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**Factors that influence motor performance:
Colour, inhibition and conscious processing**

by

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A thesis

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of the requirements for the degree

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Abstract

This thesis investigates potential psychological mechanisms that influence motor performance in sport, including colour, inhibition function, and propensity for conscious control of movement. A question was raised about whether individuals with poor inhibition function would be more likely to have a high propensity for conscious control (i.e., reinvestment) because they are less able to inhibit conscious control. However, Experiment 1 (Chapter 2) and Experiment 2 (Chapter 3) revealed a positive association between inhibition function (indexed by the Go/NoGo task) and propensity for conscious control of movement (assessed by the Movement Specific Reinvestment Scale, MSRS).

Experiment 3 (Chapter 4) examined the effect of colour on inhibition function during a basketball-specific Go/NoGo task. Worse inhibition performance was evident when participants viewed an opponent in a green uniform compared to a red and a grey uniform, possibly because green conveys the meaning to 'go' (e.g., at traffic lights). Archival data of professional netball games was analysed to examine whether teams in green uniforms made more intercepts because green lowers an opponent's ability to inhibit an ill-chosen pass. Findings revealed higher mean intercepts for teams wearing green uniforms than for teams wearing red and other-coloured uniforms.

Experiment 4 (Chapter 5) examined whether the effect of uniform colour may be due to differences in an opponent's perception of size. A side-by-side comparison task revealed that goalkeepers in a red and a blue uniform were perceived as larger than goalkeepers in a green uniform, possibly because red and blue colours convey the meaning of dominance and threat in a football context (e.g., the most successful teams, like Manchester United and Chelsea, wear red and blue colours). Experiment 5 (Chapter 6) examined whether viewing a red and a blue spectator background would elicit avoidance motivation during football penalty-kicks, because they conveyed the meaning of dominance and threat. Professional football players displayed avoidance motivation (i.e., choosing the easier option/ kicking towards the larger side of the goal) when viewing a red and a blue spectator background compared to other-coloured backgrounds. Based on Experiments 4 and 5, it was argued that viewing a red and a blue spectator background elicited avoidance motivation because red and blue convey the meaning of dominance and threat in football.

In Experiment 6 (Chapter 7), retrospective analysis of professional football games was

conducted to examine whether avoidance motivation would also be evident when facing a hostile crowd (a threatening stimulus). Consistently, penalty-kickers chose the easier option/ kicked to the larger side of the goal (i.e., avoidance motivation) more often when facing a hostile crowd rather than a supportive crowd. It was suggested that viewing a threatening stimulus (1) increases arousal levels, which exacerbates the negative emotions that are experienced by kickers during penalty-kicks in real-life or (2) viewing a threatening stimulus aids visual discrimination of available space, allowing kickers to identify and kick towards the larger side more often.

The findings of this thesis revealed a positive association between inhibition function and movement specific reinvestment propensity, which suggests that ability to inhibit inappropriate motor responses may be a function of inter-personal differences in the propensity for conscious control of movements. Support was found for the effect of colour in sporting contexts. Overall, the findings suggest that the colour effect only occurs if the colour-meaning association reaches an adequate salience threshold within a specific context. In addition, it was argued that while context influences emotional valence (positive, negative emotions), colour influences arousal, which exacerbates the level of negative emotion. An attempt is made to integrate the findings from the thesis with previous evidence to begin development of a theoretical framework for the effects of colour on human performance.

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Publications

Journal articles (direct outputs of the thesis)

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Chapter 1

General introduction

“Colour is not a quality of an object, but a perception. As such, it can symbolize anything we want it to symbolize.”

Hutchings (1997, p. 55)

1.1 Colour

1.1.1 Brief overview of the effect of colour in sports

Humans are highly visual animals. Colour is a visual factor that provides a plethora of useful information in daily life (e.g., a brown rotten apple, a green traffic light, red angry faces) and in sports (e.g., uniform colour). Colour research in sport was kick started by Hill and Barton (2005a, 2005b), who proposed that wearing red uniforms provides a psychological advantage to the wearer (or disadvantage to the viewer) because red is an inherent, testosterone-dependent signal of dominance and threat in nature.¹ Indeed, Hill and Barton (2005b) presented archival data from the 2004 Athens Olympic showing that athletes in red uniforms won more often than athletes in blue uniforms in boxing, taekwondo, Greco-Roman wrestling, and freestyle wrestling. Hill and Barton (2005b) reported that the ‘Red wins’ effect was even more prominent between contestants of similar abilities, suggesting that red might “tip the balance between losing and winning only when other factors are fairly equal” (p. 293) (cf. Rowe, Harris, & Roberts, 2005, 2006).

Subsequent research into the “Red wins” effect reports mixed findings, nonetheless. Falcó, Conchado, and Estevan (2016) examined the effect of coloured electronic body protectors in taekwondo matches (Asian and European qualification tournaments for the 2012 London Olympics) and found that red, as opposed to blue, protectors were associated with

¹ Setchell and Wickings (2005) found that male mandrills use red colouration to signify dominance among males of the species. Similar patterns were observed in rhesus macaques (Waitt, Little, Wolfensohn, Honess, Brown, Buchanan-Smith, & Perrett, 2003), widowbirds (Andersson, Pryke, Ornborg, Lawes, & Andersson, 2002), three-spined sticklebacks (Milinski & Bakker, 1990), and Gouldian finch (Pryke, 2009).

more winning outcomes in the featherweight category, but not in other weight categories (see also Vasconcelos & Del Vecchio, 2017). For team sports, Attrill, Gresty, Hill, and Barton (2008) found that football teams in red home uniforms had more wins than non-red away teams during home games (archival data from the 1946-2003 English Football League); however, the red advantage was not replicated in the Polish (Szmajke & Sorokowski, 2006), German (Kocher & Sutter, 2008), or Spanish football league (García-Rubio, Picazo-Tadeo, & González-Gómez, 2011). Allen and Jones (2014) found that average league position was higher for teams with red club colours; however, those teams did not perform any different during home games when they wore red compared to away games when they did not wear red. Allen and Jones (2014), therefore, suggested that the red advantage in football may occur because strong teams happen to wear red (e.g., Liverpool, Manchester United, Arsenal).

Another perspective on the colour effect in sport proposes that the “Red wins” effect may be an indirect effect of increased perception of dominance. Feltman and Elliot (2011) found that *wearing* red enhanced perceptions of one’s relative dominance and threat while *viewing* an opponent in red enhanced perceptions of an opponent’s relative dominance and threat. Indeed, athletes in red were judged to be more dominant and aggressive (Greenlees, Leyland, Thelwell, & Filby, 2008; Krenn, 2015; Recours & Briki, 2015; Sorokowski, Szmajke, Hamamura, Jiang, & Sorokowska, 2014). For example, referees awarded harsher tackle judgements against football players in red (Krenn, 2014) and more points to taekwondo athletes in red (Hagemann, Strauss, & Leißing, 2008), possibly due to increased perception of the dominance/aggression of the athletes in red.

1.1.2 Potential mechanism of red effect

Literature on the effect of colour in sports mainly revolves around red. Scholars have proposed different mechanisms that may underlie the red effect.

1.1.2.1 Red to elevate testosterone level

Hill and Barton (2005b) argued that wearing red may enhance performance outcomes because red, an inherent signal of dominance and threat, elevates testosterone levels of the wearer. Farrelly, Slater, Elliot, Walden, and Wetherell (2013) found evidence that competitors who chose to be represented by a red symbol had higher testosterone levels. Londe, Marocolo, Marocolo, Fisher, Neto, Souza, and De Mota (2018) also found that wearing red-coloured lenses during high-intensity intermittent exercise increased

testosterone levels (blood samples were taken after the exercise session), whereas wearing blue-coloured lenses resulted in improved parasympathetic activity (i.e., heart rate recovery). Londe et al. (2018) suggested that testosterone increase may positively influence performance outcomes of power exercises. Indeed, red has been reported to result in increased motor output (e.g., elevated heart rate and stronger leg strength, Dreiskaemper, Strauss, Hagemann, & Büsch, 2013; stronger pinch grip force and hand grip force, Elliot & Aarts, 2011). Hackney (2006), on the other hand, found no differences in testosterone level between groups wearing red and wearing blue apparel after VO_{2max} cycle ergometry exercise.

1.1.2.2 Red elicits avoidance motivation

Elliot and colleagues (Elliot & Aarts, 2011; Elliot, Kayser, Greitemeyer, Lichtenfeld, Gramzow, & Maier, 2010; Elliot & Maier, 2007; Elliot, Maier, Binser, Friedman, & Pekrun, 2009; Elliot, Maier, Moller, Friedman, & Meinhardt, 2007; Elliot & Niesta, 2008; Elliot, Payen, Brisswalter, Cury, & Thayer, 2011; Farrelly et al., 2013; Feltman & Elliot, 2011; Maier, Elliot, & Lichtenfeld, 2008; Meier, D'Agostino, Elliot, Maier, & Wilkowski, 2012; Meier, Hill, Elliot, & Barton, 2015; Moller & Elliot, 2009; Payen, Elliot, Coombes, Chalabaev, Brisswalter, & Cury, 2011; Pravossoudovitch, Cury, Young, & Elliot, 2014; Young, Elliot, & Feltman, 2013) have conducted numerous studies to investigate the role of colour on various aspects of psychological functioning.

For example, Elliot et al. (2007) conducted a series of experiments to conceptualise the psychological effect of colour, specifically, the effect of colour on approach and avoidance motivation.

Approach and avoidance motivation can be described as energisation or behaviour towards a positive stimulus or away from a negative stimulus (e.g., object, event, possibility) (Elliot & Covington, 2001). Therefore, approach and avoidance motivation differ as a function of positive and negative *valence*; that is, how the stimulus is evaluated on a good-bad dimension (Elliot, 1999). Studies suggest that people evaluate almost all encountered stimuli on a good-bad dimension (Osgood, Suci, & Tannenbaum, 1957) immediately and without intention or awareness (Bargh, 1997; Zajonc, 1998). Zajonc (1998) asserted that the approach-avoidance distinction is a primary and most rudimentary reaction to stimuli that is hardwired into an organism's system. Similarly, Elliot and Covington (2001) argued that the approach-avoidance distinction is a most

fundamental and basic form of behaviour that is evident across all animate life. For example, a single cell amoeba will approach a weak light stimulus but avoid an intense light stimulus (Schneirla, 1959), because the cell evaluates the light to be a positively or a negatively valence stimulus, respectively. Specifically, behaviours, such as retrieving food, finding shelter, and seeking mating partners all are considered A-type (approach-type) mechanisms, whereas behaviours, such as defending, huddling, and flight (protective behaviours in general) are considered W-type (withdrawal-type) mechanisms (Schneirla, 1959).

Elliot et al. (2007) proposed that red in an academic context will be evaluated as a negative stimulus because it is associated with danger, specifically, the psychological danger of failure (e.g., errors marked in red ink). Accordingly, Elliot et al. (2007) hypothesised that viewing red prior to an intelligence test (e.g., an IQ test) is likely to elicit avoidance motivation, which in turn will lead to poorer test performance. In four experiments, they consistently found that students who were exposed to the colour red (e.g., their participant number in red ink) performed poorly on intelligence tests compared to those exposed to the colour green or an achromatic colour (i.e., black, white, grey).² In a fifth experiment, students who were exposed to red displayed more avoidance behaviours (choosing more easy than difficult questions in a test) than students who were exposed to green or grey (see also Tanaka & Tokuno, 2011). In a sixth experiment, greater right relative to left prefrontal cortical activity (indicative of avoidance motivation, Davidson, Schwartz, Saron, Bennett, & Goleman, 1979; Harmon-Jones & Sigelman, 2001) was evident among students who were exposed to red. Additionally, Elliot et al. (2009) found that participants who were exposed to a red test cover page knocked on the test room door fewer times than those who were exposed to a green test cover page. In addition, participants swayed further away from the red test cover page than those who were exposed to a green or grey test cover page (Elliot et al., 2009).

According to the cued activation model proposed by Baldwin and Meunier (1999), any perceptual cue that is associated with specific interpersonal experiences can evoke strong feelings, thoughts, and behaviours. For example, "...a woman who was repeatedly criticized as a child by her piano teacher might find that the mere sight, or thought, of a

² Results were replicated in Germany (Maier et al., 2008; red vs. grey) and France (Elliot et al., 2011; red vs. blue and red vs. grey), confirming the initial findings by Elliot et al. (2007).

piano makes her somewhat uneasy and insecure. Conversely, a man routinely enjoying warm interactions with a loved one while dining on ethnic cuisine might develop a positive association to that particular comfort food” (Baldwin & Main, 2001, p. 1638). Likewise, Elliot et al. (2007) explained that students may have been classically conditioned to associate red with failure (e.g., errors marked in red ink), which subconsciously elicits avoidance motivation (by the viewer). Elliot et al. (2007) drew another conceptual parallel from the auto-motive model proposed by Bargh (1990), which states that once an association is established, it operates in an unconscious fashion and influences psychological functions automatically. Studies have found support for the implicit association between red-danger (Pravossoudovitch et al., 2014), red-failure (Moller & Elliot, 2009), red-anger (Young et al., 2013), red-aggressiveness (Geng, Hong, & Zhou, 2021), and red-dominance (Mentzel, Schücker, Hagemann, & Strauss, 2017) during implicit word association tasks or Stroop word tasks. These studies suggest that colour can act as a non-conscious prime or an “implicit affective cue”, which provokes positive or negative evaluation of the environment without explicit or conscious awareness (Friedman & Förster, 2010).

Based on such evidence, Elliot and Maier (2012) proposed a Colour-in-Context theory with six core premises (p. 66-72):

1. Colour carries meaning.
2. Viewing colour influences psychological functioning (e.g., approach-avoidance motivation).
3. Colour meanings and effects are context specific.
4. Colour effects are automatic.
5. Colour meanings (and associated responses) can be innate or learned.
6. The relationship between colour perception and affect, cognition, and behaviour are reciprocal.

As previously alluded to, viewing colour can lead to evaluative processes on a good-bad dimension associated with the event (e.g., red-dominance in a sports competition; red-failure in academia). Importantly, the meaning and the effect of colour is context specific. For example, red in a romantic context is shown to elicit approach motivation due to its positive colour-meaning association with sexual-readiness and arousal (Elliot et al., 2010; Elliot & Niesta, 2008).

Various authors have discussed the possibility that the colour association is innate or learned (Jacobs, 1981; Mollon, 1989; Byrne & Hilbert, 2003; Guilford & Rowe, 1996; Hutchings, 1997). Hill and Barton (2005b), for instance, suggest that red is a testosterone dependent signal of male quality among athletes, whereas Elliot et al. (2007) suggest that red is classically conditioned to symbolise failure among students. Elliot and Maier (2012) argued that these two explanations are not mutually exclusive but rather reinforced by one another—that perhaps social constructs are guided by biological predisposition.

1.1.2.3 Red creates an optical size illusion

Older studies suggest that colour (hue) can cause an optical illusion. Specifically, warm colours (e.g., red and yellow) relative to cool colours (e.g., blue and green) cause objects to appear to be larger (Bevan & Dukes, 1953; Cleveland & McGill, 1983; Gentilucci, Benuzzi, Bertolani, & Gangitano, 2001; Tedford Jr., Bergquist, & Flynn, 1977; Wallis, 1935), heavier (Warden & Flynn, 1926), and/or further away (McCain & Karr, 1970). Gentilucci et al. (2001) found that when participants were required to reach and grasp an object, the grasp was larger for red target-objects relative to green target-objects, suggesting that red colouration increases apparent size perception.³ However, the mechanisms behind the colour-size illusion have not been deeply explored and remain unclear.

1.1.2.4 Red attracts attention

Studies in neuropsychology suggest that the effect of colour is particularly evident in red, because red is fundamentally a more distinct and salient colour than blue, green, or yellow with respect to the *colour hierarchy* (Berlin & Kay, 1969). Tchernikov and Fallah (2010) found that automatic target selection and motion processing (i.e., smooth eye pursuit) followed a hierarchy of red, green, yellow, and blue and suggested that the hierarchy may be due to differences in colour salience (red being the highest salience). Lindsey, Brown, Reijnen, Rich, Kuzmova, and Wolfe (2010) also found that target detection for coloured stimuli was faster for warmer (i.e., reddish) colours than for cooler (i.e., purplish) colours. Evidence from electrophysical evidence supports these findings. Pomerleau and

³ Research has shown that size can influence colour perception. Specifically, colours appear brighter/lighter (with little change in hue) when they are large (e.g., a painted room) compared to when they are small (e.g., a small patch of paint) (Kutas & Bodrogi, 2007; Xiao, Luo, & Li, 2010; Xiao, Luo, Li, Cui, & Park, 2011; Xiao, Luo, Li, & Hong, 2010). Such an effect may be due to non-uniform distribution of photoreceptors across the human retina when the viewing field increases, or changes in receptor sensitivity to the background colour (Chichilnisky & Wandell, 1995).

colleagues (2014) measured event related potentials (ERP) to determine the time and magnitude of activation of specific brain regions as a result of a direct sensory event (i.e., stimulus colour). The results revealed that red stimuli elicited earlier and larger ERP components relative to blue, green, and yellow stimuli. Rakshit and Lahiri (2016) also found that red was most responsible for mental arousal and cognitive activity followed by green, blue, and yellow, using brain activation maps from electroencephalography (EEG). These studies suggest that allocation of attention may be biased to red first and foremost due to its high salience.

1.1.3 Effect of colour on inhibition function

It has been suggested that colour captures attention in the hierarchy of red, green, blue, and yellow (hierarchy sometimes changes within green, blue, and yellow, but rarely with red). Blizzard, Fierro-Rojas, and Fallah (2017) hypothesised that executive functions, which are dependent on sensory input, may be influenced by colour. Specifically, seeing red may elicit faster processing by the executive functions and, thus behavioural responses, compared to other colours.

According to Blizzard et al. (2017), motor execution and inhibition are two important facets of executive function that allow efficient and successful performance of a task. In a series of experiments, Blizzard et al. (2017) employed a Stop-Signal task (Logan & Cowan, 1984), which requires participants to respond to a go-signal (response execution), but to countermand that response when presented with a stop-signal (response inhibition). In their third experiment, for example, participants were required to respond to a left or right white arrow presented on a computer screen by pressing the left or right key on the keyboard, respectively. However, when the white arrow changed colour either to red or green, participants were required to countermand their response. The minimum amount of time needed for response inhibition (stop signal reaction time, SSRT) was found to be shorter for a red stop-signal than for a green-stop signal, indicating that red facilitated response inhibition. Blizzard et al. (2017) suggested that colour is preferentially processed by neural circuits underlying response inhibition, specifically that *red* facilitates response inhibition.

Part of this thesis focuses on the effect of colour on inhibition function in a sports context. Thus, the next part of the introduction will provide a more detailed overview of inhibition function.

1.2 Inhibition function

“Healthy adult humans are widely held to have a capacity for “self-control”. Perhaps the most obvious form that self-control takes is the inhibition of behaviours that are prepotent, but at the same time somehow maladaptive or inappropriate.”

Brass, Rigoni, and Haggard (2014, p. 234)

According to Brass et al. (2014), inhibition plays a crucial role in self-control, which allows us to carry out complex motor tasks (e.g., stopping at a red light), live harmoniously with others (e.g., waiting in line), and protect ourselves from sporadic and/or addictive impulses (e.g., drug-taking). Other researchers have defined inhibition similarly:

1. “Any mechanism that reduces or dampens neuronal, mental, or behavioural activity” (Clark, 1996, p. 128)
2. “Ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary” (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000, p. 57)
3. “Being able to control one’s attention, behaviour, thoughts, and/or emotions to override a strong internal predisposition or external lure, and instead do what’s more appropriate or needed” (Diamond, 2013, p. 137)

Inhibition, or inhibitory control, in psychology is an umbrella term that refers to the ability to suppress task-irrelevant stimuli and behavioural responses (Diamond, 2013; Miyake et al., 2000; Nigg, 2000). Miyake et al. (2000) proposed that inhibition is one of three fundamental executive functions, inhibiting, shifting,⁴ and updating⁵ (see also Diamond, 2013; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003), which are necessary for higher-order cognitive processes, such as complex reasoning, problem-solving, and flexible thinking. Nonetheless, inhibition cannot be understood without first understanding the theoretical concept of executive functions and its role in the central executive system.

⁴ Shifting concerns the ability to shift/switch back and forth between multiple tasks (Miyake et al., 2000). Diamond (2013) refers to it as cognitive flexibility which includes ability to change perspectives (e.g., “What would this look like if I viewed from a different location?”, “How would I feel if I was in his shoes?”), to think outside of the box, or to adjust to change.

⁵ Updating concerns the ability to monitor and retain incoming information (Miyake et al., 2000). Diamond (2013) refers to it as working memory and similarly refers to the ability to remain information for a short period of time.

1.2.1 Inhibition function in the central executive system

Executive functions are a set of mental skills (like tools) that are necessary in higher-order cognitive processes, such as complex reasoning, problem-solving, and flexible thinking, and are thought to be governed by the central executive system. The central executive system was first proposed by Baddeley and Hitch (1974) as a multi-faceted component in the hierarchical model of working memory. According to the model, information is briefly stored in the visuospatial sketchpad (if it is visual) and phonological loop (if it is verbal), and the central executive acts as the main control tower that monitors and coordinates the two slave systems (Baddeley, 1986). However, working memory has limited capacity, which means that only so much information can be stored and processed simultaneously (Baddeley & Hitch, 1974). As a result, inhibition plays an important role in ignoring or discarding task-*irrelevant* information so that task-*relevant* information can be attended by the central executive system in working memory (Engle, 2018; Engle & Kane, 2004; Thomas, Shobini, & Devi, 2016).

1.2.2 Measurements of inhibition: Go/NoGo task

Various task paradigms have been used to index inhibition function (e.g., Stroop task, Stop-Signal task, Flanker task, antisaccade task, directed-forgetting task, cued recall task, etc.). Of many, the Go/NoGo task paradigm is often used to assess one's inhibitory control (e.g., Bezdjian, Baker, Lozano, & Raine, 2009; Kida, Oda, & Matsumura, 2005; Nakamoto & Mori, 2008b; Smith, Jamadar, Provost, & Michie, 2013; Tiego, Testa, Bellgrove, Pantelis, & Whittle, 2018). Participants are required to respond (e.g., button-press) to Go cues (e.g., the letter P), but to inhibit responses to NoGo cues (e.g., the letter R) as quickly as possible before the next trial begins on the computer. The task is fast paced (e.g., 500ms stimulus presentation, 1500ms inter-stimulus interval) either with or without feedback. It is important to maintain a greater number of Go cues than NoGo cues (e.g., 4-to-1 ratio, 3-to-1 ratio) so that participants develop a tendency to respond (prepotency) and thereby increase the inhibitory effort necessary to successfully withhold responses to NoGo trials (Simmonds, Pekar, & Mostofsky, 2008).

There are four dependent measures in a Go/NoGo task paradigm: Go accuracy (correct response to Go cues), NoGo accuracy (correct inhibition to NoGo cues), Go response time (mean response time to all responses to Go cues), and Go response time variability (mean variability to all responses to Go cues). Studies of children with attention-

deficit/hyperactivity disorder (ADHD) often interpret low Go accuracy to be indicative of inattention (Barkley, 1991; Halperin, Wolf, Greenblatt, & Young, 1991) and low NoGo accuracy with fast Go RT to be indicative of impulsivity (Baker, Taylor, & Leyva, 1995; Bezdjian et al., 2009; Halperin et al., 1991). However, neuropsychological evidence suggests that response inhibition (NoGo accuracy) and response selection (Go accuracy) may be two sides of the same coin (Mostofsky & Simmonds, 2008; Simmonds et al., 2008). According to Simmonds et al. (2008), response inhibition is an active process, like response selection, in which individuals actively choose not to respond (see also Raud, Westerhausen, Dooley, & Huster, 2020). fMRI studies (see for review Buchsbaum, Greer, Chang, & Berman, 2005; Simmonds et al., 2008) have shown inhibitory-associated activation of the pre-SMA (rostral portion of the supplementary motor area, associated with response preparation and selection, Hoshi & Tanji, 2004). Isoda and Hikosaka (2007) found that some of the pre-SMA neurons responded to NoGo stimuli (NoGo type), some responded to Go stimuli (Go type), and some responded to both (Dual type) in rhesus monkeys. In addition, Isoda and Hikosaka (2007) found that NoGo type and Dual type neurons were activated first followed by Go type neurons during a switching task, suggesting that 1) selection of a response first involves inhibition of other responses and 2) response inhibition and selection are distinguished by temporal domains rather than spatial domains (Mostofsky & Simmonds, 2008; Simmonds et al., 2008).

Fast response times and/or low response time variability have been suggested to reflect superior processing efficiency that may not be detected via accuracy measures. Studies found that athletes had faster response times than their novice counterparts without having to trade off accuracy (e.g., Bianco, Di Russo, Perri, & Berchicci, 2017; Cona, Cavazzana, Paoli, Marcolin, Grainer, & Bisiacchi, 2015; Kida et al., 2005; Muraskin, Sherwin, & Sajda, 2015; Nakamoto & Mori, 2008a, 2008b), possibly because athletes have superior inhibitory control not only over motor responses but also over interfering distracting information (Cona et al., 2015). Nakamoto and Mori (2008a) suggested that baseball players were able to perform faster without increasing the number of commission errors (NoGo errors), because baseball players exercised stronger inhibitory control than non-baseball players during a computer-based baseball-specific Go/NoGo task (see also Muraskin et al., 2015). The same goes for response time variability. Di Russo, Taddei, Apnile, and Spinelli (2006) proposed that novice fencers took longer to respond (slow response time) and had inconsistent response times (high response time variability) than

professional fencers during a computer-based Go/NoGo task, because they were less efficient at processing Go/NoGo stimuli (i.e., early visual processing, early stimulus discrimination) and at preparing Go/NoGo responses (i.e., early response selection).

Studies have shown an association between the four measures of the Go/NoGo task. For example, Bezdjian et al. (2009) reported that response time correlated with Go and NoGo accuracy, and Bellgrove, Hester, and Garavan (2004) reported that response time variability correlated with NoGo accuracy. As a result, studies that have used the Go/NoGo task paradigm have measured all four aspects of the task and commonly interpret all these aspects to be reflective of inhibition function.

1.2.3 Inhibition and attention

The relationship between inhibition and attention can be understood by considering Attentional Control Theory (ACT) proposed by Eysenck, Derakshan, Santos, and Calvo (2007) (see also Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011). ACT proposes that anxiety reduces attentional control because anxiety impairs inhibition (i.e., the ability to ignore distracting information) and shifting (i.e., the ability to allocate attention in a flexible manner to multiple stimuli). High-anxious individuals are more susceptible to external distractions (i.e., task-irrelevant stimuli) or internal distractions (i.e., worry, self-preoccupation), which impairs the efficiency of inhibition functions (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011). Notably, the adverse effect of distraction is suggested to be greater when the distraction is threat-related (e.g., angry faces or words such as death, skill, shame, murder) rather than neutral (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Eysenck et al., 2007).

1.2.4 Inhibition, worry, rumination, and self-consciousness

Inhibition function is necessary for successful task performance as it plays a crucial role in attentional control. Indeed, evidence suggests that inter-personal differences in inhibition function may underly variations in working memory capacity (Conway & Engle, 1994; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Gernsbacher, 1993; Kuntsi, Rogers, Swinard, Börger, Van der Meere, Rijdsdijk, & Asherson, 2006; Welsh, Satterlee-Cartmell, & Stine, 1999), memory failure (Anderson, 2001), problem-solving skills (Pasolunghi, Cornoldi, & De Liberto, 1999), and general cognitive ability (Dempster & Corkill, 1999).

According to ACT, susceptibility to mental distraction, such as worry and self-preoccupation can increase when inhibition function is impaired by anxiety. Anxiety researchers (Ashcraft & Elizabeth, 2001; Eysenck, 1979; Eysenck & Keane, 1990; Wine 1971) suggest that such intrusive thoughts can compromise working memory resources that are available for primary task performance. The overarching view of these theories, often called *distraction theories*, assumes that inability to suppress distracting thoughts can reduce working memory capacity, which in turn disrupts performance (Beilock, 2007a, 2007b; Beilock & Carr, 2001, 2005; Beilock, Kulp, Holt, & Carr, 2004; Lewis & Linder, 1997; Wine, 1971).

Moreover, studies have shown an association between poor inhibitory control and rumination, brooding, and negative thoughts (e.g., Berman, Nee, Casement, Kim, Deldin, Kross, Gonzalez, Demiralp, Gotlib, Hamilton, Joormann, Waugh, & Jonides, 2011; De Lissnyder, Derakshan, De Raedt, & Koster, 2011; Joormann, 2006; Joormann & Tran, 2009). Rumination “typically involves repetitive thoughts about past events or current mood states...and people who tend to ruminate also experience more negative affect, greater worry, and perform poorer on cognitively demanding tasks” (Kinrade, Jackson, Ashford, & Bishop, 2010b, p. 1131-1132). Kinrade et al. (2010b) found that rumination tendency was significantly associated with players’ susceptibility to choking under pressure.

Subsequently, these internal thoughts (i.e., worry, rumination) can elicit an internal focus of attention (i.e., self-consciousness, introspection), which has been proposed to provoke conscious processing of movement (i.e., movement specific reinvestment) (Masters, Polman, & Hammond, 1993).

1.3 Reinvestment and conscious control of movement

A person can climb the stairs while chatting with a friend because the movements are processed automatically with little attention to each and every ‘step’ of the movements involved. However, automatic processing of the movements can be disrupted if a person invests more thought and attention in the movements (e.g., push with the calves, bring up the knee, flex the ankle, swing the opposite arm, lean forward, land on the ball of the foot, etc.). Such ‘conscious control of movement’ can be understood as an explicit and effortful process that involves isolating and focusing on specific components of the movements (Masters et al., 1993). This generally renders the movements erratic and more prone to

error. According to Baumeister (1984), “situational demands for excellent performance (i.e., pressure) cause the individual to attend consciously to his or her internal process of performance, and this consciousness disrupts that process and harms the performance” (p. 618). Masters (1992; Masters & Maxwell, 2008; Masters et al., 1993) extended this concept theoretically by suggesting that movement specific reinvestment represents conscious monitoring and controlling of movement, which can differ as a function of individual differences between people.

1.3.1 The theory of reinvestment

Masters (1992) found that skilled performance can be disrupted by reinvesting previously acquired verbal (explicit) knowledge of the skill. Participants were required to learn a golf-putting skill either explicitly (large pool of explicit knowledge) or implicitly (small pool of explicit knowledge) and to complete a test under anxiety-provoking conditions. Participants who learned explicitly performed less robustly under stress (pressure) than those who learned implicitly, presumably because an inward focus of attention (self-consciousness) resulted in conscious processing of explicit knowledge associated with the skill (see also Hardy, Mullen, & Jones, 1996; Mullen, Hardy, & Oldham, 2007). Masters et al. (1993) subsequently suggested that reinvestment of explicit knowledge for conscious control may be a dimension of personality in which some have higher propensity than others to “reinvest actions and percepts with attention” (p. 655).

The theory of reinvestment (Masters & Maxwell, 2008) proposes that reinvestment is responsible for movement disruption via “manipulation of conscious, explicit, rule based knowledge, by working memory, to control the mechanism of one’s movements during motor output” (Masters & Maxwell, 2004, p. 208). Indeed, multiple studies have shown that individuals who were more inclined to reinvest in conscious processing reported more explicit knowledge associated with their skills, yet displayed degraded performance under pressure (e.g., Chell, Graydon, Crowley, & Child, 2003; Jackson, Ashford, & Norsworthy, 2006; Liao & Masters, 2002; Maxwell, Masters, & Eves, 2000; Maxwell, Masters, & Poolton, 2006).

There are multiple propositions for how reinvestment works. For instance, the progression-regression hypothesis (Fitts, Bahrck, Noble, & Briggs, 1961; Fuchs, 1962) suggests that conscious control of a previously automated movement causes regression to early stages of learning. Masters (1992) argued that this regression is likely to be a

function of conscious processing of explicit knowledge, which causes the movement to be broken down into smaller performance units (similar to early stages of learning), which increases the likelihood for error. Alternatively, it has been proposed that conscious control of explicit task-relevant knowledge overloads working memory capacity. Indirect evidence can be drawn from studies that have used dual-task paradigms (e.g., Masters, 1992; Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007). These studies have shown that individuals who have learned a movement skill explicitly (i.e., via accumulation of task-relevant declarative knowledge) perform worse under secondary-task loading than individuals who have learned a skill implicitly (i.e., via minimal accrual of task-relevant declarative knowledge). It has been argued that processing task-relevant declarative knowledge consumes cognitive resources (e.g., working memory), leaving few resources available to process the secondary task (e.g., Masters, 1992; Masters et al., 2008; Poolton et al., 2007).

The exact underlying mechanism of reinvestment remains unclear, partially because it is difficult to *directly* measure cognitive functions⁶ and other potential mechanisms that may underpin reinvestment. Could differences in executive functions, such as inhibitory control, predispose individuals to higher or lower propensity for movement specific reinvestment?

1.3.1.1 Reinvestment propensity

Masters et al. (1993) argued that propensity to reinvest differs from person to person and developed and validated a questionnaire to measure reinvestment (the Reinvestment Scale). The 20-item Reinvestment Scale (yes/no) was pieced together by adopting different components relevant to reinvestment from three previously validated scales (Self-Consciousness Scale, Fenigstein, Scheier, & Buss, 1975; Emotional Control Questionnaire, Roger & Neshoever, 1987; Cognitive Failures Scale, Broadbent, Cooper, FitzGerald, & Parkles, 1982). The first component assesses an individual's tendency to have 'slips of action' because they are "in some ways the result of an inherent flaw in automatic processing" (Masters et al., 1993, p. 656). The second component assesses an

⁶ It has been claimed that high co-activation (measured by electroencephalography, EEG) between the left temporal T3 region of the brain, which is associated with explicit verbal processes (Springer & Deutsch, 1998), and the frontal mid-line Fz region of the brain, which is associated with movement planning (Kaufer & Lewis, 1999), is an objective indicator of conscious control of movement (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). However, this claim is currently debated (Parr, Gallicchio, Harrison, Johnen, & Wood, 2020).

individual's tendency to mentally rehearse rules and instructions related to the skill (e.g., "When I am reminded of my past failures, I feel as if they are happening all over again") because rehearsal itself is an act of conscious processing. The third and fourth components assess private self-consciousness (e.g., "I reflect about myself a lot") and public self-consciousness (e.g., "I'm concerned about my style of doing things") because Masters et al. (1993) argued that individuals with high private and public self-consciousness would be more likely to focus inward and think about what they are doing, which can lead to a greater chance of consciously monitoring and controlling their movements. The scale was shown to be negatively correlated with golf putting performance under pressure (Study 3, Masters et al., 1993) and since then similar findings have been replicated in different movement skills (e.g., Chell et al., 2003; Jackson et al., 2006; Jackson, Kinrade, Hicks, & Wills, 2013; Kinrade, Jackson, & Ashford, 2010a; Maxwell et al., 2006; Poolton, Maxwell, & Masters, 2004).

However, Jackson et al. (2006) challenged that the Reinvestment Scale was not specific to movement, so Masters, Eves, and Maxwell (2005) developed a 10-item, 6-point Likert scale inventory to assess individual propensity for movement specific reinvest (the Movement Specific Reinvestment Scale). The new questionnaire was administered to two separate samples (N=565, N=369) from which factor analysis revealed two factors: Movement Self-Consciousness (MS-C) and Conscious Motor Processing (CMP). MS-C is assumed to measure individual propensity to consciously monitor one's style of movement (e.g., "I am concerned about my style of moving"), whereas CMP is assumed to measure individual propensity to consciously monitor the mechanics of the movement (e.g., "I try to think about my movements when I carry them out"). The test-retest reliability (over a week period) was high in both MS-C ($r = 0.67, p < 0.01$) and CMP ($r = 0.76, p < 0.01$) with acceptable internal reliability (Cronbach's alpha) for MS-C ($r = 0.78$) and CMP ($r = 0.71$). The average loading on MS-C (0.73) and CMP (0.71) was substantial and there was a moderate association between the two factors (N=565 sample $r = 0.54$, N=369 sample $r = 0.43$) suggesting that MS-C and CMP are independent factors (Masters et al., 2005). Higher scores on the scale (indicative of a high propensity for movement specific reinvest) are often associated with poor performance under pressure or when multitasking (Buszard, Farrow, Zhu, & Masters, 2013; Ellmers, Cocks, Dumas, Williams, & Young, 2016; Malhotra, Poolton, Wilson, Ngo, & Masters, 2012; Malhotra, Poolton, Wilson, Uiga, & Masters, 2015).

Kinrade et al. (2010b) argued that many skills have a significant decision-making component, which may also be influenced by a person's propensity for conscious monitoring and control. Kinrade et al. (2010b), therefore, developed and validated a 13-item two-factor Decision-Specific Reinvestment Scale (DSRS). The scale assesses individual propensity to consciously monitor/control the decision-making process (decision reinvestment; "I am always trying to figure out how I make decision") and individual propensity to ruminate over poor decisions (decision rumination; "I often find myself thinking over and over about poor decisions that I have made in the past"). Internal consistency estimates for the DSRS subscales using Cronbach's alpha coefficient were high (decision reinvestment $r = 0.89$, decision rumination $r = 0.91$) (Kinrade et al., 2010b). Higher scores on the scale (indicative of a high propensity to reinvest) are often associated with poor decision-making performance under pressure (Jackson et al., 2013; Kinrade, Jackson, & Ashford, 2015; Laborde, Furley, & Schempp, 2015; Laborde, Raab, & Kinrade, 2014). The effect of decision specific reinvestment on performance may also be a function of conscious processing of explicit knowledge. For instance, Smeeton, Williams, Hodges, and Ward (2005) found that intermediate-level tennis players who received explicit instructions had significantly slower response times when anticipating serve direction, indicating that they took longer to decide where to move compared to those who did not receive explicit instructions. Additionally, Sherwood, Smith, and Masters (2019) showed that rugby players who scored high on the DSRS displayed poor recall accuracy of rugby players' positions in an image yet took longer time to decide indicating a link between high DSRS score and impaired decision-making skills.

Overall, evidence suggests that the propensity for movement specific reinvestment differs from one person to another (Masters & Maxwell, 2008); however, the reasons remain unclear. Poor inhibition function may predispose an individual to consciously control his or her movements due to an inability to suppress introspection and thus conscious control of movements.

1.4 Summary and thesis outline

Chapter 1 has summarised the core literature and evidence that underpins the thesis. The remaining chapters, with the exception of the final chapter, are presented as papers (some of which are published). The topics discussed in Chapter 1 are further developed in the introductions to the chapters/papers.

The first experimental chapter, Chapter 2, examined the association between inhibition function and propensity for movement specific reinvestment and decision-specific reinvestment. It was hypothesised that poor inhibition function would be a hallmark of high reinvestment propensity because individuals with poor inhibition function would be less able to suppress introspection and resist conscious control of their movements and/or decisions. The study employed a Go/NoGo task to index inhibition function. The Movement Specific Reinvestment Scale (MSRS, Masters et al., 2005) and the Decision-Specific Reinvestment Scale (DSRS, Kinrade et al., 2010b) were used to measure individual propensity conscious processing of movements and decisions. In addition, given that anxiety can undermine inhibition function and elicit conscious control of movement, the Trait-Anxiety subscale of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) was used to index anxiety and examine whether anxiety moderated the relationship.

Subsequently, Chapter 3 examined the association between inhibition function and movement specific reinvestment propensity during a more complex basketball-specific Go/NoGo task. Given the theoretical assumption that performance deterioration during conscious control occurs as a result of working memory overload, task complexity of the Go/NoGo task was increased by adding a motor component to the computer-based task. As a result, a computer-based and a motor-based basketball-specific Go/NoGo tasks was developed to investigate whether the association between inhibition function and reinvestment propensity differed between the two tasks. Furthermore, the colour of the uniform worn by the basketball player in the stimuli was either red, green, or grey (control). Thus, the study also examined whether uniform colour moderated the relationship between inhibition function and reinvestment propensity.

Chapter 4 further investigated the effect of uniform colour on inhibition function during the computer-based and motor-based basketball-specific Go/NoGo tasks. In addition to the laboratory-based experiment, retrospective analysis of netball games was performed

to investigate whether performance differed between teams in differently coloured uniforms.

Thus far, research has suggested that colour effects may be perceptual, physiological, and/or psychological. Consequently, Chapter 5 investigated the effect of uniform colour on size perception to examine a potential perceptual mechanism that may contribute to colour effects (in the sport context). Two perceptual tasks were employed, a side-by-side comparison task and a relative size judgment task.

Chapter 6 investigated the effect of background colour on avoidance motivation during football penalty-kicks to examine a potential psychological mechanism that may contribute to colour effects (in the sport context). Specifically, Chapter 6 aimed to examine whether red backgrounds elicit avoidance motivation and thereby avoidance behaviour during penalty-kicks in football. This would indicate that red was perceived as a negative stimulus, possibly because red is a symbol of dominance and threat to the viewer. Moreover, archival data from professional football games was analysed to examine whether the effect of background colour existed in real life. Subsequently, with the same data set, Chapter 7 examined the effect of crowd hostility on avoidance motivation during football penalty-kicks. Given the assumption that avoidance motivation was elicited because red was evaluated as a negative stimulus, it raised a question of whether a hostile crowd, as opposed to supportive crowd, is more likely to elicit avoidance motivation.

In Chapter 8, key findings are summarised and discussed in the context of the current literature. Additionally, an attempt is made to integrate previous published findings with the current findings in this thesis in order to underpin future research with a theoretical framework. Theoretical and practical implications are evaluated and potential future research directions are proposed.

Chapter 2

Inhibitory control, conscious processing of movement and anxiety⁷

2.1 Abstract

It has been suggested that a high propensity for reinvestment (i.e., conscious processing of movements) can disrupt performance, but the mechanisms responsible are not well understood. The purpose of this study was to examine whether people with superior inhibition function (i.e., ability to suppress unwanted thoughts and behaviours) were better able to suppress conscious processing of their movements (i.e., reinvestment). Inhibition function was assessed using a Go/NoGo button-press task, and individual propensity for reinvestment was assessed using the Movement Specific Reinvestment Scale (MSRS, Masters et al., 2005) and the Decision-Specific Reinvestment Scale (DSRS, Kinrade et al., 2010b). The results revealed positive associations between inhibition function and reinvestment propensity, with better inhibition function evident in people who displayed a higher propensity to reinvest (MSRS and DSRS). Hierarchical regression analyses revealed that trait anxiety moderated the relationship between inhibition and movement specific reinvestment, with higher MSRS scores associated with better inhibition function in people with low trait anxiety. This association was not significant among people with high trait anxiety. Possible explanations for these results are discussed.

2.2 Introduction

The Theory of Reinvestment (Masters, 1992; Masters & Maxwell, 2008) proposes that there are individual differences in the inclination to use executive control to regulate their behaviours. Previous research, for example, suggests that a high propensity for movement specific reinvestment may disrupt natural regulation of movements, which can reduce their efficiency (Lam, Maxwell, & Masters, 2009a, 2009b; Maxwell et al., 2000; Poolton, Masters, & Maxwell, 2006). Theoretically, the ability to inhibit executive control of

⁷ Based on: **Park, S. H.**, Lam, W. K., Hoskens, M. C. J., Uiga, L., Cooke, A. M., & Masters, R. S. W. (2020). Inhibitory control, conscious processing of movements and anxiety. *Psychological Research*, 46, 101587, <https://doi.org/10.1016/j.psychsport.2019.101587>

movements may prevent movement specific reinvestment. Consequently, the current study was designed to examine whether inhibition ability is associated with the propensity for reinvestment. Although the relationship between working memory capacity, reinvestment and attention has been examined (e.g., Buszard et al., 2013; Laborde et al., 2015; Wood, Vine, & Wilson, 2016), no previous studies, to our knowledge, have examined directly the relationship between movement specific reinvestment and inhibition.

Inhibition is considered to be one of the fundamental executive functions necessary for complex cognitive tasks, such as learning and performing motor skills and making decisions under time pressure (Diamond, 2013; Engle, 2018; Howard, Johnson, & Pascual-Leone, 2014; Miyake et al., 2000). Inhibition is thought to aid executive control by suppressing irrelevant thoughts and inappropriate behaviours, and allowing the most relevant information to be processed during performance of tasks (Diamond, 2013; Engle, 2018; Howard et al., 2014; Miyake et al., 2000).

Despite the lack of research into the relationship between inhibition and reinvestment, it has been suggested that there may be a direct association between rumination tendency and inhibition function (Berman et al., 2011; De Lissnyder et al., 2011; De Lissnyder, Koster, Derakshan, & De Raedt, 2010; Hertel & Gerstle, 2003; Joormann, 2006; Joormann & Gotlib, 2010; Joormann & Tran, 2009; Whitmer & Banich, 2007). Rumination refers to a style of thinking that involves repetitive conscious processing of one's negative emotions and experiences. People who tend to brood over negative emotions and experiences display impaired inhibition function compared to those who do not (Davis & Nolen-Hoeksema, 2000; De Lissnyder et al., 2011; De Lissnyder et al., 2010; Linville, 1996; Yang, Cao, Shields, Teng, & Liu, 2016). Thus, there is good reason to believe that there may be a link between inhibition and propensity for reinvestment, given that reinvestment involves conscious processing of one's behaviours (i.e., movements/decisions).

One of the factors that influences both inhibition function and reinvestment is anxiety. Anxiety has been shown to impair inhibition function by having an adverse effect on attentional control, a key function of the central executive. It has been suggested that anxiety increases susceptibility to distractions (e.g., task-irrelevant stimuli or worrisome thoughts), which impairs efficiency of inhibition functions (Attentional Control Theory,

Eysenck et al., 2007; see also Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011). Furthermore, anxiety has been shown to trigger reinvestment (Chell et al., 2003; Gucciardi & Dimmock, 2008; Kinrade et al., 2015; Liao & Masters, 2002; Masters, 1992; Masters & Maxwell, 2008; Wilson, Chattington, Marple-Horvat, & Smith, 2007). Studies have shown that performance by people with a high propensity for reinvestment tends to be less robust under high anxiety conditions than in people with a low propensity for reinvestment (Gucciardi & Dimmock, 2008; Masters et al., 1993; Mullen & Hardy, 2000; Mullen et al., 2007). Poolton et al. (2004) even used structural equation modelling to estimate that golf-putting performance by high reinvesters can decrease by as much as 30% in anxiety inducing situations, suggesting that under pressure high reinvesters tend to consciously process their movements more than low reinvesters.

Consequently, the purpose of this study was to investigate the association between inhibition function (i.e., the ability to suppress irrelevant thoughts or behaviours) and propensity for reinvestment (i.e., inclination to use executive control to consciously regulate behaviours) using the Movement Specific Reinvestment Scale (MSRS, Masters et al., 2005) and the Decision-Specific Reinvestment Scale (DSRS, Kinrade et al., 2010b). Given that anxiety has been shown to have a causal effect on reinvestment and a disruptive influence on inhibition function, we examined the moderating effect of anxiety on the relationship between inhibition function and propensity for reinvestment. We predicted that people with high inhibition function would have a lower propensity for reinvestment because they are less likely to use executive control to regulate their behaviours. We anticipated that anxiety would have a moderating effect on the association between inhibition function and reinvestment.

2.3 Method

2.3.1 Participants

Ninety-one university students (45 male, 46 females; mean age 19.64 years, $SD = 3.08$) were recruited for the study, which was conducted in a computer laboratory. Ethical approval for the study was provided by the University Human Research Ethics Committee and informed consent was obtained from all participants.

2.3.2 Design and Procedure

Participants were first asked to complete the Movement Specific Reinvestment Scale (MSRS, Masters et al., 2005) and the Decision-Specific Reinvestment Scale (DSRS, Kinrade et al., 2010b) as measures of individual propensity for movement-specific and decision-specific reinvestment, respectively. Trait anxiety was then assessed with the Trait-Anxiety subscale of the State-Trait Anxiety Inventory (Spielberger et al., 1983). The MSRS comprises 10 items that assess an individual's propensity to consciously monitor and control their movements (e.g., "I am always trying to think about my movements when I carry them out" or "I am concerned about my style of moving"). The items are rated on a 6-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (6). The cumulative scores range from 10 to 60, with higher scores indicating greater conscious processing associated with movement. The DSRS comprises 13 items that assess an individual's propensity to consciously monitor and control processes involved in decision-making (e.g., "I'm always trying to figure out how I make decisions" or "I often find myself thinking over and over about poor decisions that I have made in the past"). The items are rated on a 5-point Likert scale ranging from *extremely uncharacteristic* (0) to *extremely characteristic* (4). The cumulative scores range from 0 to 52, with higher scores indicating greater conscious processing of decisions associated with movement. The Trait-Anxiety subscale of the State-Trait Anxiety Inventory comprises 20 items (e.g., "I worry too much over something that doesn't really matter") that are rated on a 4-point Likert scale ranging from *almost never* (1) to *almost always* (4). The cumulative scores range from 20 to 80, with higher scores indicative of greater general anxiety.

Following administration of the questionnaires, participants completed a Go/NoGo task to assess their inhibition functions (Psychology Experiment Building Language, PEBL, Mueller & Piper, 2014).⁸ The Go/NoGo task displayed a square in the middle of the screen, with a blue star visible in the center of each quadrant of the square. Every 1500ms one of the blue stars was replaced by the letter P or R, which appeared for 500ms. Participants were instructed to respond as quickly as possible by left-clicking the mouse when the

⁸ PEBL is a free software that includes numerous psychology tasks licensed under General Public Licence. The parameters of the ready-made experimental tasks can be modified, which allowed us to adjust the number of trials. The software can be downloaded from <http://pebl.sourceforge.net/>.

letter P appeared (Go trials, response activation) but not to respond when the letter R appeared (NoGo trials, response inhibition). The task included ten practice trials with feedback, and one test block with 100 trials without feedback (Go/NoGo ratio 4:1, Bezdjian et al., 2009).

2.3.3 Data Analysis

There were four possible outcomes during the Go/NoGo task: respond on Go trials (correct), non-respond on Go trials (omission error), inhibit a response on NoGo trials (correct) and incorrectly respond on NoGo trials (commission error). All outcomes were converted into percentiles but only omission and commission errors were used in the analyses as studies have shown that omission errors reflect inattention while commission errors reflect impaired inhibition (Barkley, 1991; Bezdjian et al., 2009; Halperin et al., 1991).

In addition to response accuracy, we also computed average response time (RT) and response time variability (RTV) in trials involving Go responses to further index inhibition (see Barkley, 1991; Bellgrove et al., 2004; Bezdjian et al., 2009; Halperin et al., 1991; Kindlon, Mezzacappa, & Earls, 1995; Nakata, Sakamoto, & Kakigi, 2012; Nigg, 1999; Simmonds, Fotedar, Suskauer, Pekar, Denckla, & Mostofsky, 2007; Simmonds et al., 2008).⁹ The sum of RT for Go trials was divided by the total number of hits (i.e., correct responses to Go trials) to tabulate the average RT for Go trials (Go RT). The RTV for Go trials (Go RTV) was calculated using intra-individual coefficient of variation ($ICV = Go RT_{SD} / Go RT_M$) to control for differences in mean response time (see Bellgrove et al., 2004).

We set up four exclusion criteria adopted from Bezdjian et al. (2009). First, we removed trials with an RT less than 120ms. The average time needed for visual processing is 150ms during the Go/NoGo task (Thorpe, Fize, & Marlot, 1996), suggesting that RTs close to 120ms were not purposeful responses but an unintentional coincidence. Second, if there was a missing response to a Go trial (n th trial) prior to a trial with an RT less than 120ms

⁹ Studies have shown a high correlation between commission error and response time variability (Simmonds et al., 2007; Bezdjian et al., 2009) and a significant correlation between neural activation related to inhibition function and response time variability (Bellgrove et al., 2004; Simmonds et al., 2007; Nakata et al., 2012), indicating that increased response time variability for Go stimuli reflects poor inhibitory control.

($RT_{n+1} < 120\text{ms}$), we corrected the n th trial as “Responded.” In addition, the RT of the n th trial was corrected by combining the allotted response time (1450ms) with the RT of the next trial ($RT_n = 1450\text{ms} + RT_{n+1}$). We considered these to be slow responses to previous trials, which occurred when the next trial had appeared, although this seldom occurred. Lastly, to eliminate participants who responded/non-responded without regard to the stimuli, participants with commission errors higher than 75% and a hit rate (i.e., correct response to Go trials) lower than 75% were removed. As a result, $n=5$ participants were excluded from the study. Data were then visually screened using box-plots to check for skewness and outliers (i.e., values more than 3 times the interquartile range), and $n=3$ participants were removed from the analysis.

Pearson’s product-moment correlation coefficients were used to examine the association between propensity for reinvestment (MSRS/DSRS scores) and inhibition function. Hierarchical regression analysis was conducted to examine whether anxiety moderated the relationship between inhibition function and propensity for reinvestment (see Figure 2.1). For the analysis, we followed the steps recommended by Frazier, Tix, and Barron (2004). First, the inhibition function variables (NoGo error, Go RT, and Go RTV) and moderator variable (Anxiety) were standardized to control for problems associated with multicollinearity ($M = 0$, $SD = 1$). Next, product terms were calculated by multiplying each standardized predictor variable by the standardized moderator variable – because there were three predictor variables and one moderator variable, three product terms were produced. Variables were entered into a regression equation in a step-wise manner. In the first step, the predictor and moderator variables were entered. In the second step, the product term was entered. For the second step, a significant moderator effect was indicated by significant change in the R^2 for the product term. Regression assumptions were tested and satisfied: the average variance of inflation factor (VIF) values was not considerably greater than 1, tolerance values were greater than 0.7, and the maximum VIF values remained below 1.5. The Durbin-Watson statistics were within an acceptable range (1 to 3). The level of significance was set at $p = 0.05$.

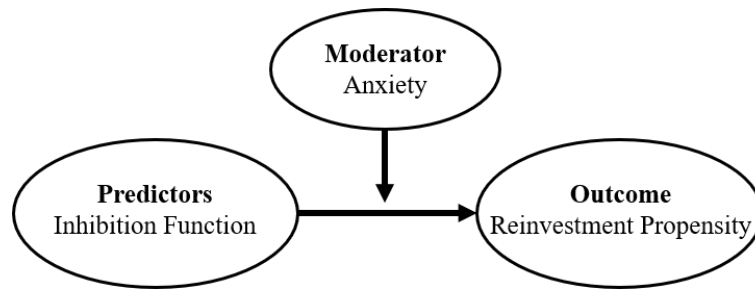


Figure 2.1. An illustrative model of the moderation effect of anxiety on the association between inhibition function and reinvestment.

2.4 Results

2.4.1 Correlational Analysis

Significant correlations were found between Go RTV and MSRS scores ($r = -.249$, $p = .023$), and Go RTV and DSRS scores ($r = -.261$, $p = .017$). Better inhibition function was associated with a high propensity for movement specific reinvestment and for decision-specific reinvestment, as indicated by less variable response times on Go trials (see Table 2.1).

Table 2.1. Correlation matrix for inhibition function, propensity for reinvestment and trait anxiety.

Variables	Mean	SD	1	2	3	4	5	6	7
Reinvestment									
1. MSRS	39.60	7.48	-						
2. DSRS	30.01	8.05	0.53**	-					
Go/NoGo task									
3. Go error (%)	1.07	2.74	-0.15	-0.10	-				
4. NoGo error (%)	38.03	17.18	-0.17	-0.11	0.05	-			
5. Go RT (ms)	404.74	39.45	0.04	0.05	0.15	-0.51**	-		
6. Go RTV (ms)	0.19	0.03	-0.25*	-0.26*	0.48**	0.30**	0.02	-	
Trait Anxiety									
7. Trait-STAI	41.46	9.04	0.22*	0.45**	0.02	0.21	0.01	0.04	-

Note: * $p < 0.05$, ** $p < 0.01$

Abbreviations: MSRS, Movement Specific Reinvestment Scale; DSRS, Decision-Specific Reinvestment Scale; RT, response time; RTV, response time variability; Trait-STAI, Trait-anxiety subscale of State-Trait Anxiety Inventory.

2.4.2 Hierarchical Regression Analysis

The results of the hierarchical regression analyses are presented in Table 2.2.

Table 2.2. Hierarchical regression analyses for testing moderator effects.

	<i>B</i>	<i>SE B</i>	95% CI	β	<i>R</i> ² Change
MSRS (Predictor NoGo error)					
Step 1					
NoGo error (z-score)	-1.67	0.81	-3.29, -0.05	-0.22*	
Anxiety (z-score)	2.01	0.81	0.40, 3.63	0.27*	0.10*
Step 2					
NoGo error x Anxiety	0.46	0.77	-1.07, 1.99	0.06	0.004
MSRS (Predictor Go RT)					
Step 1					
Go RT (z-score)	0.28	0.81	-1.34, 1.90	0.04	
Anxiety (z-score)	1.66	0.81	0.04, 3.28	0.22*	0.05
Step 2					
Go RT x Anxiety	0.55	1.12	-1.67, 2.77	0.05	0.003
MSRS (Predictor Go RTV)					
Step 1					
Go RTV (z-score)	-1.92	0.79	-3.49, -0.36	-0.26*	
Anxiety (z-score)	1.74	0.79	0.17, 3.30	0.23*	0.12**
Step 2					
Go RTV x Anxiety	2.40	0.90	0.60, 4.19	0.27**	0.07**
DSRS (Predictor NoGo error)					
Step 1					
NoGo error (z-score)	-1.68	0.80	-3.28, -0.08	-0.21*	
Anxiety (z-score)	3.94	0.80	2.35, 5.54	0.49**	0.24**
Step 2					
NoGo error x Anxiety	0.09	0.76	-1.43, 1.60	0.01	0.01
DSRS (Predictor Go RT)					
Step 1					
Go RT (z-score)	0.36	0.81	-1.24, 1.96	0.05	
Anxiety (z-score)	3.59	0.81	1.99, 5.19	0.45**	0.20**
Step 2					
Go RT x Anxiety	-0.21	1.10	-2.41, 1.98	-0.02	0.01
DSRS (Predictor Go RTV)					
Step 1					
Go RTV (z-score)	-2.24	0.77	-3.77, -0.71	-0.28**	
Anxiety (z-score)	3.68	0.77	2.15, 5.20	0.46**	0.28**
Step 2					
Go RTV x Anxiety	1.12	0.91	-0.69, 2.93	0.12	0.01

Note: * $p < 0.05$, ** $p < 0.01$

Abbreviations: MSRS, Movement Specific Reinvestment Scale; DSRS, Decision-Specific Reinvestment Scale; RT, response time; RTV, response time variability.

Results from the regression analyses revealed a significant interaction between Go RTV and Anxiety for MSRS ($B = 2.40, p = .009$). No significant interactions were found for any other inhibition variables. Post-hoc probing of the significant interaction effect was conducted using t -tests to compare each regression line against zero (Holmbeck, 2002). Regression lines were then plotted (Figure 2.1). For people with high trait anxiety, Go RTV was not significantly related to MSRS, $B = 9.40, t(82) = 0.28, p = .777$. For people with low trait anxiety, however, Go RTV was significantly and negatively associated with MSRS, with low Go RTV (better inhibition) related to higher scores on MSRS, $B = -130.53, t(82) = -3.66, p = .001$.

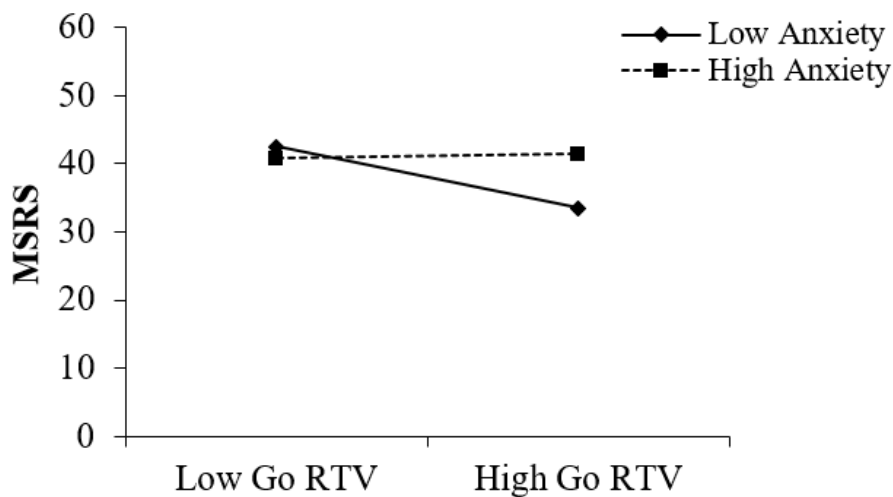


Figure 2.2. The interaction between inhibition (Go RTV) and trait anxiety for scores on the Movement Specific Reinvestment Scale (MSRS).

2.5 Discussion

This study examined the association between inhibition function and propensity for reinvestment (MSRS and DSRS) and sought to establish whether anxiety has a moderating effect on the relationship between inhibition function and propensity for reinvestment. We postulated that people with good inhibitory control would be better at suppressing executive control of their movements or decisions. Thus, we hypothesised that inhibitory function would be negatively correlated with propensity for reinvestment. Instead, in this study, superior inhibition function (reflected by lower Go RTV) was

observed among participants who scored high on the Movement Specific Reinvestment Scale (MSRS) and/or the Decision-Specific Reinvestment Scale (DSRS).

It is possible that a corollary of greater conscious processing by people with a high propensity for reinvestment was superior attention during the Go/NoGo task, and thus better inhibition scores. Superior attention to conscious processing of the movement might have facilitated performance of the Go/NoGo task. There has been much discussion of the role of conscious control in directing attention and suppressing inappropriate behaviours (e.g., Baddeley & Logie, 1999; Norman & Shallice, 1986; Schneider, Dumais, & Shiffrin, 1984). For example, Attentional Control Theory (ACT, Eysenck et al., 2007) assumes that the way attention is directed plays a key role in central executive functions, such as inhibition (and can be compromised as a result of anxiety).

On the other hand, it is also possible that those who consciously processed their movements were more likely to strategise about the task. Given the 4:1 Go/NoGo ratio, one of the strategies could have been to respond rapidly regardless of the type of stimulus present. This strategy would have resulted in 80% accuracy. However, by eliminating participants with commission error higher than seventy-five percent, we attempted to reduce the likelihood that this occurred. Nonetheless, we acknowledge that it remains a possibility and further studies are required to investigate the relationship between reinvestment and strategic behaviour.

Our moderation analyses demonstrated that anxiety moderated the relationship between inhibition function and reinvestment propensity, possibly because attention was affected by anxiety. Among low trait anxious individuals, people with high MSRS scores benefited from (goal-directed) attention and therefore exhibited good inhibition ability (reflected by low Go RTV). On the other hand, among high trait anxious individuals, there was no association between MSRS scores and inhibition ability. ACT (Eysenck et al., 2007) suggests that high anxious individuals function less efficiently than low anxious individuals, and thus use compensatory strategies (e.g., increased effort) to maintain similar performance levels despite the reduced processing efficiency. However, ACT suggests that high anxious individuals may not use these compensatory strategies during non-demanding tasks, such as our simple button-pressed Go/NoGo task. As a result, the association between superior inhibition ability and high MSRS score was not found for high anxious individuals. Further research is warranted to address these explanations, as

attention was not directly measured in our study.

So far, we have attempted to indirectly explain our results by arguing that people with a high propensity for reinvestment had superior attention on the task. It is possible, however, that they simply had better inhibition function. These individuals might have learned to suppress their tendency to consciously control movements better than people with a low propensity for reinvestment. Studies have shown negative effects of conscious control (e.g., increased accumulation of task-relevant knowledge and performance breakdown) but humans are adept at developing cognitive processes that allow them to cope with such disadvantages. Jackson et al. (2006), for example, suggested that high reinvesters performed motor tasks better than low reinvesters during skill-focused conditions (designed to cause conscious processing of their movements) because high reinvesters were acclimatized to conscious processing, as suggested by Baumeister (1984). In line with this argument, people with a high propensity for reinvestment might have learned to control their catastrophic habit by suppressing such thoughts. However, our moderation analysis suggests that such learned abilities were diminished among high trait anxious individuals. From an applied perspective, it may be the case that athletes or performers with a cocktail of both high trait anxiety and the propensity for movement specific reinvestment, which can often be problematic in high pressure situations, benefit most strongly from inhibition training.

An interesting consideration would be to examine whether a more complex Go/NoGo task, rather than our simple Go/NoGo task, would result in different inhibition scores among people with high and low reinvestment propensities. Studies have shown that performance of tasks can deteriorate when there is an overload of cognitive processes (Baddeley, 2010; Baddeley & Logie, 1999). More complex forms of Go/NoGo tasks include additional rules such as “respond only after two consecutive Go stimuli” or respond “when *both* lights in the middle of the screen are switched on”, which require more cognitive processing. Indeed, fMRI studies have shown that more complex Go/NoGo tasks recruit more brain regions than the simple Go/NoGo task (Mostofsky, Schafer, Abrams, Goldberg, Flower, Boyce, Courtney, Calhoun, Kraut, & Denckla, 2003; Simmonds et al., 2008). As a result, it would be worthwhile to investigate the effect of increased cognitive task load on people who tend to consciously process information (i.e., high reinvesters).

2.6 Conclusion

Higher propensity for reinvestment was associated with superior inhibition function. Although our study is preliminary, it provides an important departure point for further exploration of how people with different propensities for conscious control of their movements process cognitive information, and how inhibition function and anxiety might change the reinvestment process.

Chapter 3

Investigating the relationship between inhibition function, propensity for conscious control of movement, and colour^{10, 11}

In Chapter 2, individuals with a high propensity for conscious control of their movements displayed superior inhibitory control during a simple button-press Go/NoGo task. However, a question was raised about whether the association would persist during a more complex Go/NoGo task (high cognitive load) that required a gross-motor response. A computer-based and a motor-based basketball-specific Go/NoGo task was developed. The secondary aim was to probe the relationship between inhibition function, propensity for conscious control of movement and uniform colour using exploratory moderation analysis.

3.1 Abstract

In a previous study (Park et al., 2020; Chapter 2), we found a positive association between inhibition function and the propensity for conscious processing of movement (i.e., movement specific reinvestment) during a simple Go/NoGo task. The current study aimed to examine the association between inhibition function and propensity for conscious control of movements during a more complex Go/NoGo task. Colour also has been found to influence inhibition function so we also asked whether colour moderates the association. Forty-four non-professional basketball players completed a computer-based and a motor-based basketball-specific Go/NoGo task as a measure of inhibition function. Responses were required to Go/NoGo stimuli that were coloured red, green, or grey. Correlation analyses revealed that individuals with a high propensity to consciously control their movements displayed superior Go/NoGo performance in both the computer-

¹⁰ Conference presentation: **Park, S. H.**, Hoskens, M. C. J., Uiga, L., & Masters, R. S. W. (2018, November). Investigating the association between overthinking and performance in a simple Go/NoGo task. *Australasian Skill Acquisition Network Annual Conference*, Sydney, Australia.

¹¹ Based on: **Park, S. H.**, Lam, W. K., Uiga, L., Cooke, A. M., Capio, C. M., & Masters, R. S. W. (under review). Investigating the relationship between inhibition function, propensity for conscious control of movement, and colour. *Psychological Research*.

and motor-based tasks, possibly because conscious control is needed for successful inhibition of automatic responses. Moderation analysis revealed that uniform colour moderated the relationship. For green and grey uniforms, participants with a low tendency to consciously control their movements displayed poorer inhibition ability than participants with a high tendency, but for a red uniform inhibition ability remained high, regardless of whether participants had a high or a low tendency for conscious control of their movements. Our findings suggest that colour moderates inhibitory control in people who have a low propensity for movement specific reinvestment.

3.2 Introduction

Despite hours and hours of endless training, professional athletes sometimes suffer from performance deterioration at inopportune moments. The theory of reinvestment (Masters & Maxwell, 2008) predicts that performance deterioration can occur when individuals use task-relevant declarative knowledge to consciously control previously automated movements (i.e., reinvestment). Conscious, step-by-step control of movement is slow and increases opportunity for errors during actions that normally operate smoothly and effortlessly (Beilock & Carr, 2001; Masters & Maxwell, 2008). Masters and colleagues (Masters et al., 1993; Masters & Maxwell, 2008) argued that the propensity to reinvest (i.e., consciously control movements) is a function of personality and therefore differs from one person to another. Research has shown that people with a high propensity for movement specific reinvestment are more likely to show performance decrements under pressure or when multitasking (Jackson et al., 2006; Maxwell et al., 2000).

Questions about the possible mechanisms through which conscious control disrupts movement execution remain. For example, could the propensity to reinvest be associated with an inability to suppress the urge to consciously control movements? Park et al. (2020) aimed to answer this question by examining the association between inhibition function and reinvestment propensity. Inhibitory control allows suppression of irrelevant thoughts and inappropriate behaviours, which allows the most relevant information to be attended and processed during task performance (Diamond, 2013; Engle, 2018; Engle & Kane, 2004; Howard et al., 2014; Miyake et al., 2000). Inhibitory control is considered to be a fundamental executive function necessary for complex cognitive tasks, such as learning/performing motor skills and making decisions under time pressure (Diamond, 2013; Engle, 2018; Howard et al., 2014; Miyake et al., 2000). Park et al. (2020) expected

superior inhibition function to be associated with low propensity for movement specific reinvestment, possibly because individuals with superior inhibitory control abilities can better suppress thoughts associated with conscious processing of their movements (e.g., recall of task-relevant declarative knowledge). However, Park et al. (2020) found that individuals with a high propensity for movement specific reinvestment displayed better inhibitory control during a simple computer-based Go/NoGo task, possibly due to superior attention to the task.¹² Conscious control of movements entails recall and application of task-relevant declarative knowledge, which demands attention capacity. Buszard et al. (2013) found that propensity for reinvestment was positively correlated with working memory capacity, suggesting that high working memory capacity predisposes people to consciously control their movements or that a tendency to consciously control movements causes higher capacity. However, other studies indicate that when working memory capacity is compromised by pressure or anxiety, movements that are consciously controlled deteriorate significantly (e.g., Beilock & Carr, 2005; Worthy, Markman, & Maddox, 2009), presumably because too few attention resources are left available to efficiently process the information needed for effective movement. Consequently, Park et al. (2020) argued that perhaps individuals with a high propensity for movement specific reinvestment displayed better inhibition because the simplicity of the movements involved in the computer-based Go/NoGo task allowed conscious control to occur without overloading working memory capacity—that is, the movements required to complete the simple Go/NoGo task were supported by minimal task-relevant declarative knowledge, so directing attention to the movements translated to superior attention to the task, rather than disrupted motor processing.

Park et al. (2020) therefore raised a question over whether the positive association between propensity for movement specific reinvestment and inhibition function would persist during tests of inhibition function that involve more complex movements (typically supported by more task-relevant declarative knowledge), which impose a greater load on working memory capacity.

It has also been suggested that inhibition function can be influenced by colour. Blizzard

¹² In their study, participants completed the Movement Specific Reinvestment Scale (MSRS; Masters et al., 2005), the Decision-specific Reinvestment Scale (DSRS; Kinrade et al., 2010b), and a button-press Go/NoGo task (i.e., respond to P, inhibit response to R).

et al. (2017) found that a red stop signal facilitated response inhibition during a Stop-Signal task, during which participants were required to inhibit their response *after* the go signal was indicated. Blizzard et al. (2017) found that response inhibition was more sensitive to the colour red than other colours (green, yellow, or blue). They concluded that red is a more salient colour than green, yellow, or blue, so it captures attention more easily, which facilitates response inhibition.

Hence, the first object of the current study was to examine the association between inhibition function and propensity for movement specific reinvestment during a complex motor task, but a secondary aim was to probe for a moderating effect of colour on the relationship between propensity for movement specific reinvestment and inhibition function. We developed a basketball-specific Go/NoGo task that required either a simple computer-based movement response (a button press) or a complex motor-based movement response (a basketball pass). The complex movement response was likely to be supported by considerably more task-relevant declarative knowledge than the simple movement response. The basketball task utilised images of a basketball opponent in different positions to indicate Go and NoGo cues (further explained in the Methods). We expected to see a negative association between propensity for movement specific reinvestment and inhibition function for the motor-based task, because the opportunity that high reinvesters have to consciously process more complex movements is likely to overload their working memory capacity, and, thus, does not translate to superior attention to the task.

3.3 Methods

3.3.1 Participants

Forty-four non-professional basketball players (30 males; M age = 23.91 years, SD = 3.87 years; M experience = 3.72 years, SD = 3.76 years, range of experience 0 to 11 years) were recruited. Participants were screened for colour blindness at the end of the experiment to avoid alerting them to the purpose of the experiment. None of the participants were colour blind ($N=0$). Chinese instructions were available for those who preferred to use Chinese over English. Ethical approval was provided by the University Human Research Ethics Committee and informed consent was obtained from all participants.

3.3.2 Computer-based basketball-specific Go/NoGo task

Participants sat approximately 50 cm from a 15” laptop monitor (LG Gram 15Z970, 59 Hz refresh rate, 1920 x 1080 resolution, RGB colour format) situated to meet their eye level. For each trial, a basketball opponent appeared either on the left or right side of the computer screen but never in the middle so that space was always larger on one side of the player than on the other. The goal of the task was for participants to indicate their pass (“z” key for a left pass, “/” key for a right pass) towards the side with more space as quickly and accurately as possible (Go trials) unless the basketball opponent was defending that space in which case the response had to be inhibited (NoGo trial). The basketball opponent was standing with his arms in front (neutral) or with his arms reaching out towards one side (defensive) and the opponent was either wearing a red, green, or grey uniform against a white background (see Figure 3.1).

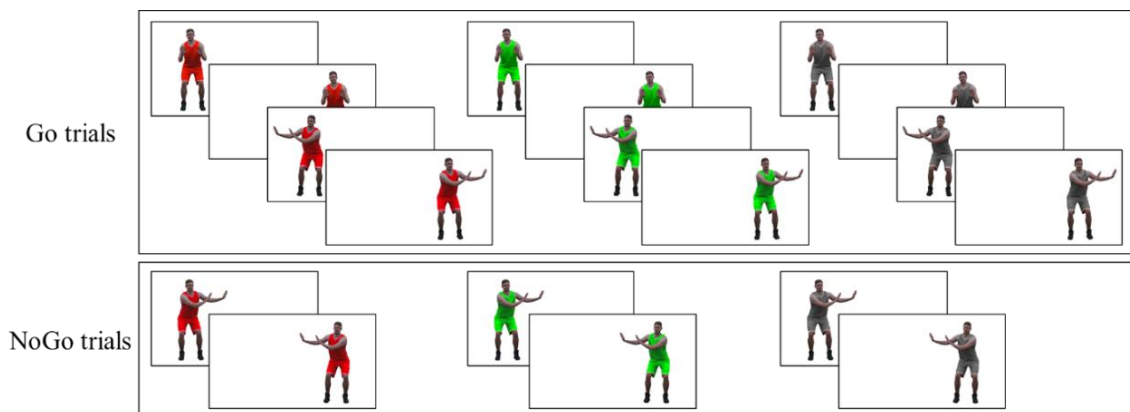


Figure 3.1. A basketball opponent appears on the left or right side of the stimulus. For Go trials, one side has more space, but the basketball opponent stands in a neutral posture or defends the side with less space. However, for NoGo trials, the side with more space is defended by the basketball opponent. The basketball opponent is shown in either red, green, or grey uniform.

There were twelve stimuli for Go trials (3 colours x 2 positions x 2 sides) and six stimuli for NoGo trials (3 colours x 1 position x 2 sides). We maintained the ratio of three-to-one Go/NoGo ratio (see Young, Sutherland, & McCoy, 2018) with 144 Go trials and 48 NoGo trials (total of 192 trials) across 4 blocks. Practice trials consisted of 8 Go trials and 2 NoGo trials with feedback to ensure that participants understood the task instructions. Each stimulus was presented in random order for 500 milliseconds with an inter-stimuli interval of 1500 milliseconds. The Go/NoGo tasks were programmed using Experiment (Krause & Lindemann, 2014) on OpenSesame (Mathôt, Schreij, & Theeuwes, 2012). If participants accidentally responded more than once during a trial, only their first response was recorded.

The colour of the uniform was photoshopped using GNU Image Manipulation Program (GNU Project). As recommended by Elliot and Maier (2014), only the hue of the colour (red, green) differed while the saturation (intensity of the colour) and value (brightness of the colour) remained constant (saturation of 100, value of 100). Due to the nature of the HSV (hue, saturation, value) colour model, saturation must be near zero for grey colours with lower value as dark grey (zero being black) and higher value as light grey (hundred being white). As a result, HSV numbers are as followed: red 0, 100, 100; green 120, 100, 100; and grey 0, 0, 50.

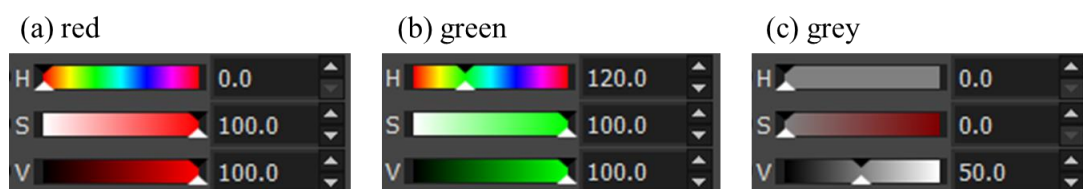


Figure 3.2. As illustrated, hue (H) determines the colour while saturation (S) and value (V) determine the intensity and brightness of the colour. For red (a) and green (b), only hue differs while saturation and value remain constant. For grey (c), hue becomes irrelevant as any colour with near zero saturation displays the colour we know as grey.

3.3.3 Motor-based basketball-specific Go/NoGo task

Like the computer-based Go/NoGo task, the goal of the motor-based task was to indicate the larger side of the space as quickly and accurately as possible. The same stimuli were used but instead of keyboard press, participants were now required to make an actual pass (see Figure 3.3).



Figure 3.3. Instructions on how to make a pass during a motor-based Go/NoGo task.

Participants were asked to hold the ball close to their chest before every trial and throw with both hands. Passing instructions were specified as such to control for different throwing technique that may influence accuracy and response time. In addition, the task was projected on a wall (149 centimeters x 260 centimeters) and the participants stood 300 centimeters away from the wall. There were 40 inflatable balls (diameter of 58 centimeters) inside a cardboard box positioned on the left side of the participant (see Figure 3.4). The inter-stimulus interval was also increased to 2,500 milliseconds to accommodate for the increased response time (e.g., ball flight time).

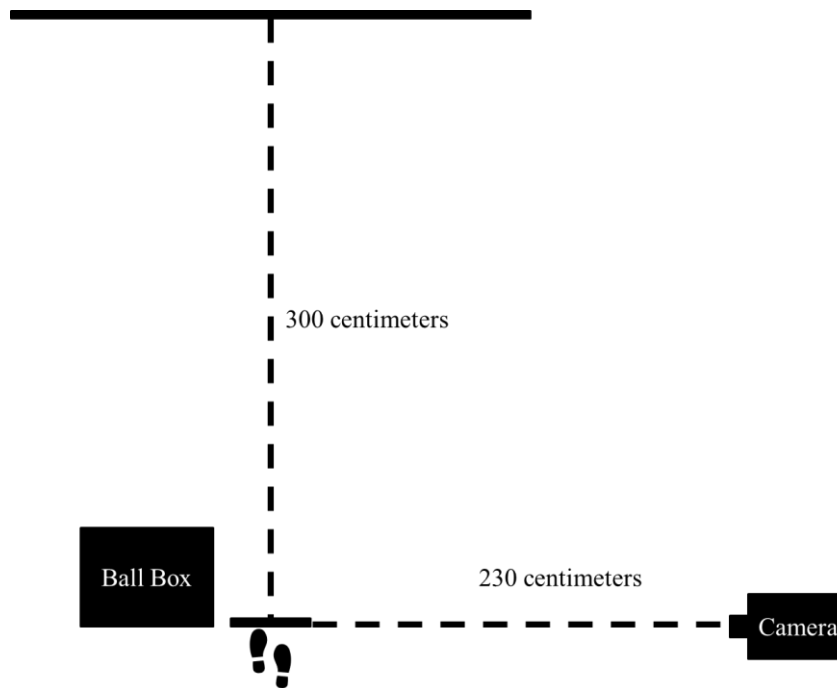


Figure 3.4. Layout of the motor-based basketball-specific Go/NoGo task.

Unlike the computer-based task, response selection and response time were not automatically recorded via OpenSesame. Thus, task performance was recorded using a high-speed video camera (GoPro Hero 6, 120 fps, 1920 x 1080 resolution, 1/480 ss, linear FOV, ISO MIN 100, ISO MAX 1600), situated 300 cm away and 230 cm off right from the center of the screen (see Figure 3.4).

3.3.4 *Experimental Procedure*

The participants were informed that the purpose of the experiment was to examine motor performance during both computer-based and motor-based basketball-specific Go/NoGo Tasks (counterbalanced). Prior to the experiment, participants were asked to complete a brief demographics questionnaire (e.g., age, sex, basketball experience).

The computer-based and motor-based basketball-specific Go/NoGo tasks were counterbalanced and in between the tasks participants completed the Movement Specific Reinvestment Scale (MSRS, Masters et al., 2005)¹³ and the Edinburgh Handedness Inventory (Oldfield, 1971) as a measure of individual propensity for reinvestment (i.e.,

¹³ For those who preferred Chinese over English instructions, MSRS-Chinese were administered (Wong, Masters, Maxwell, & Abernethy, 2008; Wong, Masters, Maxwell, & Abernethy, 2009).

conscious control of movements) and handedness (i.e., preference to use one hand more than the other), respectively. The MSRS consists of 10 items that assess individual propensity to consciously think about the style of movement (Movement Self-consciousness, MS-C, (e.g., “I am concerned about my style of moving”) and to consciously monitor the mechanics of the movements (Conscious Motor Processing, CMP, (e.g., “I am always trying to think about my movements when I carry them out”). The items are rated on a 6-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (6). The cumulative scores for each subscale range from 5 to 30, with higher scores indicating greater conscious processing associated with movement. Studies have shown differential effects of MS-C and CMP on motor performance (e.g., Iwatsuki, Van Raalte, Brewer, Petitpas, & Takahashi, 2018; Malhotra, Poolton, Wilson, Fan, & Masters, 2014; Malhotra et al., 2015; Zaback, Cleworth, Carpenter, & Adkin, 2015). Thus, to gain greater insight into the relationship between propensity for movement specific reinvestment and inhibition function, we analysed the subscales separately. The Edinburgh Handedness Inventory consists of 10 items that assess individual preference in the use of hands in different activities (e.g., writing, throwing, using toothbrush, using spoon, etc.). The scores represent -100 (always left), -50 (usually left), 0 (equally both), 50 (usually right), and 100 (always right). There were two participants who were left-handed (always left N=1, usually left N=1), but separate analysis with and without left-handed participants indicated no significant changes to the results so they were included in the subsequent analysis.

At the end of the experiment, as a verbal funnel debrief, participants were asked to reiterate the purpose of the experiment (e.g., “What do you think the current experiment was about?) and if colour was mentioned, to guess our hypothesis (e.g., “What do you think was our hypothesis?”). Five participants mentioned colour in the funnel debrief but only two participants correctly guessed our hypothesis. Similar to Elliot et al. (2007), only those who guessed our hypothesis were excluded from the study (N = 2). Next, participants completed the Ishihara’s test for colour blindness (Ishihara, 1972) available online (<https://enchroma.com/pages/color-blindness-test>) and then were briefed, thanked, and received 180 CNY (approximately 26 USD) for their participation.

3.3.5 Data Processing and Analysis

There were four dependent measures for the computer-based Go/NoGo task: Go accuracy (correct response to Go trials), NoGo accuracy (correct response to NoGo trials), Go RT (average response time to Go trials), and Go ICV (average intra-individual coefficient of variation to Go trials as a measure of response time variability, $ICV = Go RT_{SD}/Go RT_M$).

Previous studies have excluded trials with response times less than 250 milliseconds as they were considered to be pre-mature responses (Gomez, Ratcliff, & Perea, 2007; Park et al., 2020). There were no trials with response times less than 250 milliseconds in our current study.

Moreover, to eliminate anyone who was not paying attention – either constantly responding or not responding – we excluded those with low accuracy for NoGo trials (suggesting constant response) and Go trials (suggesting lack of response). Since our Go/NoGo ratio was 3 to 1, we set the accuracy cut-off to 1/3 (i.e., remove participants with Go and NoGo accuracy less than 66.67%). As a result, one participant (NoGo accuracy = 41.67%) was excluded from the study.

Similarly, the motor-based Go/NoGo task had dependent measures of Go accuracy, NoGo accuracy, Go RT, and Go ICV. Go RT was identified as time between stimulus onset until the moment that the ball left both hands (ball release – stimulus onset). We also measured the time it took for the ball to reach the wall after it had been released ($Go RT_{BF} = \text{ball hits wall} - \text{ball release}$). Response times were recorded using Dartfish (Dartfish SA, Switzerland), and Go ICV and $Go ICV_{BF}$ were calculated accordingly.

Go RTs with a Cook's distance of more than 1 (Cook & Weisberg, 1982) for both the computer-based task and the motor-based task were excluded from the study ($N = 4$). As a result, a total of thirty-seven participants were included in the data analysis (27 males; M age = 24.38 years, $SD = 3.90$ years; M experience = 3.99 years, $SD = 3.69$ years, range of experience 0 to 11 years).

Pearson's product-moment correlation coefficients were used to examine the association between propensity for MSRS (MS-C and CMP) and inhibition function (basketball-specific Go/NoGo tasks). A correlation coefficient between 0.1 to 0.3 is generally regarded as small, 0.3 to 0.5 as medium, and 0.5 to 1.0 as large (Rogers & Nicewander, 1987). The Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995) was applied

to account for multiple comparisons, with the false discovery rate set at the 5% level.

MEMORE for SPSS (MEdiation and MOderation for REpeated measures, Montoya, 2019) was used to examine the within-subject moderation effect of colour (red, green, grey) on the relationship between propensity for movement specific reinvestment and inhibition function. The analysis structure of MEMORE includes a focal predictor (X), an outcome variable (Y), and at least one between-person variable (W) in a two-condition or two-occasion within-subject/repeated design. In other words, X needs to be a two level within-subject design while W needs to be a between-person variable (categorical or continuous). According to our current study design, Go/NoGo task performance is affected by the colour of the uniform, and propensity for movement specific reinvestment differs between people. Thus, colour was input as a predictor (X), inhibition function (Go/NoGo task performance) was input as an outcome (Y), and propensity for movement specific reinvestment was input as a moderator (W). Although our predictor (X) and moderator (W) variables seem swapped, Montoya (2019) explained that X and W can be interchanged to provide the same interpretation because MEMORE holds a symmetry property in which the relationship between X and Y depends on W , which is equivalent to saying that the relationship between W and Y depends on X . In addition, because MEMORE only allows a two level within-subject design, analyses were conducted individually as a pair (red-green, red-grey, green-grey). The effects were probed at percentiles (10th, 25th, 50th, 75th, and 90th quantiles) to guarantee that the probed points were always within the observed range of the data (Hayes, 2018). For a more detailed description, MEMORE can be freely downloaded from www.akmontoya.com/spss-and-sas-macros.

3.4 Results

3.4.1 Correlation analysis between MSRS and computer-based Go/NoGo task

The correlation coefficients are displayed in for the computer-based basketball-specific Go/NoGo task. Results revealed a significant medium, positive correlation between CMP and Go accuracy ($p = 0.004$), suggesting that participants who tend to consciously control their movements were better able to correctly respond to Go stimuli. No other correlations between MSRS score (MS-C, CMP) and inhibition function (NoGo accuracy, Go RT, Go ICV) were significant.

Table 3.1. Correlation matrix for Movement Specific Reinvestment Scale score and computer-based Go/NoGo task outcomes.

Variables	Mean	SD	1	2	3	4	5	6
Reinvestment								
1. MS-C	20.240	4.850	-					
2. CMP	21.410	4.166	0.341*	-				
Computer-based Go/NoGo task								
3. Go accuracy (%)	98.836	1.621	0.125	0.457**	-			
4. NoGo accuracy (%)	84.572	9.387	0.200	0.065	0.449**	-		
5. Go RT (ms)	442.200	56.964	0.086	-0.306	-0.315	0.088	-	
6. Go ICV (ms)	0.988	0.166	-0.070	0.280	0.356*	0.116	-0.963**	-

Note: * $p < 0.05$, ** $p < 0.01$

Abbreviations: MS-C, Movement Self-Consciousness; CMP, Conscious Motor Processing; RT, response time; ICV, intra-individual coefficient of variation.

3.4.2 *Correlation analysis between MSRS and motor-based Go/NoGo task*

The correlation coefficients are displayed in for the motor-based basketball-specific Go/NoGo task. Similar to the computer-based Go/NoGo task, there was a significant large, positive correlation between CMP and Go accuracy ($p < 0.001$), suggesting that participants who tend to consciously control their movements were better able to correctly respond to Go stimuli. No other correlations between MSRS score (MS-C, CMP) and inhibition function (NoGo accuracy, Go RT, Go ICV, Go RT_{BF}, Go ICV_{BF}) were significant.

Table 3.2. Correlation matrix for Movement Specific Reinvestment Scale score and motor-based Go/NoGo task outcomes.

Variables	Mean	SD	1	2	3	4	5	6	7	8
Reinvestment										
1. MS-C	20.240	4.850	-							
2. CMP	21.410	4.166	0.341*	-						
Motor-based Go/NoGo task										
3. Go accuracy (%)	99.773	0.468	0.196	0.527**	-					
4. NoGo accuracy (%)	96.224	6.371	-0.205	-0.166	0.398*	-				
5. Go RT (ms)	589.992	69.085	0.089	-0.026	0.008	-0.012	-			
6. Go ICV (ms)	0.129	0.040	0.150	0.191	-0.244	-0.397*	-0.039	-		
7. Go RT _{BF} (ms)	463.088	209.830	0.144	-0.207	0.093	-0.014	0.326*	0.136	-	
8. Go ICV _{BF} (ms)	0.274	0.876	-0.008	-0.180	0.068	0.003	0.208	0.149	0.906**	-

Note: * $p < 0.05$, ** $p < 0.01$

Abbreviations: MS-C, Movement Self-Consciousness; CMP, Conscious Motor Processing; RT, response time; ICV, intra-individual coefficient of variation; BF, ball flight time.

3.4.3 Moderation analysis

Moderation analyses were used to examine whether the colour of the opponent's uniform (red, green, grey) moderated the relationship between CMP and Go accuracy. Model summaries for the computer-based and the motor-based tasks are shown in Table 3.3. For the computer-based task, there was a significant indirect effect of colour and CMP on Go accuracy between red and green uniforms ($p = 0.006$) and red and grey uniforms ($p = 0.002$), but not between green and grey uniforms ($p = 0.159$). For the motor-based task, there was a significant indirect effect of colour and CMP on Go accuracy between red and grey uniforms ($p = 0.017$), but not between red and green uniforms ($p = 0.148$) or between grey and green uniforms ($p = 0.163$).

Table 3.3. Model summary for indirect effects of CMP on each outcome variable (Go accuracy when viewing red, green, and grey uniforms).

Analysed pairs	R^2	B	$B SE$	p	95% CI	
					Lower	Upper
Computer-based						
Red-Green	0.197	-0.003	0.001	0.006	-0.005	-0.001
Red-Grey	0.244	-0.004	0.001	0.002	-0.007	-0.002
Green-Grey	0.056	-0.001	0.001	0.159	-0.003	< 0.001
Motor-based						
Red-Green	0.059	> -0.001	< 0.001	0.148	-0.001	< 0.001
Red-Grey	0.153	-0.001	< 0.001	0.017	-0.002	> -0.001
Green-Grey	0.055	-0.001	0.001	0.163	-0.002	< 0.001

Note: R^2 = R square-change; B = coefficient; $B SE$ = coefficient standard error; 95% CI = 95% confidence interval.

Figure 3.5 illustrates the moderating effect of colour on CMP and Go accuracy for the computer-based task. CMP was significantly and positively associated with Go accuracy for green uniforms ($B = 0.002$, $B SE = 0.001$, $t(35) = 3.236$, $p = 0.003$, 95% CI [0.001, 0.004]) and grey uniforms ($B = 0.004$, $B SE = 0.001$, $t(35) = 3.666$, $p < 0.001$, 95% CI [0.002, 0.005]). However, the slope did not significantly differ from zero for red uniforms ($B = -0.0006$, $B SE = 0.001$, $t(35) = -0.746$, $p = 0.461$, 95% CI [-0.002, 0.001]), suggesting that Go accuracy performance was similar for participants who scored low or high on the CMP sub-scale of the MSRS when viewing a red uniform.

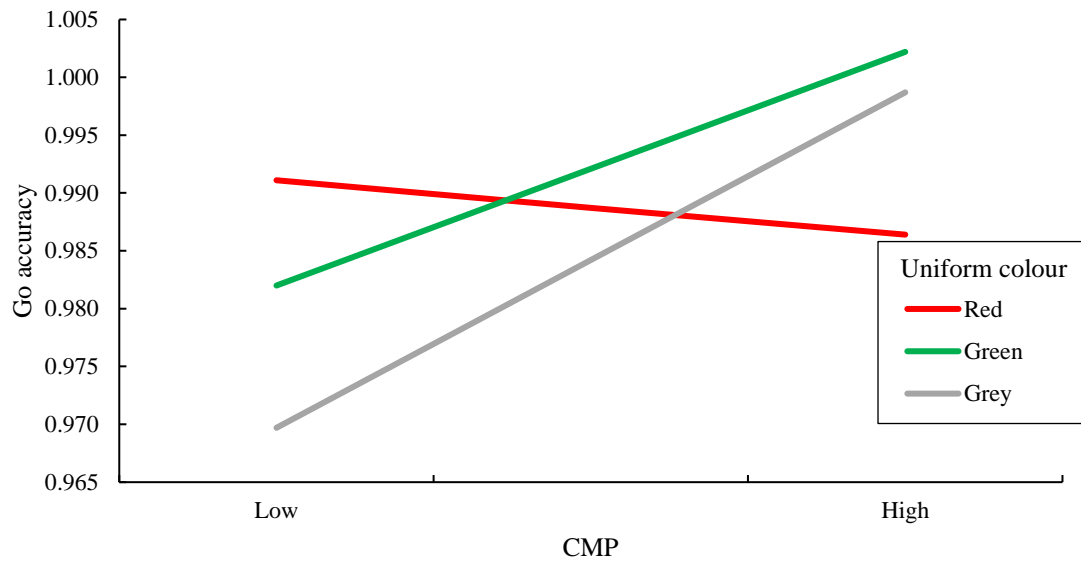


Figure 3.5. An illustrative model of the moderation effect of coloured uniform (red, green, grey) on the association between CMP (Conscious Motor Processing, continuous variable) and Go accuracy for the computer-based basketball-specific Go/NoGo task.

Figure 3.6 illustrates the moderating effect of colour on CMP and Go accuracy for the motor-based task. CMP was significantly and positively associated with Go accuracy for green uniforms ($B = 0.001$, $B SE < 0.001$, $t(35) = 2.074$, $p = 0.046$, 95% CI [<0.001 , 0.001]) and grey uniforms ($B = 0.001$, $B SE < 0.001$, $t(35) = 2.965$, $p = 0.005$, 95% CI [<0.001 , 0.002]). However, the slope did not significantly differ from zero for red uniforms ($B < 0.001$, $B SE < 0.001$, $t(35) = 0.580$, $p = 0.566$, 95% CI [>-0.001 , <0.001]). Again, these findings suggest that Go accuracy performance was similar for participants who scored low or high on the CMP sub-scale of the MSRS when viewing a red uniform.

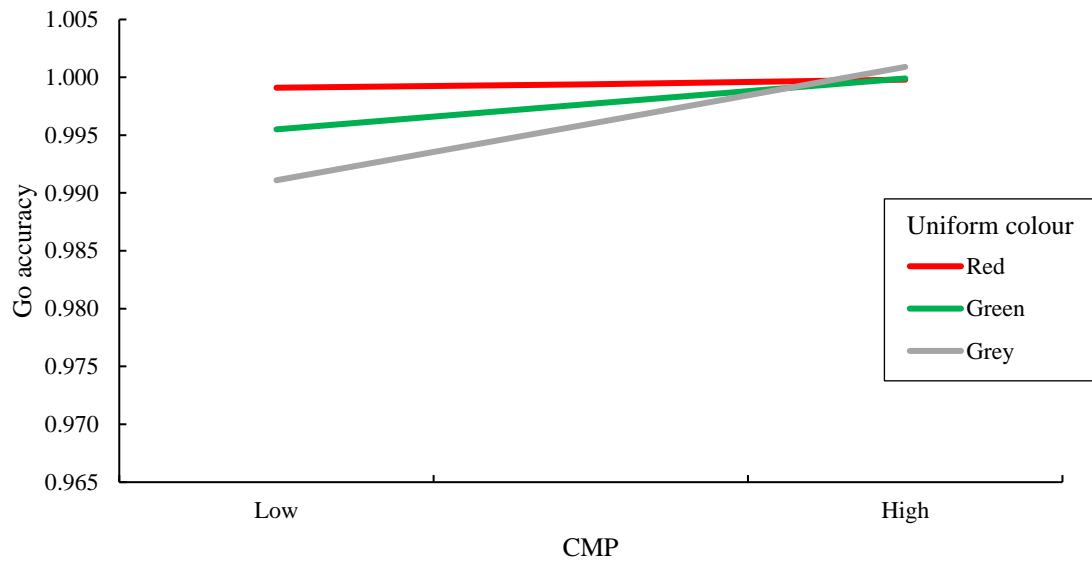


Figure 3.6. An illustrative model of the moderation effect of coloured uniform (red, green, grey) on the association between CMP (Conscious Motor Processing, continuous variable) and Go accuracy for the motor-based basketball-specific Go/NoGo task.

3.5 Discussion

Park et al. (2020) examined whether the propensity for movement specific reinvestment is associated with an inability to suppress (inhibit) the urge to consciously control movements in a simple motor task. Park et al. (2020) found a positive association between propensity for movement specific reinvestment and inhibition function (low Go RTV), possibly because the tendency for conscious control translates to better attention to the task for simple movements that do not overload working memory capacity. However, Park et al. (2020) raised a question about whether the association would persist when movement complexity increased, thus, loading working memory more heavily. Consequently, the present study developed a basketball-specific Go/NoGo task that required either a computer-based response (simple movement) or a motor-based response (complex movement).

Our results revealed a positive correlation between propensity for conscious motor processing (i.e., CMP; a subscale of the Movement Specific Reinvestment Scale) and inhibition function (i.e., higher Go accuracy), for both the simple computer-based movement response (a button press) and the complex motor-based movement response (a

basketball pass).¹⁴ We found no significant association between MS-C and inhibition function. These findings suggest that conscious control of movements (as assessed by CMP), rather than social awareness of the self as a moving object (as assessed by MS-C), is at the root of the relationship between propensity for movement specific reinvestment and inhibition function, but that greater demands on working memory capacity (caused by increasing movement complexity) do not change the direction of the relationship.

Masters and Maxwell (2008) suggested that in some cases “conscious control is needed to prevent or alter automatic responses that are inappropriate” (p. 170). Initially, we assumed that superior inhibition function would mean superior suppression, or control, of irrelevant thoughts (such as thoughts about controlling movements). However, given that conscious control is needed to inhibit automatic responses, it makes sense that superior inhibition function was evident among individuals with a high propensity for movement specific reinvestment. Metaphorically, it is easier to pause a movie reel at a specific moment when the scenes are broken down into individual scenes and manually reeled than when the scenes are played in a continuous, automatic reel. Likewise, it is easier to stop a movement that has already been dissected and consciously controlled compared to a movement as a whole.

We initially conducted the study to examine whether individuals with a high propensity for reinvestment were poor at inhibiting or suppressing task-relevant declarative knowledge that is used to consciously control movements. However, the current study utilised a Go/NoGo task, which has been proposed to measure response inhibition rather than inhibition of thoughts. Abundant research has suggested that there are multiple types of inhibition function. For instance, Friedman and Miyake (2004) described two types of inhibition: *response-distractor inhibition*, related to ignoring distracting external stimuli and *resistance to proactive interference*, related to suppression of internal stimuli (i.e., thoughts and memories). As a result, the question arises of how individuals with a high propensity for movement specific reinvestment will perform in inhibition tasks that measure suppression of distracting internal thoughts (i.e., conscious control).

¹⁴ Previous studies have suggested that Go accuracy reflects inhibitory control in the same way as NoGo accuracy (e.g., Bezdjian et al., 2009; Littman & Takács, 2017; Raud et al., 2020; Zhao, Qian, Fu, & Maes, 2017). Both have been found to activate the same brain region (i.e., pre-SMA) (see for review Mostofsky & Simmonds, 2008).

The moderation analysis revealed a positive relationship between CMP and inhibition function for both the computer-based and motor-based task when responding to opponents in green and grey uniforms but not red uniforms. Go accuracy performance when responding to green or grey uniforms was lower for low CMP individuals but higher for high CMP individuals. However, Go accuracy performance when responding to a red uniform did not differ between low and high CMP individuals. This suggests that red enhanced the performance of individuals with a low propensity for movement specific reinvestment.

It is unclear why red enhanced the performance of individuals with a low propensity for movement specific reinvestment. According to Colour-in-Context theory (Elliot & Maier, 2012), colour can influence psychological functioning in a direction consistent with the meaning that the colour carries in a given context. Red, for instance, is often used as a stop signal in everyday life (e.g., traffic signs or warning signs). Thus, in the Go/NoGo task, red may have influenced inhibition (a psychological function) in the direction consistent with the meaning of red in ‘stop or go’ contexts (i.e., stop). We, nevertheless, would like to acknowledge that the moderating effect of red uniforms on Go accuracy was relatively small—with the largest beta value being -0.004 and goodness-to-fit model (R square-change) value being 0.244 —which makes it difficult for us to definitively conclude that a red effect was present. Changes in Go accuracy may have been small due to a ceiling effect, given that Go accuracy did not fall below 91.67% for the computer-based task or 97.90% for the motor-based task. For now, we can only speculate that conscious control is necessary for successful inhibition, but perhaps inhibition is necessary for conscious control—that is, seeing red elicited inhibition which interrupted automatic processing of movement thereby creating an opportunity for individuals to engage in conscious control. However, further research is needed to investigate this speculation possibly with outcome measures that allow for a larger range of performance variance.

Chapter 4

Should I go or should I stay? Empirical and real-life observations of the effect of uniform colour on inhibitory control¹⁵

In Chapter 3, uniform colour moderated the association between inhibition function and propensity for conscious control. Subsequently, in Chapter 4, the data from Chapter 3 was re-examined to establish whether uniform colour also had an influence on inhibition function. In addition, archival data from the 2015 and 2019 Netball World Cups was analysed to examine whether performance differed for teams in different uniform colours.

4.1 Abstract

Studies have suggested that inhibitory control can be influenced by colour. Does uniform colour influence inhibitory performance in sport? In a laboratory-based experiment, thirty-seven participants were asked to respond (pass) to the more spacious side of an opponent wearing a red, green, or grey (control) uniform, but to inhibit responses (not pass) when the more spacious side was defended. NoGo accuracy (i.e., correct inhibition of responses) was lower when responding to opponents wearing a green uniform compared to red and grey uniforms, suggesting that perceiving a green uniform somehow impaired response inhibition. We therefore examined archival data to ask whether green uniforms are associated with more intercepted passes because green lowers an opponent's inhibitory control, which promotes ill-chosen passes. We found that netball teams wearing predominantly green uniforms completed significantly more intercepts than teams wearing red and other coloured uniforms. We concluded that colour may influence response inhibition in sport due to a colour-meaning association, green is 'go'.

¹⁵ Based on: **Park, S. H.**, Uiga, L., Cooke, A. M., Capiro, C. M., & Masters, R. S. W. (under review). Should I go or should I stay? Empirical and real-life observations of the effect of uniform colour on inhibitory control. *Journal of Experimental Psychology: Human Perception and Performance*.

4.2 Introduction

Studies have shown that elite athletes display superior inhibitory control than their novice counterparts, which may be one of the hallmarks of advanced skill performance (e.g., ultra-marathon runners, Cona et al., 2015; fencers, Di Russo et al., 2006; baseball players, Muraskin et al., 2015). Inhibition function, or inhibitory control, refers to the ability to control impulsive (automatic) responses, prepotencies, and reflexes (Diamond, 2013). Inhibition function is considered to be an inseparable counterpart to attention because it suppresses intrusive thoughts and inappropriate behaviours so that pertinent information can be attended (Thomas et al., 2016). Therefore, inhibition function is thought to be necessary in most, if not all, cognitive and motor tasks, including learning a new skill and making decisions under time pressure (Engle, 2018; Engle & Kane, 2004; Howard et al., 2014; Miyake et al., 2000).

It has been suggested that inhibition function can be influenced by colour. Blizzard et al. (2017) found that red stop signals elicited significantly faster response inhibition (i.e., shorter stop-signal reaction time) compared to green stop signals. The authors suggested that red stop signals may have received preferential processing by neural circuits underlying the inhibition network because red is fundamentally a more distinct and salient colour than blue, green, or yellow. Such pre-eminence in the *colour hierarchy* (Berlin & Kay, 1969) biases allocation of attention to red first and foremost (Lindsey et al., 2010; Pomerleau, Fortier-Gauthier, Corriveau, Dell'Acqua, & Jolicoeur, 2014; Tchernikov & Fallah, 2010).

This raises a question regarding whether colour influences inhibition function in sports contexts, in which performers typically wear different colours (e.g., uniforms) to signal their allegiance to a club, team, or nation. Here we ask whether competing against opponents who wear uniforms with predominantly red colouration facilitates inhibition function compared to competing against opponents who wear predominantly green or grey uniforms.

In an experimental study, thirty-seven participants (M age = 24.38 years, SD = 3.90 years; 27 males) were asked to complete a basketball specific Go/NoGo task that involved both computer-based responses (a button press) and motor-based responses (a basketball pass; ball diameter 75cm). During the Go/NoGo task, a basketball player appeared on the left or right side of the screen, leaving more or less space on either side (counterbalanced).

Participants were required to respond to Go trials by indicating the side with more space as rapidly and accurately as possible (a button press in the computer-based task / a two-handed basketball pass in the motor-based task). During Go trials, the basketball player was either positioned to the left or to the right in a neutral posture and/or defended the side with *less* space by extending both arms to that side. Participants were required to inhibit their response to NoGo trials, during which the basketball player defended the side with *more* space in the same way. For the computer-based task, stimuli were displayed on a 15-inch laptop at a distance of 50cm. For the motor-based task, stimuli were displayed on a wall (149 x 260 cm) at a distance of 300cm. The colour of the uniform worn by the basketball player in each stimulus (i.e., vest, shorts, socks) was red, green, or grey (control). Each colour was presented on an equal number of occasions (N=64) in a randomized order. The ratio of Go trials (144 Go trials = 2 positions x 2 postures x 3 colours x 12 repetitions) to NoGo trials (48 NoGo trials = 2 positions x 3 colours x 8 repetitions) was three-to-one with total of 192 trials.

We conducted one-way ANOVAs to examine the effect of uniform colour on Go accuracy (correct responses for Go trials), NoGo accuracy (correct inhibition of responses for NoGo trials), Go response time (time to respond for Go trials),¹⁶ and Go response time variability (variability of time to respond for Go trials).

For the computer-based task (a button-press), the effect of uniform colour on NoGo accuracy fell marginally short of significance, $F(72) = 2.742, p = 0.071, \eta_p^2 = 0.070$. There was no significant effect of uniform colour on Go accuracy, $F(72) = 1.516, p = 0.227, \eta_p^2 = 0.040$, Go RT, $F(72) = 1.139, p = 0.326, \eta_p^2 = 0.031$, or Go ICV, $F(72) = 2.112, p = 0.128, \eta_p^2 = 0.055$. Given that prior to analysis we expected to see an effect of red, we nevertheless proceeded to conduct paired samples t-tests (Hsu, 1996; Maxwell & Delaney, 2004). NoGo accuracy was not different between red and grey uniforms, $t(36) = -0.488, p = 0.628$, or red and green uniforms, $t(36) = 1.613, p = 0.115$; however, NoGo accuracy was higher for grey uniforms compared to green uniforms, $t(36) = -2.379, p = 0.023$ (see Figure 4.1).

¹⁶ For the computer-based task, response time represents the time between stimulus onset and the moment that the button was pressed. For the motor-based task, response time represents the time between stimulus onset and the moment that the ball was released.

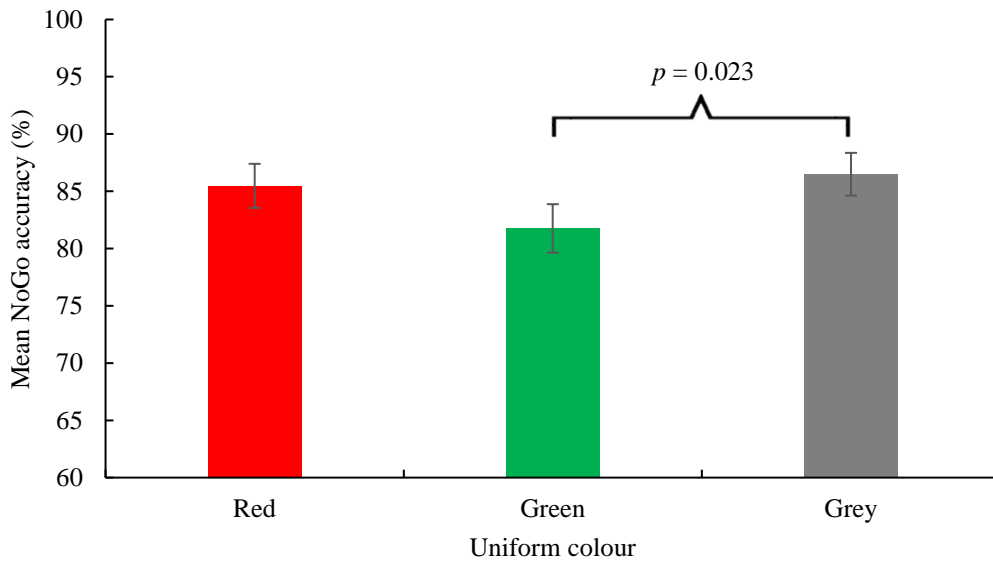


Figure 4.1. Mean NoGo accuracy score (%) when responding to basketball players in red, green, and grey uniforms, during the computer-based basketball-specific Go/NoGo task.

For the motor-based task (a basketball pass), there was a significant effect of uniform colour on NoGo accuracy, $F(72) = 3.591$, $p = 0.033$, $\eta_p^2 = 0.091$. There was no significant effect of uniform colour on Go accuracy, $F(72) = 1.980$, $p = 0.146$, $\eta_p^2 = 0.052$, Go RT, $F(72) = 0.383$, $p = 0.683$, $\eta_p^2 = 0.011$, or Go ICV, $F(72) = 0.522$, $p = 0.596$, $\eta_p^2 = 0.014$. NoGo accuracy was higher when responding to basketball players in red rather than green uniforms, $t(36) = 2.087$, $p = 0.044$, and grey rather than green uniforms, $t(36) = -2.104$, $p = 0.042$. However, there was no difference in NoGo accuracy when responding to basketball players in red compared to grey uniforms, $t(36) = -0.457$, $p = 0.651$ (see Figure 4.2).

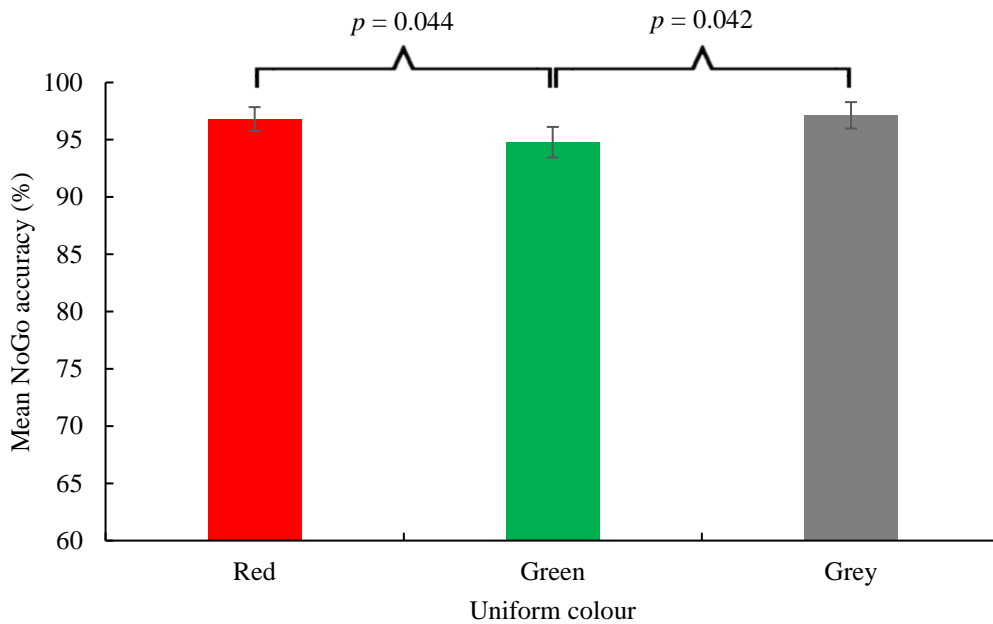


Figure 4.2. Mean NoGo accuracy score (%) when responding to basketball players in red, green, and grey uniforms during the motor-based basketball-specific Go/NoGo task.

Unlike Blizzard et al. (2017), we found no facilitative effect of red on inhibition function. The discrepancy may be due to methodological differences. Blizzard et al. (2017) used a stop-signal (SS) paradigm in which participants were required to inhibit their response *after* a go signal, whereas we used a Go/NoGo (GNG) paradigm in which participants were required to either respond or inhibit their response. Although previous studies have used the SS and GNG paradigms interchangeably (e.g., Bender, Filmer, Garner, Naughtin, & Dux, 2016; Tiego et al., 2018), there is growing evidence that the SS and GNG paradigms tap into distinct cognitive mechanisms (e.g., Littman & Takács, 2017; Raud et al., 2020). Schachar, Logan, Robaey, Chen, Ickowicz, and Barr (2007), for instance, proposed that the GNG paradigm reflects *action restraint*, which refers to the ability to withhold a strong response tendency, whereas the SS paradigm reflects *action cancellation*, which refers to the ability to reverse or cancel an ongoing action. Raud et al. (2020) suggested that inhibitory performance in the GNG task is comparable to a response selection mechanism (e.g., should I go or should I stay now) while inhibitory performance in the SS task is comparable to an intention-based reflex (e.g., sensory and motor processes are prepared to respond as soon as the stop signals appears). It is possible that during the SS paradigm inhibitory function was sensitive to red because participants were actively searching for a stop signal, and red aided visual search due to its high

salience. In contrast, during the GNG paradigm inhibition function may not have been as sensitive to red because participants were not actively searching for a stop signal but rather were trying to visually discriminate Go/NoGo cues.

Additionally, in the GNG paradigm, participants are constantly forming an association between Go cues and Go responses, and NoGo cues and NoGo responses. However, seeing a green uniform may have subconsciously impeded the association between NoGo cues and NoGo responses because green is often used to signal ‘go’ at traffic lights in daily life. Indeed, NoGo accuracy was lower when participants responded to an image of a basketball player in a green uniform compared to an image of a basketball player in a red uniform or a grey (control) uniform, indicating that a green uniform impaired response inhibition. Studies have suggested that colour can influence perception and/or psychological function without awareness (see Colour-in-Context theory by Elliot & Maier, 2012). Ho, Van Doorn, Kawabe, Watanabe, and Spence (2014), for instance, found that response times for hot/cold categorizations were reduced when participants were primed with colours that are deemed to be congruent (i.e., red-hot, blue-cold) rather than incongruent (i.e., red-cold, blue-hot). Likewise, it is feasible that green uniforms primed participants to ‘go’, which hindered their ability to stop.

In team sports, players constantly must make decisions (to run, to stop, to pass, or to shoot) that can influence the outcome of a play, and often a game. For instance, in many team ball-sports (e.g., soccer, rugby, netball, basketball) a decision to pass (rather than not to pass) can result in an interception if the line of flight is blocked by an opponent. Our findings suggest that the presence of an opponent wearing a green uniform may promote the likelihood of a ‘bad’ pass by impairing the ability to inhibit the pass.

Consequently, we conducted a retrospective analysis to examine whether playing against teams that wear predominantly green uniforms results in more passes that are ill-chosen, and can therefore be intercepted. We predicted that teams wearing green uniforms would register more intercepts of the ball than teams wearing predominantly red or grey uniforms. We initially attempted to find intercept statistics in National Basketball Association (NBA) games, but found no category equivalent to intercepts.¹⁷ Thus, we

¹⁷ An ‘interception’ is defined as a ‘steal’ in basketball. However, a ‘steal’ can also include a defensive player taking or deflecting a ball away from a dribble rather than a pass. NBA game statistics can be found on their official website (<https://stats.nba.com/teams/>, retrieved August 13, 2020).

examined netball, which is a team ball-sport that is similar to basketball.

Game statistics for the 2015 and 2019 Netball World Cups were retrieved to compare the mean number of intercepts made during games in which players wore either predominantly red, green, or other coloured uniforms.¹⁸ Among sixteen international teams, there were five teams that wore predominantly red uniforms as either their home or away kit, five teams that wore predominantly green uniforms as either their home or away kit, and thirteen teams that wore other coloured uniforms as either their home or away kit (i.e., white, orange, yellow, pink, purple, blue, and black). Uniform colours that were mixed (e.g., red-black, green-red, yellow-green, blue-yellow) were excluded from the analysis. Red uniforms were worn 40 times, green uniforms were worn 26 times, and other coloured uniforms were worn 104 times during the 124 games that were played throughout the tournament.¹⁹ We predicted that the mean number of intercepts by teams wearing green uniforms would be higher than the mean number of intercepts by teams wearing red uniforms or other coloured uniforms. *A priori* orthogonal contrast revealed that mean intercepts were statistically higher for teams wearing green uniforms compared to teams wearing red uniforms combined with teams wearing other coloured uniforms, $t(28.64) = 1.815, p = 0.040$ (one-tailed). However, the mean number of intercepts was not different between teams wearing red uniforms and teams wearing other-coloured uniforms, $t(99.54) = 0.491, p = 0.312$ (one-tailed) (see Figure 4.3).²⁰

¹⁸ Note that we were unable to examine the control colour (grey), as we did in our laboratory study, because no teams in the Netball World Cup wore predominantly grey uniforms.

¹⁹ The mean number of intercepts/game for green, red, and other-coloured uniforms were visually screened using box-plots to check for skewness and outliers (i.e., values >3 times the interquartile range). An extreme data point was removed from the analysis (N=1).

²⁰ Tests were corrected, as homogeneity of variance was violated ($p = 0.003$).

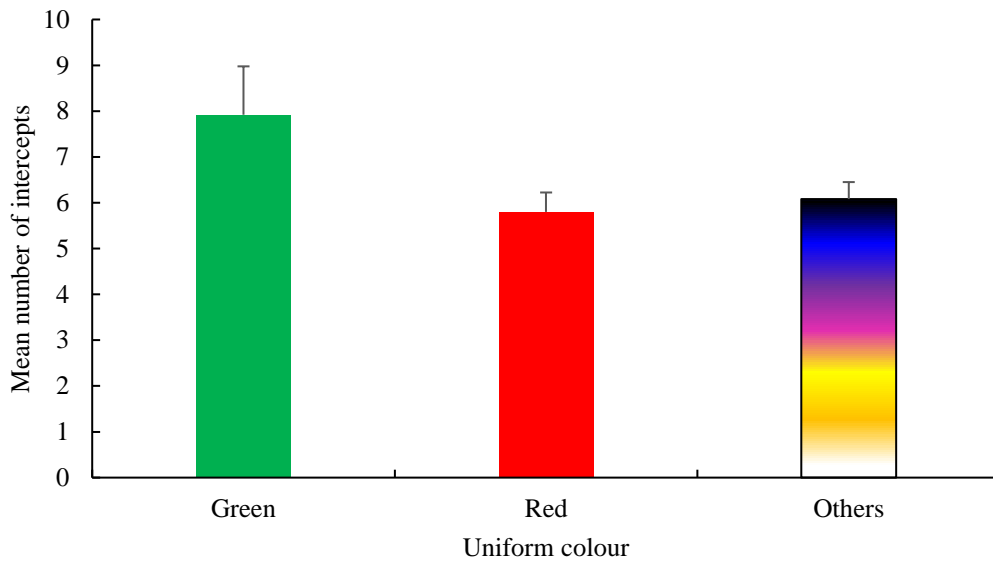


Figure 4.3. Mean number of intercepts/game by teams wearing green, red, and other-coloured (white, orange, yellow, pink, purple, blue, and black) uniforms during the 2015 and 2019 Netball World Cups. Error bars represent standard error.

4.3 Conclusion

The study examined the effect of uniform colour on inhibition function. We found that green uniforms impaired response inhibition (i.e., ability to stop passing when the space was unavailable), which generated an interesting question in sport – do predominantly green uniforms elicit passing errors because they promote poor inhibitory control? We found retrospective evidence in netball that suggested teams in green uniforms made more intercepts than teams in red and other-coloured uniforms. It is possible that teams in green uniforms were simply superior in skill, which resulted in a higher mean number of intercepts. However, separate analyses revealed that mean points scored by teams in green uniforms compared to red and other-coloured uniforms ($t(167) = 0.818, p = 0.207$), and red compared to other-coloured uniforms, were statistically non-significant ($t(167) = 1.424, p = 0.078$),²¹ indicating that differences in the mean number of intercepts was unlikely to have been a function of skill difference but more likely of uniform colour difference.

²¹ Tests were not corrected, as homogeneity of variances was not violated, ($p = 0.187$).

Alternatively, it is possible that players facing opponents in a green uniform may have been less able to refrain from making a pass that could easily be intercepted.²² This is consistent with our experimental findings in which participants failed to refrain from making a pass when seeing opponents in green uniforms. Our findings align with Colour-in-Context theory (Elliot & Maier, 2012), suggesting that (1) colour can influence psychological functioning (e.g., inhibition), (2) colour effects are consistent with the meaning of the colour in that specific context (e.g., ‘green-go’ to impair inhibition during the Go/NoGo task) and (3) colour effects occur outside conscious awareness (e.g., like Elliot, Maier, Moller, Friedman, & Meinhardt, 2007, participants in our experimental study reported no awareness of the purpose of the colour). Although we were unable to ask the netball players whether they were aware of the potential effects of uniform colour, it is unlikely in our view that they explicitly paid attention to the colour of opposing uniforms other than for team identification purposes. Nevertheless, teams wearing green uniforms made more intercepts, presumably because their opponents were primed to ‘go’, which hindered ability to inhibit an ill-chosen pass.

It is inevitable that players wearing green will also see the green uniforms of their teammates. This raises a question whether green uniform colour might influence both teammates and opponents. It may be, for example, that intercepts in netball games are higher when one team wears green as opposed to when neither team wears green, because ill-chosen passes are greater for both sides.

The majority of colour research in sport has examined what the effects of colour are (e.g., red to enhance winning outcomes; Hill & Barton, 2005b), rather than how the effects of colour occur. The current study offers an explanation that colour may affect sport performance by influencing inhibition function. It would be interesting to further examine whether colour influences outcomes via other forms of psychological functioning during sport, such as confidence or intuition.

²² One-way ANOVA revealed that there was no effect of uniform colour (red, green, other-coloured) on mean points scored per game, $F(2, 167) = 1.629$, $p = 0.199$, $\eta^2 = 0.019$, which indicates that teams wearing green, red, or other-coloured uniforms were of similar ability.

Chapter 5

Examining the colour-size illusion in a sports context: Are goalkeepers in red perceived to be larger than real life?²³

In Chapter 3 and 4, colour was shown to influence motor performance in a manner that was consistent with Colour-in-Context theory. However, it is possible that the colour effect may have been perceptual rather than psychological, so Chapter 5 examined whether uniform colours influence an opponent's perception of size.

5.1 Abstract

In two studies, we investigated the effects of colour on size perception. In Experiment 1, participants were asked to indicate which of two circles appeared to be largest in a side-by-side comparison task. The colour of the circles was either red, blue, green, or black, forming six possible colour combinations. Red circles were reliably estimated to be larger than blue, green, or black circles when they were the same size or marginally smaller. In Experiment 2, participants were asked to indicate which of two goalkeepers appeared to be largest in a side-by-side comparison task. The colour of the goalkeeper's uniform was (red, blue, green, or black). Additionally, participants completed a relative size judgement task in which they indicated the proportional size of the goalkeeper inside a goal. Goalkeepers in a red or a blue uniform were reliably estimated to be larger than goalkeepers in a green uniform during the side-by-side comparison task. However, results from the relative size judgment task were unclear. We discuss two potential underlying mechanisms that may explain our findings: red is a highly salient colour that attracts attention and thus receives priority processing or red causes a perceptual illusion that magnifies perceptions of size.

²³ Based on: **Park, S. H.**, Cooke, A. M., Capio, C. M., & Masters, R. S. W. (under review). Examining the colour-size illusion in a sports context: Are goalkeepers in red perceived to be larger than real life? *Perception*.

5.2 Introduction

Research suggests that wearing a red uniform increases the chance of victory (e.g., Attrill et al., 2008; Greenlees et al., 2008; Hagemann et al., 2008; Hill & Barton, 2005b). For instance, Greenlees, Eynon, and Thelwell (2013) found that fewer penalty-kicks were scored against goalkeepers in a red uniform compared to goalkeepers in a blue or green uniform even though goalkeepers in red were not expected to perform any better than goalkeepers in blue or green. Colour research in sports has proposed different mechanisms that might underpin the red superiority effect in sports. Most commonly, it has been theorised that red is an inherent signal of dominance and threat, which undermines performance by an opponent (e.g., Feltman & Elliot, 2011; Geng et al., 2021; Hill & Barton, 2005b), possibly by promoting avoidance motivation (e.g., Elliot et al., 2009; Elliot et al., 2007; Maier et al., 2008).

There is another potential mechanism, however, that has not been considered in colour research in sports. Namely, it is possible that wearing red might have had a perceptual effect on the viewer (e.g., appearing larger), which in turn might have influenced the chance of victory. According to the *colour-size illusion* (e.g., Holmberg, 1971; Tedford Jr. et al., 1977; Wallis, 1935; c.f., Warden & Flynn, 1926), it is possible that red may influence size perception. Tedford Jr. et al. (1977), for example, proposed that red and yellow squares were estimated to be larger than blue and green squares because warm colours (red, yellow) have ‘advancing’ qualities while cool colours (blue, green) have ‘retreating’ qualities. In other words, warm colours appear to be closer and thus larger, whereas cool colours appear to be further away and thus smaller.²⁴ In another study, Bevan and Dukes (1953) showed participants sixteen rectangular cards that were different sizes and colours (red, yellow, blue, or green). Participants were asked to select a reference card (14 different sizes, all coloured grey) that was the same size as each coloured card. A larger reference card was selected for red or yellow cards than for blue or green cards, indicating that participants perceived red and yellow cards to be larger. Bevan and Dukes (1953) argued that the ‘advancing’ and ‘retreating’ qualities of colour

²⁴ Alternatively, Tedford et al. (1977) suggested that warm colours appeared larger because they seemed to be farther away. If two objects appear similar in size next to each other, but one object is placed farther away, then our visual system automatically compensates for the distance and perceives the far object to be larger (i.e., the Ponzo illusion). Regardless of the explanation, red objects could be perceived larger than blue or green objects.

are a function of insistence (*Eindringlichkeit*, Katz, 1935), which is a higher-order variable that derives from the interaction of three basic variables: hue, brightness, and saturation.²⁵ Cleveland and McGill (1983) found that areas on a map that were shaded red were judged to be larger than areas shaded green, even though the regions on the map were the same size. Additionally, Gentilucci et al. (2001) showed that participants' grasps were larger when reaching for red target-objects than green target-objects, possibly because red causes an object to appear larger than it is.

In most sports competitions during which athletes are pitted against each other with only their physical bodies and skill sets as their main source of power and prowess, appearing larger could be quite an obvious advantage. In addition, studies have shown that size perception *can* be influenced and that appearing larger *can* influence motor behaviours of the opponents. For example, goalkeepers who embodied an amputated Müller-Lyer illusion by raising their arms were perceived to be larger than goalkeepers who had their arms down (Experiment 1, Van der Kamp & Masters, 2008). In Experiment 2, handball penalty-shots were directed farther from the goalkeepers who appeared to be larger than when they appeared to be smaller (Van der Kamp & Masters, 2008). Additionally, Müller, Best, and Cañal-Bruland (2018) showed that football penalty-kicks were directed farther away from high reputation goalkeepers (who are likely to be perceived as larger, Masters, Poolton, & Van der Kamp, 2010), and hence were more likely to miss wide of the target. These findings suggest that Greenlees et al. (2013) may have observed greater success by goalkeepers wearing red uniforms because they appeared larger, which caused penalty-shots to be directed wider, increasing the likelihood of missing the goal.

Red colouration may also cause things to be perceived as larger than blue or green colouration simply because red is a salient colour that attracts attention. Tchernikov and Fallah (2010) proposed that automatic target selection during visual search tasks follows a *colour hierarchy* of red, green, yellow, and blue. They used an eye tracker to measure smooth eye pursuit as participants visually tracked one of two superimposed surfaces that differed in colour and moved in opposing directions. Participants showed a preference to pursue red over green, yellow, and blue. Similarly, Lindsey et al. (2010) found that

²⁵ Bevan and Dukes (1953) ruled out brightness (i.e., irradiation) as a factor contributing to the colour-size illusion because red and yellow differed greatly in brightness while red and blue differed minimally. Purity (i.e., saturation) was also ruled out because red and yellow differed little from blue while blue and green differed greatly.

participants were able to indicate the presence of desaturated red targets faster than desaturated orange, green, and blue targets. Furthermore, Pomerleau et al. (2014) found that red stimuli elicited earlier and greater brain activity (i.e., event-related potentials) than blue, green, and yellow stimuli, which suggests that red is a salient colour that induces greater electrophysiological responses than other colours (see also Rakshit & Lahiri, 2016). A highly salient stimulus may increase apparent size perception due to a prior entry effect—objects that are attended first (perceived earlier) are estimated to be larger than objects attended later (Li & Yeh, 2017). Therefore, it is possible that attentional bias to red objects, due to high salience, may result in overestimation of apparent size compared to blue or green objects.

In our current study, we aimed to investigate whether the effect of colour in sports could have been perceptual rather than psychological; specifically, we asked whether uniform colour would influence perception of the size of the wearer. In Experiment 1, we first aimed to establish whether or not colour influenced size perception by asking participants to discriminate the size of two differently coloured circles (red, blue, green, or black) in a side-by-side comparison task, similar to the forced-choice comparison used by Tedford Jr. et al. (1977). In Experiment 2, we examined the effect of uniform colour on goalkeeper size perception in the same side-by-side comparison task but with goalkeepers in different coloured uniforms (red, blue, green, or black) instead of circles. In addition, we used two different size perception tasks (a side-by-side comparison task and a relative size judgement task) to further delineate why colour influences size perception. In the side-by-side comparison task, it is difficult to ascertain whether differences occur because one colour is more salient, and thus is seen first, or because one colour makes the stimulus seem larger than it is (colour-size illusion). A relative size judgement task, on the other hand, does not require comparison between two different colours, so salience is not an issue. Thus, we employed both tasks to compare the effect of uniform colour (red, blue, green, black) on goalkeeper size perception and to examine whether colour effect on size perception derives from colour salience or colour-size illusion.

Experiment 1

Experiment 1 investigated the effect of colour on size perception, with no specific interest in height (i.e., taller) or width (i.e., wider). Therefore, a circle was chosen because the center of a circle is equidistant from every point on the sphere. We predicted that red circles would be estimated to be larger than blue, green, or black circles.

5.3 Methods

5.3.1 Participants

Ninety-five participants (40 male, 45 female, M age = 20.09 years, SD = 2.89 years) were recruited for Experiment 1. Participants self-reported whether they were colour blind at the end of the experiment. Those who were colour blind were excluded from the study ($N=10$). Ethical approval was provided by the University Human Research Ethics Committee and informed consent was obtained from all participants.

5.3.2 Stimuli

Each stimulus was prepared on a PowerPoint slide and consisted of two circles, one on the left and one on the right. The distance between the center of the two circles was always 173.0mm on a 15.6-inch monitor (1280x720 pixel resolution). We either used a set of large circles or a set of small circles (see Figure 5.1). Within each set (large / small), circles were either identical in size (*same size condition*) or marginally different in size (*marginal size difference condition*). In the marginal size difference condition, one circle was always 3% larger than the other circle (large set of circles: 80mm and 83.4mm / small set of circles: 40mm and 41.2mm). The position of each circle was counterbalanced. In addition, a circle was either red, blue, green, or black in colour (six colour pairs, see Figure 5.2). Each combination of colour pairs was presented an equal number of times and the position of the colour pair (e.g., red-black, black-red) was counterbalanced. Thus, for the same size condition, there were 24 combinations: 2 sets of circles (large / small) x 6 colour pairs (red-black / red-green / red-blue / black-green / black-blue / blue-green) x 2 colour-positions (left / right). For the marginal size condition, there were 48 combinations: 2 sets of circles (large / small) x 2 sizes (larger / smaller) x 6 colour pairs (red-black / red-green / red-blue / black-green / black-blue / blue-green) x 2 colour-positions (left / right). Note that participants completed the same size condition twice, in order to match the number of trials in the marginal size difference condition.

Twenty-four catch trials were randomly introduced to establish whether participants were paying attention to the task. In the catch trials, the circles to be compared were very obviously different (80mm versus 40mm). We assumed that participants who did not discriminate which circle was larger during the catch trials were not paying attention. There were 24 combinations of catch trials: 2 sizes (larger / smaller) x 6 colour pairs (red-black / red-green / red-blue / black-green / black-blue / blue-green) x 2 colour-positions (left / right).

In sum, participants completed 120 trials of the side-by-side comparison task (48 same circle size trials, 48 marginal size difference trials, 24 catch trials). Six practice trials were completed prior to the task.

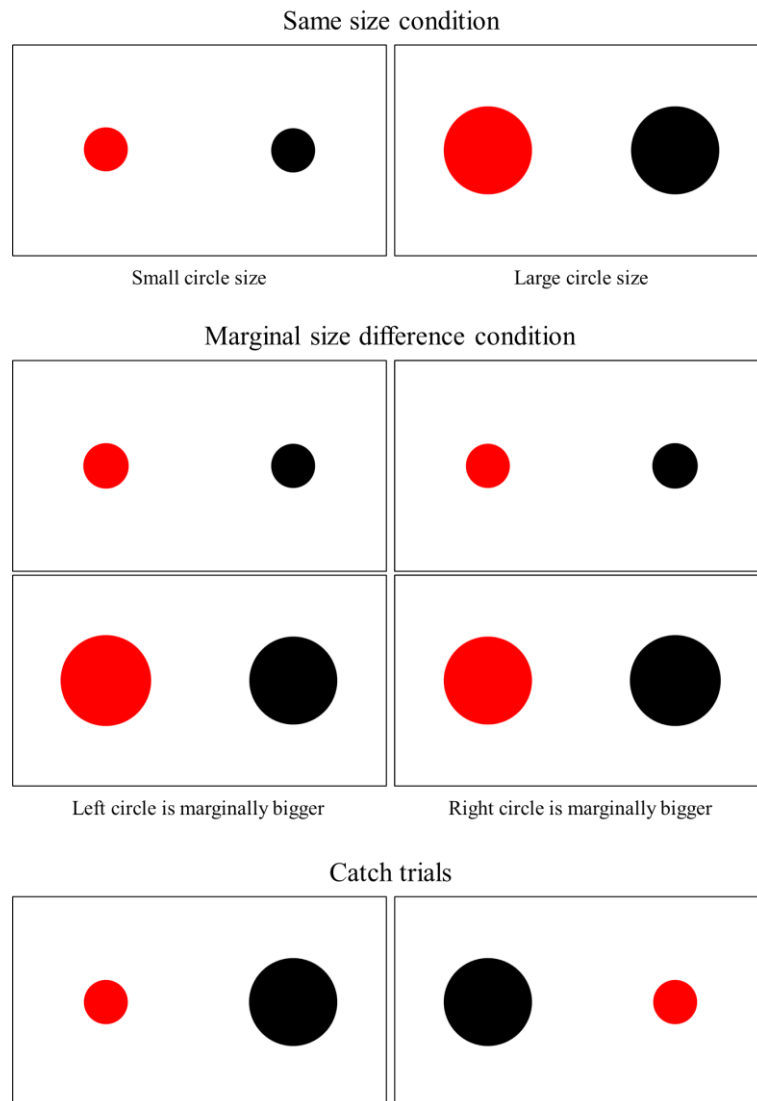


Figure 5.1. Example trials in the same size condition, marginal size difference condition, and catch trials.

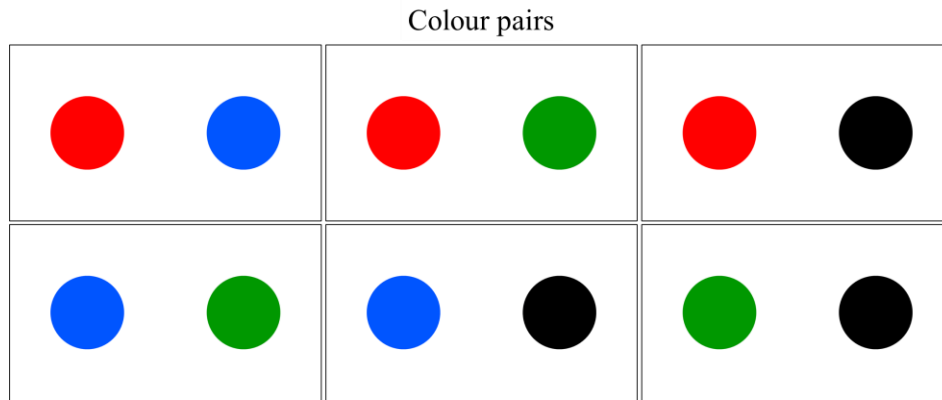


Figure 5.2. Circles in six possible colour pairs: (from left to right) red-blue, red-green, red-black, blue-green, blue-black, and green-black.

The red, blue, green, and black colours were selected based on the CIELAB colour space (also referred to as $L^*a^*b^*$ colour space). L^* defines the lightness of the colour while a^* refers to the green-red opponent and b^* refers to the blue-yellow opponent. As recommended by Elliot and Maier (2014), only the hue of the colour was altered while the brightness of the colour (L^*) remained the same: red (50, 128, 128), blue (50, 75, -128), and green (50, -128, 128). Black held the values of 0, 0, 0.

5.3.3 Procedure

Participants were invited via an online link to complete a side-by-side comparison task between two circles. The task was built using OpenSesame 3.2 (Mathôt et al., 2012), a free experiment builder available online (<https://osdoc.cogsci.nl/>). The experiment was launched on a JATOS (Just Another Tool for Online Studies, Lange, Kühn, & Filevich, 2015) server which gathered the input data that participants entered via OSWeb (an online runtime for OpenSesame experiment). Participants were informed that one circle was always larger and were instructed to select the circle that they believed was the largest by pressing the left or the right key button on the keyboard. Previous studies of the colour-size illusion did not necessarily restrict viewing time of the stimulus. Thus, a fixation cross appeared at the center for 500ms followed by a stimulus slide, which was displayed until participants responded (see Figure 5.3).

The effect of colour on apparent size perception is supposedly subtle and subconscious. Thus, participants were asked to indicate the extent of confidence in their judgement on a scale ranging from 1 (*not confident*) to 7 (*very confident*) after each trial.

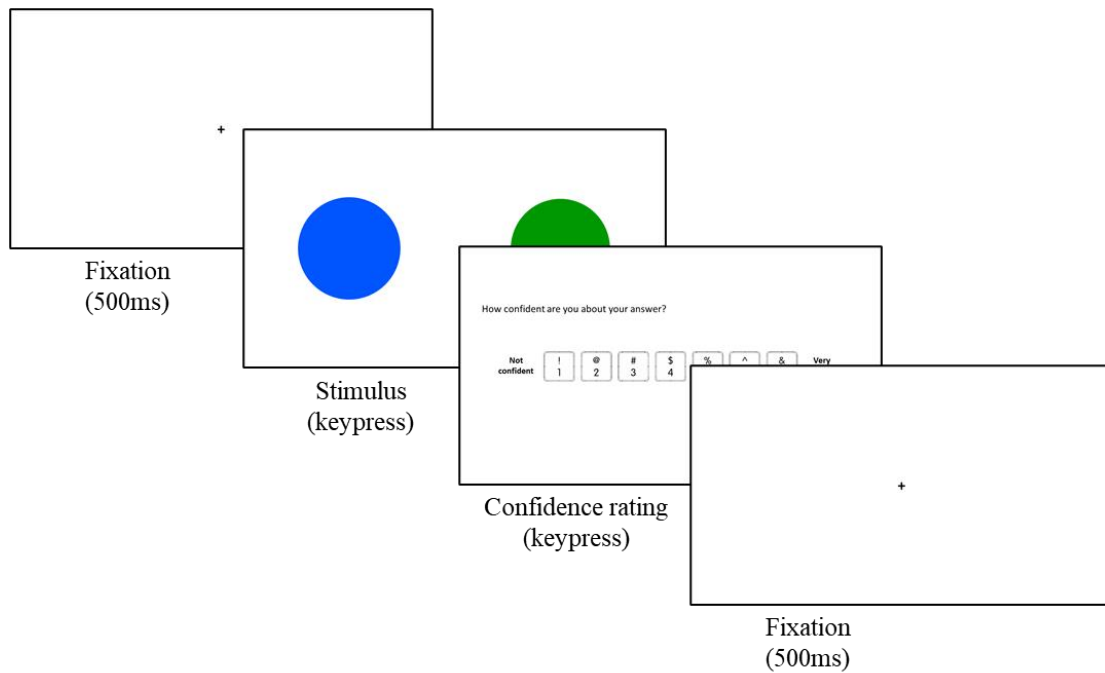


Figure 5.3. Task procedure for side-by-side comparison task between two circles.

5.3.4 Exclusion criteria

Participants with less than 95% accuracy on catch trials were excluded from the study ($N=8$), as were participants who completed less than 115 trials ($N=13$). Trials with response times less than 250 milliseconds were excluded from the study because they were considered as pre-mature responses (Gomez et al., 2007). Additionally, one participant who had 81 trials less than 250 milliseconds was excluded from the study ($N=1$).

In total, sixty-three participants were included in the analysis (31 male, 32 female, M age = 20.03 years, $SD = 2.48$ years).

5.3.5 Analysis

A three-way (2 [circle size] x 2 [size difference] x 4 [colour]) repeated measures ANOVA was conducted to compare the mean number of times red, blue, green, or black circles were perceived to be the larger circle. One-sample t-tests were also conducted to examine whether the mean number of times red, blue, green, or black circles were perceived as larger was significantly above chance (50%). Partial eta squared (η_p^2) (Cohen, 1973; Lakens, 2013) and Cohen's d (Cohen, 1988) effect sizes were reported for ANOVA and

one-sample t-tests, respectively. The same three-way ANOVA was also conducted to examine the mean confidence ratings (CR) when making the perceptual judgments. Statistical significance was set at $p < 0.050$. Pairwise t-tests were conducted as follow-up analyses, with Bonferroni corrections applied.

5.4 Results

Three-way repeated measures ANOVA revealed no significant main effect of circle size (large / small), $F(1, 62) = 0.047$, $p = 0.829$, $\eta_p^2 = 0.001$, or size difference (same / marginal), $F(1, 62) = 0.034$, $p = 0.854$, $\eta_p^2 = 0.001$, but there was a significant main effect of colour (red / blue / green / black), $F(3, 186) = 7.564$, $p < 0.001$, $\eta_p^2 = 0.109$. There were no significant two-way interactions: circle size x size difference, $F(1, 62) = 0.022$, $p = 0.883$, $\eta_p^2 < 0.001$, circle size x colour, $F(3, 186) = 1.813$, $p = 0.146$, $\eta_p^2 = 0.028$, size difference x colour, $F(3, 186) = 2.179$, $p = 0.092$, $\eta_p^2 = 0.034$. A three-way interaction was not evident: circle size x size difference x colour, $F(3, 186) = 1.184$, $p = 0.317$, $\eta_p^2 = 0.019$.

Follow-up pairwise comparisons were used, nevertheless, to examine the main effect of colour as we specifically hypothesised that red circles would be estimated to be larger than blue, green, or black circles. Red circles were perceived to be the larger circle ($54.73\% \pm 1.06$) significantly more often than blue circles ($47.72\% \pm 1.05$) (mean difference = 0.070 , $SE = 0.018$, $p = 0.002$, 95% CI [$0.021, 0.120$]), green circles ($47.96\% \pm 0.95$) (mean difference = 0.068 , $SE = 0.017$, $p < 0.001$, 95% CI [$0.022, 0.113$]), and black circles ($49.59\% \pm 1.04$) (mean difference = 0.051 , $SE = 0.016$, $p = 0.014$, 95% CI [$0.007, 0.095$]). However, there were no significant differences when comparing blue and green circles (mean difference = -0.002 , $SE = 0.015$, $p = 1.000$, 95% CI [$-0.043, 0.038$]), blue and black circles (mean difference = -0.019 , $SE = 0.018$, $p = 1.000$, 95% CI [$-0.067, 0.029$]), and green and black circles (mean difference = -0.016 , $SE = 0.017$, $p = 1.000$, 95% CI [$-0.062, 0.030$]).

To examine the extent to which choices were meaningful or occurred by chance, we conducted one-sample t-tests (test value: 50%). We collapsed circle size (large / small) and size difference (same / marginal) because main effects were not found for either condition. The results revealed that red circles only were perceived as larger more often than would be expected by chance (50%), $t(62) = 4.459$, $p < 0.001$, $d = 0.562$, 95% CI [$0.026, 0.069$] (Figure 5.4). Black circles were perceived as larger no more than would be

expected by chance, $t(62) = -0.395$, $p = 0.694$, $d = -0.050$, 95% CI [-0.025, 0.017], and blue and green circles were perceived as *smaller* more often than would be expected by chance (50%) (blue: $t(62) = 2.181$, $p = 0.033$, $d = 0.275$, 95% CI [0.002, 0.044], green: $t(62) = 2.137$, $p = 0.037$, $d = 0.269$, 95% CI [0.001, 0.039]).

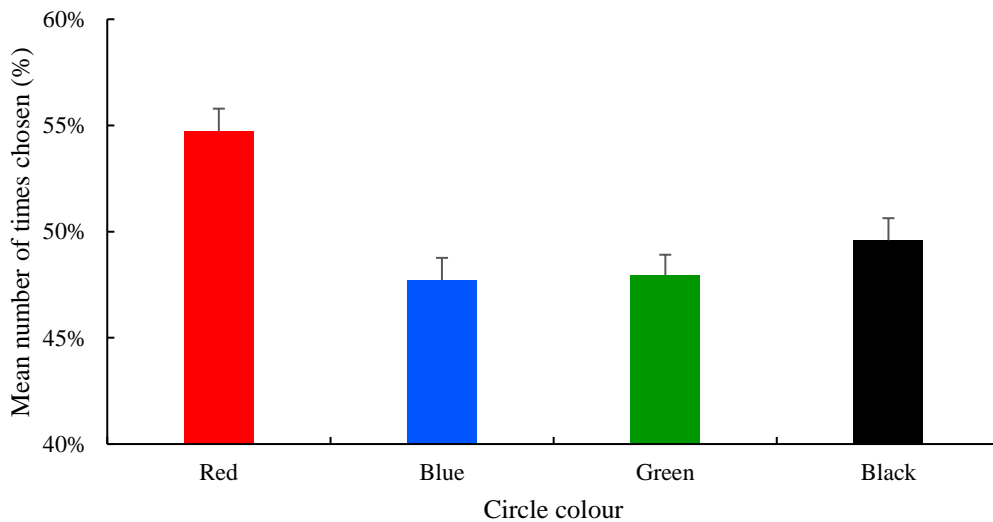


Figure 5.4. The mean number of times (%) red, blue, green, and black circles were chosen as the larger circle. Error bars represent standard error.

For the confidence ratings (CR), three-way repeated measures ANOVA revealed that there was a significant main effect of circle size, $F(1, 62) = 68.706$, $p < 0.001$, $\eta_p^2 = 0.526$, and size difference, $F(1, 62) = 38.943$, $p < 0.001$, $\eta_p^2 = 0.386$, but not of colour, $F(3, 186) = 0.484$, $p = 0.693$, $\eta_p^2 = 0.008$. Follow-up pairwise comparisons revealed that CR for large circles (3.836 ± 0.157) was higher than small circles (3.367 ± 0.171) (mean difference = 0.469, $SE = 0.057$, $p < 0.001$, 95% CI [0.356, 0.582]) and CR for the marginal size difference (3.718 ± 0.159) was higher than for the same size (3.485 ± 0.167) (mean difference = 0.233, $SE = 0.037$, $p < 0.001$, 95% CI [0.158, 0.307]). Two-way interactions were evident for: circle size x size difference, $F(1, 62) = 5.605$, $p = 0.021$, $\eta_p^2 = 0.083$, and size difference x colour, $F(3, 186) = 3.699$, $p = 0.013$, $\eta_p^2 = 0.056$. A two-way interaction was not evident for circle size x colour, $F(3, 186) = 0.148$, $p = 0.931$, $\eta_p^2 = 0.002$. A three-way interaction was not evident for circle size x size difference x colour, $F(3, 186) = 1.780$, $p = 0.152$, $\eta_p^2 = 0.028$.

Post-hoc one-way ANOVAs were conducted to investigate the interaction between circle size and size difference for CR. Results revealed a significant main effect of circle size when circles were the same size, $F(1, 62) = 34.463, p < 0.001, \eta_p^2 = 0.357$, and when the circles were marginally different in size, $F(1, 62) = 75.859, p < 0.001, \eta_p^2 = 0.550$. Follow-up pairwise comparisons revealed that confidence ratings for large circles were higher than for small circles, both when the circles were the same size (large circle 3.682 ± 0.164 versus small circle 3.288 ± 0.177 , mean difference = 0.394, $SE = 0.067, p < 0.001$, 95% CI [0.260, 0.529]) and when they were marginally different (large circle 3.990 ± 0.154 versus small circle 3.446 ± 0.169 , mean difference = 0.544, $SE = 0.062, p < 0.001$, 95% CI [0.419, 0.669]). Our findings indicate that participants were more confident when comparing large circles than when comparing small circles.

Post-hoc one-way ANOVAs were conducted to investigate the interaction between size difference and colour for CR. However, there was no main effect of colour when circles were the same size, $F(1, 62) = 2.506, p = 0.060, \eta_p^2 = 0.039$, or when the circles were marginally different in size, $F(1, 62) = 2.377, p = 0.071, \eta_p^2 = 0.037$. Our findings indicate that participants were equally unsure of their judgement regardless of the colour of the circle.

5.5 Discussion

Experiment 1 examined purely the effect of colour on size perception. As we predicted, red circles were estimated to be larger than blue, green, or black circles even though red circles were exactly the same size in some trials and marginally smaller than the blue, green, or black circles in some trials. In addition, despite reporting equally low confidence in their perceptual judgements (<4 ; range 1 to 7) regardless of the colour of the circles, participants nevertheless indicated red circles to be larger significantly more often than would be expected by chance (50%).

Experiment 2

Experiment 2 investigated the effect of uniform colour (red, blue, green, black) on goalkeeper size perception. For goalkeepers, being able to reduce the number of goals scored is a critical component to success. Previous studies indicated that appearing larger may be advantageous for goalkeepers during penalty-kick situations by subconsciously biasing penalty-takers to direct their goals farther away from the goalkeeper, which increases the chance of missing the goal (Masters et al., 2010; Müller et al., 2018; Van der Kamp & Masters, 2008). Thus, we examined whether wearing certain uniform colours cause goalkeepers to appear to be larger than they are.

Like Experiment 1, we conducted a side-by-side comparison task between two goalkeepers in differently coloured uniforms. We predicted that goalkeepers in red would be estimated to be larger than goalkeepers in blue, green, or black uniforms.

To gain further insight into the mechanism by which colour might influence perception of size, we also employed a relative size judgement task (adopted from Masters et al., 2010). We asked participants to estimate the correct size of the goalkeeper relative to the goal by selecting one of 5 images that represented a goalkeeper (a vertical bar) in the center of a goal (half a rectangle). The bars were adjusted to be 90%, 95%, 100%, 105% or 110% of the correct relative size, with 100% representing the correct relative size.

If red colouration influences perception of size because of a colour-size illusion, then participants should be more likely to select images in which the bar is greater than 100% (i.e., 105% or 110%) when the goalkeeper is wearing a red uniform but not a blue, green, or black uniform. However, if red colouration influences perception of size because it is more salient than other colours (i.e., attentional bias to red), then participants should be no more likely to select images in which the bar is greater than 100%.

5.6 Methods

5.6.1 Participants

Eighty-three participants (33 male, 43 female, 5 not specified, M age = 29.64 years, SD = 13.697 years, M football experience = 3.38 years, SD = 5.730) were recruited for Experiment 2. Participants were screened for colour blindness via self-report, as in Experiment 1, and those who were colour blind were excluded from the study ($N=9$).

Ethical approval was provided by the University Human Research Ethics Committee and informed consent was obtained from all participants.

5.6.2 Stimuli

Each trial was prepared on a PowerPoint slide. The colour of the goalkeeper's uniform was photoshopped using a GNU Image Manipulation Program (GNU Project). The colours that were used in Experiment 1 (red, blue, green, and black) were used for the shirt, shorts, gloves, and socks of the goalkeeper (see Figure 5.5).

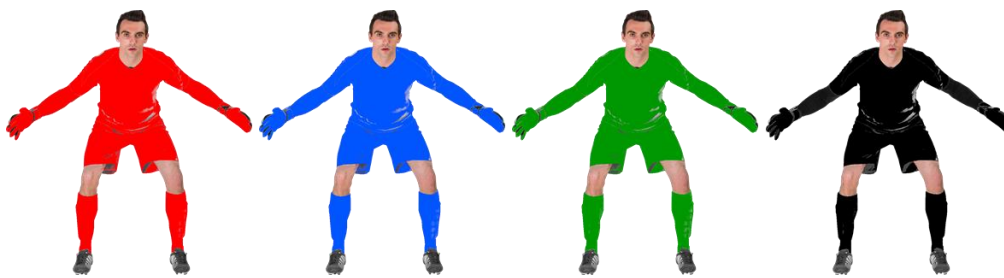


Figure 5.5. Goalkeepers in a red, blue, green, or black uniform.

5.6.3 Side-by-side comparison task

Similarly to Experiment 1, each stimulus contained two goalkeepers (left, right) for the side-by-side comparison task. Goalkeepers were displayed in a red, blue, green, or black uniform. Each combination of colours was presented an equal number of times and the position of the goalkeeper was counterbalanced by uniform colour (e.g., red-black, black-red). In each stimulus, the goalkeepers were the same size (see Figure 5.6).²⁶ However, we varied the size of the goalkeeper (large / small) between trials so that it was less obvious that the goalkeepers were the same size within trials. The large goalkeeper was 94.0mm in width and 102.0mm in height, whereas the small goalkeeper was 47.0mm in width and 51.0mm in height. Distance between the center of the two goalkeepers was always 173.0mm on a 15.6-inch monitor screen size (1280x720 pixel resolution). In total, participants completed two cycles of 24 trials of the side-by-side comparison task: 2 sets

²⁶ A main effect of circle size difference (same / marginal) was not evident in Experiment 1, so we decided to omit a marginal size difference condition in Experiment 2.

of goalkeeper sizes (large / small) x 6 colour pairs (red-black / red-green / red-blue / black-green / black-blue / blue-green) x 2 colour-positions (left / right counterbalanced) x 2 cycles.

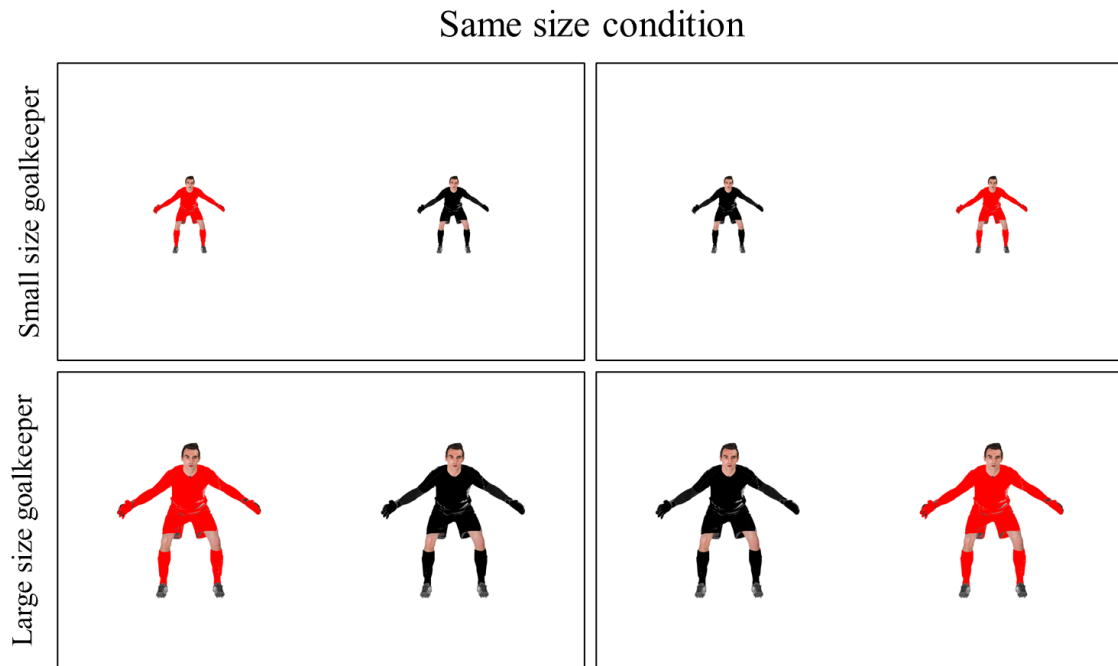


Figure 5.6. Example of small goalkeepers (top row) and large goalkeepers (bottom-row) wearing red and black uniforms (colour-position counterbalanced).

5.6.4 Relative size judgement task

Each stimulus contained a small (64.0 x 69.0mm), medium (71.0 x 76.0mm), or large (78.0 x 89.0mm) sized goalkeeper standing in a goal. The size of the goal remained the same throughout the task (311.0 x 103.0mm; approximately equivalent to a real-life goal post ratio of 0.33). Beneath the image of the goal, five bars represented the relative size of the goalkeeper in relation to the goal (see Figure 5.7). One bar represented the correct relative size of the goalkeeper in the goal, while the remaining bars ranged between 90% and 110% of the correct relative size in increments of 5%. The position of the images was randomized for each stimulus. Participants complete 4 cycles of 12 trials of the relative size judgement task: 3 goalkeeper sizes (small / medium / large) x 4 colours (red / green / blue / black) x 4 cycles.

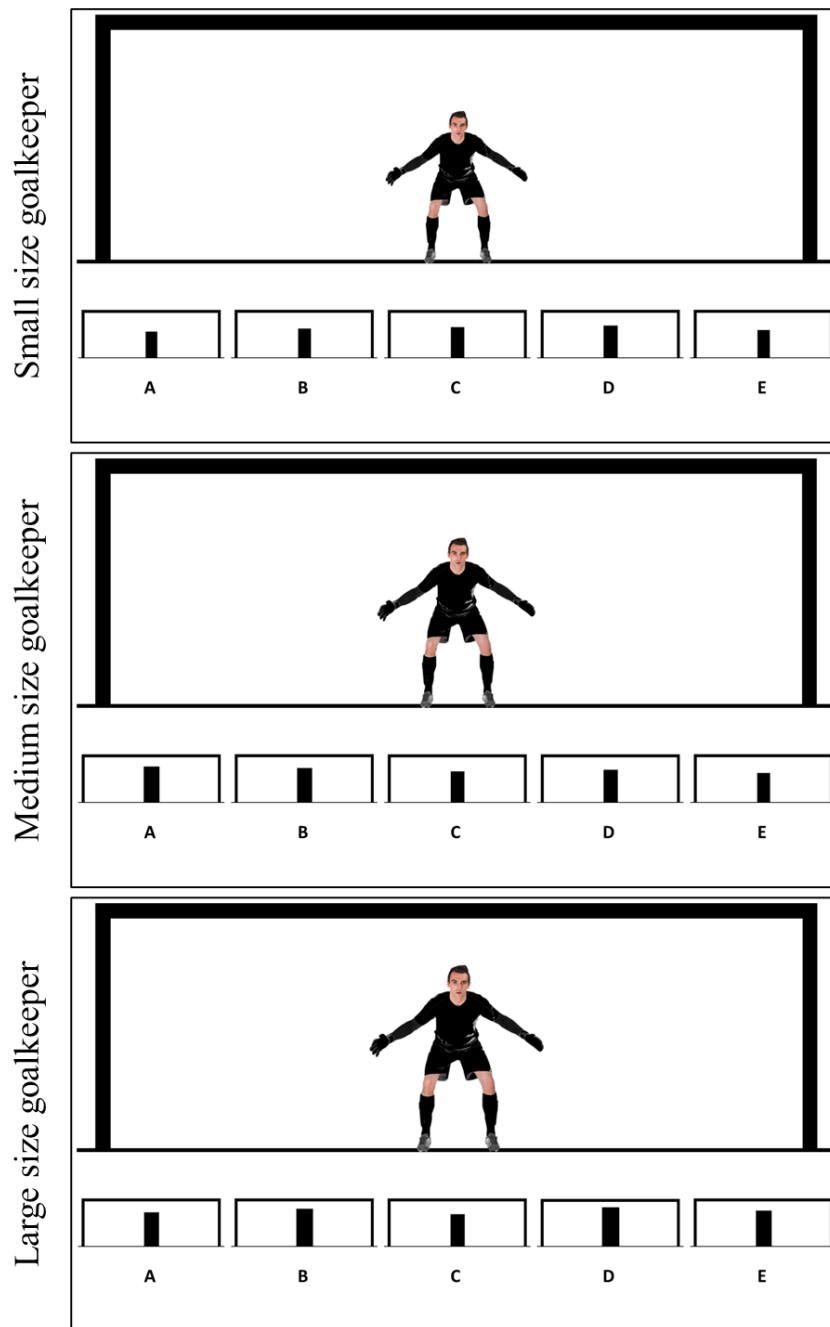


Figure 5.7. An example of a small, medium, and large size goalkeeper wearing a black uniform in the relative size judgement task.

5.6.5 Procedure

As in Experiment 1, participants were invited to participate in the experiment via an online link. Again, the task was built using OpenSesame 3.2 and launched on JATOS server via OSWeb.

Participants completed 96 trials in a mixed, randomized order (48 side-by-side comparison trials / 48 relative size judgement trials).²⁷ Stimulus presentation time remained the same as in Experiment 1 (see Figure 5.8). Six familiarization trials (3 trials per task) were provided first. Participants were informed that they would either see two goalkeepers side-by-side or one goalkeeper standing in a goal. For the side-by-side comparison task, participants were informed that one goalkeeper was always larger, and they should indicate the goalkeeper that they believed was the largest (left or right key). For the relative size judgement task, participants were instructed to choose the bar at the bottom of the screen that most accurately represented the proportional size of the goalkeeper relative to the goal. Participants responded by pressing appropriate key buttons (a, b, c, d, or e). After each trial, participants indicated the extent of their confidence in the judgement (1 *not confident* to 7 *very confident*). At the end of the experiment, participants were asked to provide their age, gender, colour blindness (yes / no), and football experience (years).

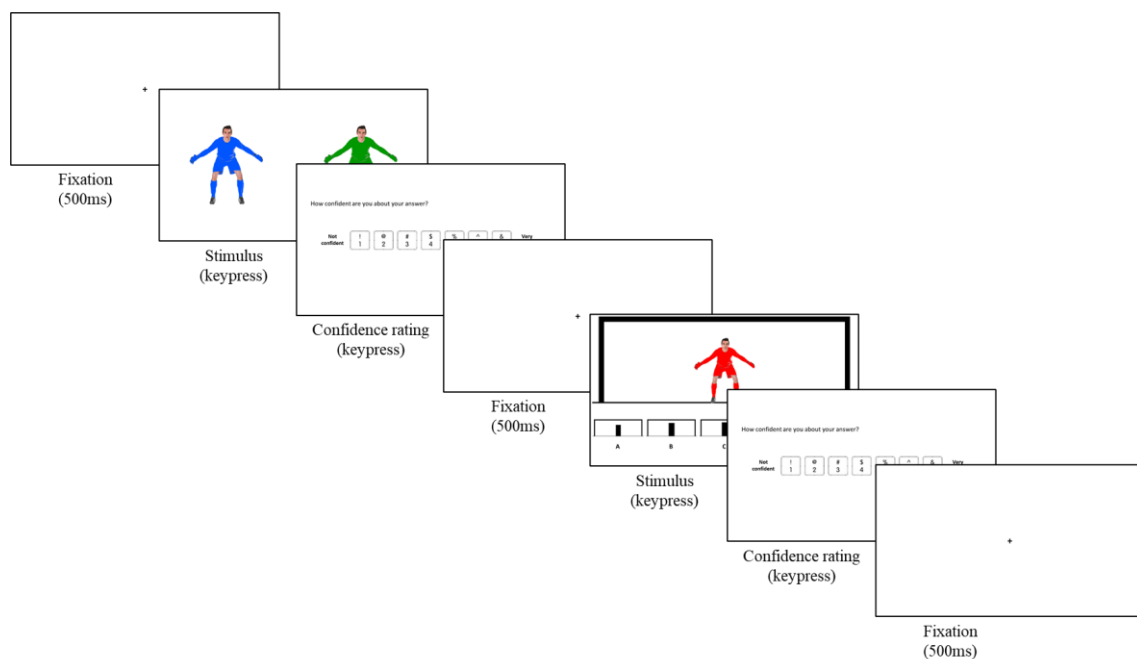


Figure 5.8. Example of stimulus order and duration.

²⁷ We mixed trials of each task to keep the task more entertaining. When the trials were completed separately during pilot tests, participants reported loss of interest in the task.

5.6.6 Exclusion criteria

Participants who completed less than 46 of 48 trials of either the side-by-side comparison task or the relative size judgement task were excluded from the study ($N=9$). Again, trials with a reaction time less than 250 milliseconds were excluded from analysis. A total of sixty-five participants were included in the analysis (29 male, 36 female, M age = 29.78 years, $SD = 13.73$ years, M football experience = 4.28 years, $SD = 6.48$).

5.6.7 Analysis

5.6.7.1 Side-by-side comparison task

A 2 (goalkeeper size: large / small) x 4 (colour: red / blue / green / black) repeated measures ANOVA was conducted to compare the mean number of times goalkeepers wearing red, blue, green, or black uniforms were chosen as the larger goalkeeper. One-sample t-tests were conducted to examine whether the mean number of times goalkeepers wearing red, blue, green, or black uniforms were perceived as larger was significantly above chance (50%). Partial eta squared (η_p^2) (Cohen, 1973; Lakens, 2013) and Cohen's d (Cohen, 1988) effect sizes were reported for ANOVA and one-sample t-tests, respectively. The same two-way ANOVA was conducted to examine the mean confidence ratings (CR) when making the perceptual judgments. Statistical significance was set at $p < 0.050$. Pairwise t-tests were conducted as follow-up analyses, with Bonferroni corrections applied.

5.6.7.2 Relative size judgement task

Participants' perceived size estimation was measured by the mean size of the bar that was chosen (90%, 95%, 100%, 105%, 110%). A 3 (goalkeeper size: large / medium / small) x 4 (colour: red / blue / green / black) ANOVA was conducted to examine estimation accuracy and CRs.

5.7 Results

5.7.1 Side-by-side comparison task

Two-way repeated measures ANOVA revealed that there was a significant main effect of colour, $F(3, 192) = 5.353$, $p = 0.001$, $\eta_p^2 = 0.077$, but not of goalkeeper size, $F(1, 64) = 0.523$, $p = 0.472$, $\eta_p^2 = 0.008$. A goalkeeper size x colour interaction was not evident, $F(3, 192) = 0.425$, $p = 0.735$, $\eta_p^2 = 0.007$. Follow-up pairwise comparisons revealed that

goalkeepers wearing a red uniform ($54.17\% \pm 1.90$) were indicated to be larger significantly more often than goalkeepers wearing a green uniform ($46.50\% \pm 1.32$) (mean difference = 0.077, $SE = 0.027$, $p = 0.038$, 95% CI [0.003, 0.151]), but not more often than goalkeepers wearing a blue uniform ($53.33\% \pm 1.39$) (mean difference = 0.008, $SE = 0.026$, $p = 1.000$, 95% CI [-0.064, 0.080]) or a black uniform ($45.80\% \pm 1.90$) (mean difference = 0.084, $SE = 0.033$, $p = 0.086$, 95% CI [-0.007, 0.174]). In addition, goalkeepers wearing a blue uniform were indicated to be larger significantly more often than goalkeepers wearing a green uniform (mean difference = 0.068, $SE = 0.020$, $p = 0.005$, 95% CI [0.015, 0.122]), but not more often than goalkeepers wearing a black uniform (mean difference = 0.075, $SE = 0.028$, $p = 0.053$, 95% CI [-0.001, 0.151]). A difference was not evident between goalkeepers wearing a green compared to a black uniform (mean difference = 0.007, $SE = 0.026$, $p = 1.000$, 95% CI [-0.063, 0.077]) (see Figure 5.9).

One-sample t-tests revealed that goalkeepers wearing a red or a blue uniform were indicated to be larger significantly more often than would be expected by chance (50%): red, $t(64) = 2.192$, $p = 0.032$, $d = 0.272$, 95% CI [0.004, 0.080]; blue, $t(64) = 2.394$, $p = 0.020$, $d = 0.297$, 95% CI [0.006, 0.061]. In addition, goalkeepers wearing a green or a black uniform were indicated to be the *smaller* goalkeeper more often than would be expected by chance (50%): green, $t(64) = 2.649$, $p = 0.010$, $d = 0.329$, 95% CI [0.009, 0.061]; black, $t(64) = 2.208$, $p = 0.031$, $d = 0.274$, 95% CI [0.004, 0.080].

The side-by-side comparison task is binary, so it is possible that goalkeepers wearing a blue uniform were selected significantly more often than by chance (50%) in comparison to goalkeepers wearing green or black uniforms but not red uniforms. We therefore conducted a paired samples t-test of trials in which participants only compared goalkeepers wearing red with goalkeepers wearing blue (8 trials). Goalkeepers wearing red were not chosen significantly more often than goalkeepers wearing blue, $t(64) = -1.109$, $p = 0.272$, $d = -0.138$, 95% CI [-0.075, 0.022].

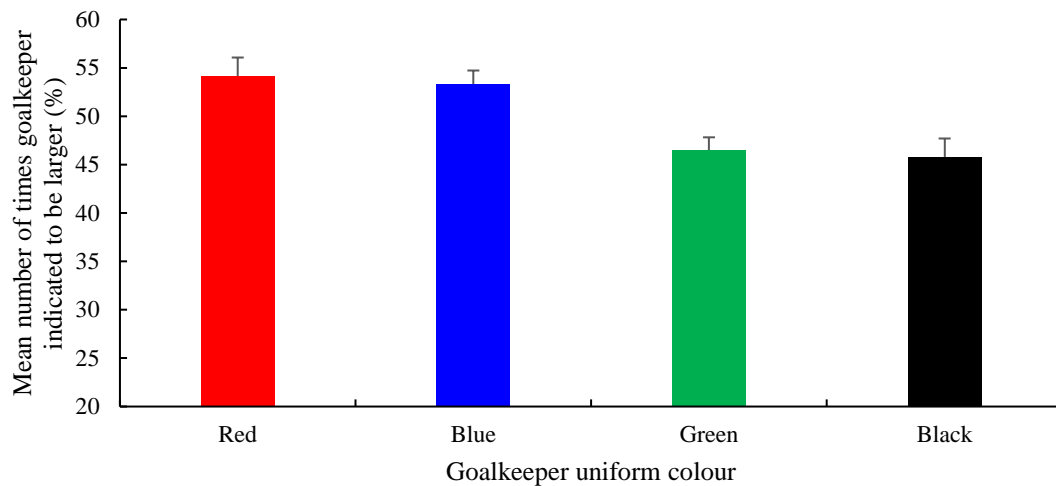


Figure 5.9. The mean number of times (%) goalkeepers wearing red, blue, green, and black uniforms were adjudged to be larger. Error bars represent standard error.

For the CRs, there was neither a main effect of colour, $F(3, 186) = 0.922, p = 0.431, \eta_p^2 = 0.015$, nor a goalkeeper size \times colour interaction, $F(3, 186) = 1.833, p = 0.143, \eta_p^2 = 0.029$. However, there was a significant main effect of size, $F(1, 62) = 10.072, p = 0.002, \eta_p^2 = 0.140$. Like Experiment 1, CRs for large goalkeepers (4.737 ± 0.143) were higher than for small goalkeepers (4.621 ± 0.149) (mean difference = 0.116, $SE = 0.037, p = 0.002, 95\% \text{ CI } [0.043, 0.189]$). However, CRs for goalkeepers in different uniform colours were not significantly different, suggesting that participants had equivalent confidence in their perceptual judgements regardless of uniform colour.

5.7.2 Relative size judgement task

A 3 (goalkeeper size) \times 4 (colour) ANOVA revealed no significant main effect of colour, $F(3, 171) = 1.240, p = 0.297, \eta_p^2 = 0.021$. However, there was a significant main effect of size, $F(2, 114) = 21.688, p < 0.001, \eta_p^2 = 0.276$, and a significant interaction between size and colour, $F(6, 342) = 6.012, p < 0.001, \eta_p^2 = 0.095$. As a result, separate one-way ANOVAs were conducted for each goalkeeper size (small / medium / large). These revealed a main effect of colour for the small, $F(3, 186) = 10.515, p < 0.001, \eta_p^2 = 0.145$, medium, $F(3, 186) = 2.650, p = 0.050, \eta_p^2 = 0.041$, and large, $F(3, 183) = 3.005, p = 0.032, \eta_p^2 = 0.047$, goalkeeper sizes. For the small goalkeeper size, estimations were closer to 100% (i.e., more accurate) for goalkeepers in a green uniform ($95.91\% \pm 0.60$), compared to a red uniform ($94.77\% \pm 0.49$) (mean difference = 1.144, $SE = 0.399, p = 0.034, 95\%$

CI [0.057, 2.232]), a blue uniform ($94.60\% \pm 0.55$) (mean difference = 1.316, $SE = 0.407$, $p = 0.012$, 95% CI [0.208, 2.425]), and a black uniform ($93.91\% \pm 0.50$) (mean difference = 2.004, $SE = 0.414$, $p = 0.012$, 95% CI [0.875, 3.133]) (see Figure 5.10). In addition, estimations were further from 100% (i.e., less accurate) for goalkeepers in a black uniform, compared to a red uniform (mean difference = -0.860, $SE = 0.272$, $p = 0.015$, 95% CI [-1.602, -0.118]). However, for medium and large sized goalkeepers, estimations were not significantly different between uniform colours (p 's > 0.050). Overall, goalkeeper size was underestimated, but underestimation was less prominent for goalkeepers wearing a green uniform compared to a red, blue, or black uniform and more prominent for goalkeepers wearing a black uniform compared to a red uniform when goalkeeper size was small.

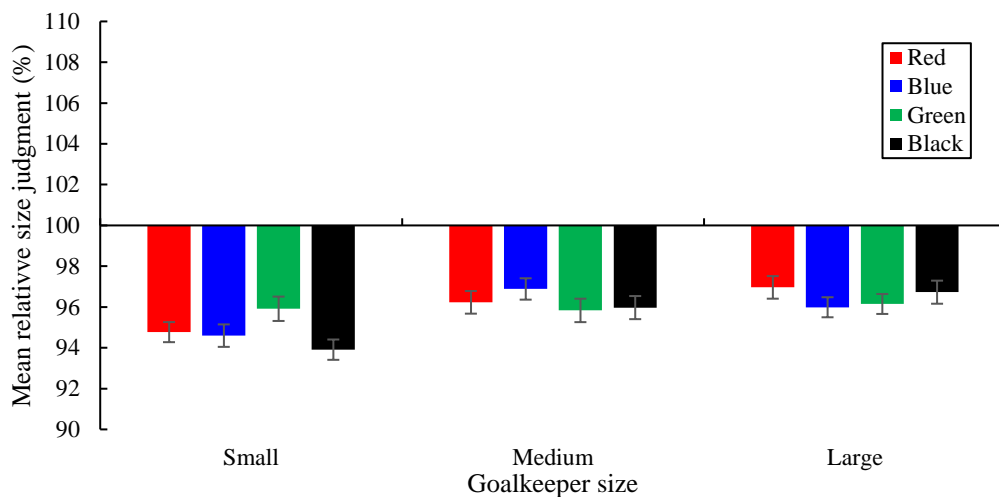


Figure 5.10. Mean relative size judgment (%) as a function of uniform colour and goalkeeper size. Error bars represent standard error.

For the CRs, there was a significant main effect of colour, $F(3, 192) = 3.577$, $p = 0.015$, $\eta_p^2 = 0.053$, but not of size, $F(2, 128) = 0.219$, $p = 0.804$, $\eta_p^2 = 0.003$. An interaction was not evident, $F(6, 384) = 1.096$, $p = 0.364$, $\eta_p^2 = 0.017$. Follow-up pairwise comparisons revealed that CRs when viewing a goalkeeper wearing a black uniform (4.831 ± 0.114) were higher than when viewing a goalkeeper wearing a green uniform (4.693 ± 0.117) (mean difference = 0.138, $SE = 0.049$, $p = 0.040$, 95% CI [0.004, 0.272]).

5.8 Discussion

We conducted Experiment 2 in order to examine whether goalkeepers who wear a red uniform are perceived to be larger compared to goalkeepers who wear other coloured uniform (i.e., blue, green, or black). Misperceptions of the size of goalkeepers who wear red may explain why they have been reported to sometimes have an advantage over goalkeepers who wear alternatively coloured uniforms.

Evidence from the side-by-side comparison task suggested that goalkeepers wearing a red or a blue uniform were estimated to be larger than goalkeepers wearing a green uniform, and were perceived to be the larger goalkeeper more often than would be expected by chance (50%). Like Experiment 1, participants displayed low confidence regardless of the uniform colour, suggesting that the colour effect took place outside conscious awareness.

Evidence from the relative size judgement task is unclear. For instance, estimations were more accurate (i.e., closer to 100%) for goalkeepers wearing a green compared to a red, blue, and black uniform, but were less accurate (i.e., further from 100%) for goalkeepers wearing a black compared to a red uniform in the small goalkeeper condition. However, such was not true in the medium and large goalkeeper condition.

The relative size judgment task was adapted from Masters et al. (2010). In their study, participants sometimes overestimated and sometimes underestimated the size of the goalkeeper. However, in our study the size of the goalkeeper was always underestimated. The discrepancy could be due to the fact that our study was conducted online rather than in person. Stefanucci, Creem-Regehr, Thompson, Lessard, and Geuss (2015) suggested that perceptual estimations on a screen-based display generally yield underestimations of size, compared to real life estimations.

In addition, the mean response accuracy for the relative size judgement task only reached 18.49% ($SE = 1.404$), suggesting that our online task might have been too difficult. Indeed, both the goalkeeper stimuli and the response options were presented together on the same screen, which might have rendered the images too small for accurate discrimination of relative sizes.

Interestingly, participants reported greater confidence in their estimations when goalkeepers were wearing a black uniform compared to a green uniform. Although

estimation accuracy was poor, participants might have been more confident because goalkeepers wearing black appeared sharper and clearer on the white background that we used, due to its maximum brightness contrast. Indeed, colour research has shown that stimuli with low brightness contrast relative to the background can cause *irradiation* or an *anti-aliasing effect*, where viewers attribute more of the border of the (low brightness contrast) stimulus to the background (Johns & Sumner, 1948; Taylor & Sumner, 1945). Likewise, a high contrast stimulus (such as a black stimulus on a white background) might have resulted in less irradiation and clearer stimulus perception, causing participants to be more confident about their estimations.

5.9 General discussion

We investigated the effect of colour on apparent size perception as a means to investigate an alternative explanation to the colour effect in sports (e.g., the red superiority effect). Experiment 1 showed that red circles were perceived to be larger than blue, green, or black circles. Experiment 2 showed that goalkeepers wearing a red and a blue uniform were perceived to be larger than goalkeepers wearing a green uniform. While Experiment 1 provides support to the proposition that the colour red influences size perception, Experiment 2 seems to provide a different story possibly due to contextual difference between Experiment 1 (non-sports context) and Experiment 2 (football specific context).

To further elaborate, we initially proposed that the ‘red advantage’ in sports may be due to a perceptual effect on size perception rather than a psychological effect on perceived prowess (i.e., red symbolises dominance and threat). For example, goalkeepers wearing red in a study by Greenlees et al. (2013) had fewer goals scored against them. This may have occurred because they appeared to be larger. Studies show that penalty takers are more likely to try to place the shot farther away from goalkeepers who appear taller (e.g., Müller et al., 2018; Van der Kamp & Masters, 2008). Consequently, penalty kickers in the Greenlees et al. (2013) study might have placed the shot farther away from the goalkeepers wearing red, and thus scored fewer goals, because they perceived the goalkeeper to be taller. However, our findings show that goalkeepers wearing a red *and* a blue uniform were perceived to be larger. It is possible that goalkeepers wearing a red and a blue uniform appeared larger than goalkeepers in a green uniform because both red and blue are associated with highly successful (dominant) teams in the modern era of

football (e.g., Manchester United, Liverpool, Arsenal, Manchester City, Chelsea).²⁸ Indeed, Masters et al. (2010) demonstrated that reputation can influence size perception and kick direction—goalkeepers with a high reputation for saving penalties were judged to be larger and kicks were directed wider of the goal compared to goalkeepers with a low reputation (see also Müller et al., 2018). This suggests that when a specific context is involved, size perception may be reliant on psychological processing of the colour meaning (i.e., Colour-in-Context). Consequently, this raises a question of whether red and blue uniforms influence size perception because of the meaning that they carry (e.g., dominance, success). This warrants further examination in future studies.

We also proposed that the ‘red advantage’ may be due to its high salience and its ability to capture attention. However, due to inconclusive findings from our relative size judgement task, we cannot eliminate the possibility that goalkeepers wearing red attract more attention. If red increases apparent size perception because red attracts attention, then it raises an interesting question as to how this might affect penalty-kick performance. Research has shown that increased attention towards goalkeepers (e.g., a distracting goalkeeper) resulted in centralized penalty-kick direction and more goals being saved (Bakker, Oudejans, & Van der Kamp, 2006; Furley, Noël, & Memmert, 2017; Wilson, Wood, & Vine, 2009; Wood & Wilson, 2010a, 2010b). It should be noted that if red had an effect on judgments during the side-by-side comparison task because it grabbed attention more readily, then red colouration may not necessarily cause objects to be perceived to be larger than they are in a relative size judgement task. If red coloured uniforms do receive priority processing it would be interesting to examine whether salience causes penalty-kicks to be more centralized towards the goalkeeper (due to increased attention) or farther away from the goalkeeper (due to overestimation of size). Previous studies have shown that gaze is more readily captured by red colours (e.g., Lindsey et al., 2010; Tchernikov & Fallah, 2010), so future studies should utilise gaze measurements to establish whether salience plays a role in perception of the size of goalkeepers. Future studies should also consider using affordance judgments rather than veridical judgements of size to determine the effect of colour on size perception. Stefanucci et al. (2015) suggested that affordance judgments may be a better way to index

²⁸ Although goalkeepers do wear different colours to differentiate them from outfield players.

size estimations because they reflect absolute size perception implicitly rather than explicitly.²⁹

The current study examined the effect of colour on size perception. Consistent with previous studies, we found that red circles were estimated to be larger than blue, green, and black circles. We also found that goalkeepers wearing a red and a blue uniform were estimated to be larger than goalkeepers wearing a green uniform. However, we were unable to determine whether the colour effect on size perception was due to colour salience or a colour-size illusion. Nevertheless, our findings support the notion that effects of colour are evident in size perception, but with a caveat that presence of context may change how colour influences size perception. That is, when there is no context involved, perceptual effects of red (whether illusion-based or salience-based) take place, but when there is a specific context involved, the psychological effect of colour (i.e., Colour-in-Context theory) may take place in lieu of or in parallel with the perceptual effect of colour. This provides further insight into the colour effect on size perception and point to a different avenue of colour research in sport—the effect of uniform colour on player perceptions and performance.

²⁹ Affordance judgements occur when participants implicitly judge the available space or the size of an object (e.g., walking sideways to go through a narrow passage or using a wider grip for picking up a larger object).

Chapter 6

The effect of red and blue spectator background on avoidance motivation during football penalty-kicks^{30, 31, 32}

Chapter 4 attempted to explore an alternative mechanism to the effect of colour; however, findings from Experiment 2 led us back to Colour-in-Context theory. Subsequently, we decided delve further into the theory. In Chapter 4 there was a clear effect of colour on inhibition function. Here, we asked whether there was also an effect of colour on avoidance motivation. According to Elliot et al. (2007), viewing a colour that conveys a negative meaning (e.g., red-danger) can elicit avoidance motivation. This raises a question of whether viewing red in sport can also elicit avoidance motivation, which may reduce performance (Hill & Barton, 2005b). Thus, Chapter 6 examined the influence of background colour on avoidance motivation during an indoor laboratory-based penalty-kicking task and during a real-life penalty-kick situation.

6.1 Abstract

Colour research in sports suggests that competing against an opponent in red leads to poorer performance outcomes. In competitive contexts, the colour red is associated with dominance and threat, which raises a question of whether red elicits avoidance motivation by the viewer. Thus, the current study examined whether a red spectator background, relative to a blue spectator background, elicited avoidance motivation during football penalty-kicks. Avoidance motivation was indexed to by kicking to the larger side of the goal (i.e., the easier option). In Experiment 1, inexperienced (N = 17) and experienced

³⁰ Based on: **Park, S. H.**, Lam, W. K., Chan, D. C. L., & Masters, R. S. W. (under review). The effect of red and blue spectator background on avoidance motivation during football penalty-kicks. *Journal of Sport and Exercise Psychology*.

³¹ Conference presentation: **Park, S. H.**, Uiga, L., & Masters, R. S. W. (2019, November). The effect of red and blue background on shot selection in an indoor football penalty-shooting task. *Sport and Exercise Science New Zealand Annual Conference*, Palmerston North, New Zealand.

³² Conference presentation: **Park, S. H.**, Lam, W. K., Uiga, L., Chan, D. C. L., & Masters, R. S. W. (2020, November). The effect of red and blue background in football penalty-kicks. *Sport and Exercise Science New Zealand Annual Conference*, Christchurch, New Zealand.

(N = 22) football players completed two blocks of penalty-kicks against a red and a blue spectator background. An image of a goalkeeper was positioned marginally off-center (1%, 2%) and obviously off-center (10%, 15%) to create a larger side (i.e., easier option) and a smaller side (i.e., harder option) of the goal. An effect of colour was evident in a competitive situation (Block 2) but not in a non-competitive situation (Block 1), suggesting that context may play a role in the effect of colour effect on performance outcomes. In Experiment 2, we used a retrospective analysis to examine the same question in professional football players. Results revealed that the players kicked to the larger side (i.e., the easier option) equally often when viewing a red spectator background and a blue spectator background, compared to other-coloured backgrounds. We discussed our findings within the framework of Colour-in-Context theory (Elliot & Maier, 2012) and pleasure-arousal theory (Feldman Barrett & Russell, 1999).

6.2 Introduction

Colour-in-Context theory (Elliot & Maier, 2012, 2014) proposes that colour conveys different meanings in different contexts and influences human behaviour in a manner consistent with the meaning that the colour carries in that specific context. For instance, red colouration in a romantic context has been shown to elicit approach motivation, because red symbolises love and sexual attraction (e.g., Elliot & Niesta, 2008). On the other hand, red colouration in an academic context has been shown to elicit avoidance motivation, because red symbolises error and failure (e.g., Elliot et al., 2007). However, whether red colouration elicits avoidance motivation in a sports context is unclear. As far as we know, it has only been *assumed* that red colouration elicits avoidance motivation in a sports context, because red symbolises dominance and aggression; however, there is no direct empirical evidence to show that this is the case (e.g., Attrill et al., 2008; Greenlees et al., 2013; Greenlees et al., 2008; Piatti, Savage, & Torgler, 2012). Thus, the current study aimed to examine whether viewing a red spectator background elicited avoidance motivation in a football context.

6.2.1 *The meaning of red colouration in football*

Colour research in animals has shown that red is a sexually selected, testosterone dependent, signal of male quality (Milinski & Bakker, 1990; Waitt, Little, Wolfensohn, Honess, Brown, Buchanan-Smith, & Perrett, 2003; Wolfenbarger, 1999; Zuk, Johnson, Thornhill, & Ligon, 1990) that communicates dominance and aggression to the opponent

(Andersson, Pryke, Örnborg, Lawes, & Andersson, 2002; Pryke, 2009; Pryke, Andersson, Lawes, & Piper, 2002). For example, male mandrills with bright red colouration on their face, back, and genitalia are challenged less frequently by male mandrills with dull red colouration, because bright red colouration indicates superior hierarchy, aggression, and fighting abilities (Setchell & Wickings, 2005). Evolutionary studies suggest that humans evolved sensitivity to the colour red because red aids in reading threatening (e.g., angry), sexual (e.g., aroused), and emotional (e.g., shy) cues that are necessary for appropriate social interactions and behaviours (Changizi, Zhang, & Shimojo, 2006; Rowland & Burriss, 2017). Consequently, Hill and Barton (2005b) suggested that the colour red may influence physical contests by humans, such as occur in sports. They proposed that evolutionary, testosterone-dependent, responses associated with red (i.e., signalling dominance and threat) elicit psychological and hormonal influences in the wearer and/or the opponent during sport (Hill & Barton, 2005a, 2005b). They reported that during the 2004 Olympic Games held in Athens, the proportion of contests won by competitors when wearing red during four types of combat sport was higher than the proportion won by competitors wearing blue (boxing, taekwondo, Greco-Roman wrestling, freestyle wrestling). In each sport, the colour of the tunic worn by each competitor (blue or red) was allocated randomly, reducing the likelihood that the red effect was caused by other factors, such as superior ability.

The symbolic representation of dominance and threat in red colouration seems to be applicable in most sport contexts, including football. Attrill, Gresty, Hill, and Barton (2008)³³ extended the findings of Hill and Barton (2005a) in a retrospective analysis of English Football League games played between 1947 and 2003. Their study revealed that teams wearing red uniforms won games played at their home ground more often than teams wearing blue, white, or yellow-orange uniforms (see also Ilie, Ioan, Zagrean, & Moldovan, 2008; Piatti et al., 2012) (cf. Allen & Jones, 2014; García-Rubio et al., 2011; Kocher & Sutter, 2008; Szmajke & Sorowkowski, 2006). Indeed, red has been shown to increase relative perception of dominance and threat in red wearers in football (Feltman & Elliot, 2011; Greenlees et al., 2013; Greenlees et al., 2008; Krenn, 2014, 2015; Recours & Briki, 2015), boxing (Feltman & Elliot, 2011; Krenn, 2015; Recours & Briki, 2015),

³³ Teams often wear differently coloured uniforms (an away strip) during games that are not played at their home ground. Interestingly, teams wearing red did not perform better than teams wearing other colours when playing away from their home ground.

and taekwondo (Hagemann et al., 2008; cf. Krenn, 2015; Krenn, Pernhaupt, & Handsteiner, 2017).

6.2.2 *A putative mechanism for red (dominance and threat) avoidance*

Approach and avoidance occur in response to positive and negative appraisal of a stimulus (e.g., object, situation, outcome possibility). We have evolved to automatically approach positively valenced, good things (e.g., cakes) and to avoid negatively valenced, bad things (e.g., snakes) (see Elliot & Covington, 2001 for discussion). This has been shown in sport. Jordet and Hartman (2008), for instance, found that football penalty-kickers displayed more avoidance behaviour (i.e., looking away from the goalkeeper, rushing shot preparation) in a negatively valenced kick condition (i.e., when missing resulted in an instant loss) compared to a positively valenced kick condition (i.e., scoring resulted in an instant win).

If red conveys the meaning of dominance and threat in football, we can assume that red should be perceived negatively by opponents. Therefore, one possible explanation of the influence of red colouration in football is that it increases avoidance behaviours by players, which can undermine performance outcomes. Avoidance motivation has been shown to negatively affect performance by causing anxiety, task distraction, and self-protective processes (e.g., selection of the easier option or self-handicapping; Elliot & McGregor, 1999; Elliot, Cury, Fryer, & Huguet, 2006; for a review see Elliot, 2005). Elliot et al. (2007), for instance, reported that viewing a red test cover page prior to an IQ test elicited avoidance motivation. Avoidance motivation was indexed by the number of times students chose the easy tasks to complete for the test.

Consequently, we aimed to examine whether a red spectator background elicits avoidance behaviour during football penalty-kicks. In Experiment 1, we conducted an indoor laboratory study to examine kicking behaviour among experienced and inexperienced football players when seeing a red and a blue background. In Experiment 2, we conducted a retrospective analysis of professional football games to investigate the effect of background colour on kicking behaviour during real life penalty-kicks.

Experiment 1

In Experiment 1, participants were asked to kick a series of football penalty-kicks against a red or a blue spectator background in two blocks of trials. We created an easy option and a hard option by positioning the goalkeeper off-center. The off-center goalkeeper paradigm was first used by Masters, Van der Kamp, and Jackson (2007). In a series of experiments, Masters et al. (2007) asked participants to judge or kick towards the side of an off-center goalkeeper that had more space. Participants were able to discriminate the side with more space even when the goalkeeper was off-center by as little as 0.5%, despite claiming to be unaware that there were differences. Participants only became aware of space differences when the goalkeeper was off-center by 3% or more (Masters et al., 2007). Consequently, we positioned the goalkeeper marginally (1%, 2%) or obviously (10%, 15%) off-center to examine the effect of colour on avoidance behaviour when participants were likely to have been aware of the easy option (10%, 15%) or unaware of the easy option (1%, 2%).

Colour-in-Context theory (Elliot & Maier, 2012, 2014) dictates that colour has an influence on psychological functions because colour conveys meaning (to the viewer) in a specific context (i.e., red is seen as a dominant and threatening colour by an opponent). However, without specific context, it is possible that the association between meaning and colour is absent. Thus, outside the competitive context (e.g., a red background in an empty room), red may not have an influence on psychological functions as it does not signal dominance and threat. To alter the context in which red was viewed, we did not assign participants to a team in Block 1, thus creating a non-competitive context. However, in Block 2, we assigned participants to a blue team, thus creating a competitive context (red team versus blue team) in which a red background therefore represented an unsupportive crowd (negative valence) and a blue background therefore represented a supportive crowd (positive valence). We hypothesised that viewing a red spectator background in Block 1 would *not* elicit avoidance motivation because an association between red and dominance/threat was less salient in the non-competitive context. However, in Block 2, we hypothesised that viewing a red spectator background would elicit avoidance motivation because an association between red and dominance/threat was more salient in the competitive context.

6.3 Method

6.3.1 Participants

Thirty-nine participants (23 males; M age = 21.85 years, SD = 4.60) were invited to complete an indoor football penalty-kick task. Participants who indicated minimal football experience (i.e., for leisure only, without training) were classified as inexperienced players (N = 17). Participants who indicated that they had played football competitively and/or had trained for one season or more were classified as experienced players (N = 22). None of the participants self-reported colour blindness. The experiment was approved by the University Human Research Ethics Committee and informed consent was obtained from all participants.

6.3.2 Task design

Participants were tested individually in a laboratory equipped with artificial grass. Stimuli projected onto a whitewashed wall (i.e., image of a football goalkeeper (height 67.88cm) inside a goal (97cm x 291cm) with a full crowd of spectators in the background). Participants were informed that the aim of the task was to score as many points as possible for their team. In the obviously off-center condition, participants had the opportunity to score 1 point if they kicked to the side with more space, but more than 1 point if they kicked to the side with less space (i.e., 1.5 points when the goalkeeper was 10% off-center or 2 points when the goalkeeper was 15% off-center). More points were awarded for successful kicks to the side with less space because it is likely that participants would have elected to always kick to the side with more space (guaranteeing a successful kick) if they were awarded the same points. In the marginally off-center condition (1%, 2%) participants were awarded one point for a successful kick to either side, because the differences in the amount of space on either side of the goalkeeper were negligible (see Figure 6.1).

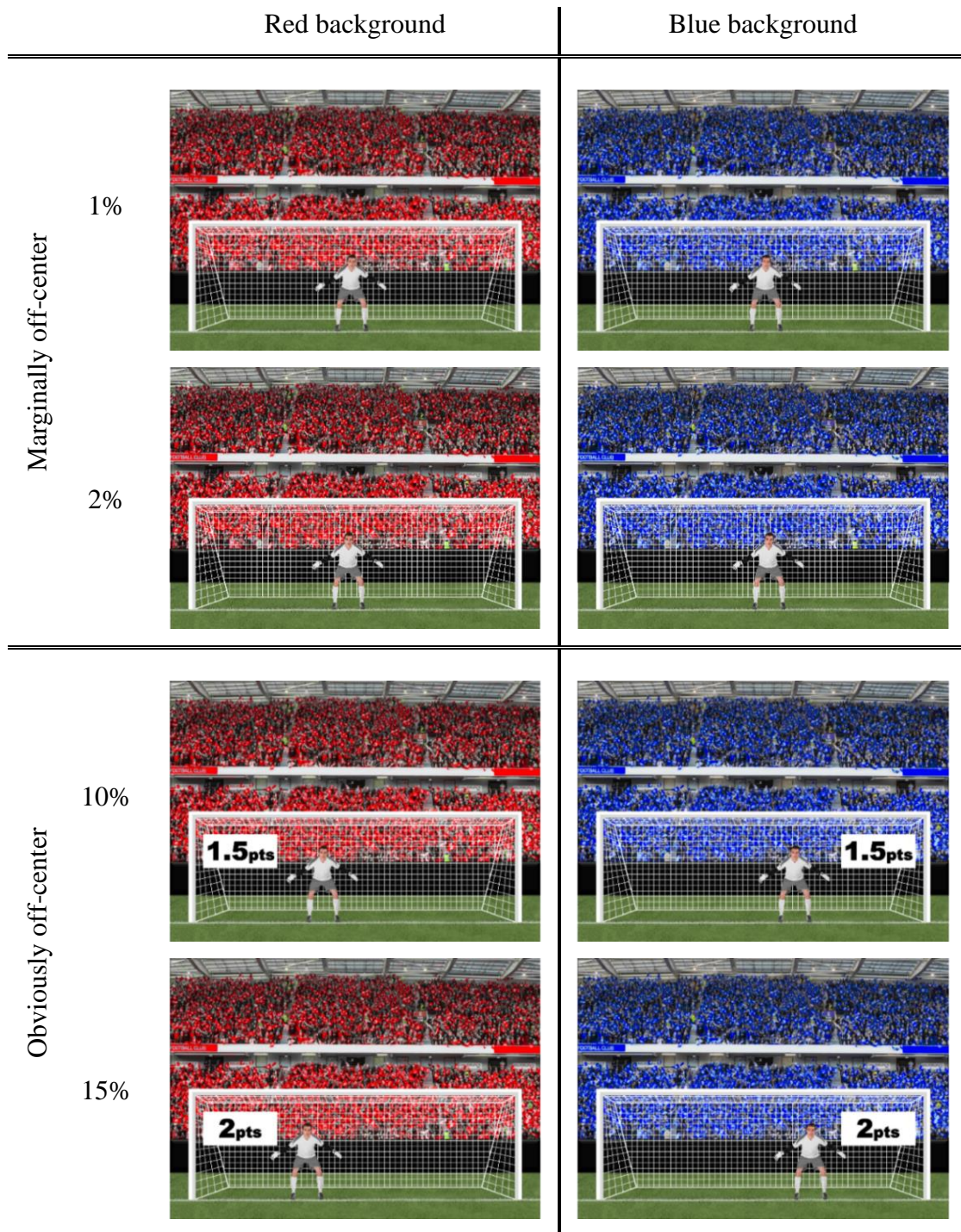


Figure 6.1. Examples of task stimuli with red (left column) and blue (right column) spectator backgrounds. The goalkeeper is positioned marginally off-center by 1% (first row) and 2% (second row) and obviously off-center by 10% (third row) and 15% (fourth row). The goalkeeper is off-center to the left in the left column and off-center to the right in the right column. Successful goals were awarded 1 point, except when participants could score 1.5 points or 2 points (as shown above).

The goalkeeper's uniform colour consisted of achromatic colours (e.g., white HSV = 0, 0, 100, grey HSV = 0, 0, 50, black HSV = 0, 0, 0) to minimise any other colour interference. The background colour was photoshopped so that spectators were predominantly red or blue, using GIMP software (GNU Image Manipulation Program) (see Figure 6.1). Only the hue of the colour (red, blue) was altered; saturation (intensity of the colour) and value (brightness of the colour) were equated on the HSV (hue, saturation, and value) model (i.e., red HSV = 0, 100, 100 and blue HSV = 240, 100, 100).³⁴ The amount of red and blue background colouration was quantified to be 40.3% and 42.1% respectively, using a "MulticolorEngine" tool (<https://labs.tineye.com/color/>).

6.3.3 Procedure

Before the experiment began, participants indicated their level of football and/or futsal experience. Participants were also informed that after their first block of kicks, they would be randomly allocated to a team of five players and that each member of the team with the highest points would receive a 20 NZD grocery voucher (approx. 13 USD). In total, participants completed four practice penalty-kicks (plain black background, goalkeeper positioned in the center) and two blocks of 32 penalty-kicks (2 trials at 1%, 2%, 10%, 15% off-set, repeated 4 times).

Participants were informed that they would complete two blocks of penalty-kicks and that they should accumulate as many points as possible in each block by directing kicks accurately to the space on either side of the goalkeeper. Kicks that missed or struck the goalpost or the goalkeeper were deemed unsuccessful and received no points. In Block 1, half of the participants kicked to a blue spectator background, whereas the other half of the participants kicked to a red spectator background. Participants were not allocated to a team during Block 1, providing insight to the effect of background colour in a non-competitive context.³⁵

In Block 2, all participants were informed that they had been selected for the blue team (and were required to don a blue bib/uniform). This created a competitive context in which participants aimed to accumulate as many points as possible for their team in order

³⁴ Elliot and Maier (2014) recommended changing one property at a time (e.g., hue) to avoid any confounding factors (e.g., saturation, value).

³⁵ In real life, penalty situations are probably always negative valenced in our view. However, this is less likely in a laboratory setting, which has little ecological validity.

to win (and therefore obtain a grocery voucher). As in Block 1, half of the participants kicked to a blue spectator background, whereas the other half kicked to a red spectator background. Consequently, for the blue spectator background, participants were kicking in front of a supportive crowd (positive valence), but for the red spectator background, participants were kicking in front of an unsupportive crowd (negative valence).

After the task, participants were interviewed about the purpose of the experiment to screen out those who may have been aware of the colour effect. No participant reported awareness of the role of colour. Once the data collection period had ended, participants were debriefed and winners of the competition were informed.

6.3.4 Data analysis

As a dependent measure, avoidance behaviour was indexed by the number of times participants chose to kick towards the larger side of the goal (i.e., easier option). The data were first visually screened for skewness and 'extreme values' (i.e., values more than 3 times the interquartile range). No outliers were found.

Two (Colour: red, blue) x 2 (Experience: experienced, inexperienced) x 2 (Off-center: marginally, obviously) mixed ANOVAs were conducted separately for Block 1 and Block 2 to examine differences in avoidance behaviour. Significant effects were further examined with Bonferroni corrected follow-up tests. In addition, one-sampled t-tests were conducted to examine whether the percentage of kicks towards the larger or smaller side of the goal was significantly different from chance (50%). Statistical significance was set at $p = 0.05$.

6.4 Results

6.4.1 Block 1–non-competitive context

Figure 6.2 shows the percentage of occasions on which participants took the easier option when they kicked towards a blue spectator background or a red spectator background. Significant main effects were not evident for Colour, $F(1, 35) = 0.002$, $p = 0.962$, $\eta_p^2 < 0.001$, or Experience, $F(1, 35) = 2.561$, $p = 0.119$, $\eta_p^2 = 0.068$, but a significant main effect was evident for the Off-center condition, $F(1, 35) = 62.900$, $p < 0.001$, $\eta_p^2 = 0.642$, showing that participants chose the easier option (i.e., penalty-kicks to the side with more space) more often when the goalkeeper was marginally off-center than obviously off-center. Interactions were not evident for Colour x Off-center, $F(1, 35) = 1.696$, $p = 0.201$,

$\eta_p^2 = 0.046$, Colour x Experience, $F(1, 35) = 0.002$, $p = 0.968$, $\eta_p^2 < 0.001$, Experience x Off-center, $F(1, 35) = 2.061$, $p = 0.160$, $\eta_p^2 = 0.056$, or Colour x Experience x Off-center, $F(1, 35) = 1.005$, $p = 0.323$, $\eta_p^2 = 0.028$.

One-sampled t-tests (two-tailed) revealed that, regardless of background colour, the easier option was chosen significantly more often than would be expected by chance (50%) when the goalkeeper was marginally off-center, $t(38) = 5.905$, $p < 0.001$, $d = 0.946$, 95% CI [0.082, 0.168]. In contrast, the harder option was chosen significantly more often than would be expected by chance when the goalkeeper was obviously off-center, $t(38) = 5.408$, $p < 0.001$, $d = 0.866$, 95% CI [-0.165, -0.363].

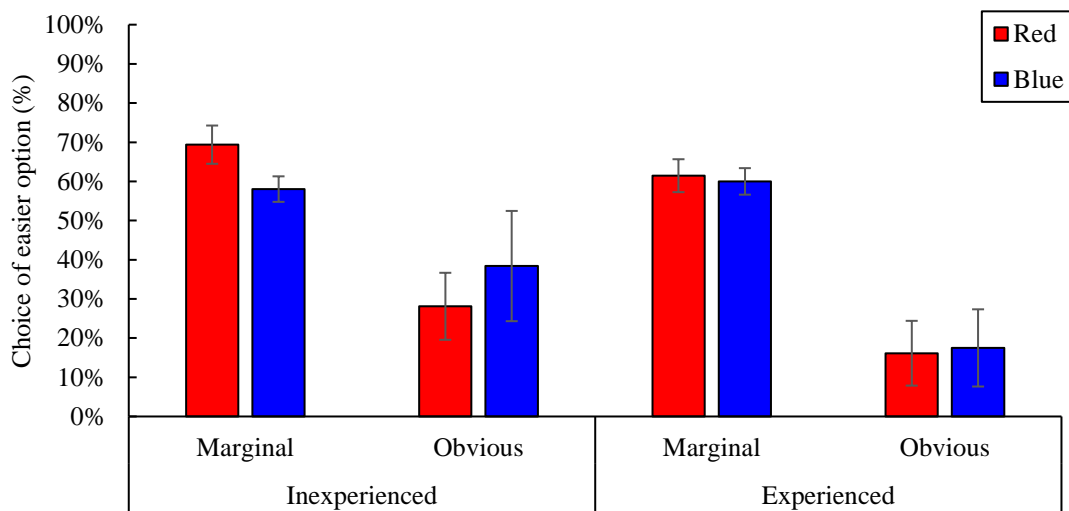


Figure 6.2. Mean percentage of occasions during Block 1 that inexperienced and experienced penalty-kickers chose the easier option in the marginally and obviously off-center condition, as a function of red and a blue spectator backgrounds.

6.4.2 Block 2—competitive context

Figure 6.3 shows the percentage of occasions on which participants took the easier option when they had been allocated to a team (blue) but kicked toward either a red spectator background or a blue spectator background. A significant main effect was not evident for Colour, $F(1, 35) = 0.681$, $p = 0.415$, $\eta_p^2 = 0.019$, but significant main effects were evident for Experience, $F(1, 35) = 4.292$, $p = 0.046$, $\eta_p^2 = 0.109$, and Off-center condition, $F(1, 35) = 51.086$, $p < 0.001$, $\eta_p^2 = 0.593$. These findings show that inexperienced football

players chose the easier option (penalty-kicks to the larger side) more often than experienced football players and that participants generally chose the easier option more often when the goalkeeper was marginally off-center rather than obviously off-center.

There was an interaction between Colour and Experience, $F(1, 35) = 6.879, p = 0.013, \eta_p^2 = 0.164$. Follow up analyses revealed an effect of colour for inexperienced players, $F(1, 15) = 7.058, p = 0.018, \eta_p^2 = 0.320$, but not for experienced players, $F(1, 20) = 1.556, p = 0.227, \eta_p^2 = 0.072$. Overall, inexperienced players chose the easier option more often when kicking to a blue spectator background ($55.36\% \pm 13.942$) compared to a red spectator background ($39.06\% \pm 11.339$). No other interaction effects were found (p 's > 0.463).

One-sampled t-tests (two-tailed) revealed that the easier option was not chosen significantly more often than would be expected by chance (50%) by inexperienced players when kicking to a blue spectator background, $t(6) = 1.017, p = 0.349, d = 0.384, 95\% \text{ CI } [-0.075, 0.183]$. However, one-sampled t-tests (two-tailed) revealed that the harder option was chosen significantly more often than would be expected by chance (50%) by inexperienced players when kicking to a red spectator background, $t(9) = 3.050, p = 0.014, d = 0.965, 95\% \text{ CI } [-0.028, -0.191]$. This suggests that the colour effect among inexperienced players may have been a function of a red spectator background rather than a blue spectator background.

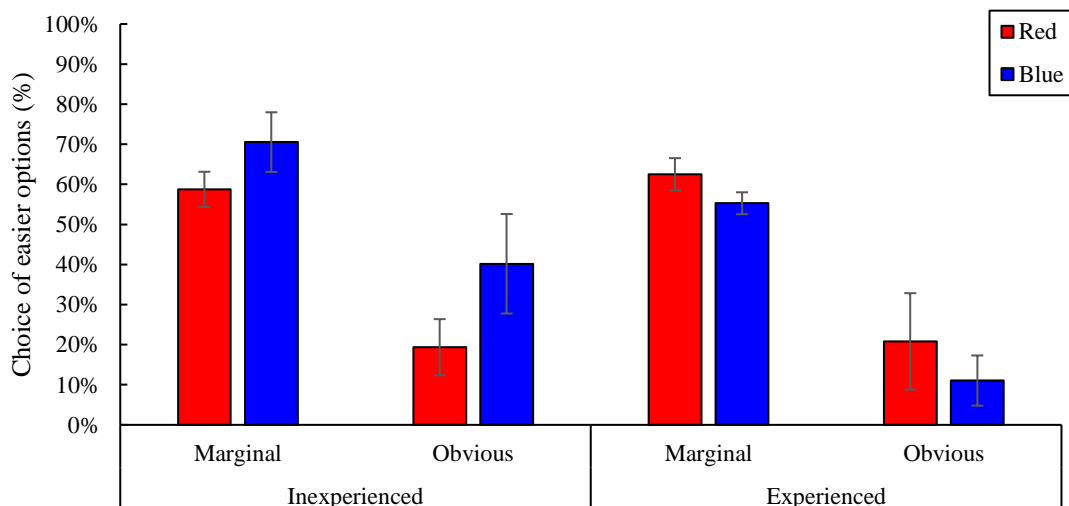


Figure 6.3. Mean percentage of occasions during Block 2 that inexperienced and experienced penalty-kickers chose the easier option in the marginally and obviously off-center condition, as a function of red and a blue spectator backgrounds.

6.5 Discussion

We asked whether a red spectator background elicits avoidance motivation (i.e., kicking towards the larger side of the goal) during football penalty-kicks, compared to a blue spectator background. Participants completed penalty-kicks when they were not part of a team (Block 1, non-competitive context) and when they were part of a team (Block 2, competitive context). In addition, we positioned the goalkeeper marginally (1%, 2%) and obviously off-center (10%, 15%) during trials to examine the effect of colour when the options (easy/hard) were easily perceived (aware) or less easily perceived (minimally aware).

In both Block 1 and Block 2, participants chose to kick towards the larger side of the goal (i.e., chose the easier option) more often when the goalkeeper was marginally off-center than obviously off-center. This is consistent with Masters et al. (2007) who reported that participants tended to choose the larger side of the goal even when goal space differences were imperceptible (similar to our marginally off-center condition). In our experiment, this effect was not evident when the goal space differences were obvious (10%, 15% offset), possibly because the incentive to score more points by kicking to the smaller side outweighed the advantage of kicking to the large, easier side. In other words, the potential to accumulate additional points by taking a risk might have tipped the balance in favour of the option to kick towards the smaller side of the goal, regardless of background colour or football experience.

Results in Block 1 indicated that there was no significant effects of colour or football experience on kick-side choices. However, in Block 2, there was a main effect of football experience and an interaction effect between colour and football experience. The different effect of colour in Block 1 (non-competitive context) compared to Block 2 (competitive context) seems to suggest that context may be crucial for colour to have a psychological influence on the viewer. Specifically, red may have conveyed the meaning of dominance and threat in the competitive context (Block 2), but less so in the non-competitive context (Block 1).

However, follow-up analysis revealed that inexperienced players chose the harder option/kicked towards the smaller side of the goal more often when viewing a red background compared to a blue background. In addition, inexperienced players kicked towards the smaller side (i.e., harder option) more often than would be expected by chance

(50%) when kicking to a red spectator background, suggesting that the colour red elicited approach, not avoidance, motivation. Many motivation theorists agree that the approach-avoidance distinction is a function of positive/negative valence (see Elliot & Covington, 2001), which dictates that for red to have elicited approach motivation, red was perceived as a positively valenced stimulus (see 6.9 General Discussion for further discussion). However, without further investigation, it remains unclear whether kicking to the smaller side in this situation can even be categorised as approach motivation.

We found no meaningful effect of colour among experienced football players. It is possible that the penalty-kick task was too easy to elicit significant motivation in experienced players. Experienced players scored more goals and earned more points than inexperienced players in both Block 1 (goals: 91.48% versus 77.21%; points: 37.59 versus 29.15) and Block 2 (goals: 92.19% versus 78.49%; points: 37.64 versus 29.62).³⁶ The task may also have lacked the necessary ecological validity to engage experienced players. Real-life penalty-kick situations are powerful motivators for penalty-takers, who can influence the outcome of a game with a single kick. Consequently, in Experiment 2, we conducted a retrospective analysis of penalty-kicks during professional football games to examine the effect of colour among experienced football players in a real-world setting.

³⁶ Independent t-tests showed that experienced players had significantly higher goal accuracy and points accumulated than inexperienced players in both Block 1 [goals: $t(37) = -3.495$, $p = 0.001$; points: $t(37) = -3.974$, $p < 0.001$], and Block 2 [goals: $t(37) = -3.503$, $p = 0.001$, points; $t(37) = -3.589$, $p = 0.001$].

Experiment 2

In Experiment 2, we examined the effect of background colour on avoidance motivation among experienced football players through a retrospective analysis of professional football games. For each penalty-kick, a goalkeeper off-center value was determined using the Weber fraction (Δ initial value/initial value) based on Weber's law of just noticeable differences (Fechner, 1860, 1966). The background colour for each penalty-kick was determined and avoidance motivation was quantified by the number of times penalty-takers kicked to the larger side of the goal (i.e., the easy option).

6.6 Method

We sourced match reports and video clips of football penalty shootouts available online from multiple platforms (e.g., English Premiere League Official website, YouTube).³⁷ In total, we collected 314 examples of penalty shootouts across 144 professional football games from 2000 to 2020.³⁸

6.6.1 Goalkeeper off-center calculation

Football penalty shootouts were screen captured so that the position of the goalkeeper relative to the goal could be calculated. We captured the final moment at which penalty-kicker appeared to be looking at the goalkeeper prior to initiating the run up (see Figure 6.4). ImageJ (Schneider, Rasband, & Eliceiri, 2012), a free software available online, was used to measure the distances in pixels.

³⁷ The videos were were sourced from public platforms, such as YouTube, official club/tournament websites or Facebook pages (e.g., video footage from TV broadcasts uploaded to these platforms after the match).

³⁸ Alphabetical order: Audi Cup 2011, Campeonato Nacional de Liga de Primera Division (or La Liga) 2013-2014, English Football League (or Carling Cup, Capital One Cup or Carabao Cup depending on sponsorship), EFL (English Football League) League One 2011-2012, English Premier League (or Barclays Premier League) 2005-2007, 2013-2015, 2017-2020, FA Cup (or Football Association Challenge Cup) 2014, FA (Football Association) Community Shield 2007, 2014, FAI Ford Cup (or Football Association of Ireland Senior Challenge Cup) 2010, Franz Beckenbauer Cup 2010, FIFA (Fédération Internationale de Football Association) World Cup (South Africa 2010, Brazil 2014, Russia 2018), UEFA (Union of European Football Association) Champions League 2004-2005, 2006-2008, 2011-2012, 2015-2016, UEFA Euro (or European Football Championship) 2000, 2004, 2012, 2016.



Figure 6.4. Example image of a football penalty-kick (Watford versus Manchester United, English Premiere League 2019/2020). Measurements for the width of the goal (w), height of the goal (h), left side of the goal (x), and right side of the goal (y) are shown.

We subtracted the distance (pixels) between the inside of the left-side goal post and the center of the goalkeeper’s head (x) from the distance between the inside of the right-side goal post and the center of the goalkeeper’s head (y) and divided it by the total width of the goal (w). We expressed the value as a percentage ($GK\%$). A positive value indicated that the goalkeeper was off-center to the right, whereas a negative value indicated that the goalkeeper was off-center to the left. Absolute $GK\%$ values between 0.5%–3.0% (1.83cm–10.98cm) were classified as marginally off-center, whereas $GK\%$ values greater than 3.0% (>10.98cm) were classified as obviously off-center.

$$GK\% = \frac{y - x}{w} \times 100$$

6.6.2 Colour quantification

Next, we determined *what* colours (e.g., red, blue, green, black, etc.) constituted the background and *how* much of each colour was present. Colour identification and quantification were achieved using “MulticolorEngine” software produced by TinEye (<https://labs.tineye.com/color/>). TinEye is an image search and recognition company that deals with computer vision, pattern recognition, neural networks, and machine learning. MulticolorEngine is a software tool that can identify colours and quantify the amount of

each colour within the image. Prior to processing the images with MulticolorEngine, each captured screen (see Figure 6.5a) was cropped (see Figure 6.5b) so that only the background was visible. Colour correction was conducted so that desaturated colours were detected by the software tool (see Figure 6.5c). For instance, prior to colour correction, the colour blue was not detected in Figure 6.5b (Figure 6.6) even though many Chelsea supporters were clearly wearing blue in the background. However, after colour correction, the software detected 17.6% violet (see Figure 6.6).³⁹

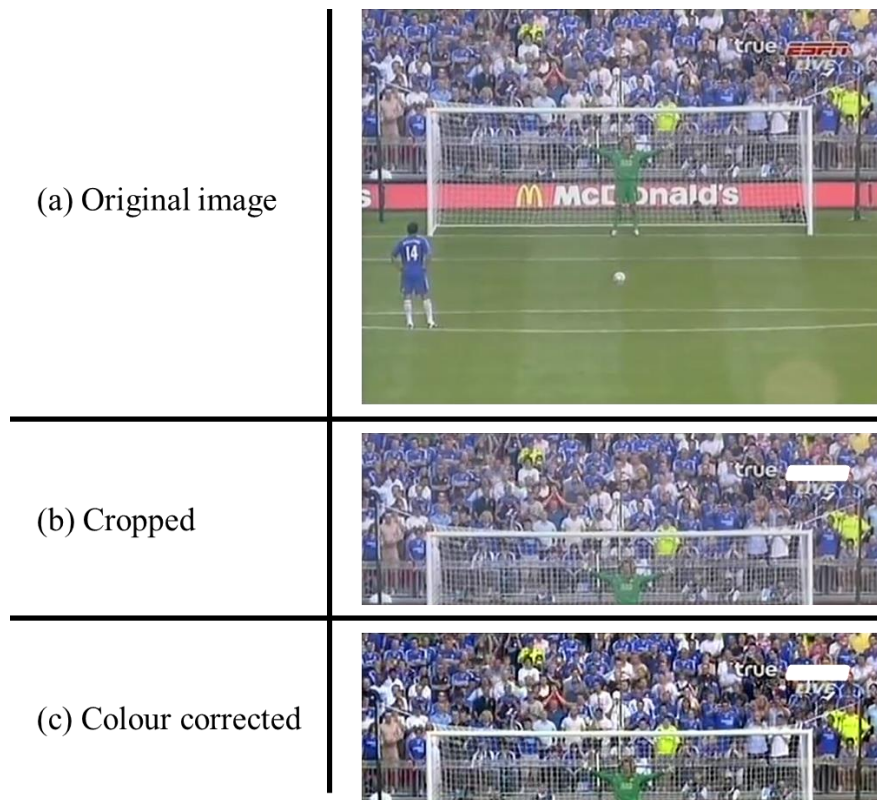


Figure 6.5. Example of an original image (top) that has been cropped (middle) and colour corrected (bottom).

³⁹ It is possible for the software to indicate violet, rather than blue, because there were other colours present in the image, which led to an average colour of violet (violet is a mixture of red and blue). Also, modern cameras automatically correct images which, might have compromised the colours slightly. We therefore cross-referenced team colour to ensure the accuracy of categorisation (e.g., that violet represented royal blue worn by Chelsea supporters).

Colour of Figure 5b			Colour of Figure 5c		
86.3 %	#868290	Grey	66.8 %	#6a6771	Grey
10.1 %	#e4e1e3	Grey	17.6 %	#4a4b79	Violet
1.1 %	#9ea079	Grey	10.8 %	#d8d8e0	Grey
0.7 %	#699675	Green	1.6 %	#52795a	Green
0.6 %	#c9da7d	Green	1.0 %	#c0c78b	Green
0.4 %	#f3eca4	Yellow	0.7 %	#5d642f	Brown
0.4 %	#e4fa73	Yellow	0.6 %	#c3db63	Green
0.3 %	#d5dda7	Grey	0.4 %	#e1fc51	Yellow
0.2 %	#dfcdad	Grey	0.2 %	#b1798a	Violet
			0.2 %	#e3cc77	Yellow

Figure 6.6. Extracted colours from MulticolorEngine for Figure 6.5b (left) and for Figure 6.5c (right).

6.6.3 Colour Categorisation

For consistency and simplicity, we categorised colours into one of three primary colours (red, blue, green). The amount of primary colouration in each image ranged from 0% to 72.40% for red ($M = 8.66\%$, $SE = 1.432$), from 0% to 66.00% for blue ($M = 7.46\%$, $SE = 1.261$), and from 0% to 4.10% for green ($M = 0.90\%$, $SE = 0.090$). Subjective visual examination of the images by three of the authors independently (SP, RM, LU) suggested that images that were categorised by the software as 12% red or greater, or 12% blue or greater, appeared to be “predominantly red” and “predominantly blue” respectively (see Figure 6.7). No images were categorised by the software as 12% green or greater. For instance, in Figure 6.7a, images with less than 12% red were subjectively judged to ‘somewhat’ red but not predominantly red. Similarly, in Figure 6.7b, the image with 11.5% blue does not necessarily seem bluer than the image with 10.8% blue, despite having a higher percentage of blue. As a result, cases where the percentage of red, blue, or green in the image ranged from 4%–12% were excluded from the analysis ($N=116$). However, images with less than 4% colour were categorised as ‘other-coloured’ background (<4%).



Figure 6.7. Example images with (a) red and (b) blue percentages shown.

6.6.4 Exclusion Criteria

According to the International Football Association Board (IFAB, Laws of the Game 2020/21), the height and width of the goal post should be 7.32 meters and 2.44 meters, respectively, which means the goal post ratio equates to 0.33. Accordingly, images with a goal post ratio of less than 0.32 and greater than 0.33 were excluded from the study to ensure that images were not distorted due to camera angles ($N = 29$). In addition, any penalty-kicks that were directed to the center of the goal ($N = 5$)⁴⁰ or that had insufficient

⁴⁰ Any kicks that landed within $\pm 50\text{cm}$ from the center of the goal ($\pm 13.67\%$ off-center) were classified as kicks directed to the center of the goal.

background displayed ($N = 15$) were excluded. Images in which the goalkeeper was less than 0.5% off-center were also excluded ($N=23$), since people cannot discriminate space differences less than 0.5% (see Masters et al., 2007). That is, goalkeepers who are off-set by less than 0.5% appear to be standing exactly in the middle, which means that it is impossible for a kicker to detect (consciously or non-consciously) a larger (easier) or smaller (harder) side to shoot to.

To double-check goalkeeper position, we also calculated the distance (in pixels) from the inside of the right-side goal post to the center of the goalkeeper's head (y) by subtracting the distance between the inside of the left-side goal post and the center of the goalkeeper's head (x) from the width of the goal ($w-x$). There was an average discrepancy between the two measurements of 6.174 pixels, possibly due to minute camera angle distortions (that were not initially filtered out). As a result, when the two measurements provided conflicting evidence of which side of the goal was larger (left or right), we excluded that case ($N=5$). In addition, when the two measurements provided conflicting evidence of whether the goalkeeper marginally or obviously off-center, we excluded that case ($N=20$) (e.g., $<0.5\%$ or $>0.5\%$, $<3.0\%$ or $>3.0\%$). We also excluded cases in which the goalkeeper was distracting (i.e., jumping around) or did not stand symmetrically (i.e., pointed to one side or the other) ($N=5$).

In total, 96 penalty-kicks (background colour: 23 red, 22 blue, 51 other-coloured) were analysed in the current study.^{41, 42}

6.6.5 Analysis

The proportion of kicks towards the larger side of the goal (i.e., the easy option) was expressed as a percentage for each background colour (red, blue, other-coloured). Given the specific direction of our hypothesis, we conducted a one-tailed z-test for two population proportions (significance set as $p < 0.05$) to examine whether differences existed in the number of penalty-kicks to the larger side when facing a predominantly red compared to a predominantly blue background, both when the goalkeeper was marginally off-center (0.5%–3%) and obviously off-center ($>3\%$). We also conducted one-sampled

⁴¹ Of 96 penalty-kicks, 53 were from penalty shootouts and 43 were in-game penalty kicks.

⁴² Of 96 penalty-kicks, 36 were from home games, 36 were from away games, and 24 were neutral (from the kicker's perspective).

t-tests to examine whether the proportion of kicks towards the larger side of the goal was significantly greater than would be expected by chance (50%) in each condition.

6.7 Results

6.7.1 Marginally off-center goalkeeper

When the goalkeeper was marginally off-center the proportion of penalty-kicks towards the larger side of the goal (i.e., the easier option) was significantly greater when kicking to a red background (76.47%) compared to other-coloured backgrounds (36.36%), $z = 2.687$, $p = 0.004$. Additionally, the proportion of penalty-kicks towards the larger side of the goal (i.e., easier option) was significantly greater when kicking to a blue background (66.67%) compared to other-coloured backgrounds (36.36%), $z = 1.809$, $p = 0.035$. However, no differences were evident between red and blue backgrounds, $z = 0.582$, $p = 0.280$. One-sampled t-tests (two-tailed) revealed that the easier option was taken significantly more often than would be expected by chance when kicking to the red background, $t(16) = 2.496$, $p = 0.024$, $d = 0.605$, 95% CI [0.040, 0.490], but not the blue background, $t(11) = 1.173$, $p = 0.266$, $d = 0.339$, 95% CI [-0.146, 0.480] or the other-coloured backgrounds, $t(32) = -1.604$, $p = 0.119$, $d = -0.279$, 95% CI [-0.310, 0.037].

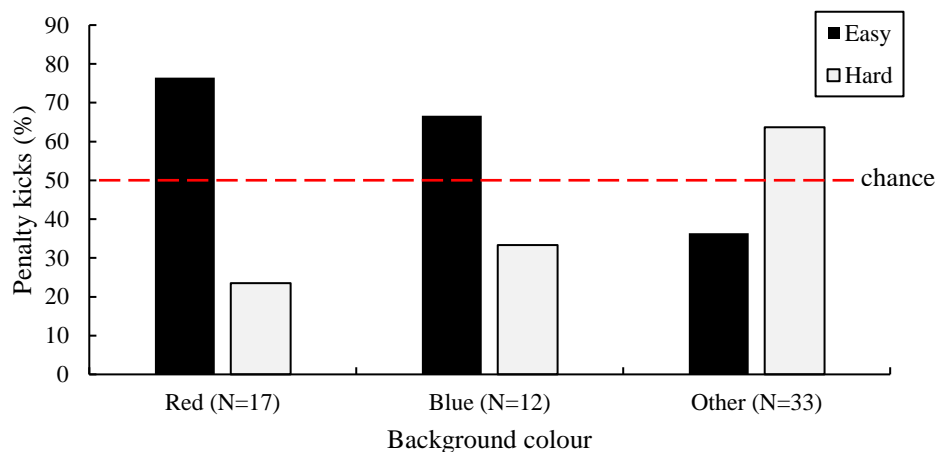


Figure 6.8. Proportion of penalty-kicks (%) to the easier and harder side as a function of red, and other-coloured backgrounds when the goalkeeper was marginally off-center (0.5%–3%).

6.7.2 Obviously off-center goalkeeper

When the goalkeeper was obviously off-center the proportion of penalty-kicks towards the larger side of the goal (i.e., the easier option) did not differ significantly for red (83.33%) compared to blue (70.00%) backgrounds, $z = 0.596$, $p = 0.275$, for red compared to other-coloured (55.56%) backgrounds, $z = 1.217$, $p = 0.112$, or for blue compared to other-coloured backgrounds, $z = 0.750$, $p = 0.227$. One-sampled t-tests (two-tailed) revealed that the penalty-takers did not choose the easier option significantly more often than would be expected by chance (50%) when kicking to the red background, $t(5) = 2.000$, $p = 0.102$, $d = 0.816$, 95% CI [-0.095, 0.762], the blue background, $t(9) = 1.309$, $p = 0.223$, $d = 0.414$, 95% CI [-0.146, 0.546], or the other-coloured backgrounds, $t(17) = 0.461$, $p = 0.651$, $d = 0.109$, 95% CI [-0.199, 0.310].

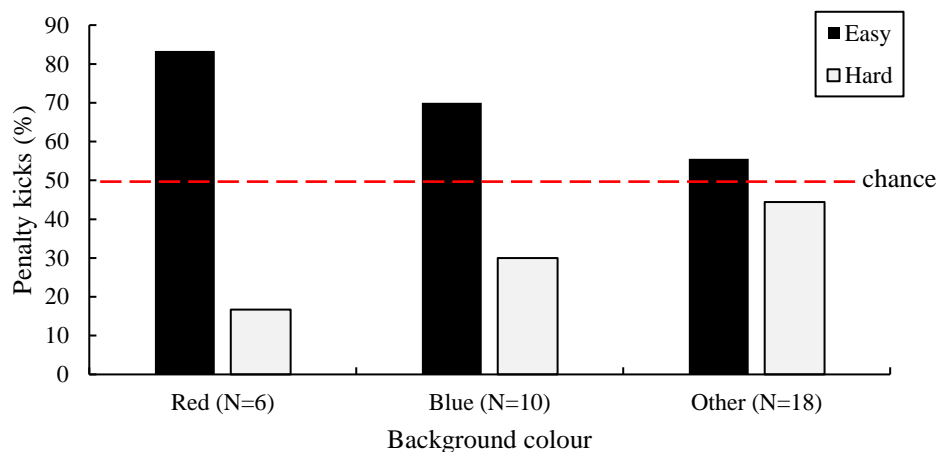


Figure 6.9. Proportion of penalty-kicks (%) to the easier and harder side as a function of red, blue, and other-coloured backgrounds when the goalkeeper was obviously off-center (> 3%).

6.8 Discussion

Our findings suggest that professional football players choose to kick towards the larger side of the goal (i.e., easier option) more often when facing a red background and a blue background compared to other-coloured backgrounds. There was no significant difference when facing a red background compared to a blue background. One-sample t-tests indicated that players kicked towards the larger side significantly more often than by chance (50%) when facing a red, but not a blue background. This was only true when

goalkeepers were marginally off-center. A similar but non-significant trend was observed when the goalkeeper was obviously off-center. We acknowledge that the low number of cases may explain this.

Nonetheless, we found evidence that a predominantly red background elicited avoidance motivation in the marginally off-center condition, suggesting that the effect of a predominantly red background occurred when information was being processed at a subliminal level. According to Colour-in-Context theory (Elliot & Maier, 2012, 2014), colour influences behaviour outside conscious awareness. Thus, it is possible that the effect of red colouration took place when information (i.e., goalkeeper placement within the goal) was being processed subconsciously.

6.9 General Discussion

We hypothesised that a red spectator background would elicit avoidance motivation (i.e., kicking towards the larger side of the goal) because red signals dominance and threat to the opponent in a competitive context. In Experiment 1, inexperienced players directed their kicks towards the smaller side more often when viewing a red spectator background, while in Experiment 2, professional football players directed their kicks towards the larger side more often when viewing a red spectator background.

One explanation for our findings is that that red elicited arousal, specifically anger, which has been shown to be associated with approach motivation. For decades, colour researchers believed that warm colours such as red and yellow are inherently arousing and anxiety inducing, whereas cool colours such as blue and green are inherently calming (Ainsworth, Simpson, & Cassell, 1993; Kwallek, Woodson, Lewis, & Sales, 1997; Levy, 1984; Nakashian, 1964; Stone & English, 1998; Whitfield & Wiltshire, 1990). Studies have shown red to induce physical arousal, such as an increased heart rate and leg strength (Dreiskaemper et al., 2013; Elliot & Aarts, 2011; Payen et al., 2011) and elevated testosterone levels (Londe et al., 2018). Harmon-Jones and Sigelman (2001) suggested that anger and aggression are approach-motivated emotions and elicit relative left (compared to right) brain activation (Hortensius, Schutter, & Harmon-Jones, 2012). Anger is most often associated with approach, rather than avoidance, motivation (Carver & Harmon-Jones, 2009; Harmon-Jones, 2003), which suggests that viewing a red spectator background elicited emotions of anger and therefore approach motivation (i.e., kicking towards the smaller side).

However, if this explanation is true, we should have observed that professional football players also kicked towards the smaller side more often when viewing a red spectator background. A more likely explanation in our view is that red increased arousal levels in both Experiment 1 and Experiment 2, but had a different effect because the penalty-kicking task in Experiment 1 was valenced as a positive or non-negative situation while the real-life penalty kick scenario in Experiment 2 was valenced as a negative situation. Real-life penalty-kick situations can result in losing the game, embarrassment and disappointment by peers, coaches, and fans, which is likely to elicit negative emotions (e.g., fear, anxiety). On the other hand, our indoor laboratory task had no real-life consequences and only had positive consequences (i.e., financial reward), which is likely to have elicited positive or non-negative emotions. According to the *pleasure-arousal theory* (Feldman Barrett & Russell, 1999; Russell, 1980), a stimulus is evaluated on two dimensions: pleasure (positive or negative emotional valence) and arousal (high-low, activation-deactivation). As a result, viewing red—an inherently arousing colour—may have activated positive emotional valence during the laboratory penalty-kicking task and thereby elicited approach motivation, but activated negative emotional valence during the real-life penalty-kick situations and thereby elicited avoidance motivation.

Like a red spectator background, we found that professional football players kicked towards the larger side more often when viewing a blue spectator background. This suggests that blue was also perceived as a highly arousing stimulus, possibly because blue was perceived as a threat. LaTour and Rotfeld (1997) argued that threatening stimuli can elicit fear, and fear has been shown to trigger a strong physiological reaction that rapidly activates the body to either confront (e.g., fight) or escape (e.g., flight) the threat (Cannon, 1929; Hyde, Ryan, & Waters, 2019; Steimer, 2002; Teatero & Penney, 2015). In football, red and blue coloured uniforms are often donned by strong and successful teams (e.g., Manchester United, Arsenal, Chelsea, Manchester City). Colour-in-Context theory (Elliot & Maier, 2012) proposes that the colour-meaning association can be learned, so it is possible that football players might have been classically conditioned to perceive red and blue as a signal of dominance and threat, which increased their arousal level.

We previously hypothesised that red would elicit avoidance motivation because red is an inherent signal of dominance and threat to the opponent. However, our current findings give rise to another possibility: perhaps red and blue are colours that are associated with dominance and threat in football which increase arousal levels and elicits avoidance

motivation. However, our data suggests that this only occurs in negatively valenced situations (i.e., real-life penalty-kicks).

Chapter 7

Crowd reception influences avoidance behaviour during football penalty-kicks, but you wouldn't know it: A retrospective analysis of professional games⁴³

In Chapter 6, avoidance motivation was elicited when viewing a red and a blue spectator background possibly because red and blue signalled dominance and threat in a football context. However, it raises a question of whether backgrounds that are perceived as a threat also elicit avoidance motivation by a penalty-kicker. As a result, Chapter 7 re-analysed the archival data from Chapter 6 to examine whether viewing a hostile crowd as opposed to a supportive crowd elicited avoidance motivation.

7.1 Abstract

For most soccer players, penalty-kicks are unpleasantly valenced, but the extent to which intensity of emotions affects their decision-making is unclear. We hypothesised that a hostile crowd raises emotional intensity more than a supportive crowd during penalty-kicks, which causes players to make avoidance based decisions more often in the presence of a hostile crowd. We sourced video footage of penalty-kicks during professional games between 2000-2005 (N=91), during which the goalkeeper was marginally off-center (1.6%–3.0%) or obviously off-center (>3.0%). Taking the easiest option is a marker of avoidance behaviour, so we analysed the proportion of penalty-kicks directed towards the larger side of the goal. Players kicked towards the larger side more often in front of a hostile crowd than a supportive crowd, but only when the goalkeeper was marginally off-center. The findings suggest that in the high-pressure environment of penalty-kicks, emotional intensity moderates the decisions that kickers make, without their awareness.

⁴³ Based on: **Park, S. H.**, Uiga, L., & Masters, R. S. W. (under review) Crowd reception influences avoidance behavior during football penalty-kicks, but you wouldn't know it: A retrospective analysis of professional games. *Psychology of Sport and Exercise*.

7.2 Introduction

Penalty-kicks in soccer are compelling viewing. Often the outcome of a penalty-kick can decide who wins or who loses. Consequently, psychological influences on players during penalty-kicks can result in pleasant (positive) or unpleasant (negative) emotional valence (e.g., Jordet, Elferink-Gemser, Lemmink, & Visscher, 2006). Theories of achievement motivation suggest that negatively valenced stimuli (e.g., objects/situations/possibilities) elicit adaptive avoidance behaviours; whereas, positively valenced stimuli elicit adaptive approach behaviours (e.g., Elliot, 1999; Elliot & Covington, 2001). Such behaviours comprise mental or physical orientation towards pleasant stimuli or away from unpleasant stimuli (e.g., Elliot, Eder, & Harmon-Jones, 2013).

Jordet and Hartman (2008) argued that approach behaviours are probable if the potential outcome of a penalty-kick is positively valenced (e.g., scoring results in an immediate team win), but avoidance behaviours are probable if the potential outcome is negatively valenced (e.g., not scoring results in an immediate team loss). Analysis of 359 penalty-kicks from World Cup, European Championship and UEFA Champions League games (1972–2004) showed that penalty-kickers displayed significantly faster kick-preparation times and faced away from the goalkeeper more (avoidance behaviours) when the potential outcome was negatively valenced compared to positively valenced.

It is unlikely, in our view, that positive valence is a function of ‘scoring a penalty goal that results in an immediate team win’. It is more likely that negative valence is the prevailing emotion during penalty-kicks; the upshot of missing is always potentially a devastating team loss. Dohmen (2008) found that penalty-kickers failed more often when their team was leading by ≤ 2 goals, indicating that increased likelihood of winning does not by default produce positive valence. Indeed, Jordet and Hartman (2008) acknowledged that behaviours in neutrally valence conditions (i.e., the outcome of the kick did not decide the game) were more similar to avoidance than approach, suggesting that penalty-kicks are generally negatively valenced.

Theories of achievement motivation assume that positive or negative appraisal of a stimulus plays a key role in approach and avoidance (Elliot & Covington, 2001; Elliot & Thrash, 2001); however, appraisal of a stimulus is guided not only by *emotional valence* (positive or negative affect) but also *arousal* (high or low activation of associated emotions). *Pleasure-arousal theory* (Russell, 1980) proposes that appraisal of a stimulus cannot

possibly be captured on one dimension (i.e., pleasure/displeasure). For instance, the complex emotional experiences that accompany penalty-kick situations arise from core affective feelings associated with the interplay between *valence* and *arousal* (Feldman Barrett & Russell, 1999). Consequently, avoidance motivation is more likely to occur during (negatively valenced) penalty-kicks when arousal levels are higher rather than lower.

To examine this possibility, we conducted a retrospective analysis of penalty-kick situations in which the crowd behind the goal was either predominantly supportive or hostile. A hostile crowd should raise arousal levels more than a supportive crowd in the negatively valenced environment of penalty-kicks, so we hypothesised that avoidance behaviours would be more common when penalty-kicks were taken with a hostile crowd behind the goal. There are various reasons for believing that a hostile crowd will raise arousal levels compared to a supportive crowd. For instance, angry faces (and gestures), which are common at soccer games, tend to be processed preferentially (e.g., Hansen & Hansen, 1988; Öhman & Mineka, 2001). This can amplify the intensity of the emotions that are perceived (the crowd-emotion-amplification effect; Goldenberg, Weisz, Sweeny, Cikara, & Gross, 2021).

We indexed avoidance motivation differently to Jordet and Hartman (2008). Elliot et al. (2007) asked students to choose easy or difficult tasks to complete during an IQ test. They argued that greater choice of easy tasks indicated the use of avoidance motivation as a self-protective measure to circumvent feelings of inadequacy associated with a poor IQ score. Consequently, we examined choice of kick direction by players. Goalkeepers seldom stand in the exact center of the goal during penalty-kicks, but not by intention (Masters, van der Kamp, & Jackson, 2007). Goalkeepers appear to inadvertently create a side of the goal with more space (and thus a side with less space). Kicking towards the larger side of the goal is generally regarded to be the easier option, whereas kicking towards the smaller side of the goal is regarded to be the harder option. In this study, we assessed how often players kicked towards the easier side of the goal (avoidance behaviour) when taking penalty-kicks in the presence of a hostile crowd thought to raise arousal levels more than a supportive crowd.

We also examined how often players kicked towards the easier side of the goal when they were likely to have been consciously aware that there was an easy option and when they were less likely to have been consciously aware that there was an easy option. We did

this by leveraging the off-center goalkeeper paradigm (Masters et al., 2007). Masters et al. (2007) showed that when a goalkeeper stands marginally off-center, penalty-kickers are unlikely to be aware that there is greater space on one side of the goal; nevertheless, they can identify that side if forced to choose.⁴⁴ More importantly, they are more likely to kick to the side with more space despite being unaware that they are doing so. This phenomenon occurred even when participants were asked not to search for the side with more space, but rather to kick only when the goalkeeper was in the exact center (Experiment 3). Remarkably, when the goalkeeper was off-center by very small margins (between 1.6%–3.0% left or right), kickers claimed that he was in the exact center of the goal, yet they directed kicks to the side with more space more often than would be expected by chance.⁴⁵ Thus, we examined penalty-kick behaviour when the goalkeeper was marginally-off-center (1.6%–3.0%) and obviously off-center (>3.0%).

To reiterate, we hypothesised that during negatively valenced (unpleasant) penalty-kicks, higher arousal levels will be elicited by the presence of a hostile crowd compared to a supportive crowd. This will cause greater avoidance motivation, indexed by more kicks to the side of the goal with more space (i.e., the easier option).

7.3 Method

We sourced 314 online videos⁴⁶ of penalty-kicks across 144 professional matches between 2000 and 2020.⁴⁷ We included penalty-kicks triggered by a draw at the end of extra time (during a shootout) or triggered by a foul in the penalty-box.

⁴⁴ These findings have been replicated by Noël, van der Kamp, and Memmert (2015).

⁴⁵ Essentially, there was no easier/harder option when the goalkeeper was off-center by $\leq 1.6\%$, because participants were unable to discriminate which side had more space.

⁴⁶ The videos were sourced from public platforms, such as YouTube, official club/tournament websites or Facebook pages (e.g., video footage from TV broadcasts uploaded to these platforms after the match).

⁴⁷ Alphabetical order: Audi Cup 2011, Campeonato Nacional de Liga de Primera Division (or La Liga) 2013-2014, English Football League (or Carling Cup, Capital One Cup or Carabao Cup depending on sponsorship), EFL (English Football League) League One 2011-2012, English Premier League (or Barclays Premier League) 2005-2007, 2013-2015, 2017-2020, FA Cup (or Football Association Challenge Cup) 2014, FA (Football Association) Community Shield 2007, 2014, FAI Ford Cup (or Football Association of Ireland Senior Challenge Cup) 2010, Franz Beckenbauer Cup 2010, FIFA (Fédération Internationale de Football Association) World Cup (South Africa 2010, Brazil 2014, Russia 2018), UEFA (Union of European Football Association) Champions League 2004-2005, 2006-2008, 2011-2012, 2015-2016, UEFA Euro (or European Football Championship) 2000, 2004, 2012, 2016.

7.3.1 Goalkeeper Position

We screen captured each football penalty-kick and calculated the position of the goalkeeper relative to the center of the goal (in pixels). We captured the final moment at which the penalty-kicker appeared to be looking at the goalkeeper prior to initiating the run up (see Figure 7.1). Using the Weber fraction (Δ initial value/ initial value) identified by Weber's Law of Just Noticeable Difference (Fechner, 1860, 1966), we calculated the extent to which the goalkeeper was off-center by subtracting the distance (pixels) from the inside of the left-side goal-post to the center of the goalkeeper's head (x) from the distance from the inside of the right-side goal-post to the center of the goalkeeper's head (y) and divided it by the total width of the goal (w). We expressed the value as a percentage ($GK\%$). A positive value indicated that the goalkeeper was off-center to the right, whereas a negative value indicated that the goalkeeper was off-center to the left. An absolute $GK\%$ between 1.6%–3.0% (5.86cm–10.98cm) was used to classify the marginally off-center condition, whereas a $GK\% >3.0\%$ ($> 10.98\text{cm}$) was used to classify the obviously off-center condition. Images in which goalkeeper was $<1.6\%$ off-center were excluded ($N=58$).



Figure 7.1. Example image of a football penalty-kick (Watford versus Manchester United, English Premier League 2019/2020). Measurements for the width of the goal (w), height of the goal (h), left side of the goal (x), and right side of the goal (y) are shown.

7.3.2 Crowd Classification

Each penalty-kick was labeled using the penalty-kicker's perspective (the same crowd behind the goal could be classified as supportive or hostile depending on the team for which the penalty-kicker played). Classification was based on club colours, reactions to the kick outcome, and auditory cues, such as cheering/booing. Another researcher independently classified 84 of the 314 kicks, with 100% agreement. Cases that were unclear or did not have a relevant crowd (e.g., Brazil fans during Netherlands versus Costa Rica, FIFA World Cup 2014) were excluded from the study (N=59).

7.3.3 Exclusion Criteria

The official height and width of the goal-posts is 2.44 meters and 7.32 meters, respectively (International Football Association Board, Laws of the Game 2020/21). This results in a goal-post ratio of 0.33 approximately. Accordingly, images with a goal-post ratio of <0.32 or >0.34 were excluded to ensure that distorted images (due to camera angle being non-perpendicular to the center of the goal) were not analysed (N=64). In addition, penalty-kicks that were directed to the center of the goal (N=6)⁴⁸ were excluded, since we were only interested in the number of kicks directed either to the larger or smaller side of the goal.

To double-check goalkeeper position, we also calculated the distance (pixels) from the inside of the right-side goal-post to the center of the goalkeeper's head (y) by subtracting the distance from the inside of the left-side goal-post to the center of the goalkeeper's head (x) from the width of the goal ($w-x$). There was an average discrepancy between the two measurements of 6.174 pixels, possibly due to minute camera angle distortions (that were not initially filtered out). Our analysis only required us to discriminate the side of the goal with more space when the penalty-kick was taken (i.e., left or right), so if the two measurements provided conflicting evidence of which side of the goal was larger we excluded that case (N=5). We also excluded cases in which the goalkeeper was distracting (i.e., jumping around) or did not stand symmetrically (i.e., pointed to one side or the other) (N=6).

⁴⁸ Any kicks that landed within ± 50 cm from the center of the goal ($\pm 13.67\%$ off-center) were classified as kicks directed to the center of the goal.

After exclusion, a total of 91 penalty-kicks were available for analysis (N=43 marginally off-center, N=48 obviously off-center).^{49, 50}

7.3.4 Analysis

A general statistical analysis (supportive/hostile conditions collapsed) was conducted to examine the average conversion rate and direction of kicks to the larger and smaller side of the goal in the marginally off-center condition, the obviously off-center condition, and in both conditions collapsed. Avoidance motivation was indexed by the number of times that a penalty-kick was directed towards the larger side of the goal relative to the number of times that a penalty-kick was directed to the smaller side of the goal (i.e., proportion of times in which the easier option was chosen, %). Given the specified direction of our hypothesis, we used a one-tailed z-test for two population proportions (significance set as $p < 0.050$) to examine whether differences existed in the number of penalty-kicks to the larger side when the crowd was hostile compared to supportive, both when the goalkeeper was marginally off-center (1.6%–3.0%, subconscious) and obviously off-center (>3.0%, conscious). We also conducted one-sampled t-tests to examine whether the proportion of kicks towards the larger side of the goal was significantly above chance (50%) in each condition. Cohen's *d* effect sizes are reported and broadly defined as small (0.20), medium (0.50) or large (0.80) (Cohen, 1988).

7.4 Results

7.4.1 General Analysis

The average conversion rate of penalty-kicks was 71.43% for both the marginally off-center and obviously off-center conditions combined (25.27% were saved, 3.30% missed). In the marginally off-center condition, the average conversion rate was 67.44% (27.91% were saved, 4.65% missed), whereas in the obviously off-center condition, the average conversion rate was 75.00% (22.92% were saved, 2.08% missed).

Overall, penalty-kicks were directed to the larger side (i.e., easier option) and the smaller side (i.e., harder option) equally often (54.95% and 45.05% respectively, $t(90) = 0.94$, p

⁴⁹ Of 91 penalty-kicks, 51 were from penalty shootouts and 40 were in-game penalty kicks

⁵⁰ Of 91 penalty-kicks, 29 were from home games, 33 were from away games, and 29 were neutral (from the kicker's perspective).

= 0.174, $d = 0.10$, 90% CI [-0.04, 0.14]), with an average absolute off-center GK% of 3.46%. Differences in side choice were not evident when the goalkeeper was marginally off-center (48.84% and 51.17% respectively, $t(42) = -0.15$, $p = 0.440$, $d = -0.02$, 90% CI [-0.14, 0.12]; average absolute off-center GK% 2.26%) or obviously off-center (60.42% and 39.58% respectively, $t(47) = 1.46$, $p = 0.075$, $d = 0.21$, 90% CI [-0.02, 0.22]; average absolute off-center GK% 4.53%).

7.4.2 Goalkeeper off-center (marginally and obviously off-center collapsed)

As shown in Figure 7.2, the proportion of times that players kicked to the larger side (i.e., the easier option) was significantly greater when facing a hostile crowd (66.67%) compared to facing a supportive crowd (46.15%), ($z = 1.95$, $p = 0.026$). A one-sample t -test revealed that the proportion of times that penalty-kicks were directed to the larger side was significantly above chance level (50%) when facing a hostile crowd, ($t(38) = 2.18$, $p = 0.018$, $d = 0.35$, 90% CI [0.04, 0.30]), but not when facing a supportive crowd, ($t(51) = -0.55$, $p = 0.292$, $d = -0.08$, 90% CI [-0.16, 0.08]).

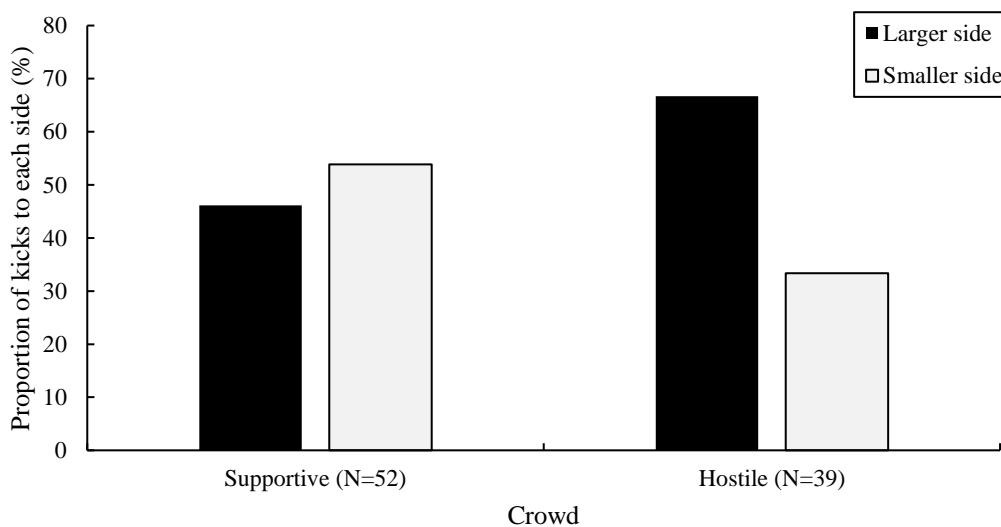


Figure 7.2. Proportion of penalty-kicks to the larger side or the smaller side of the goal (%) when facing a supportive crowd (N=52) or a hostile crowd (N=39).

7.4.3 Goalkeeper marginally off-center

Figure 7.3 shows the proportion of penalty-kicks to the larger or smaller side as a function of marginally off-center goalkeepers (1.6%–3.0%) (left panel). The proportion of times that players kicked to the larger side was significantly greater when facing a hostile crowd

(73.33%) compared to when facing a supportive crowd (35.71%), ($z = 2.35, p = 0.009$). When facing a hostile crowd, penalty-kickers directed their kicks to the larger side more often than the smaller side; whereas, when facing a supportive crowd, penalty-kickers directed their kicks to the smaller side more often. One-sample t-tests showed that the proportion of kicks directed to the larger side was significantly above chance (50%) when facing a hostile crowd ($t(14) = 1.97, p = 0.034, d = 0.51, 90\% \text{ CI } [0.03, 0.44]$), but not when facing a supportive crowd ($t(27) = -1.55, p = 0.066, d = -0.29, 90\% \text{ CI } [-0.30, 0.01]$).

7.4.4 Goalkeeper obviously off-center

Figure 7.3 shows the proportion of penalty-kicks to the larger or smaller side as a function of obviously off-center goalkeepers (>3.0%) (right panel). The proportion of times that players kicked to the larger side was not significantly different when facing a hostile crowd (62.50%), compared to when facing a supportive crowd (58.33%), ($z = 0.30, p = 0.382$). One-sample t-tests revealed that for both hostile and supportive crowds, the proportion of kicks directed to the larger side was not different from chance (50%), (hostile crowd: $t(23) = 1.24, p = 0.114, d = 0.25, 90\% \text{ CI } [-0.05, 0.30]$ and supportive crowd: $t(23) = 0.81, p = 0.213, d = 0.17, 90\% \text{ CI } [-0.09, 0.26]$).

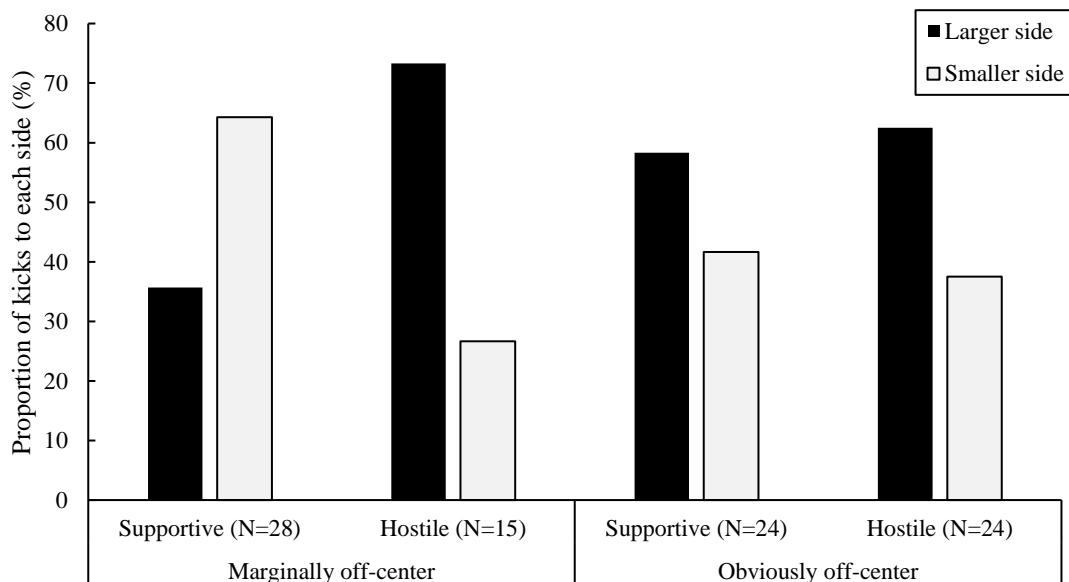


Figure 7.3. Proportion of penalty-kicks to the larger side or the smaller side of the goal (%) in the marginally off-center (1.6%–3.0%) and obviously off-center (>3.0%) goalkeeper conditions.

7.5 Discussion

We conducted retrospective analysis of the direction of penalty-kicks during important soccer games to examine the effect of crowd hostility on avoidance motivation. Avoidance motivation was indexed by the number of times kicks were directed towards the larger side of the goal (i.e., the easier option). We hypothesised that in the negatively valenced (unpleasant) environment created by high-pressure penalty-kick scenarios, the extent to which the crowd behind the goal was hostile would intensify arousal levels and thus increase the likelihood of avoidance motivated behaviour.

We first considered the collapsed data (marginally off-center goalkeeper with obviously off-center goalkeeper / hostile crowd with supportive crowd). The average penalty-kick conversion rate was 71.43%, which is consistent with Dalton, Guillon, and Naroo (2015) who reported an average conversion rate of 70.50%. The proportion of penalty-kicks directed to the larger side of the goal was not significantly above chance level (50%) in our study (54.95%), whereas it was in the Masters et al. (2007) study (59.20%). Our results revealed that the larger side (i.e., the easier option) was chosen significantly more often when the penalty-kicker faced a hostile crowd, compared to a supportive crowd, so it is possible that the discrepancy between the two studies can be accounted for by differences in the number of penalty-kicks completed when facing a hostile or a supportive crowd, which Masters et al. (2007) did not report.

When we examined only penalty-kicks to an obviously off-center goalkeeper (>3.0%), we found that the proportion of penalty-kicks to the larger side was not statistically different when facing a supportive crowd or a hostile crowd. It is likely that kickers were explicitly aware that one side had more space than the other, which made the decision to kick to that side a logical choice, regardless of whether the crowd was hostile or supportive.

However, when we examined only penalty-kicks to a marginally off-center goalkeeper (1.6%–3.0%), we found that kicks were directed to the larger, easier, side significantly more often when facing a hostile crowd compared to a supportive crowd, suggesting that in the presence of a hostile crowd avoidance behaviour was greater. Masters et al. (2007) reported that when the goalkeeper was marginally off-center by 1.6%–3.0%, penalty-kickers were unaware that there was more space on one side of the goal, yet still kicked to that side. Our findings suggest that the difference between hostile and supportive

crowds when the goalkeeper was marginally off-center may have been a function of penalty-kickers being more likely to subconsciously discriminate the space differences when facing a hostile crowd. Robinson, Storbeck, Meier, and Kirkeby (2004) argued that negative stimuli that are high in arousal capture attention more readily and are automatically processed as a threat— it is safer to assume a stimulus is hazardous than harmless (Öhman, 1997; Robinson, 1998). Detection of such stimuli occurs at a pre-attentive stage of processing, outside conscious awareness (Osgood et al., 1957; Zajonc, 1998). Consequently, in the negatively valenced environment of penalty-kicks, avoidance behaviour may have been higher because pre-attentive processes facilitated detection of space differences when the presence of a hostile crowd raised arousal levels. In contrast, avoidance behaviour may have appeared to be less common in the presence of a supportive crowd because lower arousal levels meant that detection of space differences was not facilitated. In short, penalty-kickers were unable to take the easier option when their arousal levels were less elevated, because they did not know which side had more space.

An alternative explanation exists. When facing a hostile crowd or a supportive crowd, penalty-kickers equally detected space differences, but pre-attentive processes evaluated the hostile crowd as more of a threat, which resulted in more avoidance behaviour. Valence and arousal function interactively, rather than independently. Stimuli that are negatively valenced (e.g., a spider) or high in arousal (e.g., a fast-approaching ball) elicit avoidance behaviour because they are perceived as threatening, whereas stimuli that are positively valenced (e.g., a flower) or low in arousal (e.g., 'House & Garden' magazine) elicit approach behaviour because they are perceived as safe. Consequently, stimuli that are congruent (e.g., negative valence with high arousal) interact to more potently elicit avoidance behaviours than stimuli that are incongruent (e.g., negative valence with low arousal) (Citron, Gray, Critchley, Weekes, & Ferstl, 2014; Robinson et al., 2004). Accordingly, the congruent (highly threatening) combination of a negatively valenced penalty-kick situation with a hostile crowd may have elicited more avoidance behaviour than the incongruent (less threatening) combination of a negatively valenced penalty-kick situation with a supportive crowd.

The recent COVID-19 global pandemic has caused professional soccer games to be played in the absence of crowds. Harris, Wilson, and Vine (2020) observed that in many leagues more goals have been scored during COVID-19. They suggested that this is a

consequence of reduced performance pressure in the absence of a crowd. Additionally, McCarrick, Bilalic, Neave, and Wolfson (2020) reported a reduction in the home team advantage (usually attributed to the supportive home crowd). We wonder about the role of arousal and avoidance in these trends.

Our findings consolidate Masters et al. (2007) off-center goalkeeper paradigm. Imperceptibly off-center goalkeepers can induce penalty-kickers to unwittingly kick to the larger side of the goal. However, we recommend that goalkeepers do this only when emotions are running high and the crowd behind the goal is hostile to the penalty-kicker.

Chapter 8

General discussion

The purpose of this final chapter is to provide a summation of the key findings from the research conducted, to discuss them within the framework of the theory of reinvestment, Colour-in-Context theory, and automatic processing of threat, and to provide insights into implications of the work. An integrated framework for the effect of colour is proposed on the basis of previous research and the findings from this thesis. Practical implications and interventions are discussed.

8.1 Inhibition function and reinvestment propensity

Initially, Chapter 2 hypothesised that individuals with poor inhibition function would be more likely to have a high propensity for reinvestment because they are less able to inhibit conscious control of their movements. However, the first two experiments (Chapter 2 and Chapter 3) showed a positive association between inhibition function and propensity for conscious control of movements (i.e., movement specific reinvestment). These findings suggest either that (1) greater conscious control of movement resulted in more successful Go/NoGo task performance (indicative of superior inhibitory control), or (2) people who had superior inhibitory control (i.e., more successful performance of the Go/NoGo task) were more likely to use conscious control of movements. However, the causality of the relationship is unclear.

It is possible that conscious control of movement and inhibition manifest in different ways to influence performance. Hammond (1987), for example, discussed the role of conscious control in well-learned movements. Hammond (1987) suggested that a person can exercise controlled processing of an automatic movement best left to its own devices or a person can fail to exercise controlled processing of an inappropriate automatic movement. In both cases, the outcome of this interaction between controlled processing and inhibitory behaviour can lead to disrupted or inappropriate movement. Our data suggests that high reinvesters (who tend to have strong inhibition functions) may be more likely to exercise controlled processing of an automatic movement best left to its own devices, whereas, low reinvesters (who tend to have poorer inhibition functions) may be less likely to exercise controlled processing to adapt or prevent inappropriate automatic movement.

Baddeley (1996) speculated that executive functions such as inhibition may be necessary for selective attention and conscious control by the central executive. However, literature suggests that there are *three* fundamental executive functions (e.g., inhibiting, updating, and shifting; Miyake et al., 2000), which raises a question of whether updating and shifting are also associated with propensity for movement specific reinvestment.

Executive functions have been conceptualised as a *set* of cognitive processes that work together to allow us to successfully navigate most of our daily activities (Diamond, 2013; Gilbert & Burgess, 2008; Lehto et al., 2003; Miyake et al., 2000). Indeed, there has been considerable debate about the unity and diversity of the executive functions (Duncan, Johnson, Swales, & Freer, 1997; McCabe, Roediger III, McDaniel, Balota, & Hambrick, 2010; Miyake et al., 2000; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Stuss & Alexander, 2000), with studies often showing a high correlation between each function. Accordingly, it is likely that the rest of the executive functions (updating, shifting) will be positively correlated with reinvestment propensity.

8.1.1 Updating and shifting, and their potential relationship to reinvestment propensity

Updating (Miyake et al., 2000) can be understood as the ability to replace “old, no longer relevant information with newer, more relevant information” (Miyake et al., 2000, p.57). It is often indexed by the N-back counting task or memory recall to reflect the ability to actively maintain information in working memory. Shifting (Miyake et al., 2000), or cognitive flexibility (Diamond, 2013), can be understood as the ability to switch between tasks, mental sets, or retrieval strategies. It is often measured by the plus-minus task (Miyake et al., 2000) in which participants are required to add or subtract one number from another alternatively as quickly and accurately as possible.

Diamond (2013) suggested that inhibition function may facilitate updating because for individuals to focus on task-relevant information, task-irrelevant information needs to be first ignored. Thomas et al. (2016) proposed that the inhibition function and the updating function are two sides of the same coin that cannot be separated. Attentional Control Theory (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Eysenck et al., 2007) posits that attentional control is diminished when the efficiency of inhibition function is impaired by anxiety. Similarly, evidence suggests that inhibition function precedes the shifting function to facilitate appropriate motor behaviour during various tasks (Diamond, 2013; Mostofsky & Simmonds, 2008). This was illustrated by Isoda and Hikosaka (2007),

who found that NoGo type neurons were activated earlier than Go type neurons in the pre-SMA during a response switching task, suggesting that the inhibition function and shifting function may be closely associated and distinguished by the temporal domain rather than the spatial domain in the brain. Subsequently, individuals with good inhibition function are likely to have good updating and shifting functions.

8.1.2 Diversity of inhibition function

There is a growing body of research suggesting that inhibition is not a unitary construct (Dempster, 1993; Friedman & Miyake, 2004; Harnishfeger, 1995; Howard et al., 2014; Nigg, 2000; Pascual-Leone, 1984; Tiego et al., 2018). For instance, Tiego et al. (2018) proposed that there are two types of inhibition (*response inhibition* or *attentional inhibition*), which are empirically independent from one another. *Response inhibition* concerns the ability to inhibit prepotent responses while *attentional inhibition* concerns the ability to resist interference that may disrupt attention (e.g., distracting thoughts/information). In their study, Tiego et al. (2018) indexed response inhibition with the Go/NoGo task, the Stop-Signal task, and the Simon task while automatic inhibition was indexed with the Stroop task, the Flanker task, and shape matching tasks.

Accordingly, findings from Experiment 1 (Chapter 2) and Experiment 2 (Chapter 3) can be specified to indicate that a positive association exists between *response inhibition* and movement specific reinvestment propensity. Therefore, it is left unclear how attentional inhibition may be associated with movement specific or even decision-specific reinvestment propensity. Perhaps individuals who can better ignore or forget disruptive thoughts (good attentional inhibition) display lower movement specific and decision-specific reinvestment propensity given that disruptive thoughts (e.g., worry, rumination) have been suggested to elicit conscious control of step-by-step processes (Beilock, 2007a; Liao & Masters, 2002; Masters & Maxwell, 2008).

Conversely, it is possible that attentional inhibition may also be positively associated with reinvestment propensity, particularly with decision-specific reinvestment propensity, as studies have shown a correlation between response inhibition and automatic inhibition (e.g., Howard et al., 2014; Tiego et al., 2018). Nonetheless, we did not find any association between inhibition function and decision-specific reinvestment in Experiment 1 (Chapter 2). However, this may be because feedback about performance was not provided, making it unlikely that participants would ruminate about their decisions during

the Go/NoGo task. Conversely, because the Go/NoGo task was very fast paced, there may not have been enough time for participants to ruminate about their mistakes.

8.2 The effect of colour in sport: What, when, and how?

8.2.1 Colour in context: What influence does colour have and when does it occur?

Much research has investigated the effect of colour in sport; however, the findings are often inconclusive (see for review Goldschmied, Furley, & Bush, 2020). Based on the work presented in this thesis, it is clear that there is an effect of colour. Experiment 3 (Chapter 4) revealed that inhibition of responses to NoGo cues (i.e., no passing) was poorer when viewing a basketball opponent in a green uniform. Experiment 4 (Chapter 5), on the other hand, demonstrated a red and a blue effect on size perception (i.e., goalkeepers in a red and a blue uniform were perceived to be larger) and Experiment 5 (Chapter 6) revealed that red and blue elicited avoidance motivation in football penalty-kickers (i.e., kicking towards the larger side of the goal). The colour effect found in these experiments appeared to be at least partially underpinned by Colour-in-Context theory (Elliot & Maier, 2012). The theory proposes that colour can convey different meanings in different contexts, and colour can influence psychological functions that are consistent with the meaning of the colour. For example, red in romantic contexts elicits approach motivation because red in that context symbolises love (Elliot & Niesta, 2008), whereas red in construction sites elicits avoidance motivation because red in that context signals hazards (Braun & Silver, 1995).

In line with Colour-in-Context theory (Elliot & Maier, 2012), in a Go/NoGo context, green might have conveyed the meaning of ‘go’, which impaired the ability to inhibit responses. In a football context, red and blue might have signalled dominance and threat, because of the likely association of these colours with superior teams (e.g., teams that most often won the English Premier League between 1993 and 2020 wore red or blue club colours). This may have increased the apparent size of players in these teams and elicited avoidance motivation by their opponents.

The findings in this thesis reiterate the importance of context, which determines the effect colour will have on motor behaviour. In Experiment 4 (Chapter 5), the influence of colour on size perception differed when there was no context involved (i.e., only red circles were perceived as larger) and when there was a specific context involved (i.e., goalkeepers in a red *and* a blue uniform were perceived as larger), suggesting that the disparity in results

was a function of context. In Experiment 5 (Chapter 6), there was no effect of background colour on penalty-kicking behaviour when participants were not assigned to a specific team. However, there was an effect of background colour when participants were assigned to a team. This suggests that colour effects only took place when participants had more contextual information relevant to the evaluation of the current task at hand (i.e., whether they were viewing their own supporters or opponent's supporters) and the outcome of the performance (i.e., whether they would display approach or avoidance behaviour).

8.2.2 *Colour-meaning to influence arousal level rather than emotional valence*

According to Osgood et al. (1957), people evaluate most if not all encountered stimuli on a good/bad dimension immediately and automatically (Bargh, 1997; Zajonc, 1998). For example, a person who is afraid of spiders would rate spiders to be highly negative (bad), whereas a person who loves spiders would rate spiders to be highly positive (good). Consequently, Elliot and Maier (2012) developed Colour-in-Context theory based on the assumption that colours that carry a positive meaning (e.g., red-love) trigger a positive evaluation whereas colours that carry a negative meaning (e.g., red-hazard) trigger a negative evaluation. Moreover, Elliot and Maier (2012) suggested that approach behaviour is instigated by stimuli that are deemed positive/desirable whereas avoidance behaviour is instigated by stimuli that are deemed negative/undesirable (e.g., motivational valence, Craig, 1917) (see for a review, Elliot & Covington, 2001).

However, this raises a question of whether individuals will still display approach behaviour towards a positive stimulus when the situation itself is negatively valenced (or vice versa). Additionally, what is considered approach behaviour in a negatively valenced situation (e.g., before a test, before a penalty-kick)? Indeed, studies that have mainly reported an adverse effect of red did so when testing situations were considered to be unpleasant (e.g., swaying away from red before a test, Elliot et al., 2007; less goals scored against a goalkeeper in red, Greenlees et al., 2013). On the other hand, studies that have mainly reported an advantageous effect of red did so when testing situations were considered to be pleasant (e.g., evaluation of the opposite sex on attractiveness, Elliot et al., 2010) or non-competitive (e.g., grip task performed alone, Elliot & Aarts, 2011).

Consequently, based on the work presented in this thesis, an argument can be made that colour influences the *degree* of evaluation (high/low arousal level), whereas context

determines the emotional valence (positive/negative). This can be better understood through the perspective of pleasure arousal theory (Feldman Barrett & Russell, 1999), which states that a stimulus is evaluated on two dimensions (emotional valence, arousal level). Indeed, humans do not evaluate stimuli using a binary positive/negative categorisation; rather, humans evaluate stimuli personally (emotionally) and on a wide array of emotional spectrums. For example, looking at a picture of kittens or winning a lottery are both positive but the degree of positivity varies (happy versus extremely elated). Likewise, Experiment 5 (Chapter 6) argues that while the situational context influences emotional valence, colour influences arousal level.

The interaction between negative emotional valence and high arousal has been shown to elicit avoidance motivation more than the interaction between negative emotional valence and low arousal (e.g., Citron et al., 2014; Robinson et al., 2004). Experiment 6 (Chapter 7) of this thesis also found that avoidance motivation was evident when viewing a red and a blue spectator background (highly arousing) during real-life football penalty-kicks (negative emotional valence). Therefore, an argument can be made that avoidance motivation was observed because the degree of negative emotions was exacerbated by a high level of arousal.

There is evidence to suggest that red is arousing (Briki & Hue, 2016; Hamid & Newport, 1989; Levy, 1984; Wilson, 1966) and anxiety-provoking (Jacobs & Suess, 1975; Kwallek & Lewis, 1990) compared to blue or green colours. However, evidence from Experiment 5 (Chapter 6) suggests that blue was also seen as a highly arousing colour possibly because blue as well as red carried the meaning of dominance and threat. Indeed, studies have shown that threatening stimuli induced a higher level of arousal (e.g., increased heart rate, skin conductance, probe startle reflex) (Bradley, Moulder, & Lang, 2005; Löw, Lang, Smith, & Bradley, 2008; Löw, Weymar, & Hamm, 2015). The physiological changes that occur when one encounters threat may have an evolutionary basis. For example, the fight-or-flight response is an automatic and acute stress response to threat that prepares the body to fight or flee. As a result, it is often difficult to dissociate negative emotions and high arousal. For example, Lang, Bradley, and Cuthbert (1997) reported that it was extremely difficult to find strongly negative images that were low in emotional arousal.

Subsequently, the question arises of whether viewing a highly arousing stimuli in a context that elicits positive emotional valence will exacerbate positive emotional arousal

and elicit approach motivation. Robinson et al. (2004) found that evaluation latency (e.g., judging words/images as positive/negative when high/low in arousal) was shorter for stimuli that were negative and high in arousal and stimuli that were positive and low in arousal compared to stimuli that were negative and low in arousal and stimuli that were positive and high arousal. Thus, the speed of processing information depends on the interaction between emotional valence and arousal level (see also Citron et al., 2014). In line with this, it can be argued that colours that are highly arousing in an emotionally positive context may not be processed as efficiently as other colours and thus may fail to elicit approach motivation. On the other hand, colours that are less arousing in an emotionally positive context may be processed more efficiently and thus elicit approach motivation.

It is possible that colour effects become more prevalent when colour carries a negative meaning (and thereby elicits high arousal) in negative contexts (e.g., intelligence test, penalty-kick situation), but less so when colour carries a positive meaning (and thereby elicits less arousal). Highly arousing stimuli have a special ability to capture attention (Öhman, 1997; Robinson, 1998) and are more likely to be processed at a pre-attentive stage than less arousing stimuli. Therefore, colours that are less arousing may have a smaller impact because they are less likely to be attended and processed.

Alternatively, Experiment 6 (Chapter 7) proposes that enhanced attention when viewing a highly arousing stimulus (a hostile crowd) perhaps resulted in more kicks to the larger side of the goal because detection of space differences was facilitated. Likewise, it is possible that viewing a red and a blue spectator background facilitated detection of the larger side of the goal.

As discussed above, it seems there may be several contingencies that need to be met for colour effects to occur, such as the specification of context in which meaning of colour is salient, emotional valence of context, and arousal property of colour. Perhaps research in colour often has conflicting findings because of all these factors that may influence the colour effect. However, it must be acknowledged that the effect of colour was also present in Experiment 3 (Chapter 4) in which the emotional valence of the context was ambiguous (participants were simply instructed to perform a basketball-specific Go/NoGo task) and in which green did not convey a negative meaning (not highly arousing). Hill and Barton (2005b) suggested that red “tips the balance” between winning and losing when all other

factors (strength, skill) are equally matched. Likewise, it is possible that, inside a controlled laboratory setting, other factors such as crowd, risk, motivation, and skill may have been less prevalent and thereby allowed colour to have an influence on motor behaviour.

8.2.3 *Summary, limitations, and future directions*

A positive association between inhibition function and movement specific reinvestment propensity was found in the first two experiments (Chapter 2 and Chapter 3). However, because these two studies were exploratory in nature, future studies are warranted to investigate (1) the association between updating/shifting function and movement specific reinvestment propensity⁵¹ and (2) the association between automatic inhibition and reinvestment propensity (MSRS, DSRS).

Moreover, pressure or anxiety can be induced to examine whether the direction of association between inhibition function and reinvestment propensity changes. Individuals with a high propensity for reinvestment were found to demonstrate superior task performance compared to individuals with a low propensity for reinvestment, possibly because inhibition function aids in conscious control. However, inhibition function may be compromised under pressure, which can hinder conscious control and result in performance deterioration. If so, it raises a question about whether an intervention to strengthen inhibition function under pressure may prevent performance breakdown among individuals with a high propensity for reinvestment.⁵²

Overall, we found support for the effect of colour, and that the colour effect may be sensitive to context. Specifically, the approach-avoidance distinction may be a function of positive and negative emotional evaluation of the context, in which highly arousing colours further exacerbate the degree of emotional arousal whereas less arousing colours reduce the degree of emotional arousal. However, future studies need to further

⁵¹ Buszard et al. (2013) reported a positive association between working memory capacity (updating function) and MSRS, but other studies have found equivocal results (see Buszard, Masters, & Farrow, 2017).

⁵² Studies often try to prevent conscious control of movement by limiting accumulation of explicit task-relevant declarative knowledge through analogy learning (Lam et al., 2009a, 2009b; Liao & Masters, 2001; Poolton et al., 2006), error-reduced practice (Masters, MacMahon, & Pall, 2004; Maxwell, Masters, Kerr, & Weedon, 2001), or dual-task learning (Hardy et al., 1996; MacMahon & Masters, 2002; Masters, 1992). However, if conscious control is only detrimental under pressure possibly due to impaired inhibition function, why not try and strengthen inhibition function in order to maintain the efficiency of conscious control under pressure?

investigate the interaction between colour arousal and emotional valence, possibly with the inclusion of measurements of physiological arousal level using heart rate monitoring, galvanic skin responses, or electromyography.

One of the limitations of the studies presented in this thesis was that a colour-meaning association in different contexts was assumed. In addition, the emotional valence of the context was also assumed. As a result, future studies should consider subjective (e.g., self-report) or objective (e.g., implicit association test) measures to probe the meaning of colour in different contexts. There are various factors that predispose people to harness an approach or avoidance goal (e.g., to strive for success or to avoid failure), such as competence, personality, and task difficulty. For example, real-life football penalty-kicks were assumed to be a negative situation whereas the laboratory penalty-kicking task was assumed to be a positive situation. However, individual differences in skill-level (competence) or personality may influence the emotional valence of the situation. As a result, interpersonal differences in the emotional valence of a context needs to be carefully considered and indexed.

In retrospect, there is a clear need for a theoretical framework that integrates the different (proposed) underlying mechanisms for the effect of colour in sport. Colour research has *very* mixed findings on the red superiority effect in sports (see Goldschmied et al., 2020 for a review), and discerning which mechanisms are at play for different colour effects is difficult because of overlap between the mechanisms (see Figure 8.1). For example, according to the colour hierarchy, red is the highest in the hierarchy because red attracts attention, but is the attraction to red due to its high perceptual salience or is it due to wavelength differences? Does colour influence psychological functioning (e.g., Colour-in-Context theory), physiological responses (e.g., changes in testosterone level), or perceptual processes (e.g., colour-size illusions)? Does colour elevate testosterone levels because colour symbolises dominance and threat or is the effect innate? With a growing body of research on the effects of colour, it seems imperative for an integrated framework to emerge to provide insights into exactly when and how colour effects are triggered. This will allow research in the future to make better *a priori* predictions and develop evidence-based interventions that can be leveraged in sports.

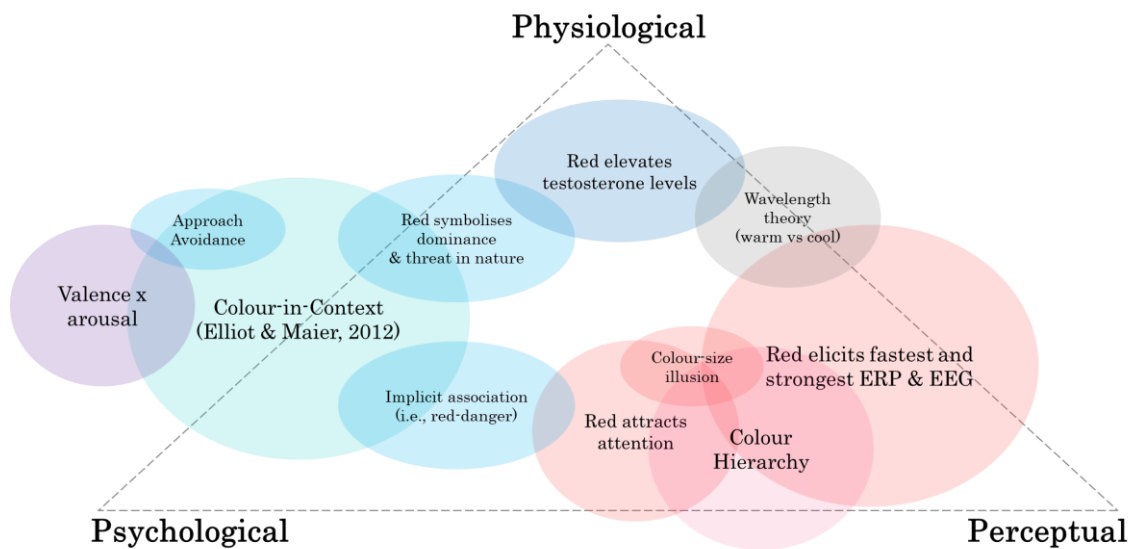


Figure 8.1. An integrated framework for the effect of colour.

A possible avenue for research in the future includes further investigation into the perceptual effects of colour. For example, Chapter 5 investigated the effect of colour on size perception during computer-based tasks, but whether colour can influence size perception for action remains unclear. There is evidence to suggest that colour can influence size perception for actions. For example, Gentilucci et al. (2001) found that grasp sizes were bigger for red coloured objects than for other coloured objects. Although the two-stream hypothesis views ‘vision for perception’ (ventral stream) and ‘vision for action’ (dorsal stream) separately (Ungerleider & Mishkin, 1982; Milner & Goodale, 2008), recent evidence suggests that visual motor tasks utilise both the ventral and dorsal stream to discriminate colour (Claeys, Dupont, Cornette, Sunaert, Van Hecke, De Schutter, & Orban, 2004). Empirical evidence is yet to accumulate, but if colour can change size perception as well as motor behaviour, then the applications to the real world will be many in sports. Nonetheless, the use of colour does not need to be limited only to sports. The ubiquitous nature of colour allows for potential application of colour effects in any field of research. For example, the use of red-stop and green-go colour signals as cues may be an eloquent and inexpensive solution to treat freezing in patients with Parkinson’s disease. Parkinson’s disease (PD) is a neurodegenerative condition that causes movement disruptions, such as tremor, rigidity, dystonia, and slowness of movement (Braak & Braak, 2000). Freezing, especially freezing of gait (FOG), is a common yet disabling symptom in patients with advanced PD (Bartels, Balash, Gurevich, Schaafsma, Hausdorff, & Giladi, 2003; Bloem, Hausdorff, Visser, & Giladi, 2004; Fahn,

1995; Giladi, McDermott, Fahn, Przedborski, Jankovic, Stern, & Tanner, 2001; Giladi, Treves, Simon, Shabtai, Orlov, Kandinov, Paleacu, & Korczyn, 2001; Macht, Kaussner, Möller, Stiasny-Kolster, Eggert, Krüger, & Ellgring, 2007; Nutt, Bloem, Giladi, Hallett, Horak, & Nieuwboer, 2011). Patients with FOG typically are unable to start their gait movements (start hesitation) or turn (turn hesitation) despite their intention to move. FOG can be triggered by walking towards doorways or obstacles, turning direction, or diverting attention to another task.

The underlying mechanism of FOG is unclear; however, it has been suggested that freezing may be linked to deficits in cognitive mechanisms (Amboni, Cozzolino, Longo, Picillo, & Barone, 2008)—particularly, deficits in inhibition function (Cohen, Klein, Nomura, Fleming, Mancini, Giladi, Nutt, & Horak, 2014; Gauggel, Reiger, & Feghoff, 2004; Lewis & Shine, 2016; Obeso, Wilkinson, Casabona, Bringas, Álvarez, Álvarez, Pavón, Rodríguez-Oroz, Macías, Obeso, & Jahanshahi, 2011; Van Wouwe, Van den Wildenberg, Claassen, Kanoff, Bashore, & Wylie, 2014). Cohen et al. (2014) showed that FOG was correlated with both failures to respond to Go trials and with failures to inhibit responses to NoGo trials in the Go/NoGo task. Bissett, Logan, Van Wouwe, Tolleson, Phibbs, Claassen, and Wylie (2015) examined whether stop-signal task performance differed between PD patients with and without freezing symptoms. PD patients with freezing symptoms displayed significantly slower stop-signal response times (indicative of poor inhibition function) compared to PD patients without freezing symptoms. This finding is consistent with the idea that freezing may be linked to a dysfunctional hyper-direct fronto-STN pathway (Lewis & Shine, 2016), the putative mechanism responsible for response inhibition (Aaron, Behrens, Smith, Frank, & Poldrack, 2007; Aron, Robbins, & Poldrack, 2014). Bissett et al. (2015) proposed that deficits in inhibition function (i.e., dysfunctional hyper-direct fronto-STN pathway) would result in inability to engage and then disengage the inhibition system. In other words, inhibition function may not only be responsible for the inhibition of motor movements but also the initiation (execution) of motor movement.

This raises a question of whether red-stop and green-go colour signals can facilitate the ability to engage and then disengage the inhibition system appropriately. Interestingly, Blizzard et al. (2017) argued that “the fast action of the hyper-direct pathway might preserve the advantage for red” (p. 8), suggesting that colour may be an effective way to influence inhibition function.

The use of different auditory or counting cues to initiate movement is not a new technique for physiotherapists treating PD patients who freeze. Nonetheless, the use of colour as a cue may be a better option than auditory cues since colour can be an effective vessel to convey messages. For example, a small key chain size device that lights up with red-yellow-green lights (e.g., traffic lights) in a slow sequence may remind patients to STOP and breath (red light), shift weight onto one leg (yellow light), and to GO ahead and step forward (green light). The colour-meaning association occurs at a subconscious level, so patients may not need to remember individual details to combat freezing (which can overload the working memory and create even greater processing conflict), but simply look at the traffic lights to initiate their movements implicitly.

This thesis aimed to examine different factors that can influence motor performance. The findings revealed insights into the relationship between conscious processing of movement and inhibition function and into the role of context in the effects of colour, which is consistent with the Colour-in-Context theory. However, the thesis also proposed a different perspective from Colour-in-Context theory –perhaps colour influences arousal level rather than emotional valence. Perhaps the colour effect is most prominent when colours carry a negative meaning (high in arousal) and is observed in a context that elicits negative emotional valence. The thesis calls for an integrated framework to underpin the colour effect as a means to further understand colour effect phenomena and to accurately leverage colour to elicit desired motor behaviours, not only in sports but also non-sports contexts.

References

- Aaron, A. R., Behrens, T. E., Smith, S. A., Frank, M. J., & Poldrack, R. A. (2007). Triangulating a cognitive control network using diffusion-weighted magnetic resonance imaging (MRI) and functional MRI. *Journal of Neuroscience*, 27(14), 3743-3752. <https://doi.org/10.1523/JNEUROSCI.0519-07.2007>
- Ainsworth, R. A., Simpson, L., & Cassell, D. (1993). Effects of three colors in an office interior on mood and performance. *Perceptual and Motor Skills*, 76(1), 235-241. <https://doi.org/10.2466/pms.1993.76.1.235>
- Allen, M. S., & Jones, M. V. (2014). The home advantage over the first 20 seasons of the English Premier League: Effects of shirt colour, team ability and time trends. *International Journal of Sport and Exercise Psychology*, 12(1), 10-18. <https://doi.org/10.1080/1612197X.2012.756230>
- Amboni, M., Cozzolino, A., Longo, K., Picillo, M., & Barone, P. (2008). Freezing of gait and executive functions in patients with Parkinson's disease. *Movement Disorders*, 23(3), 395-400. <https://doi.org/10.1002/mds.21850>
- Anderson, M. C. (2001). Active forgetting: Evidence for functional inhibition as a source of memory failure. *Journal of Aggression, Maltreatment, and Trauma*, 4(2), 185-210. https://doi.org/10.1300/J146v04n02_09
- Andersson, S., Pryke, S. R., Örnborg, J., Lawes, M. J., & Andersson, M. (2002). Multiple receivers, multiple ornaments, and a trade - off between agonistic and epigamic signaling in a widowbird. . *The American Naturalist*, 160(5), 683-691. <https://doi.org/10.1086/342817>
- Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2014). Inhibition and the right inferior frontal cortex: One decade on. *Trends in Cognitive Sciences*, 18(4), 177-185. <https://doi.org/10.1016/j.tics.2013.12.003>
- Attrill, M. J., Gresty, K. A., Hill, R. A., & Barton, R. A. (2008). Red shirt colour is associated with long-term team success in English football. *Journal of Sports Sciences*, 26(6), 577-582. <https://doi.org/10.1080/02640410701736244>
- Baddeley, A. (1986). *Working memory*. New York, NY: Oxford University Press.
- Baddeley, A. D. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology Section A*, 49(1), 5-28.
- Baddeley, A. D. (2010). Working memory. *Current Biology*, 20(4), R136-R140.
- Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation*, 8, 47-89. [https://doi.org/10.1016/S0079-7421\(08\)60452-1](https://doi.org/10.1016/S0079-7421(08)60452-1)
- Baddeley, A. D., & Logie, R. H. (1999). *The multiple-component model*. Cambridge, UK: Cambridge University Press.
- Baker, D. B., Taylor, C. J., & Leyva, C. (1995). Continuous performance tests: A

- comparison of modalities. *Journal of Clinical Psychology*, 51, 548-551.
- Bakker, F. C., Oudejans, R. R. D., & Van der Kamp, J. (2006). Penalty shooting and gaze behaviour. *International Journal of Sport Psychology*, 37, 265-280.
- Baldwin, M. W., & Main, K. J. (2001). Social anxiety and the cued activation of relational knowledge. *Personality and Social Psychology Bulletin*, 27(12), 1637-1647. <https://doi.org/10.1177/01461672012712007>
- Baldwin, M. W., & Meunier, J. (1999). The cued activation of attachment relational schemas. *Social Cognition*, 17(2), 209-227.
- Bargh, J. A. (1990). *Auto-motives: Preconscious determinants of social interaction* (Vol. 2). New York, NY: Guilford.
- Bargh, J. A. (1997). *The automaticity of everyday life* (Vol. 10). New Jersey, NJ: Lawrence Erlbaum Associates.
- Barkley, R. A. (1991). The ecological validity of laboratory and analogue assessment methods of ADHD symptoms. *Journal of Abnormal Child Psychology*, 19(2), 149-178.
- Bartels, A. L., Balash, Y., Gurevich, T., Schaafsma, J. D., Hausdorff, J. M., & Giladi, N. (2003). Relationship between freezing of gait (FOG) and other features of Parkinson's: FOG is not correlated with bradykinesia. *Journal of Clinical Neuroscience*, 10(5), 584-588. [https://doi.org/10.1016/s0967-5868\(03\)00192-9](https://doi.org/10.1016/s0967-5868(03)00192-9)
- Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology*, 46(3), 610.
- Beilock, S. L. (2007a). Choking under pressure. In R. F. Baumeister & K. D. Vohs (Eds.), *Encyclopedia of social psychology* (pp. 140-141). Thousand Oaks, CA: Sage.
- Beilock, S. L. (2007b). *Understanding skilled performance: Memory, attention, and 'choking under pressure'*: West Virginia University.
- Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General*, 130(4), 701.
- Beilock, S. L., & Carr, T. H. (2005). When high-powered people fail: Working memory and "choking under pressure" in math. *Psychological Sciences*, 16(2), 101-105. <https://doi.org/10.1111/j.0956-7976.2005.00789.x>
- Beilock, S. L., Kulp, C. A., Holt, L. E., & Carr, T. H. (2004). More on the fragility of performance: Choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General*, 133(4), 584-600. <https://doi.org/10.1037/0096-3445.133.4.584>
- Bellgrove, M. A., Hester, R., & Garavan, H. (2004). The functional neuroanatomical correlates of response variability: Evidence from a response inhibition task.

Neuropsychologia, 42(14), 1910-1916.

- Bender, A. D., Filmer, H. L., Garner, K. G., Naughtin, C. K., & Dux, P. E. (2016). On the relationship between response selection and response inhibition: An individual differences approach. *Attention, Perception, and Psychophysics*, 78, 2420-2432. <https://doi.org/10.3758/s13414-016-1158-8>
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, 57(1), 289-300.
- Berlin, B., & Kay, P. (1969). *Basic color terms: Their universality and evolution*. Berkeley, CA: University of California Press.
- Berman, M. G., Nee, D. E., Casement, M., Kim, H. S., Deldin, P., Kross, E., . . . Jonides, J. (2011). Neural and behavioural effects of interference resolution in depression and rumination. *Cognitive, Affect, and Behavioural Neuroscience*, 11, 85-96.
- Bevan, W., & Dukes, W. F. (1953). Color as a variable in the judgement of size. *The American Journal of Psychology*, 66(2), 283-288. <https://doi.org/10.2307/1418734>
- Bezdjian, S., Baker, L. A., Lozano, D. I., & Raine, A. (2009). Assessing inattention and impulsivity in children during the Go/NoGo task. *British Journal of Developmental Psychology*, 27(2), 365-383.
- Bianco, V., Di Russo, F., Perri, R. L., & Berchicci, M. (2017). Different proactive and reactive action control in fencers' and boxers' brain. *Neuroscience*, 343, 260-268. <https://doi.org/10.1016/j.neuroscience.2016.12.006>
- Bissett, P. G., Logan, G. D., Van Wouwe, N. C., Tolleson, C. M., Phibbs, F. T., Claassen, D. O., & Wylie, S. A. (2015). Generalised motor inhibitory deficit in Parkinson's disease patients who freeze. *Journal of Neural Transmission*, 122, 1693-1701. <https://doi.org/10.1007/s00702-015-1454-9>
- Blizzard, S. C., Fierro-Rojas, A., & Fallah, M. (2017). Response inhibition is facilitated by a change to red over green in the stop signal paradigm. *Frontiers in Human Neuroscience*, 10(655). <https://doi.org/10.3389/fnhum.2016.00655>
- Bloem, B. R., Hausdorff, J. M., Visser, J. E., & Giladi, N. (2004). Falls and freezing of gait in Parkinson's disease: A review of two interconnected, episodic phenomena. *Movement Disorders*, 19(8), 871-884. <https://doi.org/10.1002/mds.20115>
- Braak, H., & Braak, E. (2000). Pathoanatomy of Parkinson's disease. *Journal of Neurology*, 247, II/3-II/10. <https://doi.org/10.1007/PL00007758>
- Bradley, M. M., Moulder, B., & Lang, P. J. (2005). When good things go bad: The reflex physiology of defense. *Psychological Science*, 16(6), 468-473. <https://doi.org/10.1111/j.0956-7976.2005.01558.x>
- Brass, M., Rigoni, D., & Haggard, P. (2014). Intentional inhibition: From motor suppression to self-control. *Neuropsychologia*, 65, 234-235.

<https://doi.org/10.1016/j.neuropsychologia.2014.11.016>

- Braun, C. C., & Silver, N. C. (1995). Interaction of signal word and colour on warning labels: Differences in perceived hazard and behavioural compliance. *Ergonomics*, 38(11), 2207-2220. <https://doi.org/10.1080/00140139508925263>
- Briki, W., & Hue, O. (2016). How red, blue, and green are affectively judged. *Applied Cognitive Psychology*, 30(2), 301-304. <https://doi.org/10.1002/acp.3206>
- Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkles, K. R. (1982). The Cognitive Failures Questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology*, 11, 510-519.
- Buchsbaum, B., Greer, S., Chang, W. L., & Berman, K. F. (2005). Meta-analysis of neuroimaging studies of the Wisconsin card-sorting task and component processes. *Human Brain Mapping*, 25(1), 35-45. <https://doi.org/10.1002/hbm.20128>
- Buszard, T., Farrow, D., Zhu, F. F., & Masters, R. S. W. (2013). Examining movement specific reinvestment and working memory capacity in adults and children. *International Journal of Sport Psychology*, 44(4), 351-366.
- Buszard, T., Masters, R. S. W., & Farrow, D. (2017). The generalizability of working-memory capacity in sport domain. *Current Opinion in Psychology*, 16, 54-57. <https://doi.org/10.1016/j.copsyc.2017.04.018>
- Cannon, W. B. (1929). *Bodily changes in pain, hunger, fear, and rage*. Oxford, UK: Appleton.
- Carver, C. S., & Harmon-Jones, E. (2009). Anger is an approach-related affect: Evidence and implications. *Psychological Bulletin*, 135(2), 183-204. <https://doi.org/10.1037/a0013965>
- Changizi, M. A., Zhang, Q., & Shimojo, S. (2006). Bare skin, blood and the evolution of primate colour vision. *Biology Letters*, 2(2), 217-221. <https://doi.org/10.1098/rsbl.2006.0440>
- Chell, B. J., Graydon, J. K., Crowley, P. L., & Child, M. (2003). Manipulated stress and dispositional reinvestment in a wall-volley task: An investigation into controlled processing. *Perceptual and Motor Skills*, 97(2), 435-448.
- Chichilnisky, E. J., & Wandell, B. A. (1995). Photoreceptor sensitivity changes explain color appearance shifts induced by large uniform backgrounds in dichoptic matching. *Vision Research*, 35(2), 239-254. [https://doi.org/10.1016/0042-6989\(94\)00122-3](https://doi.org/10.1016/0042-6989(94)00122-3)
- Citron, F. M. M., Gray, M. A., Critchley, H. D., Weekes, B. S., & Ferstl, E. C. (2014). Emotional valence and arousal affect reading in an interactive way: Neuroimaging evidence for an approach-withdrawal framework. *Neuropsychologia*, 56, 79-89. <https://doi.org/10.1016/j.neuropsychologia.2014.01.002>
- Claeys, K. G., Dupont, P., Cornette, L., Sunaert, S., Van Hecke, P., De Schutter, E., &

- Orban, G. A. (2004). Color discrimination involves ventral and dorsal stream visual areas. *Cerebral Cortex*, *14*(7), 803-822. <https://doi.org/10.1093/cercor/bhh040>
- Clark, J. M. (1996). Contributions of inhibitory mechanisms to unified theory in neuroscience and psychology. *Brain and Cognition*, *30*(1), 127-152. <https://doi.org/10.1006/brcg.1996.0008>
- Cleveland, W. S., & McGill, R. (1983). A color-caused optical illusion on a statistical graph. *The American Statistician*, *37*(2), 101-105. <https://doi.org/10.2307/2685868>
- Cohen, J. (1973). Eta-squared and partial eta-squared in fixed factor ANOVA designs. *Educational and Psychological Measurement*, *33*, 107-114. <https://doi.org/10.1177/001316447303300111>
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Cohen, R. G., Klein, K. A., Nomura, M., Fleming, M., Mancini, M., Giladi, N., . . . Horak, F. B. (2014). Inhibition, executive function, and freezing of gait. *Journal of Parkinson's Disease*, *4*(1), 111-122. <https://doi.org/10.3233/JPD-130221>
- Cona, G., Cavazzana, A., Paoli, A., Marcolin, G., Grainer, A., & Bisiacchi, P. S. (2015). It's a matter of mind! Cognitive functioning predicts the athletic performance in ultra-marathon runners. *PLoS ONE*, *10*(7), e0132943. <https://doi.org/10.1371/journal.pone.0132943>
- Conway, A. R. A., & Engle, R. W. (1994). Working memory and retrieval: A resource-dependent inhibition model. *Journal of Experimental Psychology: General*, *123*(4), 354-373. <https://doi.org/10.1037/0096-3445.123.4.354>
- Cook, R. D., & Weisberg, S. (1982). *Residuals and influence in regression*. New York, NY: Chapman & Hall.
- Craig, W. (1917). Appetites and aversions as constituents of instincts. *Biological Bulletin*, *34*, 91-107.
- Dalton, K., Guillon, M., & Naroo, S. A. (2015). An analysis of penalty kicks in elite football post 1997. *International Journal of Sports Science and Coaching*, *10*(5), 815-827. <https://doi.org/10.1260/1747-9541.10.5.815>
- Davidson, R. J., Schwartz, G. E., Saron, C., Bennett, J., & Goleman, D. J. (1979). Frontal versus parietal EEG asymmetry during positive and negative affect. *Psychophysiology*, *16*, 202-203.
- Davis, R. N., & Nolen-Hoeksema, S. (2000). Cognitive inflexibility among ruminators and nonruminators. *Cognitive Therapy and Research*, *24*(6), 699-711.
- De Beni, R., Palladino, P., Pazzaglia, F., & Cornoldi, C. (1998). Increases in intrusion errors and working memory deficit of poor comprehenders. *The Quarterly Journal of Experimental Psychology Section A*, *51*(2), 305-320.

<https://doi.org/10.1080/713755761>

- De Lissnyder, E., Derakshan, N., De Raedt, R., & Koster, E. H. W. (2011). Depressive symptoms and cognitive control in a mixed antisaccade task: Specific effects of depressive rumination. *Cognition and Emotion*, *25*(5), 886-897.
- De Lissnyder, E., Koster, E. H. W., Derakshan, N., & De Raedt, R. (2010). The association between depressive symptoms and executive control impairments in response to emotional and non-emotional information. *Cognition and Emotion*, *24*(2), 264-280.
- Dempster, F. N. (1993). *Resistance to interference: Developmental changes in a basic processing dimension* (Vol. 1). New York, NY: Springer-Verlag.
- Dempster, F. N., & Corkill, A. J. (1999). Individual differences in susceptibility to interference and general cognitive ability. *Acta Psychologica*, *101*(2-3), 395-416. [https://doi.org/10.1016/S0001-6918\(99\)00013-X](https://doi.org/10.1016/S0001-6918(99)00013-X)
- Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: New developments from Attentional Control Theory. *European Psychologist*, *14*(2), 168-176. <https://doi.org/10.1027/1016-9040.14.2.168>
- Di Russo, F., Taddei, F., Apnile, T., & Spinelli, D. (2006). Neural correlates of fast stimulus discrimination and response selection in top-level fencers. *Neuroscience Letters*, *408*(2), 113-118. <https://doi.org/10.1016/j.neulet.2006.08.085>
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135-168.
- Dreiskaemper, D., Strauss, B., Hagemann, N., & Büsch, D. (2013). Influence of red jersey color on physical parameters in combat sports. *Journal of Sport and Exercise Psychology*, *35*, 44-49. <https://doi.org/10.1123/jsep.35.1.44>
- Duncan, J., Johnson, R., Swales, M., & Freer, C. (1997). Frontal lobe deficits after head injury: Unity and diversity of function. *Cognitive Neuropsychology*, *14*(5), 713-741. <https://doi.org/10.1080/026432997381420>
- Elliot, A. J. (1999). Approach and avoidance motivation and achievement goals. *Educational Psychologist*, *34*, 169-189. https://doi.org/10.1207/s15326985ep3403_3
- Elliot, A. J. (2005). *A conceptual history of the achievement goal construct*. New York, NY: Guilford.
- Elliot, A. J., & Aarts, H. (2011). Perception of the color red enhances the force and velocity of motor output. *Emotion*, *11*(2), 445-449. <https://doi.org/10.1037/a0022599>
- Elliot, A. J., & Covington, M. V. (2001). Approach and avoidance motivation. *Educational Psychology Review*, *13*(2), 73-92. <https://doi.org/10.1023/A:1009009018235>
- Elliot, A. J., Cury, F., Fryer, J. W., & Huguet, P. (2006). Achievement goals, self-

- handicapping, and performance attainment: A mediational analysis. *Journal of Sport and Exercise Psychology*, 28(3), 344-361. <https://doi.org/10.1123/jsep.28.3.344>
- Elliot, A. J., Eder, A. B., & Harmon-Jones, E. (2013). Approach-avoidance motivation and emotion: Convergence and divergence. *Emotion Review*, 5(3), 308-311. <https://doi.org/10.1177/1754073913477517>
- Elliot, A. J., Kayser, D. N., Greitemeyer, T., Lichtenfeld, S., Gramzow, R. H., & Maier, M. A. (2010). Red, rank, and romance in women viewing men. *Journal of Experimental Psychology: General*, 139(3), 339-417. <https://doi.org/10.1037/a0019689>
- Elliot, A. J., & Maier, M. A. (2007). Color and psychological functioning. *Current Direction in Psychological Science*, 16(5), 250-254.
- Elliot, A. J., & Maier, M. A. (2012). Color-in-context theory. *Advances in Experimental Social Psychology*, 45, 61-126. <https://doi.org/10.1016/B978-0-12-394286-9.00002-0>
- Elliot, A. J., & Maier, M. A. (2014). Color psychology: Effects of perceiving color on psychological functioning in humans. *Annual Review of Psychology*, 65(1), 95-120. <https://doi.org/10.1146/annurev-psych-010213-115035>
- Elliot, A. J., Maier, M. A., Binser, M. J., Friedman, R., & Pekrun, R. (2009). The effect of red on avoidance behavior in achievement contexts. *Personality and Social Psychology Bulletin*, 35(3), 365-375. <https://doi.org/10.1177/0146167208328330>
- Elliot, A. J., Maier, M. A., Moller, A. C., Friedman, R., & Meinhardt, J. (2007). Color and psychological functioning: The effect of red on performance attainment. *Journal of Experimental Psychology: General*, 136(1), 154-168. <https://doi.org/10.1037/0096-3445.136.1.154>
- Elliot, A. J., & McGregor, H. A. (1999). A hierarchical model of approach and avoidance achievement motivation. *Journal of Personality and Social Psychology*, 76(4), 628-644. <https://doi.org/10.1037/0022-3514.72.1.218>
- Elliot, A. J., & Niesta, D. (2008). Romantic red: Red enhances men's attraction to women. *Journal of Personality and Social Psychology*, 95(5), 1150-1164. <https://doi.org/10.1037/0022-3514.95.5.1150>
- Elliot, A. J., Payen, V., Brisswalter, J., Cury, F., & Thayer, J. F. (2011). A subtle threat cue, heart rate variability, and cognitive performance. *Psychophysiology*, 48(10), 1340-1345. <https://doi.org/10.1111/j.1469-8986.2011.01216.x>
- Elliot, A. J., & Thrash, T. M. (2001). Achievement goals and the hierarchical model of achievement motivation. *Educational Psychology Review*, 13(2), 139-156.
- Ellmers, T. J., Cocks, A. J., Dumas, M., Williams, A. M., & Young, W. R. (2016). Gazing into thin air: The dual-task costs of movement planning and execution during adaptive gait. *PLoS One*, 11(11), e0166063. <https://doi.org/10.1371/journal.pone.0166063>

- Engle, R. W. (2018). Working memory and executive attention: A revisit. *Perspectives on Psychological Science*, 13(2), 190-193. <https://doi.org/10.1177/1745691617720478>
- Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of Learning and Motivation*, 44, 145-200.
- Eysenck, M. W., & Derakshan, N. (2011). New perspectives in attentional control theory. *Personality and Individual Differences*, 50(7), 955-960.
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion*, 7(2), 336-353. <https://doi.org/10.1037/1528-3542.7.2.336>
- Fahn, S. (1995). The freezing phenomenon in parkinsonism. *Advances in Neurology*, 67, 53-63.
- Falcó, C., Conchado, A., & Estevan, I. (2016). The effect of color on the use of electronic body protectors in taekwondo matches. *Perceptual and Motor Skills*, 122(3), 812-824. <https://doi.org/10.1177/0031512516649958>
- Farrelly, D., Slater, R., Elliot, H. R., Walden, H. R., & Wetherell, M. A. (2013). Competitors who choose to be red have higher testosterone levels. *Psychological Science*, 24(10), 2122-2124. <https://doi.org/10.1177/0956797613482945>
- Fechner, G. T. (1860). *Elemente der psychophysik* (Vol. 2). Leipzig, DE: Breitkopf & Härtel.
- Fechner, G. T. (1966). *Elements of psychophysics*. New York, NY: Holt, Rinehart and Winston.
- Feldman Barrett, L., & Russell, J. A. (1999). The structure of current affect: Controversies and emerging consensus. *Psychological Society*, 8(1), 10-14.
- Feltman, R., & Elliot, A. J. (2011). The influence of red on perceptions of relative dominance and threat in a competitive context. *Journal of Sport and Exercise Psychology*, 33(2), 308-314. <https://doi.org/10.1123/jsep.33.2.308>
- Fenigstein, A., Scheier, M. F., & Buss, A. H. (1975). Public and private self-consciousness: assessment and theory. *Journal of Consulting and Clinical Psychology*, 43, 522-527.
- Fitts, P. M., Bahrnick, H. P., Noble, M., & Briggs, G. (1961). *Skilled performance*. New York, NY: Wiley.
- Frazier, P. A., Tix, A. P., & Barron, K. E. (2004). Testing moderator and mediator effects in counseling psychology research. *Journal of Counseling Psychology*, 51(1), 115.
- Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, 133(1), 101-135. <https://doi.org/10.1037/0096-3445.133.1.101>

- Friedman, R. S., & Förster, J. (2010). Implicit affective cues and attentional tuning: An integrative review. *Psychological Bulletin*, 136(5), 875-893. <https://doi.org/10.1037/a0020495>
- Fuchs, A. H. (1962). The progression-regression hypotheses in perceptual-motor skill learning. *Journal of Experimental Psychology*, 62(2), 177-182.
- Furley, P., Noël, B., & Memmert, D. (2017). Attention towards the goalkeeper and distraction during penalty shootouts in association football: A retrospective analysis of penalty shootouts from 1984 to 2012. *Journal of Sport Sciences*, 35(9), 873-879. <https://doi.org/10.1080/02640414.2016.1195912>
- García-Rubio, M. A., Picazo-Tadeo, A. J., & González-Gómez, F. (2011). Does a red shirt improve sporting performance? Evidence from Spanish football. *Applied Economics Letters*, 18(11), 1001-1004. <https://doi.org/10.1080/13504851.2010.520666>
- Gauggel, S., Reiger, M., & Feghoff, T.-A. (2004). Inhibition of ongoing responses in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery and Psychiatry*, 75, 539-544. <https://doi.org/10.1136/jnnp.2003.016469>
- Geng, L., Hong, X., & Zhou, Y. (2021). Exploring the implicit link between red and aggressiveness as well as blue and agreeableness. *Frontiers in Psychology*, 11, 1-8. <https://doi.org/10.3389/fpsyg.2020.570534>
- Gentilucci, M., Benuzzi, F., Bertolani, L., & Gangitano, M. (2001). Influence of stimulus color on the control of reaching-grasping movements. *Experimental Brain Research*, 137, 36-44. <https://doi.org/10.1007/s002210000639>
- Gernsbacher, M. A. (1993). Less skilled readers have less efficient suppression mechanisms. *Psychological Science*, 4, 294-298. <https://doi.org/10.1111/j.1467-9280.1993.tb00567.x>
- Giladi, N., McDermott, M. P., Fahn, S., Przedborski, S., Jankovic, J., Stern, M., & Tanner, C. (2001). Freezing of gait in PD: Prospective assessment in the DATATOP cohort. *Neurology*, 56(12), 1712-1721. <https://doi.org/10.1212/wnl.56.12.1712>
- Giladi, N., Treves, T. A., Simon, E. S., Shabtai, H., Orlov, Y., Kandinov, B., . . . Korczyn, A. D. (2001). Freezing of gait in patients with advanced Parkinson's disease. *Journal of Neural Transmission*, 108(1), 53-61. <https://doi.org/10.1007/s007020170096>
- Gilbert, S. J., & Burgess, P. W. (2008). Executive function. *Current Biology*, 18(3), R110-R114.
- Goldenberg, A., Weisz, E., Sweeny, T. D., Cikara, M., & Gross, J. J. (2021). The crowd-emotion-amplification effect. *Psychological Science*, 1-14. <https://doi.org/10.1177/0956797620970561>
- Goldschmied, N., Furley, P., & Bush, R. (2020). Critical review of uniform color effects in sports. *International Review of Sport and Exercise Psychology*, 1-26. <https://doi.org/10.1080/1750984X.2020.1855668>

- Gomez, P., Ratcliff, R., & Perea, M. (2007). A model of the go/no-go task. *Journal of Experimental Psychology General*, 136(3), 389-413. <https://doi.org/10.1037/0096-3445.136.3.389>
- Greenlees, I. A., Eynon, M., & Thelwell, R. C. (2013). Color of soccer goalkeepers' uniforms influences the outcome of penalty kicks. *Perceptual and Motor Skills*, 117(1), 1-10. <https://doi.org/10.2466/30.24.PMS.117x14z6>
- Greenlees, I. A., Leyland, A., Thelwell, R. C., & Filby, W. (2008). Soccer penalty takers' uniform colour and pre-penalty kick gaze affect the impressions formed of them by opposing goalkeepers. *Journal of Sports Sciences*, 26(6), 569-576. <https://doi.org/10.1080/02640410701744446>
- Gucciardi, D. F., & Dimmock, J. A. (2008). Choking under pressure in sensorimotor skills: Conscious processing or depleted attentional resources? *Psychology of Sport and Exercise*, 9(1), 45-59. <https://doi.org/10.1016/j.psychsport.2006.10.007>
- Hackney, A. C. (2006). Testosterone and human performance: Influence of the color red. *European Journal of Applied Physiology*, 96(3), 330-333.
- Hagemann, N., Strauss, B., & Leißing, J. (2008). When the referees sees red... *Psychological Science*, 19(8), 769-771. <https://doi.org/10.1111/j.1467-9280.2008.02155.x>
- Halperin, J. M., Wolf, L., Greenblatt, E. R., & Young, G. (1991). Subtype analysis of commission errors on the continuous performance test in children. *Developmental Neuropsychology*, 7(2), 207-217.
- Hamid, P. N., & Newport, A. G. (1989). Effect of colour on physical strength and mood in children. *Perceptual and Motor Skills*, 69(1), 179-185. <https://doi.org/10.2466/pms.1989.69.1.179>
- Hammond, N. V. (1987). *Principles from the psychology of skill acquisition*. London, UK: Wiley.
- Hansen, C., & Hansen, R. (1988). Finding the face-in-the-crowd: An anger superiority effect. *Journal of Personality and Social Psychology*, 54, 917-924.
- Hardy, L., Mullen, R., & Jones, G. (1996). Knowledge and conscious control of motor actions under stress. *British Journal of Psychology*, 87, 621-636. <https://doi.org/10.1111/j.2044-8295.1996.tb02612.x>
- Harmon-Jones, E. (2003). Anger and behavioral approach system. *Personality and Individual Differences*, 35(5), 995-1005. [https://doi.org/10.1016/S0191-8869\(02\)00313-6](https://doi.org/10.1016/S0191-8869(02)00313-6)
- Harmon-Jones, E., & Sigelman, J. (2001). State anger and prefrontal brain activity: Evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. *Journal of Personality and Social Psychology*, 80(5), 797.
- Harnishfeger, K. K. (1995). *The development of cognitive inhibition: Theories, definitions,*

and research evidence. San Diego, CA: Academic Press.

- Harris, D. J., Wilson, M. R., & Vine, S. J. (2020). *The effect of crowd removal on goal scoring in professional football*. PsyArXiv. Retrieved from <https://doi.org/10.31234/osf.io/n4egb>
- Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis* (2nd ed.). New York, NY: Guilford Press.
- Hertel, P. T., & Gerstle, M. (2003). Depressive deficits in forgetting. *Psychological Science*, *14*(6), 573-578.
- Hill, R. A., & Barton, R. A. (2005a). Hill & Barton reply. *Nature*, *437*(7063), E10-E11. <https://doi.org/10.1038/nature04307>
- Hill, R. A., & Barton, R. A. (2005b). Psychology: Red enhances human performance in contests. *Nature*, *435*(7040), 293. <https://doi.org/10.1038/435293a>
- Ho, H. N., Van Doorn, G. H., Kawabe, T., Watanabe, J., & Spence, C. (2014). Colour-temperature correspondence: When reactions to thermal stimuli are influenced by colour. *PLoS One*, *9*(3), e91854. <https://doi.org/10.1371/journal.pone.0091854>
- Holmbeck, G. N. (2002). Post-hoc probing of significant moderational and mediational effects in studies of pediatric populations. *Journal of Pediatric Psychology*, *27*(1), 87-96.
- Holmberg, L. (1971). Size estimations and color vision dimensions. *Psychological Research Bulletin*, *11*(16), 8.
- Hortensius, R., Schutter, D. J. L. G., & Harmon-Jones, E. (2012). When anger leads to aggression: Induction of relative left frontal cortical activity with transcranial direct current stimulation increases the anger-aggression relationship. *Social Cognitive Affective Neuroscience*, *7*, 342-347. <https://doi.org/10.1093/scan/nsr012>
- Hoshi, E., & Tanji, J. (2004). Differential roles of neuronal activity in the supplementary and presupplementary motor areas: From information retrieval to motor planning and execution. *Journal of Neurophysiology*, *92*(6), 3482-3499. <https://doi.org/10.1152/jn.00547.2004>
- Howard, S. J., Johnson, J., & Pascual-Leone, J. (2014). Clarifying inhibitory control: Diversity and development of attentional inhibition. *Cognitive Development*, *31*, 1-21.
- Hsu, J. C. (1996). *Multiple comparisons: Theory and methods* (1 ed.). London, UK: CRC Press.
- Hutchings, J. (1997). Folklore and Symbolism of Green. *Folklore*, *108*(1-2), 55-63. <https://doi.org/10.1080/0015587X.1997.9715937>
- Hyde, J., Ryan, K. M., & Waters, A. M. (2019). Psychophysiological markers of fear and anxiety. *Current Psychiatry Reports*, *21*, 1-10. <https://doi.org/10.1007/s11920->

- Ilie, A., Ioan, S., Zagrean, L., & Moldovan, M. (2008). Better to be red than blue in virtual competition. *CyberPsychology and Behaviour*, *11*(3), 375-377. <https://doi.org/10.1089/cpb.2007.0122>
- Ishihara, S. (1972). *Tests for colour-blindness: 24 plates edition*. Tokyo, JP: Kanehara Shuppan.
- Isoda, M., & Hikosaka, O. (2007). Switching from automatic to controlled action by monkey medial frontal cortex. *Nature Neuroscience*, *10*(2), 240-248. <https://doi.org/10.1038/nn1830>
- Iwatsuki, T., Van Raalte, J. L., Brewer, B. W., Petitpas, A., & Takahashi, M. (2018). Relations among reinvestment, self-regulation, and perception of choking under pressure. *Journal of Human Kinetics*, *65*, 281-290. <https://doi.org/10.2478/hukin-2018-0042>
- Jackson, R. C., Ashford, K. J., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport and Exercise Psychology*, *28*, 49-68.
- Jackson, R. C., Kinrade, N. P., Hicks, T., & Wills, R. (2013). Individual propensity for reinvestment: Field-based evidence for the predictive validity of three scales. *International Journal of Sport Psychology*, *44*(4), 331-350. <https://doi.org/10.7352/IJSP.2013.44.331>
- Jacobs, K. W., & Suess, J. F. (1975). Effects of four psychological primary colors on anxiety state. *Perceptual and Motor Skills*, *41*, 207-210.
- Johns, E. H., & Sumner, F. C. (1948). Relation of the brightness differences of colors to their apparent distance. *Journal of Psychology*, *26*(1), 25-29. <https://doi.org/10.1080/00223980.1948.9917393>
- Joormann, J. (2006). Differential effects of rumination and dysphoria on the inhibition of irrelevant emotional material: Evidence from a negative priming task. *Cognitive Therapy and Research*, *30*(2), 149-160.
- Joormann, J., & Gotlib, I. H. (2010). Emotion regulation in depression: Relation to cognitive inhibition. *Cognition and Emotion*, *24*(2), 281-298.
- Joormann, J., & Tran, T. B. (2009). Rumination and intentional forgetting of emotional material. *Cognition and Emotion*, *23*(6), 1233-1246.
- Jordet, G., Elferink-Gemser, M. T., Lemmink, K. A. P. M., & Visscher, C. (2006). The "Roussian roulette" of soccer?: Perceived control and anxiety in a major tournament penalty shootout. *International Journal of Sport Psychology*, *37*(2), 281-298. <https://doi.org/10.1080/10413200.2011.619000>
- Jordet, G., & Hartman, E. (2008). Avoidance motivation and choking under pressure in soccer penalty shootouts. *Journal of Sport and Exercise Psychology*, *30*, 450-457. <https://doi.org/10.1123/jsep.30.4.450>

- Katz, D. (1935). *The world of colour* (R. B. MacLeod, Trans.). London, UK: Kegan Paul, Trench, Trübner & Co.
- Kaufer, D. I., & Lewis, D. A. (1999). *Frontal lobe anatomy and cortical connectivity*. New York, NY: Guildford Press.
- Kida, N., Oda, S., & Matsumura, M. (2005). Intensive baseball practice improves the Go/Nogo reaction time, but not the simple reaction time. *Cognitive Brain Research*, 22(2), 257-264.
- Kindlon, D., Mezzacappa, E., & Earls, F. (1995). Psychometric properties of impulsivity measures: Temporal stability, validity and factor structure. *Journal of Child Psychology and Psychiatry*, 36(4), 645-661.
- Kinrade, N. P., Jackson, R. C., & Ashford, K. J. (2010a). Reinvestment, task complexity and decision making under pressure in basketball. *Psychology of Sport & Exercise*, 20, 11-19. <https://doi.org/10.1016/j.psychsport.2015.03.007>
- Kinrade, N. P., Jackson, R. C., & Ashford, K. J. (2015). Reinvestment, task complexity and decision making under pressure in basketball. *Psychology of Sport and Exercise*, 20, 11-19.
- Kinrade, N. P., Jackson, R. C., Ashford, K. J., & Bishop, D. T. (2010b). Development and validation of the decision-specific reinvestment scale. *Journal of Sports Sciences*, 28(10), 1127-1135.
- Kocher, M. G., & Sutter, M. (2008). *Shirt colour and team performance in football*. Newcastle, UK: Cambridge Scholars Publishing.
- Krause, F., & Lindemann, O. (2014). Expyriment: A Python library for cognitive and neuroscientific experiments. *Behavior Research Methods*, 46(2), 416-428. <https://doi.org/10.3758/s13428-013-0390-6>
- Krenn, B. (2014). The impact of uniform color on judging tackles in association football. *Psychology of Sport and Exercise*, 15, 222-225. <https://doi.org/10.1016/j.psychsport.2013.11.007>
- Krenn, B. (2015). The effect of uniform color on judging athletes' aggressiveness, fairness, and chance of winning. *Journal of Sport and Exercise Psychology*, 37, 207-212. <https://doi.org/10.1123/jsep.2014-0274>
- Krenn, B., Pernhaupt, N., & Handsteiner, M. (2017). Do red and blue uniforms matter in football and handball penalties? *Journal of Sports Science & Medicine*, 16, 565-573.
- Kuntsi, J., Rogers, H., Swinard, G., Börger, N., Van der Meere, J., Rijdsdijk, F., & Asherson, P. (2006). Reaction time, inhibition, working memory and 'delay aversion' performance: Genetic influences and their interpretation. *Psychological Medicine*, 36(11), 1613-1624. <https://doi.org/10.1017/S0033291706008580>
- Kutas, G., & Bodrogi, P. (2007). Color appearance of a large homogenous visual field. *Color Research and Application*, 33(1), 45-54. <https://doi.org/10.1002/col.20367>

- Kwallek, N., & Lewis, C. M. (1990). Effects of Environmental colour on males and females: A red or white or green office. *Applied Ergonomics*, *21*(4), 275-278. [https://doi.org/10.1016/0003-6870\(90\)90197-6](https://doi.org/10.1016/0003-6870(90)90197-6)
- Kwallek, N., Woodson, H., Lewis, C. M., & Sales, C. (1997). Impact of three interior color schemes on worker mood and performance relative to individual environmental sensitivity. *Color Research and Application*, *22*(2), 121-132.
- Laborde, S., Furley, P., & Schempp, C. (2015). The relationship between working memory, reinvestment, and heart rate variability. *Physiology and Behavior*, *139*, 430-436.
- Laborde, S., Raab, M., & Kinrade, N. P. (2014). Is the ability to keep your mind sharp under pressure reflected in your heart? Evidence for the neurophysiological bases of decision reinvestment. *Biological Psychology*, *100*, 34-42. <https://doi.org/10.1016/j.biopsycho.2014.05.003>
- Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for *t*-tests and ANOVAs. *Frontiers in Psychology*, *4*, 1-12. <https://doi.org/10.3389/fpsyg.2013.00863>
- Lam, W. K., Maxwell, J. P., & Masters, R. S. W. (2009a). Analogy learning and the performance of motor skills under pressure. *Journal of Sport and Exercise Psychology*, *31*(3), 337-357.
- Lam, W. K., Maxwell, J. P., & Masters, R. S. W. (2009b). Analogy versus explicit learning of a modified basketball shooting task: Performance and kinematic outcomes. *Journal of Sports Sciences*, *27*(2), 179-191.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). *Motivated attention: Affect, activation, and action*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Lange, K., Kühn, S., & Filevich, E. (2015). "Just Another Tool for Online Studies" (JATOS): An easy solution for setup and management of web servers supporting online studies. *PLoS ONE*, *10*(7), e0134073. <https://doi.org/10.1371/journal.pone.0134073>
- LaTour, M. S., & Rotfeld, H. J. (1997). There are threats and (maybe) fear-caused arousal: Theory and confusions of appeals to fear and fear arousal itself. *Journal of Advertising*, *26*(3), 45-59.
- Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology*, *21*, 59-80. <https://doi.org/10.1348/026151003321164627>
- Levy, B. I. (1984). Research into the psychological meaning of color. *American Journal of Art Therapy*, *23*(2), 58-62.
- Lewis, B., & Linder, D. (1997). Thinking about choking? Attentional processes and paradoxical performance. *Personality and Social Psychology Bulletin*, *23*, 937-944.

- Lewis, S. J. G., & Shine, J. M. (2016). The next step: A common neural mechanism for freezing gait. *The Neuroscientist*, 22(1), 72-82. <https://doi.org/10.1177/1073858414559101>
- Li, K. A., & Yeh, S. L. (2017). Mean size estimation yields left-side bias: Role of attention on perceptual averaging. *Attention, Perception, and Psychophysics*, 79, 2538-2551. <https://doi.org/10.3758/s13414-017-1409-3>
- Liao, C. M., & Masters, R. S. W. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences*, 19(5), 307-319.
- Liao, C. M., & Masters, R. S. W. (2002). Self-Focused Attention and Performance Failure under Psychological Stress. *Journal of Sport and Exercise Psychology*, 24(3), 289-305. <https://doi.org/10.1123/jsep.24.3.289>
- Lindsey, D. T., Brown, A. M., Reijnen, E., Rich, A. N., Kuzmova, Y. I., & Wolfe, J. M. (2010). Color channels, not color appearance or color categories, guide visual search for desaturated color targets. *Psychological Science*, 21(9), 1208-1214. <https://doi.org/10.1177/0956797610379861>
- Linville, P. (1996). *Attention inhibition: Does it underlie ruminative thought?* (Vol. 9). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Littman, R., & Takács, Á. (2017). Do all inhibitions act alike? A study of go/no-go and stop-signal paradigms. *PLoS One*, 12(10), e0186774. <https://doi.org/10.1371/journal.pone.0186774>
- Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, 91(3), 295.
- Londe, A. M., Marocolo, M., Marocolo, I. C., Fisher, J., Neto, O. B., Souza, M. V. C., & De Mota, G. (2018). Wearing colored glasses can influence exercise performance and testosterone concentration? *Sports Medicine International Open*, 2, 1-6. <https://doi.org/10.1055/a-0601-7250>
- Löw, A., Lang, P. J., Smith, C., & Bradley, M. M. (2008). Both predator and prey: Emotional arousal in threat and reward. *Psychological Science*, 19(9), 865-873. <https://doi.org/10.1111/j.1467-9280.2008.02170.x>
- Löw, A., Weymar, M., & Hamm, A. O. (2015). When threat is near, get out of here: Dynamics of defensive behavior during freezing and active avoidance. *Psychological Science*, 26(11), 1706-1716. <https://doi.org/10.1177/0956797615597332>
- Macht, M., Kaussner, Y., Möller, J. C., Stiasny-Kolster, K., Eggert, K. M., Krüger, H.-P., & Ellgring, H. (2007). Predictors of freezing in Parkinson's disease: A survey of 6,620 patients. *Movement Disorders*, 22(7), 953-956. <https://doi.org/10.1002/mds.21458>
- MacMahon, K. M. A., & Masters, R. S. W. (2002). The effects of a secondary task on implicit motor skill performance. *International Journal of Sport Psychology*, 33(307-324).

- Maier, M. A., Elliot, A. J., & Lichtenfeld, S. (2008). Mediation of the negative effect of red on intellectual performance. *Personality and Social Psychology Bulletin*, 34(11), 1530-1540. <https://doi.org/10.1177/0146167208323104>
- Malhotra, N., Poolton, J. M., Wilson, M. R., Fan, J. K. M., & Masters, R. S. W. (2014). Conscious motor processing and movement self-consciousness: Two dimensions of personality that influence laparoscopic training. *Journal of Surgical Education*, 71(6), 798-804. <https://doi.org/10.1016/j.jsurg.2014.04.003>
- Malhotra, N., Poolton, J. M., Wilson, M. R., Ngo, K., & Masters, R. S. W. (2012). Conscious monitoring and control (reinvestment) in surgical performance under pressure. *Surgical Endoscopy*, 26, 2423-2429. <https://doi.org/10.1007/s00464-012-2193-8>
- Malhotra, N., Poolton, J. M., Wilson, M. R., Uiga, L., & Masters, R. S. W. (2015). Examining movement-specific reinvestment and performance in demanding contexts. *Journal of Sport and Exercise Psychology*, 37(3), 327-338. <https://doi.org/10.1123/jsep.2014-0220>
- Masters, R. S. W. (1992). Knowledge, knerves and know - how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology*, 83(3), 343-358.
- Masters, R. S. W., Eves, F. F., & Maxwell, J. P. (2005). *Development of a movement specific reinvestment scale*. Paper presented at the International Society of Sport Psychology (ISSP) World Congress.
- Masters, R. S. W., MacMahon, K. M. A., & Pall, H. S. (2004). Implicit motor learning in Parkinson's disease. *Rehabilitation Psychology*, 49(1), 79-82.
- Masters, R. S. W., & Maxwell, J. P. (2004). *Implicit motor learning, reinvestment and movement disruption: What you don't know won't hurt you*. London, UK: Routledge.
- Masters, R. S. W., & Maxwell, J. P. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology*, 1(2), 160-183.
- Masters, R. S. W., Polman, R. C. J., & Hammond, N. V. (1993). 'Reinvestment': A dimension of personality implicated in skill breakdown under pressure. *Personality and Individual Differences*, 14(5), 655-666.
- Masters, R. S. W., Poolton, J. M., & Maxwell, J. P. (2008). Stable implicit motor processes despite aerobic locomotor fatigue. *Consciousness and Cognition*, 17(1), 335-338. <https://doi.org/10.1016/j.concog.2007.03.009>
- Masters, R. S. W., Poolton, J. M., & Van der Kamp, J. (2010). Regard and perceptions of size in soccer: Better is bigger. *Perception*, 39(9), 1290-1295.
- Masters, R. S. W., Van der Kamp, J., & Jackson, R. C. (2007). Imperceptibly off-center goalkeepers influence penalty-kick direction in soccer. *Psychological Science*, 18(3), 222-223. <https://doi.org/10.1111/j.1467-9280.2007.01878.x>

- Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, *44*, 314-324. <https://doi.org/10.3758/s13428-011-0168-7>
- Maxwell, J. P., Masters, R. S. W., & Eves, F. F. (2000). From novice to no know-how: A longitudinal study of implicit motor learning. *Journal of Sports Sciences*, *18*(2), 111-120.
- Maxwell, J. P., Masters, R. S. W., Kerr, E., & Weedon, E. (2001). The implicit benefit of learning without errors. *The Quarterly Journal of Experimental Psychology Section A*, *54*(4), 1049-1068. <https://doi.org/10.1080/713756014>
- Maxwell, J. P., Masters, R. S. W., & Poolton, J. M. (2006). Performance breakdown in sport: The roles of reinvestment and verbal knowledge. *Research Quarterly for Exercise and Sport*, *77*(2), 271-276.
- Maxwell, S. E., & Delaney, H. D. (2004). *Designing experiments and analyzing data: A model comparison perspective* (2 ed.). New York, NY: Lawrence Erlbaum Associates.
- McCabe, D. P., Roediger III, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology*, *24*(2), 222-243. <https://doi.org/10.1037/a0017619>
- McCain, C. N., & Karr, A. (1970). *Color and subjective distance*. Aberdeen, MD: U.S. Army Aberdeen Research & Development Center.
- McCarrick, D., Bilalic, M., Neave, N., & Wolfson, S. (2020). *Home advantage during the COVID-19 Pandemic in European football*. PsyArXiv. Retrieved from <https://doi.org/10.31234/osf.io/2gkht>
- Meier, B. P., D'Agostino, P. R., Elliot, A. J., Maier, M. A., & Wilkowski, B. M. (2012). Color in context: Psychological context moderates the influence of red on approach-and avoidance-motivated behavior. *PLoS ONE*, *7*(7), e40333. <https://doi.org/10.1371/journal.pone.0040333>
- Meier, M. A., Hill, R. A., Elliot, A. J., & Barton, R. A. (2015). *Color in achievement contexts in humans*. Cambridge, UK: Cambridge University Press.
- Mentzel, S. V., Schücker, L., Hagemann, N., & Strauss, B. (2017). Emotionality of colors: An implicit link between red and dominance. *Frontiers in Psychology*, *8*, 1-6. <https://doi.org/10.3389/fpsyg.2017.00317>
- Milinski, M., & Bakker, T. C. M. (1990). Female sticklebacks use male coloration in mate choice and hence avoid parasitized males. *Nature*, *344*(6264), 330-333.
- 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*(1), 49-100. <https://doi.org/10.1006/cogp.1999.0734>

- Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent variable analysis. *Journal of Experimental Psychology: General*, *130*, 621-640. <https://doi.org/10.1006/cogp.1999.0734>
- Moller, A. C., & Elliot, A. J. (2009). Basic hue-meaning associations. *Emotion*, *9*(6), 898-902. <https://doi.org/10.1037/a0017811>
- Montaya, A. K. (2019). Moderation analysis in two-instance repeated measures designs: Probing methods and multiple moderator models. *Behavior Research Methods*, *51*, 61-82. <https://doi.org/10.3758/s13428-018-1088-6>
- Mostofsky, S. H., Schafer, J. G. B., Abrams, M. T., Goldberg, M. C., Flower, A. A., Boyce, A., . . . Denckla, M. B. (2003). fMRI evidence that the neural basis of response inhibition is task-dependent. *Cognitive Brain Research*, *17*(2), 419-430.
- Mostofsky, S. H., & Simmonds, D. J. (2008). Response inhibition and response selection: Two sides of the same coin. *Journal of Cognitive Neuroscience*, *20*(5), 751-761. <https://doi.org/10.1162/jocn.2008.20500>
- Mueller, S. T., & Piper, B. J. (2014). The psychology experiment building language (PEBL) and PEBL test battery. *Journal of Neuroscience Methods*, *222*, 250-259.
- Mullen, R., & Hardy, L. (2000). State anxiety and motor performance: Testing the conscious processing hypothesis. *Journal of Sports Sciences*, *18*(10), 785-799. <https://doi.org/10.1080/026404100419847>
- Mullen, R., Hardy, L., & Oldham, A. (2007). Implicit and explicit control of motor actions: Revisiting some early evidence. *British Journal of Psychology*, *98*, 141-156. <https://doi.org/10.1348/000712606X114336>
- Müller, F., Best, J. F., & Cañal-Bruland, R. (2018). Goalkeepers' reputation bias shot placement in soccer penalties. *Journal of Sport and Exercise Psychology*, *40*, 128-134. <https://doi.org/10.1123/jsep.2017-00358>
- Muraskin, J., Sherwin, J., & Sajda, P. (2015). Knowing when not to swing: EEG evidence that enhanced perception-action coupling underlies baseball batter expertise. *NeuroImage*, *123*, 1-10.
- Nakamoto, H., & Mori, S. (2008a). Effects of stimulus-response compatibility in mediating expert performance in baseball players. *Brain Research*, *1189*, 179-188.
- Nakamoto, H., & Mori, S. (2008b). Sport-specific decision-making in a Go/NoGo reaction task: Difference among nonathletes and baseball and basketball players. *Percept Mot Skills*, *106*(1), 163-170. <https://doi.org/10.2466/pms.106.1.163-170>
- Nakashian, J. S. (1964). The effects of red and green surroundings on behavior. *Journal of General Psychology*, *70*, 143-162. <https://doi.org/10.1080/00221309.1964.9920584>
- Nakata, H., Sakamoto, K., & Kakigi, R. (2012). The relationship between reaction time and response variability and somatosensory No-go potentials. *European Journal*

of Applied Physiology, 112(1), 207-214.

- Nigg, J. T. (1999). The ADHD response-inhibition deficit as measured by the stop task: Replication with DSM-IV combined type, extension, and qualification. *Journal of Abnormal Child Psychology*, 27(5), 393-402.
- Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, 126(2), 220.
- Norman, D. A., & Shallice, T. (1986). Attention to action *Consciousness and Self-Regulation* (pp. 1-18): Springer.
- Nutt, J. G., Bloem, B. R., Giladi, N., Hallett, M., Horak, F. B., & Nieuwboer, A. (2011). Freezing of gait: Moving forward on a mysterious clinical phenomenon. *The Lancet Neurology*, 10(8), 734-744. [https://doi.org/10.1016/S1474-4422\(11\)70143-0](https://doi.org/10.1016/S1474-4422(11)70143-0)
- Obeso, I., Wilkinson, L., Casabona, E., Bringas, M. L., Álvarez, M., Álvarez, L., . . . Jahanshahi, M. (2011). Deficits in inhibitory control and conflict resolution on cognitive and motor tasks in Parkinson's disease. *Experimental Brain Research*, 212, 371-384. <https://doi.org/10.1007/s00221-011-2736-6>
- Öhman, A. (1997). *As fast as the blink of an eye: Evolutionary preparedness for preattentive processing of threat*. Hillsdale, NJ: Erlbaum.
- Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Towards an evolved module of fear and fear learning. *Psychological Review*, 108, 483-522.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, 9, 97-113.
- Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). *The measurement of meaning*. Urbana and Chicago, IL: University of Illinois Press.
- Park, S. H., Lam, W. K., Hoskens, M. C. J., Uiga, L., Cooke, A. M., & Masters, R. S. W. (2020). Inhibitory control, conscious processing of movement and anxiety. *Psychological Research*, 46, 101587. <https://doi.org/10.1016/j.psychsport.2019.101587>
- Park, S. H., Uiga, L., & Masters, R. S. W. (under review). Crowd reception influences avoidance behavior during football penalty-kicks, but you wouldn't know it: A retrospective analysis of professional games. *Psychology of Sport and Exercise*.
- Parr, J. V. V., Gallicchio, G., Harrison, N. R., Johnen, A. K., & Wood, G. (2020). All talk? Challenging the use of left-temporal EEG alpha oscillations as valid measures of verbal processing and conscious motor control. *Biological Psychology*, 155, 107943. <https://doi.org/10.1016/j.biopsycho.2020.107943>
- Pascual-Leone, J. (1984). *Attention, dialectic, and mental effort: Towards an organismic theory of life stages*. New York, NY: Praeger.

- Pasolunghi, M. C., Cornoldi, C., & De Liberto, S. (1999). Working memory and intrusions of irrelevant information in a group of specific poor problem solvers. *Memory and Cognition*, 27(5), 779-790.
- Payen, V., Elliot, A. J., Coombes, S. A., Chalabaev, A., Brisswalter, J., & Cury, F. (2011). Viewing red prior to a strength test inhibits motor output. *Neuroscience Letters*, 495(1), 44-48. <https://doi.org/10.1016/j.neulet.2011.03.032>
- Piatti, M., Savage, D. A., & Torgler, B. (2012). The red mist? Red shirts, success and team sports. *Sport in Society*, 15(9), 1209-1227. <https://doi.org/10.1080/17430437.2012.690400>
- Pomerleau, V. J., Fortier-Gauthier, U., Corriveau, I., Dell'Acqua, R., & Jolicoeur, P. (2014). Colour-specific differences in attentional deployment for equiluminant pop-out colours: Evidence from lateralised potentials. *International Journal of Psychophysiology*, 91, 194-205. <https://doi.org/10.1016/j.ijpsycho.2013.10.016>
- Poolton, J. M., Masters, R. S. W., & Maxwell, J. P. (2006). The influence of analogy learning on decision-making in table tennis: Evidence from behavioural data. *Psychology of Sport and Exercise*, 7(6), 677-688.
- Poolton, J. M., Masters, R. S. W., & Maxwell, J. P. (2007). Passing thoughts on the evolutionary stability of implicit motor behaviour: Performance retention under physiological fatigue. *Consciousness and Cognition*, 16(2), 456-468. <https://doi.org/10.1016/j.concog.2006.06.008>
- Poolton, J. M., Maxwell, J. P., & Masters, R. S. W. (2004). Rules for reinvestment. *Perceptual and Motor Skills*, 99(3 Pt 1), 771-774. <https://doi.org/10.2466/pms.99.3.771-774>
- Pravossoudovitch, K., Cury, F., Young, S. G., & Elliot, A. J. (2014). Is red the colour of danger? Testing an implicit red-danger association. *Ergonomics*, 57(4), 503-510. <https://doi.org/10.1080/00140139.2014.889220>
- Pryke, S. R. (2009). Is red an innate or learned signal of aggression and intimidation? *Animal Behaviour*, 78, 393-398. <https://doi.org/10.1016/j.anbehav.2009.05.013>
- Pryke, S. R., Andersson, S., Lawes, M. J., & Piper, S. E. (2002). Carotenoid status signaling in captive and wild red-collared widowbirds: Independent effects of badge size and color. *Behavioral Ecology*, 13(5), 622-631. <https://doi.org/10.1093/beheco/13.5.622>
- Rakshit, A., & Lahiri, R. (2016). *Discriminating different color from EEG signal using Interval-Type 2 fuzzy space classifier (A neuro-marketing study on the effect of color to cognitive state)*. Paper presented at the 2016 IEEE 1st International Conference on Power Electronics; Intelligent Control and Energy Systems (ICPEICES-2016), Delhi, India.
- Raud, L., Westerhausen, R., Dooley, N., & Huster, R. (2020). Differences in unity: The go/no-go and stop signal tasks rely on different mechanisms. *NeuroImage*, 210, 116582. <https://doi.org/10.1016/j.neuroimage.2020.116582>

- Recours, R., & Briki, W. (2015). The effect of red and blue uniforms on competitive anxiety and self-confidence in virtual sports contests. *Revue Européenne de Psychologie Appliquée*, *65*, 67-69. <https://doi.org/10.1016/j.erap.2015.02.004>
- Robinson, M. D. (1998). Running from William James' bear: A review of preattentive mechanisms and their contributions to emotional experience. *Cognition and Emotion*, *12*, 667-696.
- Robinson, M. D., Storbeck, J., Meier, B. P., & Kirkeby, B. S. (2004). Watch out! That could be dangerous: Valence-arousal interactions in evaluative processing. *Personality and Social Psychology Bulletin*, *30*(11), 1472-1484. <https://doi.org/10.1177/0146167204266647>
- Roger, D., & Nesselrover, W. (1987). The construction and preliminary validation of a scale for measuring emotional control. *Personality and Individual Differences*, *8*, 527-534.
- Rowe, C., Harris, J. M., & Roberts, S. C. (2005). Sporting contests: Seeing red? Putting sportswear in context. *Nature*, *437*(7063), E10. <https://doi.org/10.1038/nature04306>
- Rowe, C., Harris, J. M., & Roberts, S. C. (2006). (Corrigendum) Sporting contests: Seeing red? Putting sportswear into context. *Nature*, *441*, E3. <https://doi.org/10.1038/nature04848>
- Rowland, H. M., & Burriss, R. P. (2017). Human colour in mate choice and competition. *Philosophical Transactions of the Royal Society B*, *372*, 20160350. <https://doi.org/10.1098/rstb.2016.0350>
- Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*, 1161-1178.
- Schachar, R. J., Logan, G. D., Robaey, P., Chen, S. Y., Ickowicz, A., & Barr, C. (2007). Restraint and cancellation: Multiple inhibition deficits in attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology*, *35*, 229-238. <https://doi.org/10.1007/s10802-006-9075-2>
- Schneider, C. A., Rasband, W. S., & Eliceiri, K. W. (2012). NIH Image to ImageJ: 25 years of image analysis. *Nature Methods*, *9*(7), 671-675.
- Schneider, W., Dumais, S. T., & Shiffrin, R. M. (1984). *Automatic and controlled processing and attention*. New York, NY: Academic Press.
- Schneirla, T. C. (1959). *An evolutionary and developmental theory of biphasic processes underlying approach and withdrawal* (Vol. 4). Lincoln, NE: University of Nebraska Press.
- Setchell, J. M., & Wickings, E. J. (2005). Dominance, status signals and coloration in male mandrills (*Mandrillus sphinx*). *Ethology*, *111*(1), 25-50. <https://doi.org/10.1111/j.1439-0310.2004.01054.x>
- Sherwood, S. M., Smith, T. B., & Masters, R. S. W. (2019). Decision reinvestment,

- pattern recall and decision making in rugby union. *Psychology of Sport and Exercise*, 43, 226-232. <https://doi.org/10.1016/j.psychsport.2019.03.002>
- Simmonds, D. J., Fotedar, S. G., Suskauer, S. J., Pekar, J. J., Denckla, M. B., & Mostofsky, S. H. (2007). Functional brain correlates of response time variability in children. *Neuropsychologia*, 45(9), 2147-2157.
- Simmonds, D. J., Pekar, J. J., & Mostofsky, S. H. (2008). Meta-analysis of Go/No-go tasks demonstrating that fMRI activation associated with response inhibition is task-dependent. *Neuropsychologia*, 46(1), 224-232. <https://doi.org/10.1016/j.neuropsychologia.2007.07.015>
- Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of various instructional approaches in developing anticipation skill. *Journal of Experimental Psychology: Applied*, 11(2), 98-110. <https://doi.org/10.1037/1076-898X.11.2.98>
- Smith, J. L., Jamadar, S., Provost, A. L., & Michie, P. T. (2013). Motor and non-motor inhibition in the Go/NoGo task: An ERP and fMRI study. *International Journal of Psychophysiology*, 87(3), 244-253.
- Sorokowski, P., Szmajke, A., Hamamura, T., Jiang, F., & Sorokowska, A. (2014). "Red wins", "black wins" and "blue loses" effects are in the eye of beholder; but they are culturally universal: A cross-cultural analysis of the influence of outfit colours on sports performance. *Polish Psychological Bulletin*, 45(3), 318-325. <https://doi.org/10.2478/ppb-2014-0039>
- Spielberger, C. D., Gorsuch, P. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). State-trait inventory for adults. *Mind Garden*.
- Springer, S. P., & Deutsch, G. (1998). *Left brain, right brain*. San Francisco, CA: W. H. Freeman.
- Stefanucci, J. K., Creem-Regehr, S. H., Thompson, W. B., Lessard, D. A., & Geuss, M. N. (2015). Evaluating the accuracy of size perception on screen-based displays: Displayed objects appear smaller than real objects. *Journal of Experimental Psychology: Applied*, 21(3), 215-223. <https://doi.org/10.1037/xap0000051>
- Steimer, T. (2002). The biology of fear- and anxiety-related behaviors. *Dialogues in Clinical Neuroscience*, 4(3), 231-249. <https://doi.org/10.31887/DCNS.2002.4.3/tsteimer>
- Stone, N. J., & English, A. J. (1998). Task type, posters, and workspace color on mood, satisfaction, and performance. *Journal of Environmental Psychology*, 18(2), 175-185. <https://doi.org/10.1006/jevp.1998.0084>
- Stuss, D. T., & Alexander, M. P. (2000). Executive functions and the frontal lobes: A conceptual view. *Psychological Research*, 63, 289-298. <https://doi.org/10.1007/s004269900007>
- Szmajke, A., & Sorokowski, P. (2006). Permit support in sport: The influence of sportsmen's wear colour on competitions in sport [in Polish]. *Medicina Sportiva*,

10, 119-122.

- Tanaka, A., & Tokuno, Y. (2011). The effect of the color red on avoidance motivation. *Social Behavior and Personality: An International Journal*, 39(2), 287-289.
- Taylor, I. L., & Sumner, F. C. (1945). Actual brightness and distance of individual colors when their apparent distance is held constant. *Journal of Psychology*, 19(1), 79-85. <https://doi.org/10.1080/00223980.1945.9917222>
- Tchernikov, I., & Fallah, M. (2010). A color hierarchy for automatic target selection. *PLoS ONE*, 5(2), e9338. <https://doi.org/10.1371/journal.pone.0009338>
- Teatero, M. L., & Penney, A. M. (2015). Fight-or-flight response. In I. Milosevic & R. E. McCabe (Eds.), *Phobias: The psychology of irrational fear* (pp. 179-181): ABC-CLIO.
- Tedford Jr., W. H., Bergquist, S. L., & Flynn, W. E. (1977). The size-color illusion. *Journal of General Psychology*, 97, 145-149. <https://doi.org/10.1080/00221309.1977.9918511>
- Thomas, S., Shobini, L. R., & Devi, B. I. (2016). Relationship between attention and inhibition: Are they two sides of the same coin? *Journal of Indian Academy of Applied Psychology*, 42(2), 337-343. <https://doi.org/10.1162/jocn.2008.20500>
- Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature*, 381(6582), 520.
- Tiego, J., Testa, R., Bellgrove, M. A., Pantelis, C., & Whittle, S. (2018). A hierarchical model of inhibitory control. *Frontiers in Psychology*, 9, 1339. <https://doi.org/10.3389/fpsyg.2018.01339>
- Van der Kamp, J., & Masters, R. S. W. (2008). The human Muller-Lyer illusion in goalkeeping. *Perception*, 37(6), 951-954. <https://doi.org/10.1068/p6010>
- Van Wouwe, N. C., Van den Wildenberg, W. P. M., Claassen, D. O., Kanoff, K., Bashore, T. R., & Wylie, S. A. (2014). Speed pressure in conflict situations impedes inhibitory action control in Parkinson's disease. *Biological Psychology*, 101, 44-60. <https://doi.org/10.1016/j.biopsycho.2014.07.002>
- Vasconcelos, B. B., & Del Vecchio, F. B. (2017). Wushu Sanda: Color bias, home advantage and motor action analysis in female matches' from the 13th World Championships. *Revista de Artes Marciales Asiáticas*, 12(1), 1-9. <https://doi.org/10.18002/rama.v12i1.4858>
- Waite, C., Little, A. C., Wolfensohn, S., Honess, P., Brown, A. P., Buchanan-Smith, H. M., & Perrett, D. I. (2003). Evidence from rhesus macaques suggests that male coloration plays a role in female primate mate choice. *Proceedings of the Royal Society B: Biological Sciences*, 270, S144-146. <https://doi.org/10.1098/rsbl.2003.0065>
- Wallis, W. A. (1935). The influence of color on apparent size. *The Journal of General Psychology*, 13, 193-199. <https://doi.org/10.1080/00221309.1935.9917877>

- Warden, C. J., & Flynn, E. L. (1926). The effect of color on apparent size and weight. *The American Journal of Psychology*, 37(3), 398-401.
- Welsh, M. C., Satterlee-Cartmell, T., & Stine, M. (1999). Towers of Hanoi and London: Contribution of working memory and inhibition to performance. *Brain and Cognition*, 41(2), 231-242. <https://doi.org/10.1006/brcg.1999.1123>
- Whitfield, T. W., & Wiltshire, T. J. (1990). Color psychology: A critical review. *Genetic Social and General Psychology Monographs*, 116(4), 385-411.
- Whitmer, A. J., & Banich, M. T. (2007). Inhibition versus switching deficits in different forms of rumination. *Psychological Science*, 18(6), 546-553.
- Wilson, G. D. (1966). Arousal properties of red versus green. *Perceptual and Motor Skills*, 23, 947-949.
- Wilson, M., Chattington, M., Marple-Horvat, D. E., & Smith, N. C. (2007). A comparison of self-focus versus attentional explanations of choking. *Journal of Sport and Exercise Psychology*, 29(4), 439-456.
- Wilson, M. R., Wood, G., & Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport and Exercise Psychology*, 31, 761-775. <https://doi.org/10.1123/jsep.31.6.761>
- Wine, J. (1971). Test anxiety and direction of attention. *Psychological Bulletin*, 76(2), 92-104.
- Wolfenbarger, L. L. (1999). Red coloration of male northern cardinals correlates with mate quality and territory quality. *Behavioral Ecology*, 10(1), 80-90. <https://doi.org/10.1093/beheco/10.1.80>
- Wong, W. L., Masters, R. S. W., Maxwell, J. P., & Abernethy, A. B. (2008). Reinvestment and falls in community-dwelling older adults. *Neurorehabilitation and Neural Repair*, 22, 410-414. <https://doi.org/10.1177/1545968307313510>
- Wong, W. L., Masters, R. S. W., Maxwell, J. P., & Abernethy, B. (2009). The role of reinvestment in walking and falling in community-dwelling older adults. *Journal of the American Geriatrics Society*, 57(5), 920-922. <https://doi.org/10.1111/j.1532-5415.2009.02228.x>
- Wood, G., Vine, S. J., & Wilson, M. R. (2016). Working memory capacity, controlled attention and aiming performance under pressure. *Psychological Research*, 80, 510-517.
- Wood, G., & Wilson, M. R. (2010a). Gaze behaviour and shooting strategies in football penalty kicks: Implications of a 'keeper-dependent' approach. *International Journal of Sport Psychology*, 41, 293-312.
- Wood, G., & Wilson, M. R. (2010b). A moving goalkeeper distracts penalty takers and impairs shooting accuracy. *Journal of Sport Sciences*, 28(9), 937-946. <https://doi.org/10.1080/02640414.2010.495995>

- Worthy, D. A., Markman, A. B., & Maddox, W. T. (2009). Choking and excelling under pressure in experienced classifiers. *Attention, Perception, and Psychophysics*, 71(4), 924-935. <https://doi.org/10.3758/APP.71.4.924>
- Xiao, K., Luo, M. R., & Li, C. (2010). Colour size effect modelling. *Color Research and Application*, 37(4), 4-12. <https://doi.org/10.1002/col.20650>
- Xiao, K., Luo, M. R., Li, C., Cui, G., & Park, D. (2011). Investigation of colour size effect for colour appearance assessment. *Color Research and Application*, 36(3), 201-209. <https://doi.org/10.1002/col.20610>
- Xiao, K., Luo, M. R., Li, C., & Hong, G. (2010). Colour appearance of room colours. *Color Research and Application*, 35(4), 284-293. <https://doi.org/10.1002/col.20575>
- Yang, Y., Cao, S., Shields, G. S., Teng, Z., & Liu, Y. (2016). The relationships between rumination and core executive functions: A meta-analysis. *Depression and Anxiety*, 34(1), 37-50. <https://doi.org/10.1002/da.22539>
- Young, M. E., Sutherland, S. C., & McCoy, A. W. (2018). Optimal go/no-go ratios to maximize false alarms. *Behavior Research Methods*, 50, 1020-1029. <https://doi.org/10.3758/s13428-017-0923-5>
- Young, S. G., Elliot, A. J., & Feltman, R. (2013). Red enhances the processing of facial expressions of anger. *Emotion*, 13(3), 380-384. <https://doi.org/10.1037/a0032471>
- Zaback, M., Cleworth, T. W., Carpenter, M. G., & Adkin, A. L. (2015). Personality traits and individual differences predict threat-induced changes in postural control. *Human Movement Science*, 40, 393-409. <https://doi.org/10.1016/j.humov.2015.01.015>
- Zajonc, R. B. (1998). *Emotion* (4 ed.). New York, NY: McGraw-Hill.
- Zhao, X., Qian, W., Fu, L., & Maes, J. H. R. (2017). Deficits in go/no-go task performance in male undergraduate high-risk alcohol users are driven by speeded responding to go stimuli. *The American Journal of Drug and Alcohol Abuse*, 43(6), 656-663. <https://doi.org/10.1080/00952990.2017.1282502>
- Zhu, F. F., Poolton, J. M., Wilson, M. R., Maxwell, J. P., & Masters, R. S. W. (2011). Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology*, 87(1), 66-73. <https://doi.org/10.1016/j.biopsycho.2011.02.004>
- Zuk, M., Johnson, K., Thornhill, R., & Ligon, J. D. (1990). Mechanisms of female choice in red jungle fowl. *Evolution*, 44(3), 477-485. <https://doi.org/10.1111/j.1558-5646.1990.tb05933.x>

Appendices

Appendix 1: Co-authorship forms



Co-Authorship Form

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This form is to accompany the submission of any PhD that contains research reported in published or unpublished co-authored work. Please include one copy of this form for each co-authored work. Completed forms should be included in your appendices for all the copies of your thesis submitted for examination and library deposit (including digital deposit).

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Park, S. H., Lam, W. K., Hoskens, M. C. J., Uiga, L., Cooke, A. M., & Masters, R. S. W. (2020).
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Nature of contribution by PhD candidate: Investigator, conception, design, data collection, analysis, interpretation, drafting, revisions
Extent of contribution by PhD candidate (%): >50%

CO-AUTHORS

Name	Nature of Contribution
Lam, W. K.	Comments
Hoskens, M. C. J.	Data collection, analysis
Uiga, L.	Data collection, interpretations, comments, paper editing
Cooke, A. M.	Comments
Masters, R. S. W.	Conception, interpretation, comments, paper editing

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
Dr. Gilbert W. K. Lam		May 27, 2021
Dr. Merel C. J. Hoskens		May 27, 2021
Dr. Liis Uiga		May 27, 2021
Dr. Andrew M. Cooke		May 27, 2021
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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Investigating the relationship between inhibition function, propensity for conscious control of movement, and colour.

Nature of contribution by PhD candidate

Investigator, conception, design, data collection, analysis, interpretation, drafting, revisions

Extent of contribution by PhD candidate (%)

>50%

CO-AUTHORS

Name	Nature of Contribution
Lam, W. K.	Data collection, comments
Uiga, L.	Design, analysis, interpretation, comments
Cooke, A. M.	Design, analysis, comments
Capio, C. M.	Comments
Masters, R. S. W.	Conception, design, interpretation, comments, paper editing

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Should I go or should I stay? Empirical and real-life observations of the effect of uniform colour on inhibitory control

Nature of contribution by PhD candidate

Investigator, conception, design, data collection, analysis, interpretation, drafting, revisions

Extent of contribution by PhD candidate (%)

>50%

CO-AUTHORS

Name	Nature of Contribution
Lam, W. K.	Comments
Uiga, L.	Design, analysis, interpretation, comments
Cooke, A. M.	Design, comments
Capio, C. M.	Comments
Masters, R. S. W.	Conception, design, interpretation, comments, paper editing

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Examining the colour-size illusion in a sports context: Are goalkeepers in red perceived to be larger than real life?

Nature of contribution by PhD candidate

Extent of contribution by PhD candidate (%)

CO-AUTHORS

Name	Nature of Contribution
Uiga, L.	Design, analysis, interpretation, comments, paper editing
Cooke, A. M.	Interpretation, comments
Capio, C. M.	Comments
Masters, R. S. W.	Design, interpretation, comments, paper editing

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Dr. Catherine M. Capio		May 27, 2021
Prof. Rich S. W. Masters		May 27, 2021
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The effect of red and blue spectator background on avoidance motivation during football penalty-kicks

Nature of contribution
by PhD candidate

Investigator, conception, design, data collection, analysis, interpretation, drafting, revisions

Extent of contribution
by PhD candidate (%)

>50%

CO-AUTHORS

Name	Nature of Contribution
Uiga, L.	Design, interpretation, comments, paper editing
Lam, W. K.	Comments
Chan, D. C. L.	Data collection
Prof. Rich S. W. Masters	Conception, design, analysis, interpretation, comments, paper editing

Certification by Co-Authors

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Dr. Gilbert W. K. Lam		May 27, 2021
Dr. Debbie C. L. Chan		May 27, 2021
Prof. Rich S. W. Masters		May 27, 2021

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Crowd reception influences avoidance behavior during football penalty-kicks, but you wouldn't know it:
A retrospective analysis of professional games

Nature of contribution
by PhD candidate

Investigator, conception, design, data collection, analysis, interpretation, drafting, revisions

Extent of contribution
by PhD candidate (%)

>50%

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Uiga, L.	Design, interpretation, comments
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