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Park, So Hyun; Lam, Wing-Kai; Uiga, Liis; Cooke, Andrew; Capio, Catherine; Masters, Rich

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Park, S. H. [1], Lam, W. K. [2], Uiga, L. [3], Cooke, A.[4], Capio, C. M.[5], and Masters, R. S. W. [1]

[1] Te Huataki Waiora School of Health, University of Waikato, New Zealand

[2] Sports Information and External Affairs Centre, Hong Kong Sports Institute, Hong Kong, China

[3] Department of Sport and Exercise Sciences, Manchester Metropolitan University, UK

[4] Institute for the Psychology of Elite Performance (IPEP), School of Human and Behavioural Sciences, Bangor University, United Kingdom

[5] Faculty of Education and Human Development, The Education University of Hong Kong, Hong Kong, China

Corresponding author:

So Hyun Park,

Te Huataki Waiora School of Health

The University of Waikato

Private Bag 3105

Hamilton 3240, New Zealand.

Email: shp24@students.waikato.ac.nz

ORCID 0000-0002-8475-9289

Abstract

Inhibitory control is a cognitive process that can be influenced by colour. We asked whether inhibitory control during sport can be influenced by uniform colour. Thirty-seven participants were instructed to pass to the more spacious side of an opponent wearing a red, green, or grey (control) uniform, but to inhibit passes 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 a grey uniform, but not when responding to opponents wearing a red uniform compared to a grey uniform. This suggests that perceiving a green uniform impaired inhibition. We therefore examined archival data to ask whether green uniforms are associated with more intercepted passes, because green impairs an opponent's inhibitory control, which promotes ill-chosen passes. Netball teams wearing predominantly green uniforms completed significantly more intercepts than teams wearing other-coloured (control) uniforms, suggesting that the colour of their uniform may have promoted a higher proportion of ill-chosen passes by opponents. We concluded that colour may influence inhibition in sport due to a colour-meaning association–green is 'go'.

Keywords: Green, uniform colour, Go/NoGo task, inhibition function, basketball, netball

Word count: ~~3330~~3549 words

Manuscript

Studies have shown that elite athletes display superior inhibitory control compared to their novice counterparts, which may be one of the hallmarks of advanced skill performance (e.g., ultra-marathon runners, Cona, Cavazzana, Paoli, Marcolin, Grainer, & Bisiacchi, 2015; fencers, Di Russo, Taddei, Apnile, & Spinelli, 2006; baseball players, Muraskin, Sherwin, & Sajda, 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 indispensable component of attention, because it suppresses intrusive thoughts and inappropriate behaviours so that pertinent information can be attended (Thomas, Shobini, & Devi, 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, Johnson, & Pascual-Leone, 2014; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000).

It has been suggested that inhibition function can be influenced by colour. Blizzard, Fierro-Rojas, and Fallah (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 a 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, Brown, Reijnen, Rich, Kuzmova, & Wolfe, 2010; Pomerleau, Fortier-Gauthier, Corriveau, Dell'Acqua, & Jolicoeur, 2014; Tchernikov & Fallah, 2010).

Blizzard et al. (2017) did not include a control colour in their study, so it is possible that rather than red stop-signals facilitating response inhibition green stop-signals impaired response inhibition. Colour-in-Context theory (Elliot & Maier, 2012) proposes that colour can influence behaviours in a manner that is congruent with the meaning that the colour carries (e.g., in this case, red to stop and green to go), so it is possible that red facilitated response inhibition and/or green impaired response inhibition.

This raises a question of whether colour influences inhibition function in sports contexts, where performers typically wear different colours (e.g., uniforms) to signal their allegiance to a club, team, or nation. We predicted that competing against opponents in red uniforms facilitates inhibition function compared to grey (control) uniforms, but competing against opponents in green uniforms impairs inhibition function compared to grey (control) uniforms.

In an experimental study, ~~thirty-seven~~forty-one participants (*M* age = 24.00~~24.38~~, years, *SD* = 3.94~~3.90~~ years; 28~~27~~ males) who passed the online Ishihara test for colour blindness (Ishihara, 1972, enchroma.com/pages/color-blindness-test) 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).[1] During the Go/NoGo task, a basketball player

[1] A priori sample size calculation for planned contrasts with a medium effect size (d = 0.5), alpha of 0.05, and 95% power suggested that 45 participants were adequate to test our hypothesis. We

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). For 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 (Figure 1). 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 projected onto a wall (149 x 260 cm) and participants were positioned 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). Red and green only differed by hue, whereas saturation and value remained the same on the HSV (hue, saturation, value) colour model (red 0, 100, 100; green 120, 100, 100). 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 a total of 192 trials. Stimuli were presented in random order with a stimulus duration of 500 milliseconds. An inter-stimulus interval of 1500 milliseconds was used in the computer-based task, whereas an inter-stimulus interval of 2500 milliseconds was used in the motor-based task to accommodate ball flight time. For the motor-based task, participants' 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). Response times were determined using Dartfish (Dartfish SA, Switzerland). The experimenter was blind to the colour condition when processing the video file. This was done by using a black-and-white filter to camouflage the colour.

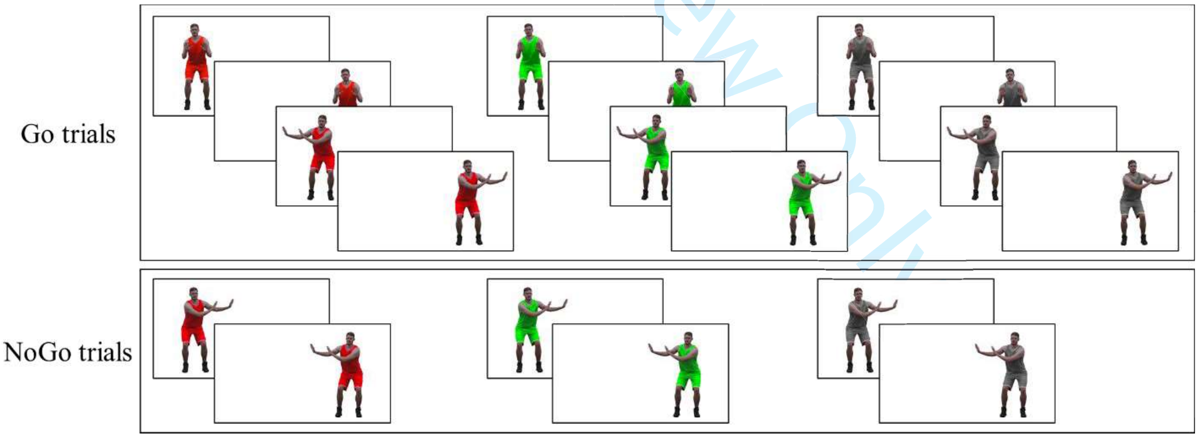

Figure 1. Stimuli used in the basketball-specific Go/NoGo task. For Go trials, participants were required to indicate (computer-based task) or pass to (motor-based task) the side with more

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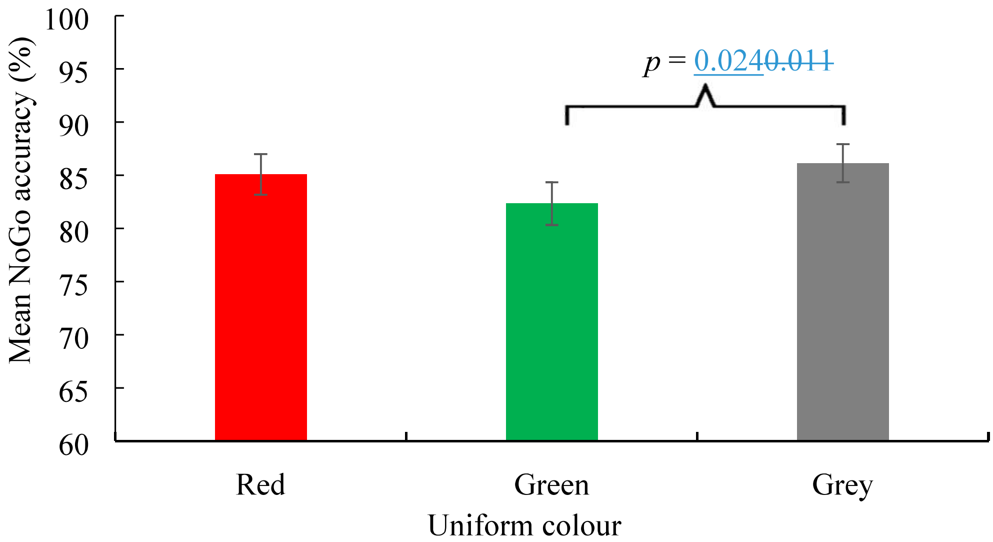
initially recruited forty-four participants but after applying exclusion criteria (e.g., those who guessed our colour hypothesis N=2, those with less than 66.67% accuracy N=1~~, Go RTs with Cook's distance of more than 1 N=4)~~, we ended up with ~~thirty-seven~~forty-one participants.

space, but for NoGo trials participants were required to inhibit their response when the side with more space was being defended.

For both the computer-based task (a button press) and the motor-based task (a basketball pass), we conducted planned comparisons using t-tests, with~~(simple contrasts) using~~ grey as a reference category. While some researchers argue against the use of Bonferroni correction (Armstrong, 2014; Nakagawa, 2004; Perneger, 1998), w~~W~~e nevertheless conducted Bonferroni adjustments to correct for multiple testing (0.05/2 = 0.025). We did this for NoGo accuracy (correct inhibition of responses for NoGo trials) as a direct measure of inhibition function.[2]

For the computer-based task, NoGo accuracy was lower for green uniforms compared to grey uniforms, $t(40) = 2.031$, $p = 0.024$, Cohen's $d = 0.317$, 95% CI [0.002, 0.629]~~$F(1,36) = 5.658$, $p = 0.011$, $\eta_p^2 = 0.136$~~ (one-tailed); however, NoGo accuracy was not higher for red uniforms compared to grey uniforms, $t(40) = 0.519$, $p = 0.303$, Cohen's $d = 0.081$, 95% CI [-0.226, 0.387]~~$F(1,36) = 0.238$, $p = 0.314$, $\eta_p^2 = 0.007$~~ (one-tailed) (see Figure 2).



[2] There are three other outcome measures from the Go/NoGo task paradigm: Go accuracy (correct responses for Go trials), Go response time (stimuli onset to response initiation for Go trials), and Go response time variability (variability of time to respond for Go trials; intra-individual coefficient of variation = Go RT_{SD}/Go RT_{M}). However, these measures are often argued to be an 'indirect' or correlated measure of inhibition as Go accuracy has been used to index inattention (Bezdjian, Baker, Lozano, & Raine, 2009), Go response time to index working memory capacity (Trueblood, Endres, Busemeyer, & Finn, 2011), and Go response time variability to index information processing efficiency and/or executive control (Bellgrove, Hester, & Garavan, 2004).

Figure 2. Mean NoGo accuracy score (%) when responding to basketball players in red, green, and grey uniforms, during the computer-based basketball-specific Go/NoGo task. Error bars represent standard error.

For the motor-based task (a basketball pass), NoGo accuracy was significantly lower for green uniforms compared to grey uniforms, $t(40) = 2.237$, $p = 0.015$, Cohen's $d = 0.349$, 95% CI [0.032, 0.663]~~$F(1,36) = 4.428$, $p = 0.021$, $\eta_p^2 = 0.110$~~ (one-tailed); however, NoGo accuracy was not higher for red uniforms compared to grey uniforms, $t(40) = 1.035$, $p = 0.153$, Cohen's $d = 0.162$, 95% CI [-0.147, 0.469]~~$F(1,36) = 0.209$, $p = 0.325$, $\eta_p^2 = 0.006$~~ (one-tailed) (see Figure 3).

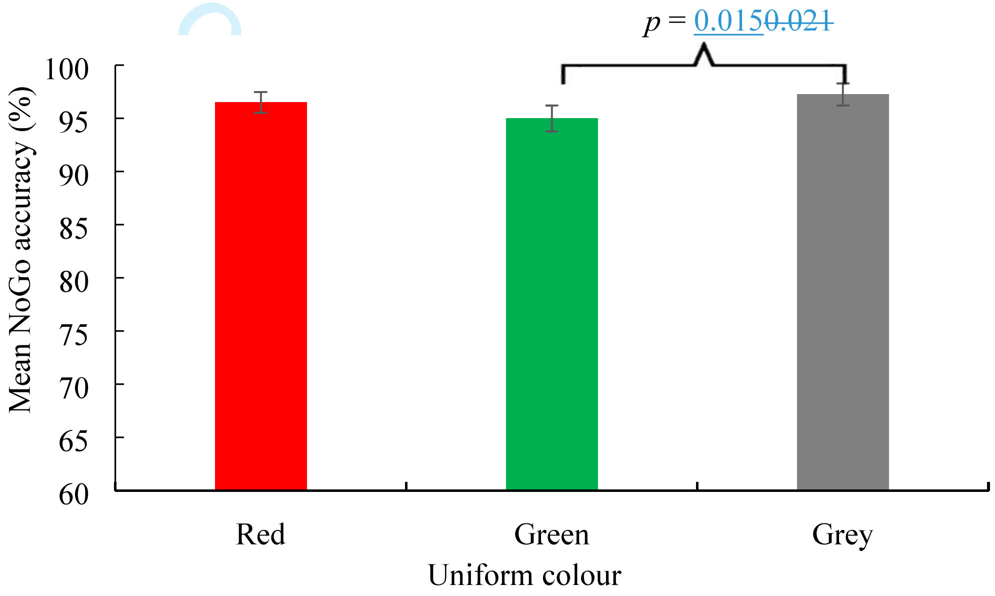


Figure 3. Mean NoGo accuracy score (%) when responding to basketball players in red, green, and grey uniforms during the motor-based basketball-specific Go/NoGo task. Error bars represent standard error.

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 task in which participants were required to inhibit their response *after* their response had been initiated, whereas we used a Go/NoGo task in which participants were required either to initiate or to inhibit their response. Although previous studies have used the stop-signal and Go/NoGo tasks interchangeably (e.g., Bender, Filmer, Garner, Naughtin, & Dux, 2016; Tiego, Testa, Bellgrove, Pantelis, & Whittle, 2018), there is growing evidence that the stop-signal and Go/NoGo tasks tap into different cognitive mechanisms (e.g., Schachar, Logan, Robaey, Chen, Ickowicz, & Barr, 2007; Littman & Takács, 2017; Raud, Westerhausen, Dooley, & Huster, 2020). Raud et al. (2020) suggested that inhibitory performance in the stop-signal 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) while inhibitory performance in the Go/NoGo task is comparable to a response selection mechanism (e.g., should I go or should I stay now). Logan and Cowan (1984) used a horse-racing analogy to explain inhibitory performance (response inhibition), with successful inhibition dependent upon whether the *stop process* wins the race with the *go process*. In the stop-signal task, the *stop process* begins the race as soon as the stop-signal appears, which means winning the race (successful inhibition) requires fast identification of the stop-signal so that the *stop process* can outrun the *go process*. However, in the Go/NoGo task, only one horse runs (*stop process* or *go process*), so winning the race (successful inhibition) is dependent not on fast stop-signal detection but upon whether the correct decision is made to initiate the *stop process* rather than the *go process*.

Thus, it is possible that during the stop-signal task, inhibitory performance may have been facilitated by red because participants were faster at identifying the stop-signal – red has been shown to promote faster visual search (and therefore identification) because of its high salience (Tchernikov & Fallah, 2010). In the Go/NoGo task, however, the salience of red may have a less obvious effect on inhibitory performance because faster visual search may benefit identification of but not discrimination between Go and NoGo cues.

Green, on the other hand, was shown to impede inhibitory performance in our study. 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 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 deemed to be congruent (i.e., red-hot, blue-cold) rather than incongruent (i.e., red-cold, blue-hot) (see also Pravossoudovitch, Cury, Young, & Elliot, 2014; Mentzel, Schücker, Hagemann, & Strauss, 2017; Geng, Hong, & Zhou, 2021). Likewise, green is often used to signal 'go' at traffic lights in daily life, and superimposing the colour green on NoGo cues would have conveyed incongruent messages (to go and not to go, respectively) which might have disrupted correct discrimination of NoGo cues. Thus, 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 ball 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 grey (control) uniforms. We initially attempted to find intercept statistics in National Basketball Association (NBA) games, but found no recorded statistic equivalent to an intercept category.[3] Thus, we 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.[4] 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 analysis. Red uniforms were worn 41 times, green uniforms were worn 26 times, and other coloured uniforms were worn 103 times during the 124 games that were played throughout the tournament.[5] Based on our findings in the first experiment, 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 other-coloured uniforms. We did not expect to find a difference between teams wearing red and teams wearing other-coloured uniforms. Like Experiment 1, we conducted planned comparisons using t-tests, with ~~(simple contrasts) using~~ other-coloured uniforms as a reference category. Again, w~~W~~e conducted Bonferroni adjustments to correct for multiple testing (0.05/2 = 0.025). The mean number of intercepts was statistically higher for teams wearing green uniforms compared to teams wearing other-coloured uniforms, $t(127) = 1.985$, $p = 0.025$, Cohen's $d = 0.436$, 95% CI [0.001, 0.868]~~$t(167) = 2.184$, $p = 0.015$, $d = 0.479$~~ (one-tailed). However, the mean number of intercepts was not different between teams wearing red uniforms and teams wearing other-coloured uniforms, $t(142) = 0.631$, $p = 0.265$, Cohen's $d = 0.116$, 95% CI [0.246, 0.478]~~$t(167) = -0.386$, $p = 0.350$, $d = -0.072$~~ (one-tailed).

[3] 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).
[4] Note that we were unable to use grey as our control colour (as we did in our laboratory study) because no teams in the Netball World Cup wore predominantly grey uniforms.
[5] The mean number of intercepts per 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).

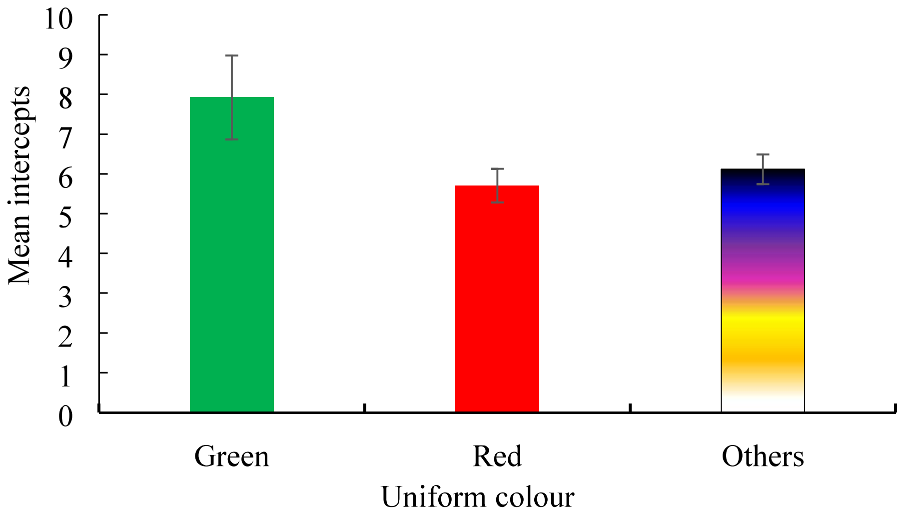


Figure 4. Mean number of intercepts per game by teams wearing green, red, and other-coloured (white, orange, yellow, pink, purple, blue, and black) uniforms during the 2015 and 2019 Netball World Cups. Error bars represent standard error.

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 the mean number of points scored by teams in green uniforms compared to other-coloured uniforms, $t(127) = 1.370$, $p = 0.087$, Cohen's $d = 0.301$, 95% CI [-0.132, 0.732]~~$t(167) = 1.414$, $p = 0.080$, $d = 0.310$~~ (one-tailed), and red compared to other-coloured uniforms, were statistically non-significant $t(142) = 1.389$, $p = 0.084$, Cohen's $d = 0.256$, 95% CI [-0.107, 0.619]~~$t(167) = 1.424$, $p = 0.078$, $d = 0.265$~~ (one-tailed), 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.

Thus, it is likely that players facing opponents in a green uniform may have been less able to refrain from making a pass that could easily be intercepted. 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 of whether green uniform colour might influence both teammates and opponents. It may be, for example, that intercepts in netball games are higher when either team wears green (as opposed to when neither team wears green), because ill-chosen passes are greater for ~~either~~ both teams. However, analysis revealed that this was not the case. The mean number of intercepts when green uniforms were present on the court (either team) was not significantly different from when green uniforms were absent from the court, $t(144) = 0.545$, $p = 0.587$, Cohen's $d = 0.100$, 95% CI [-0.259, 0.458]~~$t(167) = 0.570$, $p = 0.569$, $d = 0.104$~~ (two-tailed), suggesting that players were only affected when viewing opponents in green. Possibly, for teams that wear green uniforms, associated priming effects are reduced by familiarity. If so, wearing green could hinder the decision-making of opposing players without influencing the behavioural responses of the wearer. Nonetheless, we acknowledge that this is a speculation that requires further investigation.

The majority of colour research in sport has examined what the effects of colour are (e.g., red enhances winning outcomes, Hill & Barton, 2005), 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.

Acknowledgement

We are grateful to Li Ning Sports Science Research Center, Li-Ning (China) Sports Goods Co. Ltd, Beijing, for their support in conducting the research.

We have reported how we determined our sample size, all data exclusions and manipulations, and we have provided justification for why we do not report all measures in the study.

Disclosure of Interest

The authors report no conflict of interest.

Data Availability

The data that support the findings of this study are openly available in figshare at https://doi.org/10.6084/m9.figshare.22637698.

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