index of attentional control validated for tennis. The principal aim of Experiment 3 was to expand on these findings by assessing objective, gaze measures of inhibitory control during the performance of a tennis task. Training improved inhibitory control and performance when pressure was elevated, confirming the mechanisms by which cognitive anxiety impacts upon performance. These results suggest that attentional control training can improve inhibition and reduce task-specific distractibility with promise of transfer to more efficient sporting performance in competitive contexts.

Keywords: anxiety, working memory, inhibition, distractibility, tennis

Training attentional control improves cognitive and motor task performance

The ability to perform when confronted with high pressure and anxiety provoking situations is a critical determinant of attainment in sports (Bortoli, Bertollo, Hanin & Robazza, 2012; Nicholls, Holt, Polman & James, 2005). Recent developments in sport psychology underline that difficulties in maintaining optimal levels of performance when faced with high-pressure situations are directly related to an athlete's inability to sustain sufficient levels of attention control (e.g., Vine, Lee, Moore & Wilson, 2013; Wilson, Vine & Wood, 2009). These developments emanate from research in the area of cognitive neuroscience investigating the adverse effect of anxiety on attentional control and working memory capacity in cognitive tasks (see Berggren & Derakshan 2013, for a review). The current series of experiments aim to demonstrate if training attentional control, which has been shown to benefit cognitive task performance, can also be effective for performance in sporting tasks.

According to recent models of working memory (e.g., Miyake et al., 2000; Unsworth, Redick, Spillers & Brewer, 2012), attentional control refers to the relative efficiency of the main executive functions of working memory in attaining a task goal, that include inhibition (e.g., resistance to distraction), shifting (e.g., within-task control), and updating (e.g., memory-based updating of information). Processing efficiency of these executive functions plays an important role in goal-directed behavior in general (Duncan & Humphreys, 1989) and sports in particular (Han, Cheong et al., 2014; Furley, Schweizer & Bertrams, 2015). According to the Attentional Control Theory of Anxiety (ACT; Eysenck, Derakshan, Santos & Calvo, 2007) anxious apprehension as well as worrying about performance outcome can disrupt the efficient exercise of attentional control, leading to increased distractibility by task irrelevant stimuli and reducing processing efficiency.

While various accounts of the anxiety-performance relationship exist (e.g., Carson & Collins, 2016), recent research in sport psychology has supported ACT's predictions that

deficiencies in the top-down regulation of attention impair performance in pressurized sporting situations. Specifically, impaired attentional control tends to result in inefficient processing of the information necessary to plan and execute a skilled movement, as it becomes more difficult to inhibit task irrelevant information (see Wilson, 2012; Eysenck & Wilson, 2016 for recent reviews). For example, Oudejans, Kuijpers, Kooijman and Bakker (2011) found that thoughts related to distraction were more common than any other thought category among elite performers in high pressure sporting situations. Englert and Oudejans (2014) demonstrated that reported levels of distraction and an inability to inhibit distracting thoughts mediated the negative effect of anxiety on the performance of a tennis serving task.

Additionally, research has revealed that objective measures of optimal goal-directed attention control are sensitive to the effects of pressure. For example, anxiety-related distractibility tends to attenuate the Quiet Eye (QE) period; the duration of the final fixation or tracking gaze to a target initiated prior to a movement (Vickers, 1996). This impairment in inhibitory control leads to profound decrements in motor performance in various sporting tasks, including golf putting (Vine et al., 2013), basketball free-throw shooting (Wilson et al., 2009), shotgun shooting (Causser, Holmes, Smith & Williams, 2011), archery (Behan & Wilson, 2008), biathlon (Vickers & Williams, 2007), football penalty taking (Wilson, Wood & Vine, 2009), and dart throwing (Nibbeling, Oudejans & Daanen, 2012).

Interventions aimed at training longer QE periods have been successful in protecting movement outcomes (Causser, Holmes & Williams, 2011; Moore, Vine, Cooke, Ring & Wilson, 2012), perceptions of control (Wood & Wilson, 2012), and muscular and cardiovascular efficiency (Moore et al., 2012) under pressure. It remains unclear to what extent the beneficial effects of QE training may be due to improved inhibitory control per se (Vine, Moore & Wilson, 2014) as such training methods cannot isolate the specific cognitive mechanisms by which the beneficial effects of training occur. There is therefore a need to

explore more direct attentional control training interventions in sport, which can isolate and influence the inhibition function. Additionally, a further advantage of training specific functions of attentional control such as inhibition, as opposed to a specific explicit gaze behavior (e.g., QE), is that training related benefits may transfer to more than one aspect of performance.

The motivation for the current project was the promising recent demonstration that attention control can be trained in healthy (Jaeggi, Buschkuhl, Jonides & Shah, 2011) as well as emotionally vulnerable populations affected by anxiety (Sari, Koster, Pourtois & Derakshan, 2016), and depression (e.g., Owens, Koster & Derakshan, 2013), with transferrable gains to multiple neural, behavioral, and cognitive outcomes. Similarly, visual search training tasks that promote the inhibition of threat-related distractors can reduce cognitive biases for threat in anxious and depressed populations (Dandeneu & Baldwin, 2004). Capitalizing on the above-mentioned promising findings, the overall aim of the current study was to examine if training attentional control, using a visual search training task specifically designed to target inhibitory control, could result in transferrable training-related gains in cognitive and sporting task performance.

Experiment 1 was designed to validate the training protocol by determining near transfer effects in a cognitive task designed to assess inhibitory control (i.e., antisaccade task; Hallet, 1978). Second, the principal aim of Experiment 2 was to pilot the training paradigm in tennis, using a subjective measure of attentional control specifically developed for tennis (Lafont, 2007, 2008) to assess far transfer. Finally, in Experiment 3 we assessed the effect of training on an objective tennis-specific gaze measure of attentional control (using mobile eye trackers) and performance measures under competitive pressure.

Experiment 1

The antisaccade task is believed to provide a process pure measure of inhibition (see Friedman & Miyake, 2004) and has been extensively used to measure attentional control in diverse populations (see Ettinger et al., 2008, for a review). The antisaccade task necessitates the efficient suppression of a reflexive saccade towards an abrupt peripheral stimulus and a voluntary shift of attention to its mirror position, implicating the effective exercise of inhibitory control for successful task performance. Antisaccade performance is usually compared to performance on a prosaccade task where participants are required to saccade towards the abrupt peripheral stimulus, necessitating no inhibitory control (Olk & Kingstone, 2003). It was hypothesized that the inhibition training group would reveal greater training related gains on antisaccade (but not prosaccade) performance than the active control group.

Method

Participants

33 participants were recruited via advertisements placed at the University of London (11 males, 22 females; M age = 27.13, SD = 4.86). All participants were randomly allocated to a control or training group and were naïve to their allocation. Participants had normal or corrected-to-normal vision and wore glasses or contact lenses if necessary. All participants gave informed consent and were debriefed at the end of the experiment.

Materials

Training task. The training task (based on Theeuwes, 1992; see Figure 1) was a visual search task delivered online using PHP and JavaScript (jQuery). The search array was preceded by a fixation cross and presented for 800ms. This was followed by a gap interval of 2000ms allowing for responses to be made (press '1' if target present and '2' if target absent). The ten images employed (tennis ball, basketball, dice, golf ball, halved lime, football, lemon, apple, rubber ball, practice golf ball) were sourced online and edited with Adobe Photoshop software. The size of all selected images was reduced to 100x100 pixels and all

stimuli were matched for luminosity and brightness. Eight green-yellow images appeared in a circular formation in the visual search array.

**** Figure 1 ****

Participants were asked to determine whether the target item (a tennis ball), which appeared on 50% of all trials, was present in the array. For the inhibition training group, a red color version of one of the non-target items acted as a singleton distractor, and appeared randomly on 50% of the trials. The active control group performed the same visual search task (locating the yellow tennis ball target in the array), but without any red singleton distractors. This control task therefore differed from the training task only in terms of the demands on inhibitory control; a critical requirement when trying to disentangle proposed training benefits in research aiming to examine specific functions of working memory (Shipstead, Harrison & Engle, 2012). The position of the different items in the visual array was randomized for both groups. The task included 4 blocks of 80 trials and lasted about 20 minutes.

Antisaccade and prosaccade tasks. Eye-movements were recorded using an SR Research Eyelink 1000 eye-tracker (SR Research, ON, Canada). Only one eye was tracked during the experiment and nine-point calibration across the computer screen was used to ensure tracking accuracy was within 1° of visual angle. Images were presented on a 21" Mitsubishi Diamond Pro 2070 CRT monitor (85 Hz) and a chinrest was used to guarantee a constant viewing distance of 60 cm. The experiment was designed and presented using the SR Research Experiment Builder software. The stimulus used for the antisaccade and prosaccade tasks consisted of a white oval-shaped object subtending $2.58^\circ \times 4.77^\circ$ and measuring 35 x 63 mm in dimension which was presented on a black background. This oval shape served as a "Target". Additionally, each trial started with a fixation cross subtending $0.95^\circ \times 0.95^\circ$ and measuring 12 x 12 mm presented in the center of the screen for 1000ms.

Participants were provided with verbal instructions on the anti- and pro-saccade tasks, before undergoing calibration procedures. For each condition, participants undertook 2 blocks of training comprising 4 trials each. In the antisaccade and prosaccade conditions participants were instructed to fixate the fixation cross until it disappeared. If participants fixated the cross between 500 and 1000ms after its onset, the trial moved forward immediately, acting as a drift correction to tracking. The oval shaped target then appeared with equal probability to the left or right of the fixation cross at 11.04° and for 600ms. Participants were required to direct their gaze, as quickly and as accurately as possible “TOWARDS” the target for prosaccade blocks or “AWAY” from the target and to its mirror image location for antisaccade blocks. The experiment comprised 4 blocks with 2 blocks comprising 35 antisaccade trials and 2 blocks comprising 35 prosaccade trials (cf. Derakshan, Ansari, Shoker, Hansard & Eysenck, 2009). The order of presentation of anti-saccade and pro-saccade blocks was counterbalanced across participants and groups for pre- and post-intervention testing sessions.

Procedure

The design followed a pre-test, intervention, and post-test format. Pre- and post-testing sessions each lasted for approximately 25 minutes and took place in a sound-protected and dimly lit sound-proofed testing cubicle. Upon arriving for the pre-testing session, participants first completed a consent form and the STAI state and trait anxiety questionnaires (Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983), before completing the antisaccade/prosaccade tasks. The experimenter matched participants on pre-test measures of trait anxiety (Control $M = 38.66$, $SD = 10.93$; Training $M = 42.68$, $SD = 11.51$) and age (Control $M = 25.67$, $SD = 4.49$; Training $M = 29.19$, $SD = 5.3$), before pseudo-randomly allocating them to active control or inhibition training groups, and demonstrating the relevant training task.

Participants were sent a designated web link via e-mail to access the training task at home. The intervention involved online training on the visual search task for 6 consecutive days. Participants were instructed to create a quiet environment in order to avoid potential distractions and undertook the task at approximately the same time every day, with their performance being monitored remotely by the experimenter. Upon completing the post-test pro- and antisaccade tasks, participants were debriefed, thanked and remunerated £20 for their participation.

Data Analysis

A General Linear Model Mixed design ANOVA with Group (Training, Control), Task (Antisaccade, Prosaccade) and Time (Pre, Post intervention) as factors was performed on response latencies using SPSS (version 21) software.

Results

Manipulation Check: Training Task

One participant in the control group dropped out during the training phase of the experiment and one participant in the training group was excluded from the study due to poor performance on the pro/anti-saccade tasks (less than 50% accuracy), leaving a final sample of 31 participants. For the training group, the extent of performance improvement as indicated by the reduction of distractor costs in the visual training task was calculated by subtracting reaction times on target-present trials without a distractor from reaction times on trials with a distractor. The ability to inhibit distractors when identifying targets in the visual search task gradually improved across the period of training, as indicated by a t-test that showed that distractor costs towards the end of training (i.e., days 5 and 6: $M = -19.55$, $SE = 8.27$) were significantly lower than distractor costs at the beginning of the training (i.e., days 1 and 2: $M = 2.63$, $SE = 6.04$), $t(15) = 2.55$, $p = .02$.

Antisaccade and Prosaccade Task Performance

Only response latencies for accurate trials in both the antisaccade and prosaccade conditions are reported¹. The data of one participant in the training group were removed from the final analysis due to being higher than 3SDs of the average performance. Thus, data for 30 participants (15 in each group) were used in the analysis. Trials with saccadic latencies below 83ms (less than 3% of the data: 1.3% for training and 1.25% for control) were considered anticipatory (see Fischer et al., 1993) and together with trials where no saccade was made (less than 1.3%) were excluded from the analysis.

The ANOVA revealed significant main effects for Time; $F(1, 28) = 9.88, p = .004, \eta^2_p = .26$, and Task; $F(1, 28) = 123.63, p = .001, \eta^2_p = .81$, but not Group; $F(1, 28) = 2.20, p = .14$. Performance improved from pre- ($M = 227.79\text{ms}, SD = 30.74$) to post- ($M = 217.77\text{ms}, SD = 33.18$) intervention. The main effect of Task showed that antisaccade latencies ($M = 253.50\text{ms}, SD = 35.54$) were generally slower compared with the prosaccade ($M = 195.50\text{ms}, SD = 30.74$) task. The lack of a main effect of Group showed that the groups did not differ from each other on saccadic latencies (Training: $M = 229.79, SD = 31.28$; Control: $M = 215.77, SD = 18.92$). The two-way interactions of Task X Group, $F(1, 28) < 1$, and Time X Group, $F(1, 28) = 2.82, p = .10$, were also not significant. There was a trend for the Group X Task interaction to be significant, $F(1, 28) = 3.57, p = .06$, which was qualified by a trend for the hypothesized 3-way Time X Group X Task interaction; $F(1, 28) = 3.16, p = .08, \eta^2_p = .10$. Because of its direct relevance to the main predictions of the study, the three way interaction was followed up by relevant t-tests that showed that the improvement over time was driven primarily by the training group's significant decrease in response latency in the antisaccade task; $t(14) = 3.78, p = .002$, compared to the control group who revealed no significant improvement in antisaccade task performance, $t(14) = 0.73, p = .47$ (see Figure 2a). For the prosaccade task, there was no significant pre- to post- changes in response latency for either

the training group: $t(14) = 1.50, p = .15$ or the control group; $t(14) = 1.25, p = .23$ (see Figure 2b).

****Figure 2****

Discussion

The aim of Experiment 1 was to investigate whether training on a visual search task designed to promote distractor inhibition would provide near transfer to antisaccade task performance; considered to provide an excellent measure of inhibition and resistance to distraction (Friedman & Miyake, 2004; Derakshan et al., 2009). Results showed that participants allocated to the training group significantly reduced their response latencies for the antisaccade task after the intervention, whereas the control group remained at pre-test levels. Neither group significantly improved their prosaccade performance. These findings provide strong support that the underlying mechanisms of near transfer are related to improved inhibition. Inhibition training enabled a greater ability to inhibit task-irrelevant distracting information when needed, something that the active control group (despite performing the same visual search training task) was unable to do. Interpretations surrounding the reliability of transfer related gains on response time latencies, in training designs lacking an active control group, have been raised elsewhere (see Enge et al., 2014). The design of the current paradigm overcomes this potential problem with the inclusion of an active control group.

Experiment 2

The results of Experiment 1 provide direct evidence for the effectiveness of the training task in targeting inhibitory control as measured by antisaccade task performance. Effective top down attentional control, and the inhibition of irrelevant distractions, is also important in the planning and control of goal-directed motor responses (Corbetta & Shulman, 2002) and for efficient sports performance (Kao, Huang & Hung, 2015; Chuang, Huang & Hung, 2013). For example, Kasper, Elliott and Giesbrecht (2012) found that putting accuracy

of novice golfers was strongly related with the efficiency of the inhibition function. An initial field tennis experiment was therefore conducted to test the potential effectiveness of this form of attentional control training in a sample of recreational tennis players undertaking a series of returns of serve. Return of tennis serve was chosen as a relevant transfer task, due to the attentional demands involved in optimizing efficient motor preparation and control within a constrained time period (e.g., Williams, Ward, Smeeton & Allen, 2004).

Attentional control was assessed via expert ratings of the players' behaviors, determined from video footage. This method was taken from previous research in tennis by Lafont (2007, 2008) who, following a detailed photo analysis, observed that elite tennis players usually show a characteristic head fixation toward the area of contact with the ball from the time of impact and through the early phase of the follow through. More specifically, not only did they fixate on the ball-racquet contact at the time of the hit, but this gaze also remained steady even after the contact point, when the ball was already on its way towards the opponent. Lafont (2007, 2008) consequently argued that this measure of visual attentional control – resembling QE – is indicative of superior tennis performance. This is also consistent with previous research in golf (Vine et al., 2013), which demonstrated that unsuccessful putts generally resulted from a shorter fixation on the ball at the time of impact and an earlier attempt to fixate the hole (i.e., impaired inhibition). Specifically, we assessed the orientation of the players' eyes or head (i.e., gaze) on the ball during and following contact with the racquet. We hypothesized that participants in the training group would reveal superior post-training visual attentional control, compared to their control group counterparts.

Method

Participants

Participants were recruited from an opportunity sample of recreational tennis players who engage in tennis activities between 1 and 3 times per week at the Highbury Field Tennis Club

and at the Islington Tennis Centre, London, UK. The sample included 26 participants (11 males, 15 females; M age = 49 years, SD = 6.66). Participants gave informed consent and were debriefed at the end of the experiment. Ethical permission was obtained prior to the study.

Materials and Stimuli

Training task. The training task was the same attentional capture task employed in Experiment 1, delivered online using PHP and JavaScript (jQuery).

Tennis field task. There were two tennis testing sessions where standard tennis racquets and 24 new tennis balls were used. All testing sessions took place on an indoor tennis court at the Islington Tennis Centre. Participants attempted to return all serves from the same side of the court for both pre- and post-tests sessions. A tablet computer with a capture rate of 30fps was used to record participants' tennis performance in detail. The tablet stood on the side of the returner just outside the double side-line leveled with the service line. All shots were recorded individually and captured a full view of the player. During the tennis test, participants were required to return 16 tennis serves delivered by two experienced level 4 LTA licensed tennis coaches blind to participants' group allocation. The server ensured that the difficulty of the serves to be returned were appropriate to the participants' skill level (as assessed during pilot testing). All serves that landed out were retaken and participants received an equal number of serves to the right and the left of their body with the server serving to a different location in a pseudo-random order for all participants. Participants were instructed to stand behind the baseline and to return the ball inside the court for each serve as they would in a regular game of tennis. The two tennis coaches served to the same participants in pre- and post- tennis tests.

All returns were later viewed in slow motion via Quick Time (Apple) and the orientation of the players' eyes or head (i.e., gaze) on the ball during and following contact

with the racquet, was rated independently by two qualified LTA level 4 tennis coaches (one of whom was blind to training group allocation) on a scale of 1 to 5. A score of 1 reflected excellent attentional control (with gaze being maintained prior to, during and after racquet-ball contact) and 5 reflected very poor attentional control (no or limited focus on the ball preceding, or during racquet-ball contact).

Procedure

The design of the experiment followed a pre-test, intervention, post-test format. Participants were told that the study was investigating ‘anxiety and attention in tennis’ and were randomly allocated to the training and control groups. Participants were naïve to their group allocation and were matched as closely as possible on pre-test measures of trait anxiety (STAI: Control $M = 34.25$, $SD = 7.86$; Training $M = 35.25$, $SD = 8.02$), age (Control $M = 50.25$, $SD = 6.00$; Training $M = 46.75$, $SD = 7.08$) and tennis ability as assessed by the tennis experts during warm-up sessions. At pre-test all participants performed the return of serve task. The training paradigm followed the same procedures as in Experiment 1. At post-test, participants were assessed on the tennis test in the same format as at pre-test. Participants were then thanked for their participation and offered a free future tennis class as remuneration.

Data Analysis

2 x 2 mixed design ANOVA with Group (Training and Control) and Time (Pre- and Post-Intervention) as factors were computed for coach ratings in SPSS (version 21).

Results

Manipulation Check: Training Task

One participant in each of the training and control groups dropped out during the training phase leaving a final sample of 24 participants. Distractor costs (see Experiment 1) towards the end of the training phase (i.e., days 5 and 6: $M = -4.21$, $SE = 7.61$) were significantly

lower than distractor costs at the beginning of training (i.e., days 1 and 2: $M = 53.38$, $SE = 26.27$), $t(11) = 2.23$, $p = .04$. This finding indicated that training improved the inhibition of distractors in the visual search task across the six days of training.

Reliability Analysis

A reliability analysis was conducted on the ratings of the 2 independent raters for pre and post intervention ratings. These appeared to have acceptable internal consistency for both the pre ($\alpha = .72$) and post ($\alpha = .75$) intervention periods (Kline, 2000).

Attentional Control Ratings

ANOVA revealed a significant main effect of Time, $F(1, 22) = 11.30$, $p = .003$, $\eta^2_p = .34$, but not Group; $F < 1$. A significant Time X Group interaction, $F(1, 22) = 4.55$, $p = .04$, $\eta^2_p = .18$, revealed that significant training-related gains in attentional control occurred for the training group, $t(11) = 4.00$, $p = .002$, but not the control group, $t < 1$ (see Figure 3).

**** Figure 3 ****

Discussion

Experiment 2 was designed to investigate if our novel inhibition training task would lead to improvements in task specific attention control in recreational tennis players, as assessed by coach ratings of their gaze orientation during and beyond racquet-ball contact. As such, its main aim was to examine if the near transfer effects found in Experiment 1 could be replicated and extended to a sporting task; thus further supporting the utility of exploring generalized inhibitory control training for real-world tasks (Kao et al., 2015; Chuang et al., 2013; Kasper et al., 2012). The independent ratings demonstrated that a critical component of attention control when hitting a tennis ball (Lafont, 2007, 2008) was significantly improved after the training intervention compared with the control group whose performance did not improve. When interpreted together with the findings from the anti and prosaccade tasks in Experiment 1, these transfer effects appear to be driven by improved efficiency of the

inhibition function. The results suggest that such training has a generalized effect; supporting task performance irrespective of the source of task-specific distraction, or the response mode.

While providing promising initial support for the transferability of the attentional control training paradigm to a motor task, the measure of gaze control was relatively crude (cf. Experiment 1), and no measure of performance for the return of serve was taken.

Additionally, our rationale for training inhibition in sporting tasks was primarily due to its potential in modulating the influence of competitive pressure on performance (Englert & Oudejans, 2014; Oudejans et al., 2011), yet no pressure manipulation was included in Experiment 2. Experiment 3 was designed to address both these limitations.

Experiment 3

Encouraging transfer effects of inhibition training were observed on a lab based measure of inhibitory control and gaze behavior (Experiment 1) and on independent ratings of attentional control in the field (Experiment 2). However, a stronger test of the utility of the training paradigm requires the measurement of relevant and objective measures of attentional control and performance in tennis. Additionally, potential detrimental effects of anxiety on performance and any protective influence of the visual search training paradigm need to be assessed, given the theoretical (e.g., ACT; Eysenck et al., 2007) and empirical (e.g., QE attenuation under pressure; Vine et al., 2013) backdrop to the research.

As such we employed a tennis volleying task in Experiment 3, where participants were required to hit a thrown tennis ball to a circular (archery) target. This task allowed an objective measure of tennis performance to be obtained whilst gaze behaviors were recorded. As outlined in the introduction, previous research has demonstrated that objective gaze measures of visual attention (e.g., QE) during the performance of motor tasks are susceptible to pressure. For example, Vine et al. (2013) revealed that when skilled golfers missed a putt during a competitive shootout, this failure was accompanied by a shorter final aiming fixation

on the ball (QE) and an earlier attempt to fixate the hole, compared to successful attempts. The authors postulated that apprehension about performance outcome makes it harder to inhibit the desire to direct gaze towards the hole, rather than maintain goal-directed focus on ensuring a good contact between putter and ball. Training the maintenance of goal-directed attention (QE training) has been shown to insulate against outcome-focused distraction and protect performance under pressure (e.g., Vine et al., 2011).

The principal aim of Experiment 3 was to examine if our novel inhibition training could reveal similar benefits to sport skill performance as previously found for QE training. In tennis, it is important to maintain attentional focus on the hit zone during and beyond racquet-ball contact to ensure accuracy (Lafont, 2007, 2008), and it was shown in Experiment 2 that this strategy reflects efficient inhibition control. Based on the predictions of ACT (Eysenck et al., 2007; Eysenck & Wilson, 2016) and the findings of Vine et al. (2013) in golf putting, we first hypothesized that pressure would disrupt the efficiency of the inhibition function; tennis players would not maintain a goal-directed focus on the hit point, but would rather direct an earlier fixation to the scoring target. However, we also hypothesized that inhibition training would modulate this effect: the trained participants would maintain their focus on the impact area (racquet and ball) and have later fixations to the target under pressure compared to the control participants.

Methods

Participants

An opportunity sample of 22 recreational tennis players who usually engage in tennis activities between 1 and 3 times per week were recruited via advertisements placed at the University of Exeter and around Exeter local tennis clubs (11 males, 11 females; 2 left handed, 20 right handed; M age = 27.84, SD = 5.63). Participants had normal or corrected-to-normal vision and wore contact lenses if necessary. All participants gave informed consent

and were debriefed upon completing the final tests. Ethical approval was obtained prior to the conduction of the study.

Materials and stimuli

Training task. The training task was the same attentional capture task employed in Experiments 1 and 2, delivered online using PHP and JavaScript (jQuery).

Tennis task. A volleying task was designed, to enable performance accuracy to be assessed whilst gaze could be recorded. The tennis volley is one of the most technically difficult shots to execute and since it is mostly used to conclude a point (cf. rallying groundstrokes or service return) it can be prone to break down under pressure (Roetert & Groppe, 2001). Participants were required to execute a series of volleys as accurately as possible into a target area (a 120cm x 120cm FITA approved archery target) placed on a blank wall at a distance of 460cm from the player and 100cm from the floor. This distance was determined as it mimics on-court conditions for volleying, and when compared to other distances used in pilot testing, it revealed a consistent ratio between misses and hits (minimizing possible ceiling and floor effects).

The task comprised 20 trials, divided into 2 blocks of 5 forehands and 2 blocks of 5 backhands. A set of 20 Dunlop Fort All Courts balls and a Babolat Pure Drive tennis racket were employed for the duration of the study. The feeder stood at a distance of 70 cm laterally to the left or right of the target, for forehand and backhand volleys respectively. The position of the feeder was reversed for left handed players. The feeder threw the ball in an underhand motion, and aimed to keep the speed of the delivery constant across trials². Participants were instructed to aim for the center of the archery target on every shot.

Measures

State anxiety. Cognitive state anxiety was assessed at 3 time points; before the first block of 5 shots, after the second block (midway), and after the fourth block (at the end),

using the Mental Readiness Form (MRF-3; Krane 1994). The MRF-3 comprises 3 bipolar 11-point Likert scales that are anchored between ‘not worried – worried’ for the cognitive anxiety scale; ‘not tense – tense’ for the somatic anxiety scale; and ‘not confident – confident’ for the self-confidence scale. The cognitive anxiety subscale has been frequently employed by researchers seeking to assess the experience of competitive sporting pressure (e.g., Vine et al., 2011; Wilson et al., 2009). A mean value across the three time points was used for subsequent analyses.

Tennis field performance. Performance was assessed as a percentage of shots that missed the target area. Such ‘misses’ reflect poor performance (e.g., Vickers, 1996) and are more likely to occur under competitive pressure (Vine et al., 2013). A Go Pro Hero 4 camera recorded shot outcome at 30 fps and at a resolution of 720 dpi, employing medium angle of view. Depending of the shot to be executed (forehand or backhand) the camera was set on a tripod which was placed on either side (100cm) and behind (20cm) of where the player stood.

First target fixation (FTF). ‘SensoMotoric Instrument’ (SMI ETG) Mobile Eye Tracking glasses were used to measure and record momentary gaze (at 30 Hz). The resolution of the scene camera was 1024x720p at 30 fps. A circular cursor (representing 1° of visual angle) indicating the location of gaze in a video image of the scene (spatial accuracy of $\pm 0.5^\circ$ visual angle; 0.1° precision) was recorded for offline analysis. Gaze data were analyzed in a frame-by-frame manner using Quiet Eye Solutions software (www.QuietEyeSolutions.com). FTF was defined for the present study to represent an objective measure of ‘inhibition’ during the volleying tennis task. Instead of calculating the attenuation of gaze period on a stationary object (cf. Vine et al., 2013 in golf putting), we calculated its corollary: the speed at which the target was fixated (the time of first target fixation; FTF). Specifically, the FTF was operationally defined as the length of time in milliseconds that elapsed between racquet to ball contact and the onset of a fixation on the target. Longer durations therefore reflect an

optimal strategy similar to that identified by Lafont (2007, 2008) and more efficient inhibition of the target (cf. antisaccade performance; Experiment 1).

Procedure

The design of the experiment followed a pre-test, intervention, post-test format. Participants were initially matched on pre-test measures of trait anxiety (Control $M = 33.36$, $SD = 5.23$; Training $M = 33.90$, $SD = 7.21$), age (Control $M = 22.09$, $SD = 8.68$; Training $M = 24.81$, $SD = 13.54$) and tennis performance (Control $M = 40.00\%$, $SD = 19.36$; Training $M = 41.81\%$, $SD = 14.19$) and pseudo-randomly allocated to a control or a training group. At pre intervention, participants were initially given brief instructions on how to proceed with the online home training task (identical to Experiments 1 and 2) and undertook a short practice on the tennis task. The eye-tracking equipment was then fitted and calibrated using a 3-point calibration procedure. Lastly participants were asked to complete the MRF-3.

Participants were required to volley a tennis ball, which was hand fed by a tennis coach, onto an archery target placed onto a blank wall. Participants were instructed to stand with both feet on a designated line whilst keeping a steady ready position holding their racquet with both hands around waist height. The task comprised 20 trials, divided into 2 blocks of 5 forehands and 2 blocks of 5 backhands and lasted around 5 minutes. Upon finishing the first 2 blocks consisting of 5 forehands and 5 backhand volleys, participants were required to complete the MRF-3, which was completed again at the end of the whole task.

In the post-training session, participants initially completed the same procedures as in the pre-training session. However, they were then instructed to repeat the tennis task in a pressurized condition. As in previous research interested in the effect of pressure on sports performance (e.g., Wilson et al., 2009; Vine et al., 2011) a variety of approaches were employed to increase cognitive anxiety. First of all, participants were told that their data may

be used in a proposed sports science TV program and that their performance will be evaluated by tennis experts against the performance of other participants taking part in the study (a mock consent form which included TV branding was completed). Participants were also told that the tennis experts would analyze their facial expression during the task. Lastly they were informed that a ranking system based on their tennis scores had been put in place. Non-contingent feedback was given, with participants being told that their scores from the previous 20 volleys in the pre-test tennis task would put them in the bottom 30% when compared to participants who had already completed the study. They were encouraged to try and improve upon their performance and told that otherwise their data could not be used. Upon completing the pressure condition tennis task participants were debriefed about the study's aims and thanked for their participation. Participants were compensated with £20 pounds for around three and a half experimental hours.

Data Analysis

As there were no group differences between any of our dependent variables at pre-test³ we focus our analysis on the post training conditions (Low pressure vs. High pressure).

Dependent variables were therefore subjected to 2 x 2 Group (Control vs. Training) x Condition (Low vs. High pressure) mixed analyses of variance. Linear regression was also conducted to assess whether FTF predicted tennis performance (aggregated across both Low and High pressure testing sessions).

Results

Training Task Manipulation Check

As in Experiments 1 and 2, the ability to inhibit distractors when identifying targets in the visual search task gradually improved across the period of training, as indicated by a t-test that showed that distractor costs towards the end of training (i.e., days 4, 5 and 6; $M = .53$, SD

= 8.17) were significantly lower; $t(10) = 3.02, p = .013$, than distractor costs at the beginning of the training (i.e., days 1, 2 and 3; $M = 7.52, SD = 11.55$).

Cognitive Anxiety

ANOVA revealed a significant main effect of Condition, $F(1, 20) = 15.40, p = .001, \eta^2_p = .43$, with participants reporting significantly higher levels of cognitive anxiety in the high ($M = 4.19, SD = 2.09$) as opposed to low-pressure session ($M = 2.96, SD = 1.83$), indicating that the pressure manipulation was successful. There was no main effect of Group, and no Condition X Group interaction ($F_s < 1$), reflecting that both groups had similar reactions to the pressure manipulation.

Tennis Performance

ANOVA revealed no significant main effect of Time, $F(1, 20) = 2.41, p = .13, \eta^2_p = .11$, or Group; $F < 1$. However, there was a Time X Group interaction, $F(1, 20) = 4.74, p = .04, \eta^2_p = .19$, driven by a significant decrease in the percentage of misses made by the training group ($p = .01$) compared to the control group who revealed no significant improvement ($p = .70$); see Table 1.

First Target Fixation (FTF)

8.7 % of trials across testing sessions were lost due to calibration errors or no eye-movements to the target at the time of contact with the ball. Ten percent of the FTF data were analyzed by a second independent rater who was blind to both the aims of the experiment and participants' group allocation. Results revealed high levels of agreement between the two raters, $r = .97, p < .001$, confirming the reliability of the coding process (Vine et al., 2011).

The main effect of Group was not significant $F < 1$. However, ANOVA revealed a significant main effect of Condition, $F(1, 19) = 8.65, p = .008, \eta^2_p = .30$, indicating a general reduction in the length of FTF from the low pressure ($M = 106.63\text{ms}, SD = 134.63$) to the high pressure session ($M = 81.63\text{ms}, SD = 107.15$). This was qualified by a significant

Condition X Group interaction, $F(1, 19) = 8.17, p = .01, \eta^2_p = .30$. Further analyses indicated that this interaction was driven by significant reductions in the length of FTF for the control group ($p = .005$), compared to the training group who showed no significant reduction in the length of FTF between the two testing sessions: ($p = .94$; see Table 1).

**** Table 1 ****

Tennis performance and FTF

Regression analysis confirmed that the FTF significantly predicted 13% of the variance in tennis performance (Unstandardized $\beta = -.36, t = 2.52, p = .01$).

Discussion

Experiment 3 was conducted with the aim of combining the objective measurement of eye movements and performance in a cognitive task from Experiment 1, with the interesting application to tennis, as piloted in Experiment 2. Additionally, we sought to test the predictions of ACT (Eysenck et al., 2007; Eysenck & Wilson, 2016) with regards to the role of anxiety in disrupting inhibitory control in sporting tasks. Specifically, a prediction was made that training goal directed inhibitory control processes would protect against the negative influence of anxiety on objective, task-specific measures of attentional control and performance.

The performance data (percentage of missed shots) revealed the predicted interaction effect, with training benefitting participants when performing under heightened levels of anxiety in comparison to their control group counterparts (see Table 1). The training group's performance significantly improved under pressure compared to post training, whereas the control group's performance did not change. As the pressure session always followed immediately after the post training session, task improvement between conditions could be expected for this novel task if no manipulation was performed in the second condition. Therefore, the training group participants were able to realize these potential task learning

effects, whereas the control group's learning was attenuated due to the negative impact of the pressure manipulation.

We predicted that this relative difference in performance under pressure would be driven by attentional differences (cf. Experiments 1 and 2). Indeed, the significant interaction effect for FTF revealed that while the control group demonstrated a diminished ability to inhibit a fixation to the target during ball contact under pressure (revealing a significantly quicker FTF), the training group maintained similar FTFs. Taken together with the performance data, it is evident that while the training group were insulated from any negative influence of increased anxiety, the control group were not. The regression analysis further revealed that this ability to inhibit a target fixation around the time of contact with the ball was a significant predictor of performance, underlining the importance of optimal top down control for successful sporting execution under pressure (Englert & Oudejans, 2014; Kasper et al., 2012; Vine et al., 2013).

To conclude, the training effects observed in Experiment 3 are consistent with both previous research employing similar training methods to provide beneficial outcome in healthy and vulnerable populations (Jaeggi et al., 2011, Owens et al., 2013; Sari et al., 2015) and those adopting QE training methods in sport (e.g., Vine et al., 2011; Wood & Wilson, 2011). Two potential advantages of translating attentional training from mainstream psychology, compared to QE training, are that training does not require detailed knowledge of the task specific expert gaze strategy being modeled (i.e., training is more generalized), and, the mechanisms underpinning the improvements in performance under pressure (i.e., improved inhibitory control) are more explicitly targeted.

General Discussion

The current study provides encouraging evidence that enhancing the efficiency of the inhibition function (and resistance to distraction) can facilitate sport performance, with

considerable benefits in competitive, high-pressured environments. In Experiment 1, results demonstrated that training the inhibition function improved inhibitory control on an untrained anti-saccade task (near transfer). In Experiment 2, results indicated that training-related gains led to improved observed attentional control during the performance of a tennis service return task (far transfer). Lastly, the outcome of experiment 3 underlined far transfer effects of training on tennis volleying performance and attentional control when anxiety levels were elevated. Taken together, inhibition training revealed positive effects irrespective of the nature of the task demands (e.g., response format) or the distracting stimuli that needed to be inhibited.

The present results confirm and extend the main predictions of ACT as applied to sports (see Eysenck & Wilson, 2016, for a review); that it is possible to enhance sporting performance via manipulating and targeting the inhibition function of working memory. They also provide direct evidence that processing efficiency in distractor inhibition can act as a causal mechanism by which attentional control related benefits transfer to sporting performance outcomes. Our results show that training inhibitory processes of working memory can play a vital role in increasing attentional control related indices of performance, with direct transfer effects on an eye-tracking index of inhibition necessary for accurate performance.

There are a number of ways in which future research can build on the exciting potential of these novel findings. First, future research will need to determine whether the training task provides a generic improvement in inhibitory control, or whether the search object – the tennis ball in the current study - needs to be domain specific. We suggest that the results observed in Experiment 1; where neither the participants nor the transfer task were related to tennis; are strongly supportive of a generalizable benefit. Second, the transferability of training effects to other sporting skills should also be examined. For example, would the

tennis players in experiment 3 also reveal better attentional control in other tennis tasks (e.g., tennis serving, or service return)? Third, while we specifically focused on the effectiveness of inhibition training – based on the strong evidence relating distractibility to impaired performance under competitive pressure (Englert & Oudejans, 2015; Oudejans et al., 2011), future research should investigate the efficacy of targeting other executive functions of WM, such as switching and updating, for sport performance (Furley et al., 2015). Finally, whilst the online presentation of the training is a novel and time effective way of delivering cognitive training, future research should ensure that specific procedures are in place to ensure that all participants recruited to undertake training can be identified as the ones doing the daily task. It is worthy to note that since our data show significant transfer effects across all three experiments, this is unlikely to have been a concern in the present study.

Conclusions

In sum, this is the first study to show that training the efficiency of the inhibition function (resistance to distraction) can result in transferrable training-related gains in motor performance in attentionally demanding sports such as tennis. Our results can hopefully pave the way for exciting research to extend the applications of training to improving attentional control in motor performance to a number of sporting activities under competitive and ego challenging situations.

Footnotes

¹ We did also assess error rates, but these were low throughout the experiment (Mean error rate = 12.5 % for antisaccade task and 2.29% for prosaccade task). ANOVA revealed no main effects for Time, Group, or Task, nor any interaction effects (all $F_s < 1$).

² Ball flight times were consistently between 500ms and 510ms ($SDs \sim 40ms$) across all conditions. ANOVA revealed no significant differences between groups or over time (all $F_s < 1$).

³ The duration from contact to fixating the target (First Target Fixation, FTF) was comparable ($t < 1$) for both control ($M = 90.73ms$, $SD = 124.96$) and training ($M = 113.33ms$, $SD = 105.29$) group. Performance (% misses) was also similar ($t < 1$) for both control ($M = 40.00$ %, $SD = 19.36$) and training ($M = 41.81$ %, $SD = 14.19$) group.

References

- Behan, M., & Wilson, M. (2008). State anxiety and visual attention: The role of the quiet eye period in aiming to a far target. *Journal of Sport Sciences, 26*, 207-215. doi: 10.1080/02640410701446919
- Berggren, N., & Derakshan, N. (2013). Attentional control deficits in anxiety: Why you see them and why you don't. *Biological Psychology, 92*, 440-446. doi: 10.1016/j.biopsycho.2012.03.007
- Bortoli, L., Bertollo, M., Hanin, Y., & Robazza, C. (2012). Striving for excellence: A multi-action plan intervention model for shooters. *Psychology of Sport & Exercise, 13*, 693-701. doi:10.1016/j.psychsport.2012.04.006
- Carson, H. J., & Collins, D. (2016). The fourth dimension: A motoric perspective on the anxiety-performance relationship. *International Review of Sport & Exercise Psychology 9*, 1-21. doi:10.1080/1750984X.2015.1072231
- Causser, J., Holmes, P. S., Smith, N. C., & Williams, A. M. (2011a). Anxiety, movement kinematics, and visual attention in elite-level performers. *Emotion, 11*, 595-602. doi: 10.1037/a0023225
- Causser, J., Holmes, P. S., & Williams, A. M. (2011b). Quiet eye training in a visuomotor control task. *Medicine & Science in Sports & Exercise, 43*, 1042-1049. doi: 10.1249/MSS.06013e3182035de6
- Chuang, L. Y., Huang, C. J., & Hung, T. M. (2013). The differences in frontal midline Theta power between successful and unsuccessful basketball free throws of elite basketball players. *International Journal of Psychophysiology 90*, 321-328. doi: 10.1016/j.ijpsycho.2013.10.002

- Dandeneu, S. D., & Baldwin, M. W. (2004). The inhibition of socially rejecting information among people with high versus low self-esteem: The role of attentional bias and the effects of bias reduction training. *Journal of Social & Clinical Psychology, 23*, 584-602. doi: 10.1521/jscp.23.4.584.40306
- Derakshan, N., Ansari, T. L., Shoker, L., Hansard, M. E., & Eysenck, M. W. (2009). Anxiety, inhibition, efficiency and effectiveness: An investigation using the antisaccade task. *Experimental Psychology, 56* (1), 48 - 55. doi: 10.1027/1618-3169.56.1.48
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96*, 433-458.
- Enge, S., Behnke, A., Fleischhauer, M., Küttler, L., Kliegel, M., & Strobel, A. (2014). No evidence for true training and transfer effects after inhibitory control training in young healthy adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*, 987-1001. doi: 10.1037/a0036165
- Englert, C., & Oudejans, R. R. D. (2014). Is choking under pressure a consequence of skill-focus or increased distractibility? Results from a tennis serve task. *Psychology, 5*, 1035-1043. <http://dx.doi.org/10.4236/psych.2014.59116>
- Ettinger, U., Ffytche, D. H., Kumari, V., Kathmann, N., Reuter, B., & Zelaya, F. (2008). Decomposing the neural correlates of antisaccade eye-movements using event-related fMRI. *Cerebral Cortex, 18*, 1148-1159.
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*, 336-353.
- Eysenck, M. W., & Wilson, M. R. (2016). Pressure and sport performance: A cognitive approach. Introducing Attentional Control Theory: Sport. In D. Groome & M. Eysenck (eds). *An introduction to applied cognitive psychology* (pp. 329-350). London: Routledge.

- Fischer, B., Weber, H., Biscaldi, M., Aiple, F., Otto, P., & Stuhr, V. (1993). Separate populations of visually guided saccades in humans: reaction times and amplitudes. *Experimental Brain Research*, *92*, 528-541.
- Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent variable analysis. *Journal of Experimental Psychology*, *133*, 101-135.
- Furley, P., Schweizer, G., & Bertrams, A. (2015). The two modes of an athlete: Dual-process theories in the field of sport. *International Review of Sport & Exercise Psychology* *8*, 106-124. doi:10.1080/1750984X.2015.1022203
- Hallet, P. E. (1978). Primary and secondary saccades to goals defined by instructions. *Vision Research*, *18*, 1279-1296.
- Hoorelbeke, K., Koster, E.H., Vanderhasselt, M. A., Callewaert, S., & Demeyer, I. (2015). The influence of cognitive control training on stress reactivity and rumination in response to a lab stressor and naturalistic stress. *Behaviour Research & Therapy*, *69*, 1-10. doi:10.1016/j.brat.2015.03.010
- Jaeggi, S. M., Buschkuhl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences of the USA*, *108*, 10081-10086.
- Kao, S. C., Huang, C. J., & Hung, T. M. (2013). Frontal midline theta is a specific indicator of optimal attentional engagement during skilled putting performance. *Journal of Sport & Exercise Psychology* *35*, 470-478.
- Kline, P. (2000). *Handbook of Psychological Testing*. London, Routledge.
- Kasper, R. W., Elliott, J. C., & Giesbrecht, B. (2012). Multiple measures of visual attention predict novice motor skill performance when attention is

focused externally. *Human Movement Science*, 31, 1161-1174. doi:

10.1016/j.humov.2011.11.005

Lafont, D. (2007). Towards a new hitting model in tennis. *International Journal of Performance Analysis in Sport*, 7(3), 106-116.

Lafont, D. (2008). Gaze control during the hitting phase in tennis: a preliminary study, *International Journal of Performance Analysis in Sport*, 8(1), 85-100.

Krane, V. (1994). The mental readiness form as a measure of competitive state anxiety. *The Sport Psychologist*, 8, 189-202.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, 41, 49-100.

Moore, L., Vine, S. J., Cooke, A. M., Ring, C., & Wilson, M. R. (2012). Quiet eye training expedites motor learning and aids performance under pressure: The roles of response programming and external attention. *Psychophysiology*, 49, 1005-1015.

doi:10.1111/j.1469-8986.2012.01379.x

Nibbeling, N., Oudejans, R. R. D., & Daanen, H. A. M. (2012). Effects of anxiety, a cognitive secondary task, and expertise on gaze behaviour and performance in a far aiming task. *Psychology of Sport & Exercise*, 13, 427-435.

doi:10.1016/j.psychsport.2012.02.002

Nicholls, A. R., Holt, N. L., & Polman, R. C. J. (2005c). Think aloud: Performance-related stressors and coping during golf performance. *Journal of Sports Sciences*, 21(3), 283-294. doi: 10.1080/10615800701609207

Olk, B., & Kingstone, A. (2003). Why are antisaccades slower than prosaccades? A novel finding using a new paradigm. *Neuroreport*, 14, 151-155.

- Oudejans, R. R. D., Kuijpers, W., Kooijman, C. C., & Bakker, F. C. (2011). Thoughts and attention of athletes under pressure: Skill-focus or performance worries? *Anxiety, Stress & Coping*, *24*, 59-73. doi: 10.1080/10615806.2010.481331
- Owens, M., Koster, E. H. W., & Derakshan, N. (2013). Improving attention control in dysphoria through cognitive training: Transfer effects on working memory capacity and filtering efficiency. *Psychophysiology*, *50*(3), 297-307. doi: 10.1111/psyp.12010
- Roetert, E. P., & Groppe, J. L. (2001). *World Class Tennis Technique*. Champaign, IL: Human Kinetics.
- Sari, B. A., Koster, E. H. W., Pourtois, G., & Derakshan, N. (2015). Training working memory to improve attentional control in anxiety: A proof-of-principle study using behavioural and electrophysiological measures. *Biological Psychology*. doi: 10.1016/j.biopsycho.2015.09.008
- Shipstead, Z., Harrison, T. L., & Engle, R. W. (2012). Working memory capacity and visual attention: Top-down and bottom-up guidance. *The Quarterly Journal of Experimental Psychology*, *65*(3), 401-407. doi: 10.1080/17470218.2012.655698
- Spielberger, C. C., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.
- Theeuwes, J. (1992). Perceptual selectivity for colour and form. *Perception & Psychophysics*, *51*, 599-606.
- Unsworth, N., Redick, T. S., Spillers, G. J., & Brewer, G. A. (2012). Variation in working memory capacity and cognitive control: Goal maintenance and micro adjustments of control. *The Quarterly Journal of Experimental Psychology*, *65*(2), 326-355. doi: 10.1080/17470218.2011.597865
- Vickers, J. N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology: Human Perception & Performance*, *2*, 324-354.

- Vickers, J. N., & Williams, A. M. (2007). Performing under pressure: The effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior*, *39*, 381-394. doi:10.3200/JMBR.39.5.381-394
- Vine, S. J., Lee, D., Moore, L. J., & Wilson, M. R. (2013). Quiet eye and choking: Online control breaks down at the point of performance failure. *Medicine & Science in Sports & Exercise*, *45*, 1988-1994. doi.org/10.1249/MSS.0b013e31829406c7
- Vine, S. J., & Wilson, M. R. (2011). The influence of Quiet Eye training and pressure on attentional control in a visuo-motor task. *Acta Psychologica*, *136*, 340-346. doi: 10.1016/j.actpsy.2010.12.008
- Williams, A. M., Ward, P., Smeeton, N. J., & Allen, D. (2004). Developing anticipation skills in tennis using on-court instruction: Perception versus perception and action. *Journal of Applied Sport Psychology*, *16*, 350-360. doi: 10.1080/10413200490518002
- Wilson, M. R. (2012). Anxiety: Attention, the brain, the body and performance. In S. Murphy (Eds), *The Oxford handbook of sport and performance psychology*. New York, NY: Oxford University Press. p. 173-90.
- Wilson, M. R., Vine, S. J. & Wood, G. (2009a). The influence of anxiety on visual attentional control in basketball free-throw shooting. *Journal of Sport & Exercise Psychology*, *31*, 152-168.
- Wilson, M. R., Wood, G. & Vine, S. J. (2009b). Anxiety, attentional control and performance impairment in penalty kicks. *Journal of Sport & Exercise Psychology*, *31*, 761-775.
- Wood, G. & Wilson, M. R. (2012). Quiet-eye training, perceived control and performing under pressure. *Psychology of Sport and Exercise*, *13*, 721-728. doi:10.1016/j.psychsport.2012.05.003

Table 1: Mean (SD) tennis performance (% missed target) and inhibition control (time to first target fixation; FTF) for each training group across low and high pressure conditions.

Condition	Group	% Missed Target	FTF (ms)
Low Pressure	Training	39.09 (11.79)	106.63 (134.6)
High Pressure	Training	28.18 (15.53)	81.63 (107.15)
Low Pressure	Control	40.45 (19.93)	96.18 (96.63)
High Pressure	Control	42.27 (16.33)	95.50 (101.23)

Figures captions

Figure 1: Example of distractor trials from the inhibition-training task version of the 8-item visual search array; with distractor (red [dark grey] golf ball at “12 o’clock”) and target (yellow-green [light grey] tennis ball at “3 o’clock”) both present.

Figure 2: Mean Antisaccade (a) and Prosaccade (b) latencies (in milliseconds) for training and control groups across conditions (Error bars = SEM).

Figure 3: Mean coach ratings of attentional control (gaze) during the hitting phase of the tennis stroke for training and control groups across conditions (Error bars = SEM).

Figure 1

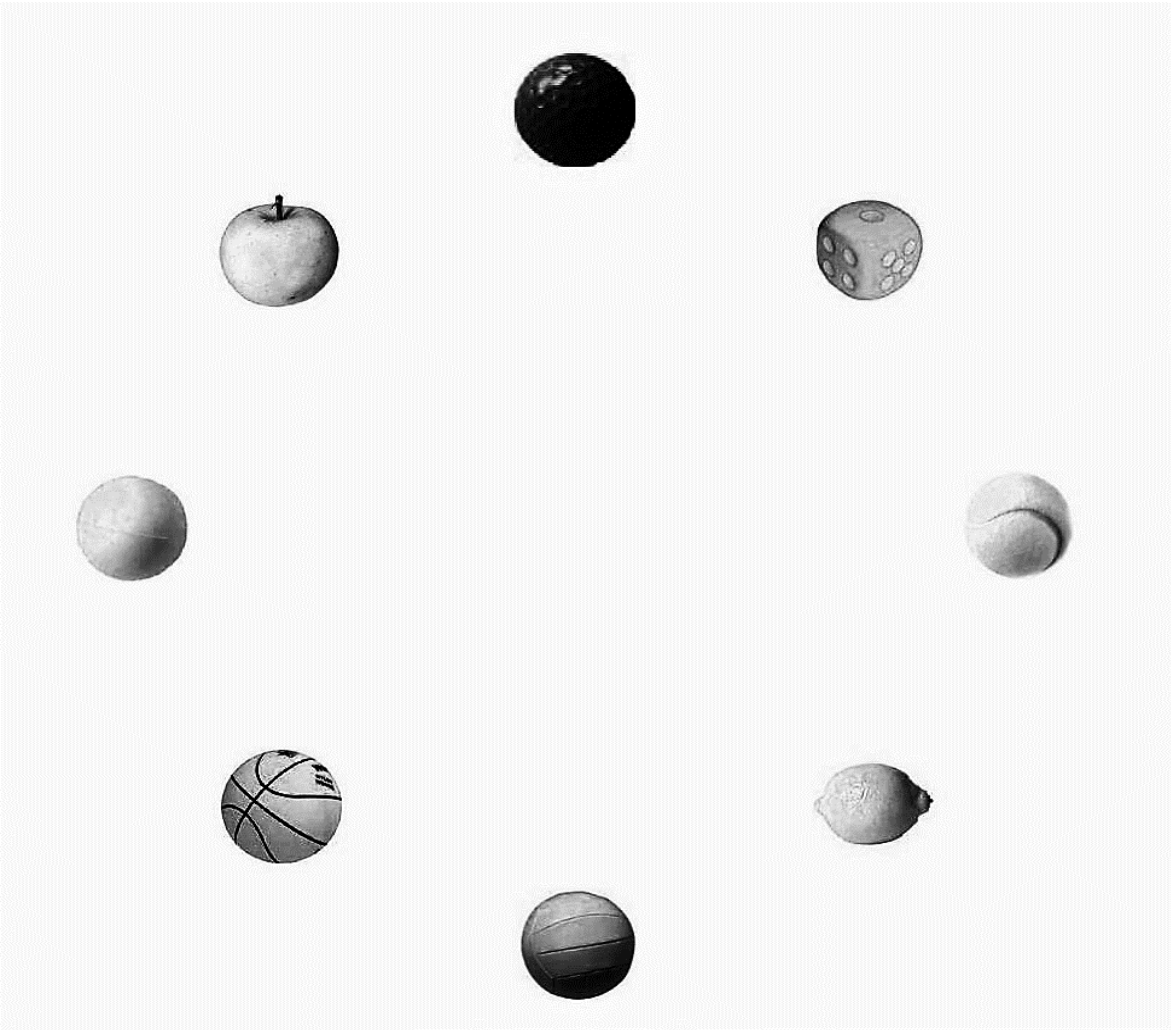


Figure 2a:

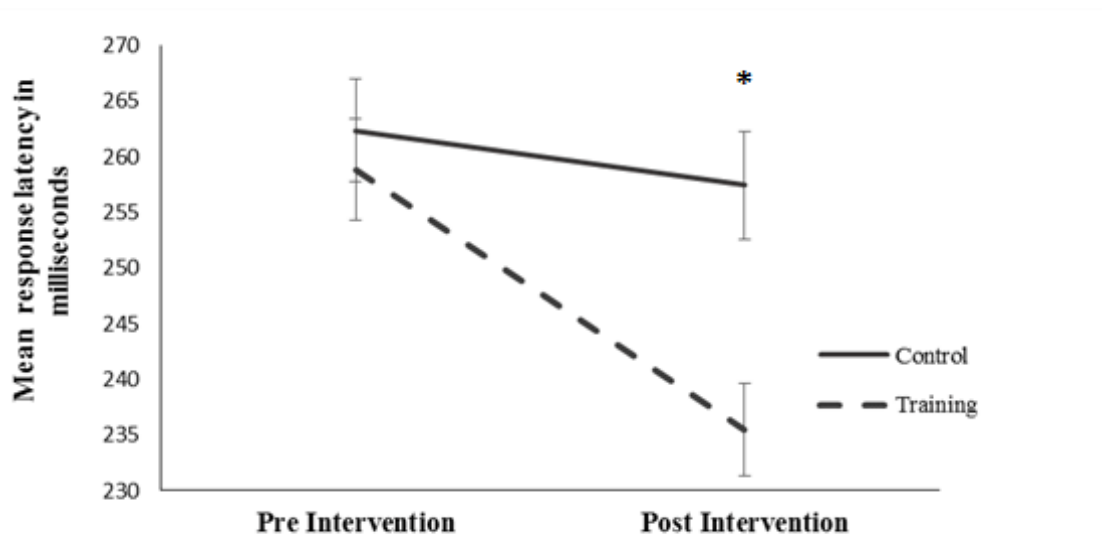


Figure 2b

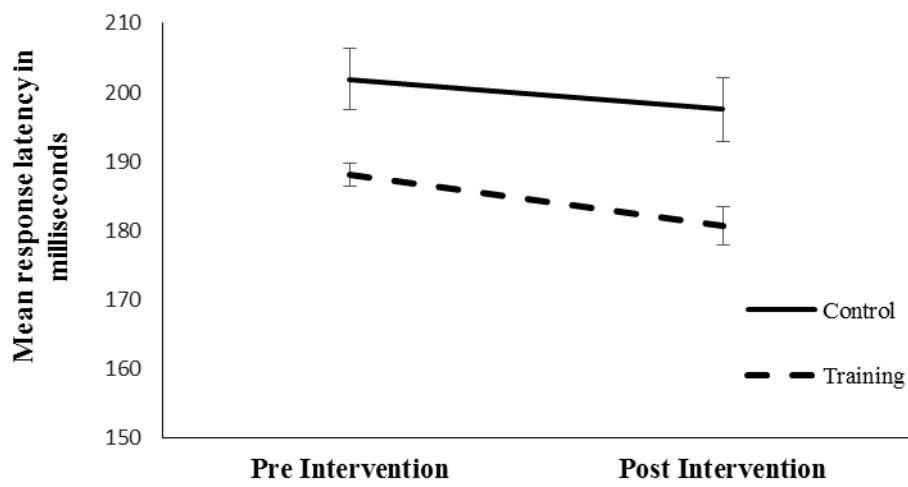


Figure 3:

