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An Investigation into Handedness and Choking under Pressure in Sport

Christopher Mesagno

Jacob Garvey

Stephanie J. Tibbert

School of Health and Life Sciences,

Federation University, Australia

Peter Gröpel

Department of Applied Psychology: Work, Education, Economy

University of Vienna, Austria

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Please direct all correspondence to Christopher Mesagno, Ph.D.
School of Health and Life Sciences
Federation University Australia
P.O. Box 663
Ballarat, Victoria 3353
AUSTRALIA
Phone: 61 3 5327 6136
Email: c.mesagno@federation.edu.au

Abstract

When athletes fail to perform at an expected level during an important moment, it is implied the athletes have experienced “choking under pressure” (i.e., choking). Researchers have reported that persistent left-hemispheric activation patterns occur when an athlete experiences considerable performance deteriorations under pressure. Researchers have also observed differences in brain activation patterns between left- and right-handed people on a variety of physical and cognitive tests, with the left-hemispheric activation more pronounced in right-handed participants. **Purpose:** The purpose of this study was to investigate whether athletes’ handedness may be linked to choking-susceptibility (i.e., likelihood to experience performance decline under pressure). **Method:** Twenty right-handed and 13 left-handed experienced Australian football players completed 15 shot attempts, in both a low-pressure and a high-pressure condition. Both groups displayed equal state anxiety increases due to the pressure manipulation, indicating similar increases in anxiety in both handedness groups. **Results:** Results also indicated differences in performance between the left- and right-handed groups during the high-pressure condition, with the left-handed group maintaining, and the right-handed participants declining, performance. **Conclusion:** Future electroencephalogram (EEG) research investigating this link may clarify the effect between handedness and choking.

Keywords: Performance; Brain Activation; Hemispheric Asymmetry; Anxiety

An Investigation into Handedness and Choking under Pressure in Sport

Choking under pressure (i.e., choking) is defined as “an acute and considerable decrease in skill execution and performance when self-expected standards are normally achievable, which is the result of increased anxiety under perceived pressure” (Mesagno & Hill, 2013, p. 273). Researchers have spent over two decades attempting to understand why some athletes appear more susceptible to choking than others. These investigations have given rise to several theories, with the most prominent explanations centered on the anxiety-attention relationship: the distraction (e.g., Mullen, Hardy, & Tattersall, 2005) and the self-focus (e.g., Beilock & Carr, 2001) models of choking. Choking models are based on the assumption that when anxiety is present an altered cognitive process interrupts optimal performance. Researchers advocating the distraction model suggest anxiety will be processed alongside the information that is needed to execute the skill, leading to inefficient processing of task-relevant cues, which increases choking-susceptibility (e.g., Mesagno, Geukes, & Larkin, 2015; Mullen et al., 2005). Self-focus theorists suggest that the alteration of cognition under pressure is a redirecting of the performer’s attention to internal movements, so when a performer consciously attempts to control a normally automatic movement there is disruption of skill execution that adversely affects performance (e.g., Beckmann, Gröpel, & Ehrlenspiel, 2013; Beilock & Carr, 2001). Recognizing that the self-focus models of choking have arguably received most empirical support (Mesagno et al., 2015), research attention has turned to understanding the neurological processes during this cognitive disruption.

To understand the neurological processes involved in choking, researchers must first identify the neurological processes in successful performance. For example, Hatfield, Landers, and Ray (1984) monitored brain activity via electroencephalogram (EEG) of elite marksmen before and during performance. They observed that as experience marksmen prepared to fire a rifle, a shift occurred from predominantly left- to right-hemispheric activation, resulting in more

bilateral brain activation. Similarly, Crews and Landers (1993) monitored brain activity of highly skilled golfers during a putting task and found that during the final second prior to the golfers' successful putts, there were increased right-hemispheric and decreased left-hemispheric activation. Moreover, the stronger right-hemispheric activation and left-hemispheric inhibition were correlated with and predicted better accuracy during golf putting. This neurological pattern appears to be associated with optimal performance, with the same findings being reported in several studies with participants from a variety of skill levels, and types of sports (e.g., Buszard, Farrow, Zhu, & Masters, 2016; Deeny, Hillman, Janelle, & Hatfield, 2003).

The left-hemispheric inhibition during skill execution is similar to the final stage of skill learning, whereby Fitts and Posner (1967) explained, when a skill is learned, it passes through three distinct phases: cognitive, associative, and autonomous. During the cognitive phase, the left hemisphere plays a significant role in developing mental images of the action, with verbal representations of the action facilitating development of those mental images and verbal instructions allowing the performer to develop basic understanding of how to perform the action (Beckmann et al., 2013). In the associative stage, the skill is refined with increases in both timing and efficiency of the physical movement and brain activation (Deeny et al., 2003). During the final autonomous stage, the skill becomes automatic and can be performed with little conscious thought (Fitts & Posner, 1967) and the initial verbal representation is no longer necessary. The verbal-analytical centers in the left hemisphere need only be activated when initiating a learned movement while the visual-spatial processes in the right hemisphere take over with automatic, skilled performance (Beckmann et al., 2013).

Thus, after a skill has become automatic, the performer no longer needs conscious control over movement execution and left-hemispheric inhibition follows. If the performer attempts to control the execution, however, she/he may regress to the earlier cognitive learning phase, with motor behavior consciously organized through verbal representations (Fitts & Posner, 1967),

which may interfere with automatic skill execution and lead to its breakdown (e.g., Beilock & Carr, 2001; Gröpel, & Mesagno, 2017). In terms of hemispheric asymmetry, it may be argued that the predominant left-hemispheric activation with the verbal-analytic processes (indicative of the cognitive phase) persist during skill execution, thereby hindering the visuospatial processes needed for successful performance to dominate. Indeed, researchers who investigate choking have found that dominant left-hemispheric activation predicted inferior performance when participants were under pressure (e.g., Hatfield et al., 2013; Woo, Kim, Ko, & Kwon, 2014). In contrast, when participants learned the skill implicitly, that is, without having acquired much declarative knowledge about the skill, they exhibited less left-hemispheric activation and performed better under pressure than those who had learned the skill explicitly (Buszard et al., 2016). Masters and Maxwell (2008) explained that if there is limited declarative knowledge about the skill, the performer cannot “reinvest” the declarative knowledge and consciously control skill execution.

The above evidence implies that a persistent left-hemispheric dominance may be linked to choking, whereas a symmetrical brain activation may underlie superior, skilled performance, which has been supported by Beckmann et al. (2013) who primed the right hemisphere using left-hand contractions immediately prior to skill execution under pressure. Based on research demonstrating that people’s right and left hand are mainly controlled via the contralateral brain hemisphere (Kim et al., 1993), Beckmann et al. primed the right hemisphere by asking participants to squeeze a ball in their left hand for 30 seconds prior to task attempts. Control group participants squeezed the ball in their right hand. Beckmann et al.’s results indicated that the priming successfully increased performance and minimized choking. Although Beckmann et al. did not actively monitor brain activation patterns using any EEG or other neurofeedback instrument analysis, the effects of left-hand contractions on right-hemispheric priming were subsequently confirmed in a follow-up study including EEG analysis (Cross-Villasana, Gröpel,

Doppelmayr, & Beckmann, 2015). Thus, symmetrical brain activation patterns during skill execution under pressure leads to less likelihood of choking because there is less activation of the verbal-analytic centers and less conscious attention that interferes with automatic movement execution. Based on these studies, athletes who perform a skill with more bilateral brain activation pattern appear less likely to experience choking.

Handedness

One concept, significantly linked to more bilateral brain activation is handedness (Cherbuin & Brinkman, 2006). Left-handed individuals have demonstrated more bilateral brain activation than people who are right-handed (e.g., de Nooijer, van Gog, Paas, & Zwann, 2013) using both cognitive and physical tasks with EEG and functional magnetic resonance imaging (fMRI) analysis. In certain problem solving, or learning tasks requiring bilateral, or right hemispheric brain engagement, researchers have found that left-handed individuals often outperform their right-handed counterparts (e.g., Beratis, Rabavilas, Kyprianou, Papadimitriou, & Papageorgiou, 2013; de Nooijer et al., 2013). When comparing right and left-handed individuals on executive functioning designed to engage the right hemisphere, Beratis et al. (2013) found that left-handed people had greater engagement with the right-hemisphere, which facilitated performance on tasks requiring certain forms of cognition and mental flexibility. Differences in brain activation patterns have also been observed between left and right-handed individuals in simple finger and hand movement studies using EEG and fMRI analysis (e.g., Kim et al., 1993). In one study, Solodkin, Hlustik, Noll, and Small (2001) analyzed simple and sequential single-hand movements using fMRI and found left-handed people had significantly more bilateral brain activity, and a larger number of brain areas activated than their right-handed counterparts of both dominant and non-dominant hands.

Numerous explanations have been suggested for the difference in brain activation patterns from physical brain differences. For example, Witelson (1985) reported that left-handed

individuals had a larger corpus callosum, which allows greater interhemispheric transfer to the method in which a left-handed individual has to learn a skill. Since left-handed people live in a right-hand dominant world, with approximately only 10% of the population being left-handed (Willems, Van der Haegen, Fisher, & Francks 2014), they learn skills in a different manner to most right-handed individuals. When learning a skill, a left-handed individual will often learn skills from a right-handed instructor, which may necessitate the left-handed individual learning the skill rather implicitly. Notably, researchers have demonstrated that participants who learned a skill implicitly showed less hemispheric asymmetry and better performance under pressure (Buszard et al., 2016). Parish, Dwelly, Baghurst, and Lirgg (2013) reviewed sport skill learning that compared handedness and found left-handed participants performed better, had better form, and acquired a new skill more quickly when demonstrated by a right-handed individual, compared to right-handed participants who watched a demonstration from a left-handed individual. When learning motor skills, left-handed people appear more able, than right-handed people, to acquire the relevant information about the skill, regardless of the nature in which they were taught, again implying an implicit method of learning.

Hence, differences in right-hemispheric engagement, learning, and interhemispheric communication have been highlighted as factors related to choking-susceptibility (Deeny et al., 2003; Hatfield et al., 2013; Masters & Maxwell, 2008) and handedness (Beratis et al., 2013; Parish et al., 2013; Solodkin et al., 2001), but there has been no research investigating the effect between handedness and choking directly. Thus, the purpose of the present study was to examine whether handedness may influence athletes' choking-susceptibility. Given the evidence reviewed, it was expected that left-handed athletes would experience less choking compared to right-handed athletes on a familiar goal-kicking task.

Method

Participants

A priori sample-size calculation (G*Power; Faul, Erdfelder, Buchner, & Lang, 2009) for two groups and two repeated measurements, based on moderate effect size ($f = .25$), predicted that a total sample size of 34 would give sufficient power (.80) to detect a significant difference at the alpha level of .05. Thirty-five male, active Australian football (AF) players were recruited from clubs. For inclusion in the study, participants were 18 years and older, currently playing AF competitively and had at least five years competitive playing experience. As indicated by the Flinders Handedness Survey (Nicholls, Thomas, Loetscher, & Grimshaw, 2013), one participant was ambidextrous, and his data was therefore removed from the analyses. One other participant (left-handed) was identified as an outlier, as his pretest performance was more than 3 SD worse than the group mean. The final sample consisted of 13 left-handed and 20 right-handed AF players aged 18 to 32 years ($M_{age} = 24.5$ years, $SD_{age} = 3.68$) with on average 12.79 years of AF experience ($SD = 3.02$) and attended 2.18 ($SD = 0.88$) team trainings per week.

Task and apparatus

The participants' task was to deliver five kicks from three separate cones, positioned on a standard AF ground, towards a scoring area (see Figure 1); 15 kicks were taken in total. Each kick was awarded a score between 0 and 10, with the center scoring zone being the highest and a gradual decrease in points toward the peripheral scoring zones. A score of 10 points was awarded for a kick that travelled through the center gap; nine points awarded for a kick going directly above, or hitting, either pole creating the center gap; eight points awarded for a kick travelling through either gap adjacent to the center gap; this pattern continued until the end of the scoring area was reached, where one point was awarded for hitting the outer most pole. Any kick travelling outside the scoring area was awarded zero points. Scores from each kick were

combined to provide a total score for each phase. The maximum obtainable score for each phase was 150, with higher scores representing better performance.

Insert Figure 1 here

Participants used a standard full-sized brand Australian football, and the experiment was conducted on a standard AF competition ground. The scoring zone (see Figure 1) was created using the official football goals and consisted of 10 posts sectioned into nine scoring gaps, with a distance of 2.2 m (7.22 ft) for each gap. Participants were advised that each kick must clear the height of the 2.6 m (8.53 ft) dividing poles; this replicated a potential defender with his hands up attempting to touch the ball as it goes through the goals, thereby increasing the ecological validity of the task (Beseler, Mesagno, Young, & Harvey, 2016). Failing to kick over this height resulted in a score of zero because the “defender” would likely have blocked the attempt. Cones were placed at the required 30 meter (98.43 ft) kicking positions with one directly in line with the center of the goals (i.e., 90° angle), and the other two cones positioned at 55° angles either side of the center line. These angles and distances were determined through consultation and pilot testing with AF coaches and players to determine a moderately challenging, but not overly simplistic task, and are similar to those used in previous studies (e.g., Beseler et al., 2016).

Measures

Demographics questionnaire. Demographics including questions about age, gender, football playing experience, the highest level of competitive football played, usual playing position, any existing injuries, and amount of training sessions per week. The demographics questionnaire also asked players if they had seen a sport psychologist, which may be potential confounding variable because they were exposed to interventions aimed at alleviating choking.

Flinders Handedness Survey (FHS; Nicholls et al., 2013). The FHS was used to assess participants’ handedness. The scale consisted of 10 items related to the use of the hands, with questions related to writing, drawing, throwing, or using a hammer. Participants selected either

left (-1), or right (+1), or either (0) for each item. Scores were then summed and a total laterality quotient calculated between -10 and +10. Positive values indicated the tendency toward right-handedness, whereas negative values indicated the tendency to left-handedness. A person is considered to be right-handed when his or her value is greater than +5, and left-handed when his or her value is below -5. Good validity and reliability of the scale has been established previously (Nicholls et al., 2013) and in the present study, Cronbach's alpha was .99.

Mental Readiness Form (MRF-3; Krane, 1994). The participant's level of competitive state anxiety was measured using the MRF-3. The MRF-3 consists of three separate 100-millimetre lines, anchored between *relaxed* and *tense* for somatic anxiety, *calm* and *worried* for cognitive anxiety, and *confident* and *not confident* for self-confidence. Only the somatic and cognitive subscales for the analyses were used since anxiety was important for the outcomes of the current study. Each participant placed a mark on each line to indicate his current level of anxiety; the score was determined by measuring from the left edge of each line to the participant's mark. Scores range from 0 to 100, with higher scores indicating higher anxiety. Krane (1994) reported that the MRF-3 has high concurrent validity with the widely used Competitive State Anxiety Inventory-2 (CSAI-2; Martens, Burton, Vealey, Bump, & Smith, 1990), with correlations between MRF-3 subscales and CSAI-2 subscales being .69 for somatic anxiety and .76 for cognitive anxiety. The MRF-3 was selected because it is short, easily administrable, and has been found to reliably gauge participant's anxiety levels in similar studies (e.g., Beseler et al., 2016).

Procedure

Prior to any data collection, the protocol was approved by the University ethics committee, which included providing informed consent to each participant. The study consisted of two phases: a low-pressure pretest followed by a posttest under high pressure. These pressure-inducing methods are similar to, and have been used in, other choking-specific studies (see

Gröpel & Mesagno, 2017, for a review). Upon arrival, the participant completed the FHS and demographic questionnaires. The kicking task was then explained with the scoring method explicitly stated using a prepared set of instructions. Following a warm up, the pretest consisted of five practice kicks followed by 15 test kicks (five kicks from each of the three markers). The order of which angle participants took their kicks was randomized for each participant. The MRF-3 was administered after the first five test kicks. Following completion of the MRF-3, the participant completed the remaining 10 kicks. During the pretest, each participant was tested individually with only the second author (hereafter called researcher) present.

The posttest was identical to the pretest with the exception that the participant performed the kicking task under pressure. To induce pressure, a small audience consisting of teammates, a video camera, and a monetary incentive to increase competitiveness were used. Each participant was informed that five teammates would watch him complete the next 15 attempts. One teammate was positioned five meters (16.40 ft) in front of the marker simulating being “on the mark” in AF. The remaining teammates were positioned 10 meters (32.81 ft) either side of the kicker in his field of vision, which is the minimum distance players must stand away from a player having a set-shot in an AF match (see Figure 1). All observing teammates, including the person “on the mark” remained silent, as different levels of encouragement or criticism may affect performance. A video camera was set up on a tripod in front of the kicker, next to the teammate that was “on the mark”. Before commencing kicking, the researcher told the participant that the video camera was in place to analyze kicking mechanics and may be used in the university sport science class in the future (although no analysis took place and the video was deleted). The participant was also told that during this phase he was paired with an anonymous participant, and the highest combined total for the pair across the study would receive a \$100 (Australian dollars) gift card each. The participant was also informed that the other member of the pair had already completed this second set of kicks, and their pair was currently placed in the

top three, and it was “theirs to lose”. These pressure manipulations have been used previously and successfully to increase perception of pressure (e.g., Beckmann et al., 2013).

Similar to the pretest condition, each participant completed the first five kicks, then the MRF-3, and continued with the remaining 10 kicks during the posttest. After every participant had finished the posttest, the two participants who obtained the highest combined score for both low-pressure and high-pressure kicking tasks were awarded a \$100 gift card each. Following the completion of the testing phase, participants were fully debriefed and the small deceptions used in the study were explained with time given for any related questions.

To maintain control over external environmental factors, such as weather and ground conditions, and to decrease fatigue effects, each participant was tested on the same field with similar weather conditions over two separate days. Data collection only took place on days in which wind levels were below 20km/h (12.42 mi/h) and not raining, which was advised through consultation with two AF coaches to be conditions that would not affect kicking ability.

Results

Preliminary analyses

Demographic and psychological characteristics of left-handed and right-handed participants are presented in Table 1. Only two left-handed and one right-handed participant stated they had worked with a sport psychologist before. The groups did not differ in age, playing experience, or sport psychology training. A significant training amount difference was found, $t(31) = 2.31, p = .028$, Cohen’s $d = .84$, with the left-handed group training less than the right-handed group. Consequently, we controlled for training amount in the main analyses. The groups also differed significantly in pretest performance, $t(31) = 2.66, p = .012$, Cohen’s $d = .97$ with the right-handed participants performing better than the left-handed group (Table 1).

Insert Table 1 here

Pressure-inducing method

To test the effect of pressure induction, multiple 2×2 (Group $\times$ Phase) repeated measures ANOVAs were conducted using the cognitive and somatic anxiety scores. Neither the Group main effects nor the Group $\times$ Phase interactions were significant. A significant Phase main effect on somatic anxiety $F(1, 31) = 11.28, p = .002, \eta_p^2 = .27$ and cognitive anxiety $F(1, 31) = 4.39, p = .044, \eta_p^2 = .12$ occurred, indicating that participants exhibited higher somatic and cognitive anxiety in the posttest compared to the pretest condition. These results suggest that the pressure induction effectively increased participants' anxiety in both groups. Means and standard deviations are presented in Table 1.

Task performance

We applied a 2×2 (Group $\times$ Phase) repeated measures ANOVA on task performance with training amount as a covariate. The Group main effect was not significant, but the Group $\times$ Phase interaction approached significance, $F(1, 30) = 3.99, p = .055, \eta_p^2 = .12$. Subsequent simple effects analysis revealed that this interaction was due to a performance decline in the right-handed group that also approached significance, $t(19) = 2.05, p = .055$, Cohen's $d_z = .46$, whereas performance did not decline for the left-handed group, $t(12) = 0.78, p = .45$, Cohen's $d_z = .22$ (see Figure 2). The overall Phase main effect was significant, whereby performance worsened from 118.21 ($SD = 9.45$) in the pretest to 111.61 ($SD = 14.49$) in the posttest, $F(1, 30) = 6.91, p = .013, \eta_p^2 = .19$.

Insert Figure 2 here

Discussion

The aim of the current study was to investigate whether handedness may predispose athletes to choking; specifically, whether a greater choking response would be observed in right-handed, compared to left-handed, athletes in the execution of a familiar skill under pressure. The results indicated that differences may exist between handedness and the likelihood to experience choking. Testing for homogeneity between the groups, there were no significant differences in

terms of age, experience, sport psychology training, and highest level of football played. The one factor that was different between the groups was amount of training. When the amount of training was controlled for, the left-handed group minimally changed performance levels under pressure, while a larger reduction in performance was observed in the right-handed group under pressure.

Pressure-inducing method

It was first necessary to determine whether the pressure manipulations were effective in increasing participants' state anxiety. The results suggested that the combination of the pressure-inducing manipulation was an effective method to increase state anxiety in a sport-related task. These findings are consistent with other studies that have adopted similar pressure-inducing methods in choking-related research (cf. Gröpel & Mesagno, 2017) and lend support for the use of multiple pressure-inducing manipulations to produce changes in anxiety levels. Since the pressure manipulation increased state anxiety levels for both the right and left-handed participants, and the amount of increase was not significantly different between the groups enhanced the validity of these results, which allow performance scores to be interpreted with greater certainty.

The finding that the pressure manipulation increased state anxiety levels equally for the right and left-handed participants is an important finding. Research findings investigating state anxiety and handedness is somewhat equivocal. That is, some researchers have found that differences in anxiety levels between left- and right-handed participants exist (e.g., Wright & Hardie, 2012), while other researchers have been contradictory (e.g., Lyle, Chapman, & Hatton, 2013). For example, Wright and Hardie (2012) found left-handed people reported significantly higher scores on a state-anxiety measure, and Hardie and Wright (2014) reported higher left-handed scores on a behavioral avoidance measure, which was linked to state anxiety. One possible reason for the disparate findings during the current study is that these other studies (e.g., Hardie & Wright, 2014; Wright & Hardie, 2012) did not have explicit pressure. Although there has been

contention in the field of state anxiety and handedness, in our study both groups displayed an equivalent increase in anxiety in the high-pressure condition.

Task performance and handedness

The pattern of performance change was as expected with left-handed participants minimally changing performance under pressure while the right-handed group displayed drastic decreases in performance in the high-pressure condition, with the difference in scores between the groups approaching significance. This finding has relevance to the current literature because it indicates that handedness may influence individual's ability to perform under pressure.

These results may indirectly indicate a predisposed neurological pattern that favors left-handed athletes under pressure. This explanation comes from two research areas: brain activation patterns and self-focus model of choking. First, the brain activation pattern of left-handed individuals indicates that left-handed individuals demonstrate more bilateral brain activation with increased right hemispheric involvement than right-handed individuals who exhibit more left lateralized brain functioning (e.g., Beratis et al., 2013; Serrien, Sovijarvi-Spape, & Spape, 2012). Second, the direction of the difference in change in performance from low-pressure to high-pressure between the handedness groups could be explained through the self-focus models of choking. Left-handed individuals are more likely to learn a skill implicitly (Parish et al., 2013), which makes them less vulnerable than right-handed individuals to reinvest in declarative knowledge and consciously control skill execution (Masters & Maxwell, 2008), which helps prevent interference from the verbal-analytical centers of the left hemisphere (Buszard et al., 2016). The minimized performance decline for left-handed participants under pressure may be due to differences in lateralization, implying that left-handed athletes may have a neurological advantage over their right-handed counterparts when performing under pressure.

The research investigating choking has actively excluded left-handed participants (e.g., Beckmann et al., 2013; Cross-Villasana et al., 2015; Gröpel & Beckmann, 2017), but in the current

study, choking was monitored for both left and right-handed athletes. Willems et al. (2014) suggested that actively excluding left-handed participants from neurological studies reduced the ability for inferences to be made across the population. In sport, Willems et al.'s statement is especially relevant because left-handers are disproportionately overrepresented compared with the average population (Loffing & Hagemann, 2012). The overrepresentation of left-handed athletes in several sports is rarely disputed (Loffing & Hagemann, 2012), while the theories behind why there is an overrepresentation are the cause of much conjecture. One overrepresentation theory is the theory of frequency-dependent advantage (Loffing & Hagemann, 2012), which indicates that any disproportionate sporting prowess observed by left-handed athletes is due to an asymmetrical battle against a right-handed player who is often unpracticed in facing a left-handed opponent. Since the present study was not about overrepresentation in sport, but essentially performance under pressure, it does not necessarily challenge the frequency-dependent advantage theory nor offer an explanation for why left-handed athletes are overrepresented. Instead, this study lends indirect support for the innate superiority theory (see Grouios, 2004 for a review), which states that left-handed athletes have a natural, neurological (and attention-based) advantage due to their enlarged right-hemispheric brain regions. If extending the innate superiority theory of overrepresentation into performance under pressure research, we would argue the Reinvestment Theory (Masters & Maxwell, 2008) should be integrated into the explanation extending it from a "nature" based theory to a combined "nature-nurture" explanation. That is, left-handed athletes may be naturally gifted as explained through the innate superiority theory, but the implicit method in which they learn from coaches (considering their coaches are likely right-hand dominant) might help left-handed athletes reduce the amount of reinvestment in declarative knowledge and allows for more bilateral activation under pressure. The importance of the left-handed pattern of increased right hemisphere, inhibited left hemisphere, and bilateral activation in motor skill performance under pressure is supported (Crews & Landers, 1993; Deeny et al., 2003). Although this is largely

speculative and theoretically in its infancy, it encourages further research and testing especially through cortical activation technology.

Limitations and future research

Although the present study was carefully designed, some methodological limitations may have restricted results. One limitation was the lack of knowledge about the exact differences occurring within the brain of left and right-handed athletes while performing the kicking tasks. The present study design was based on EEG findings from choking and handedness studies, however, without the use of EEG technology it is impossible to determine which, if any, brain activation patterns were causing athletes to experience choking. Future research could explore EEG analyses and provide a detailed outline of differences occurring in the cortical activation of right and left-handed athletes when performing a specific sport task under pressure. Another limitation of the present study was the sample size. Various logistical issues at each club contributed to the sample size issue. Group numbers were consistent with many previous choking studies (e.g., Beckmann et al., 2013; Beseler et al., 2016), and handedness literature (e.g., Serrien et al., 2012). Replicating the present study with more participants to increase the power of the study may provide results that are more definitive. Finally, although we used a game-like situation (especially in the posttest), we did not include a defender at the goal line and asked spectators to remain silent during performance. This was largely because the presence of a defender and the crowd noise would distract participants rather than elevate anxiety. In future, researchers could replicate our findings in actual AF games that both pressurize and distract performers.

Conclusions

The purpose of the current study was to investigate if left-handed athletes are less likely to experience choking than their right-handed counterparts in a sporting context. This study demonstrated that left-handed athletes may be less susceptible to choking than right-handed athletes. Findings from the present study extends our research understanding of performance under

pressure to the potential advantage of left-handed athletes, and may aid in future intervention development to reduce the likelihood of choking.

What Does This Article Add?

Masters and Maxwell (2008) originally postulated the possibility of left-handed athletes' advantage under pressure when they asked the questions "Is it possible that right-handers are disadvantaged...? ... is it possible that left hand dominant performers are less likely to suffer interference from the left-hemisphere because the chain of command is in a sense less direct?" (p. 167). The current study seems to partially answer these questions with the result that although left-handed and right-handed athletes experience similar anxiety intensity, detrimental performance effects may occur more for right-handed, than left-handed, athletes. These findings begin to fill a significant gap in the choking literature, but only one-step to determining the potential left-handed athlete advantage in sport. It also provides further evidence for the self-focus model of choking (e.g., Beilock & Carr, 2001; Masters & Maxwell, 2008). An integral part of this theory is the role of brain lateralization as a key predictor in skill execution under pressure. We indirectly speculate that improved brain lateralization may be due to the method in which left-handed athletes implicitly learn skills since they live within a "right-handed dominant world" that encourages left-handed athletes to encode explicit rule-based knowledge differently than right-handed athletes. Future research may benefit from using advanced technology, such as EEG analysis, to gain a clearer understanding of what specific brain differences that contribute to performance under pressure variations between left- and right-handed athletes to answer Masters and Maxwell's questions more definitively.

References

- Beckmann, J., Gröpel, P., & Ehrlenspiel, F. (2013). Preventing motor skill failure through hemisphere-specific priming: Cases from choking under pressure. *Journal of Experimental Psychology: General*, *142*, 679-691. doi:10.1037/a0029852
- Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General*, *130*, 701–725. doi:10.1037/0096-3445.130.4.701
- Beratis, I. N., Rabavilas, A. D., Kyprianou, M., Papadimitriou, G. N., & Papageorgiou, C. (2013). Investigation of the link between higher order cognitive functions and handedness. *Journal of Clinical and Experimental Neuropsychology*, *35*, 393-403. doi:10.1080/13803395.2013.778231
- Beseler, B., Mesagno, C., Young, W., & Harvey, J. (2016). Igniting the pressure acclimatization training debate: Contradictory pilot-study evidence from Australian football. *Journal of Sport Behavior*, *39*, 22-38.
- Buszard, T., Farrow, D., Zhu, F. F., & Masters, R. S. W. (2016). The relationship between working memory capacity and cortical activity during performance of a novel motor task. *Psychology of Sport and Exercise*, *22*, 247-254. doi:10.1016/j.psychsport.2015.07.005
- Cherbuin, N., & Brinkman, C. (2006). Hemispheric interactions are different in left-handed individuals. *Neuropsychology*, *20*, 700–707. doi:10.1037/0894-4105.20.6.700
- Crews, D. J., & Landers, D. M. (1993). Electroencephalographic measures of attentional patterns prior to the golf putt. *Medicine & Science in Sports & Exercise*, *25*, 116–126. doi:10.1249/00005768-199301000-00016
- Cross-Villasana, F., Gröpel, P., Doppelmayr, M., & Beckmann, J. (2015). Unilateral left-hand contractions produce widespread depression of cortical activity after their execution. *PLoS One*, *10*(12), e0145867. doi:10.1371/journal.pone.0145867

- de Nooijer, J. A., van Gog, T., Paas, F., & Zwaan, R. A. (2013). When left is not right: Handedness effects on learning object-manipulation words using pictures with left- or right-handed first-person perspectives. *Psychological Science*, 24, 2515-2521.
doi:10.1177/0956797613498908
- Deeny, S. P., Hillman, C. H., Janelle, C. M., & Hatfield, B. D. (2003). Cortico-cortical communication and superior performance in skilled marksmen: An EEG coherence analysis. *Journal of Sport & Exercise Psychology*, 25, 188–204. doi:10.1123/jsep.25.2.188
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149-1160. doi:10.3758/BRM.41.4.1149
- Fitts, P., & Posner, M. (1967). *Human Performance*. Belmont, CA: Brooke/Cole.
- Gröpel, P., & Beckmann, J. (2017). A pre-performance routine to optimize competition performance in artistic gymnastics. *The Sport Psychologist*, 31, 199–207.
doi:10.1123/tsp.2016-0054
- Gröpel, P., & Mesagno, C. (2017). Choking interventions in sports: A systematic review. *International Review of Sport and Exercise Psychology*. Advance online publication.
doi:10.1080/1750984X.2017.1408134
- Grouios, G. (2004). Motoric dominance and sporting excellence: Training versus heredity. *Perceptual and Motor Skills*, 98, 53-66. doi:10.2466/pms.98.1.53-66.
- Hardie, S. M., & Wright, L. (2014). Differences between left- and right-handers in approach/avoidance motivation: Influence of consistency of handedness measures. *Frontiers in Psychology*, 5. doi:10.3389/fpsyg.2014.00134
- Hatfield, B. D., Costanzo, M. E., Goodman, R. N., Lo, L. C., Oh, H., Rietschel, J. C., & Haufler, A. (2013). The influence of social evaluation on cerebral cortical activity and motor performance: A study of “real-life” competition. *International Journal of*

- Psychophysiology*, 90, 240-249. doi:10.1016/j.ijpsycho.2013.08.002
- Hatfield, B. D., Landers, D. M., & Ray, W. J. (1984). Cognitive processes during self-paced motor performance: An electroencephalographic profile of skilled marksmen. *Journal of Sport Psychology*, 6, 42–59. doi:10.1123/jsp.6.1.42
- Kim, S. G., Ashe, J., Hendrich, K., Ellermann, J. M., Merkle, H., Ugurbil, K., & Georgopoulos, A. P. (1993). Functional magnetic resonance imaging of motor cortex: Hemispheric asymmetry and handedness. *Science*, 261, 615-617. doi:10.1126/science.8342027
- Krane, V. (1994). The mental readiness form as a measure of competitive state anxiety. *The Sport Psychologist*, 8, 189-189. doi:10.1123/tsp.8.2.189
- Loffing, F., & Hagemann, N. (2012). Side bias in human performance: A review on the left-handers' advantage in sports. In T. Dutta, M. Mandal, & S. Kumar (Eds.), *Bias in Human Behaviour* (pp. 163-182). Hauppauge, NY: Nova Science.
- Lyle, K. B., Chapman, L. K., & Hatton, J. M. (2013). Is handedness related to anxiety? New answers to an old question. *Laterality: Asymmetries of Body, Brain and Cognition*, 18, 520-535. doi:10.1080/1357650X.2013.783044
- Martens, R., Burton, D., Vealey, R. S., Bump, L. A., & Smith, D. E. (1990). Development and validation of the CSAI-2. In R. Martens, R. S. Vealey, & D. Burton (Eds.), *Competitive anxiety in sport* (pp. 117-190). Champaign, IL: Human Kinetics.
- Masters, R., & Maxwell, J. (2008). The Theory of Reinvestment. *International Review of Sport and Exercise Psychology*, 1, 160-183. doi:10.1080/17509840802287218
- Mesagno, C., Geukes, K., & Larkin, P. (2015). Choking under pressure: A review of current debates, literature, and interventions. In S. Mellalieu & S. Hanton (Eds.), *Contemporary Advances in Sport Psychology* (pp. 148-170). London: Routledge.
- Mesagno, C., & Hill, D. M. (2013). Definition of choking in sport: Re-conceptualization and debate. *International Journal of Sport Psychology*, 44, 267-277.

doi:0.7352/IJSP2013.44.267

- Mullen, R., Hardy, L., & Tattersall, A. (2005). The effect of anxiety on motor performance: A test of the conscious processing hypothesis. *Journal of Sport & Exercise Psychology*, 27, 212-225. doi:10.1123/jsep.27.2.212
- Nicholls, M. E., Thomas, N. A., Loetscher, T., & Grimshaw, G. M. (2013). The Flinders Handedness survey (FLANDERS): A brief measure of skilled hand preference. *Cortex*, 49, 2914-2926. doi:10.1016/j.cortex.2013.02.002
- Parish, A., Dwelly, P., Baghurst, T., & Lirgg, C. (2013). Effect of handedness on gross motor skill acquisition in a novel sports skill task. *Perceptual and Motor Skills*, 117, 449-456. doi:10.2466/25.30.PMS.117x18z8
- Serrien, D. J., Sovijarvi-Spape, M. M., & Farnsworth, B. (2012). Bimanual control processes and the role of handedness. *Neuropsychology*, 26, 802-807. doi:10.1037/a0030154
- Solodkin, A., Hlustik, P., Noll, D., & Small, S. (2001). Lateralisation of motor circuits and handedness during finger movements. *European Journal of Neurology*, 8, 425-434. doi:10.1046/j.1468-1331.2001.00242.x
- Willems, R. M., Van der Haegen, L., Fisher, S. E., & Francks, C. (2014). On the other hand: Including left-handers in cognitive neuroscience and neurogenetics. *Nature Reviews Neuroscience*, 15, 193-201. doi:10.1038/nrn3679
- Witelson, S. F. (1985). The brain connection: The corpus callosum is larger in left-handers. *Science*, 229, 665-668. doi:10.1126/science.4023705
- Woo, M., Kim, J., Ko, E., & Kwon, E. (2014). The influence of stress on shooting performance and cortico-cortical communication: An EEG coherence analysis. *Personality and Individual Differences*, 60, 65-73. doi:10.1016/j.paid.2013.07.328
- Wright, L., & Hardie, S. (2012). Are left-handers really more anxious? *Laterality: Asymmetries of Body, Brain and Cognition*, 17, 629-642. doi:10.1080/1357650x.2011.615126

Table 1
Description of the study groups

	Left-Handed (<i>n</i> = 13)	Right-Handed (<i>n</i> = 20)	<i>t</i> -test
Age (years)	25.46 ± 2.33	23.85 ± 4.28	1.24
Experience (years)	13.00 ± 2.86	12.65 ± 3.18	0.32
Training per week	1.77 ± 0.73	2.45 ± 0.89	2.31*
Somatic Anxiety (Pretest)	21.73 ± 16.52	26.75 ± 19.49	0.77
Somatic Anxiety (Posttest)	37.85 ± 20.36	38.80 ± 21.85	0.13
Cognitive Anxiety (Pretest)	17.31 ± 15.83	22.95 ± 15.86	1.00
Cognitive Anxiety (Posttest)	24.65 ± 13.74	30.55 ± 19.83	0.93
Performance (Pretest)	113.23 ± 7.42	121.45 ± 9.36	2.66*
Performance (Posttest)	111.31 ± 10.16	111.80 ± 16.98	0.09

Note. Data are presented as mean ± standard deviation; **p* < .05

Figure 2. Mean performance of left-handed and right-handed groups in the pretest and the posttest (*Ms* are adjusted with training amount as a covariate).