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Preventing Motor Skill Failure Through Hemisphere-Specific Priming: Cases From Choking Under Pressure

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When well-learned motor skills fail, such as when elderly persons fall or when athletes "choke under pressure," it is assumed that attention is directed toward the execution of the action. Research findings suggest that this controlled execution and subsequent inferior performance depend on a dominant left-hemispheric activation. In a series of 3 experiments, we tested whether increasing right-hemispheric activation by the use of hemisphere-specific priming extenuates motor skill failure. We compared the performances of a sample of experienced athletes in different sports (soccer, tae kwon do, and badminton) in a pressure-free situation with that performed under pressure. As expected, the hemisphere-specific priming extenuated a performance decrease after pressure induction when compared with a control condition. The results suggest that hemisphere-specific priming may prevent motor skill failure. It is argued that this hemispheric priming should be task dependent and can be understood as a functional regulation of the activation in the hemispheres.

Keywords: choking under pressure, hemisphere-specific priming, sport, skilled performance, motor skill failure

Although over the course of learning, the execution of motor skills becomes more effortless and automatic, well-learned skills sometimes break down. This may be caused by more physiological circumstances, such as after a stroke, or by more psychological circumstances such as performing in a sport competition. Why does this failure occur and how can we prevent it? Empirical evidence indicates that a performer's attention toward a movement execution—whether after a stroke or under pressure—is responsible for the inferior performance, as it engenders conscious control of performance, which disrupts the automatic nature of the movement execution. Persons after a stroke and patients with Parkinson's disease have been shown to have a higher propensity to consciously monitor their movements and to more readily "reinvest" (Masters, 1992) explicit knowledge about the movement compared with control (Masters, Pall, MacMahon, & Eves, 2007; Orrell, Masters, & Eves, 2009). Moreover, they benefited from an attention instruction that directs the focus away from movement execution (Wulf, Landers, Lewthwaite, & Töllner, 2009). Also, despite general difficulties in performing a cognitive task during walking, elderly persons showed more stable walking patterns when confronted with a simple cognitive task, diverting their focus of attention from movement execution (Huxhold, Li, Schmiedeck, & Lindenberger, 2006; Verrel, Lovden, Schellenbach, Schaefer, & Lindenberger, 2009). Still, most evidence concerning the detrimental effects of consciously monitoring one's movement execution comes from the examination of motor skills under psychological pressure (e.g., Baumeister, 1984; Beilock & Carr, 2001; Liao & Masters, 2002). In the present article, we aimed to extend the previous explanation of motor skill failure through conscious processing by considering underlying brain processes that are based on existing neurophysiological research. Inadequate hemispheric activation is assumed to play a crucial role. We draw implications and test them by the use of hemisphere-specific priming in a series of experimental settings.

Choking Under Pressure and Attentional Theories

A soccer player has practiced the penalty shot a thousand times until it has become completely automated, but when shooting the penalty shot that could decide the world championship, it goes wide. Such situations are often called *choking under pressure* (referred to hereafter simply as *choking*), a metaphorical expression that describes performance decrements under pressure conditions despite individual striving to perform well (Baumeister, 1984). *Pressure* has been defined as any factor or combination of factors that increases the importance of optimal or superior performance and includes competition, the presence of audience, reward or punishment contingency, and ego relevance (Baumeister & Showers, 1986). In addition, a given performance can be labeled choking only if it is obvious that the performer could have done better and that the performer had the intention to do better. A missed penalty shot by a novice, therefore, does not qualify as

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choking, whereas a shot going wide as taken by a skilled professional does.

Attentional theories assume that performance changes under pressure are due to altered cognitive processes. Two main views exist, distraction and self-focus, which overlap to some degree (Ehrlenspiel, 2006). The *distraction theories* propose that actors under pressure do not focus their attention on task-relevant stimuli. Obviously, if the soccer player cannot focus on where to shoot, he will probably miss the goal. The *self-focus theories* assume that performers under pressure turn their attentional focus inward. Regarding motor skill failure, the self-focus theories are the more widely supported of the two choking views (Mesagno & Mullane-Grant, 2010); however, both explanations are still relevant (Beilock, Kulp, Holt, & Carr, 2004).

Within the self-focus approach, Baumeister (1984) first proposed that pressure increases conscious attention on the process of performance and that this in turn disrupts the automatic or overlearned nature of its execution. This idea is reflected in the explicit monitoring approach (Beilock & Carr, 2001), which links decreased performance under pressure to an increase in attention paid to a well-learned skill and its step-by-step execution. Most evidence for the detrimental effects of explicit monitoring comes from studies in which participants did not choke, either because they were adapted to self-monitoring (e.g., Lewis & Linder, 1997) or because self-monitoring under pressure was inhibited by directing attention to a distractor task (e.g., Beilock & Carr, 2001). More directly, Masters (1992) showed that participants who had acquired declarative knowledge about a task choked when they performed it under pressure, whereas participants who had learned the task implicitly did not choke. Masters postulated a "reinvestment hypothesis," assuming that explicit monitoring results in reinvestment of explicit knowledge that is not available after implicit learning (see also Hardy, Mullen, & Jones, 1996). Further evidence for explicit monitoring under pressure comes from studies showing that actors apply more perceptually guided "closed-loop" control than pre-programmed "open-loop" control (Ehrlenspiel, Wei, & Sternad, 2010; Vickers & Williams, 2007).

The Acquisition of Motor Behavior and Its Breakdown

According to Fitts and Posner (1967), the acquisition of motor behavior passes through three phases: cognitive, associative, and autonomous. The cognitive phase involves cognitive (mostly verbal) representations of a motor action that help a performer develop a mental image of the action and provide a fuller understanding of the required execution process. During the associative phase, the performer physically practices the execution of the action learned in the cognitive phase and thus associates the cognitive representations with behavioral experiences. Finally, in the autonomous phase, the performer learns to carry out the action with little conscious effort. A conscious verbal representation of the movement is usually no longer present. Hence, there is no need to think about what to do. But what happens if one does?

With regard to the model of Fitts and Posner (1967), in such a case the performer regresses to the early cognitive acquisition phase, with motor behavior consciously organized through verbal representations. However, conscious control interferes with the automatic execution of that behavior (Baumeister, 1984; Beilock & Carr, 2001; Deeny, Hillman, Janelle, & Hatfield, 2003; Hatfield, Haufler, Hung, & Spalding, 2004), which may lead to its breakdown. This finding was supported in an experimental study performed by Hossner and Ehrlenspiel (2010), who asked experienced basketball players to focus on verbally marked parts of a basketball free throw. They found that when participants focused on these so-called nodal points in the motion sequence, muscular activation in these parts of the motion sequence increased overproportionally. This activation interrupted the flow of motor behavior and resulted in increased kinematic variability, leading to poorer performance compared with a condition in which the participants were instructed to think "just shoot."

Hemispheric Asymmetries and Skilled Performance

Prior research has found brain-activation patterns that are in accord with the assumed phases. During the learning of a novel motor task, there is increased prefrontal activity (e.g., Doyon & Ungerleider, 2002; Lacourse, Orr, Cramer, & Cohen, 2005; van Mier, Tempel, Perlmutter, Raichle, & Petersen, 1998), and it appears that especially left temporal regions, including language centers, are also involved (Deeny et al., 2003; Springer & Deutsch, 1998). Zhu and colleagues (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011), for example, found that providing learners with explicit knowledge about task performance (here, golf-putting) led to a stronger coactivation of motor regions and of (left-hemispheric) verbal-analytical regions in the brain, especially under pressure. With practice time, prefrontal activation decreases and control passes to the parietal cortex (van Mier et al., 1998) and the basal ganglia (Doyon, Penhune, & Ungerleider, 2003; Lacourse et al., 2005; Penhune & Doyon, 2002). The left hemisphere becomes less active (Landers et al., 1994), and visual-spatial processes located in the right hemisphere become more dominant (Salazar et al., 1990).

A large amount of research evidence suggests that fronto-temoral areas of the left hemisphere are involved in initiating a skilled motor behavior, but these areas become inhibited (or suppressed) after starting the behavior. This inhibition appears to remain until the end of the performance (e.g., Crews & Landers, 1993; Hatfield et al., 2004; Hatfield, Landers, & Ray, 1984; Hillman, Apparies, Janelle, & Hatfield, 2000; Salazar et al., 1990). Hatfield and colleagues (1984), for example, examined hemispheric activation among elite marksmen. As shooters prepared to fire a rifle, a shift occurred from predominantly left- to right-hemispheric activation. Similar hemispheric patterns have also been observed among elite archers (Salazar et al., 1990) and golfers (Crews & Landers, 1993). Left-hemispheric inhibition was stronger in experts than in lesser skilled individuals (Deeny et al., 2003; Haufler, Spalding, Santa Maria, & Hatfield, 2000), which supports the notion of Fitts and Posner (1967) that individuals do not need to control the execution of a task consciously after it has become automated.

Moreover, a stronger left-hemispheric inhibition was associated with better performance (Crews, 2004; Kerick, Douglass, & Hatfield, 2004; Landers et al., 1994). For example, Crews (2004) studied experienced golfers and found that high activation of the left hemisphere predicted inferior hit accuracy during golf putting, whereas left-hemispheric inhibition predicted better performance. Similar results have been observed in clinical research among patients with deficiencies in the fronto-temporal lobe of the left hemisphere. These deficiencies (i.e., left-hemispheric inhibition) were correlated with superior performance in automated behaviors such as those used when painting and performing music (Gordon, 2005; Miller, Boone, Cummings, Read, & Mishkin, 2000; Miller et al., 1998).

In addition, activation in the right hemisphere has been associated with skilled performance (e.g., Hatfield et al., 1984; Hillman et al., 2000; Salazar et al., 1990). Activation in the right central, temporal, and parietal regions has been linked to visual-spatial processing (Sperry, 1973) and holistic organization of motor task execution (cf. Hellige, 1993; Hughdahl & Davidson, 2003), which most motor activities depend on (Blaxton, 1996). Rebert and Low (1978) and Rebert, Low, and Larsen (1984) found increased activity in the right hemisphere during the performance of complex visuomotor tasks (i.e., playing the video game Pong). Moreover, increasing right-hemispheric activity via neurofeedback training resulted in significant improvement in motor performance among pre-elite archers, whereas an increase in left-hemispheric activity provided the opposite results (Landers, Petruzzello, Salazar, & Crews, 1991).

In sum, these studies provide evidence that for a skilled performance, left-hemispheric activity should be reduced and right-hemispheric activity enhanced. However, inferior performance among skilled individuals has been associated with higher left-hemispheric activation (Crews, 2004; Salazar et al., 1990). It can be argued that this disadvantageous hemispheric asymmetry reflects a regression to the cognitive phase of motor learning, which occurs under pressure and, in turn, produces choking. Pressure engenders the desire to perform well, which directs attention inward in order to consciously monitor the execution of a motor action (Baumeister, 1984; Beilock & Carr, 2001). Directing attention toward one's own motion has been associated with the activation of Broca's region (Binkofski et al., 2000), which is involved in language production (Hellige, 1993; Liberman, 1996). Accordingly, Beilock and Carr (2001) found that in a golf task that required attention to execution ("funny putter"), experts reported more generic and more episodic knowledge, compared with a regular task and compared with novices (see also Beilock, Wierenga, & Carr, 2002). Hence, verbal representations of the action, as acquired during the cognitive phase, are turned on. This results in increased involvement of cognition with motor processes (Deeny et al., 2003; Zhu et al., 2011), which disrupts the automatic execution of a skilled behavior, leading to its breakdown. For example, experienced golfers who were instructed to focus on verbal step-by-step cues when putting showed performance decrements under pressure, whereas golfers focusing on task-irrelevant verbal cues showed improvements (Gucciardi & Dimmock, 2008).

Although this logic implies that a specific brain-activation pattern may be linked to choking, it also suggests possibilities for prevention. Inhibiting the activity of the left hemisphere or enhancing the activity of the right hemisphere may prevent choking. Indeed, Snyder et al. (2003) found performance enhancement after they inhibited the left fronto-temporal lobe by using transcranial magnetic stimulation. Similarly, activating the right hemisphere via neurofeedback facilitated performance (Landers et al., 1991). In the present research, we induced an increase in right-hemispheric activation to test whether the increased activation eliminates performance decrements under pressure. Instead of using technical equipment, we applied hemisphere-specific priming, as described in the next section.

Hemisphere-Specific Priming

Priming is usually described as facilitation in stimulus processing induced by prior exposure to a related stimulus (Morton, 1969). The contemporary study of priming has focused on the phenomenon whereby a prior presentation of a stimulus, usually a word or a picture, facilitates subsequent processing of that stimulus or a related stimulus. Regarding the two brain hemispheres, Hellige (1993) proposes that imposing concurrent activity that selectively activates one hemisphere creates an advantage for the performance of an activity that relies on the functions of that hemisphere. This is referred to as *hemisphere-specific priming*.

The upper limbs are exclusively connected to the cross-lateral brain hemispheres. A number of studies show that unilateral muscle contractions activate the contralateral brain hemispheres and the functions associated with them (e.g., Baumann, Kuhl, & Kazén, 2005; Goldstein, Revivo, Kreitler, & Metuki, 2010; Kim, Ashe, Hendrich, & Ellermann, 1993; Martin & Shrira, 2001; Peterson, Shackman, & Harmon-Jones, 2008; Schiff, Guirguis, Kenwood, & Herman, 1998; Schiff & Lamon, 1994). Kim and colleagues (1993), for example, tested hemispheric asymmetry in the functional activation of the motor cortex during contralateral and ipsilateral finger movements by using functional magnetic resonance imaging. They found significant right-hemispheric activation during contralateral finger movements when compared with ipsilateral movements. The effect of right-hand finger movements on left-hemispheric activation was similar but weaker. Schiff et al. (1998) increased left-hemispheric activation by unilateral muscle contractions in the right hand (i.e., squeezing a soft ball). They found that persistence in attempting to solve unsolvable problems was greater after left-hemispheric priming. Baumann et al. (2005) have used this technique to test the assumption that self-infiltration, a false self-ascription of assigned goals, can be reduced by activation of the right hemisphere. They found that left-hand muscle contractions activated right-hemispheric processing, as validated by a line bisection task, and protected participants from falsely attributing assigned goals as self-selected in memory, whereas right-hand muscle contractions did not. Similarly, Goldstein et al. (2010) found that contracting the left hand resulted in enhanced right-hemispheric activation as indicated by better performance on a creative thinking task. Peterson et al. (2008) examined the effect of the left- and right-hand contractions on asymmetrical electroencephalographic (EEG) activity. They found a greater relative left activation during the right-hand contractions and a greater relative right activation during the left-hand contractions.

The ball-squeezing task does not allow precise regional specification of hemispheric activation. Nevertheless, the findings of widely spreading activation and interaction among systems cited earlier suggest that this simple manipulation may be used for hemisphere-specific priming. Squeezing a soft ball with the left hand prior to the execution of a skilled motor task should thus enhance right-hemispheric activation, thereby helping the visuospatial processes needed for successful performance to dominate. Enhancing right-hemispheric activation may additionally suppress left-hemispheric activation, thereby reducing verbal-analytic processing within the left hemisphere activated through pressure (cf. Kuhl, 2001). Hence, although performance pressure may stimulate dominant left-hemispheric activation, which increases the risk of decrements in skilled performance, activating the right hemisphere may eliminate left hemisphere dominance and, in turn, prevent choking. Accordingly, we hypothesize that squeezing the left hand before performing a skilled motor task under pressure will eliminate performance decrements in this task.

The Present Research

We tested this hypothesis in a series of three experiments. As Baumeister and Showers (1986) argue, one can only speak of choking if the performer has already established a certain standard of performance and, hence, could have done better. Therefore, we focused on skilled motor performance in sports in a sample of well-trained athletes. The motor performance included penalty shots in soccer (Experiments 1), a compilation of kicks in tae kwon do (Experiment 2), and serves in badminton (Experiment 3). Each experiment consisted of a pretest pressure-free phase followed by one or two test phases under pressure. The induction of pressure included combinations of features such as competition, the presence of an audience, ego relevance, and reward contingency (cf. Baumeister & Showers, 1986). In addition, self-focus instructions adopted from Liao and Masters (2002) were used. In Experiments 1 and 2, we compared the performance under pressure with the baseline (as obtained in the pressure-free phase) and examined the effect of hemisphere-specific priming under pressure conditions. In Experiment 3, which consisted of two test phases under pressure, we first examined the main effect of pressure on performance (i.e., the occurrence of choking), and then used hemisphere-specific priming to test its effect.

Experiment 1

In Experiment 1, we sought to address the impact of hemisphere-specific priming on shooting performance in soccer under pressure circumstances. We let experienced soccer players compete in penalty shots and measured the accuracy of the shots made as a dependent variable. They made six penalty shots in a pressure-free situation (i.e., pre-pressure) and another six shots after pressure induction (i.e., post-pressure). Half the players squeezed a soft ball in their left hand before the second six shots were performed (i.e., left-hand squeezing condition); the other half squeezed the ball by using the right hand (i.e., right-hand squeezing condition). We chose right-hand squeezing as the control condition because recent research showed that performing simple behavioral steps prior to task execution under pressure reduces choking by optimizing concentration (Mesagno & Mullane-Grant, 2010). Comparing the experimental condition with no-hand squeezing might therefore confound the interpretation of assumed benefits of left-hand squeezing, as we would not be able to decide whether reduced choking occurred because of enhanced activation of the right hemisphere or because of optimized concentration. As a cover story, we told participants that we were investigating the effect of concentration on shot accuracy and that the hand squeezing represents an easy exercise to facilitate it. In truth, however, we examined whether the participants who squeezed their left hand differed from those who squeezed their right hand in shot accuracy post-pressure when compared with the pre-pressure phase.

Method

Participants. Thirty semiprofessional male soccer players participated voluntarily in the experiment. They were experienced active players who participated regularly in competitions. As indicated by the Edinburgh Handedness Inventory (Oldfield, 1971), one participant was left-handed, and his data were therefore removed from the analyses. The final sample consisted of 29 right-handed participants with a mean age of 24.3 years (range = 20–28 years). Their mean laterality quotient was +89.6 (range = +60–+100).

Task and apparatus. The participants' task was to shoot a soccer ball from the standard indoor soccer penalty distance (i.e., 6 m; Fédération Internationale de Football Association, 2010) into either of two holes of a goal wall. The goal wall (270 × 188 cm) is commercially available training equipment that is composed of four wall elements (135 × 94 cm each), two of which contain goal shot holes, each 50 cm in diameter. Athletes were instructed to make six penalty shots, three shots into the lower right hole, followed by three shots into the upper left hole. Their performance was measured by scoring each shot on a 6-point scale: 6 for a clean shot in, 5 for rim-and-in, 4 for rim-and-out, 3 for a shot in the surrounding wall element, 2 for a shot in the goal wall (other than in the surrounding wall element), and 1 for a complete miss. A similar scale was used by Hardy and Parfitt (1991) to assess the quality of basketball shots.

Instruments. Two self-report scales were used. First, we administered the German adaptation of the Edinburgh Handedness Inventory (Oldfield, 1971) to assess participants' handedness. The scale consists of 10 items related to the use of the hands, such as writing, drawing, throwing, or using scissors. Laterality coefficients range from −100 to +100. Positive values indicate the tendency to right-handedness, whereas negative values indicate the tendency to left-handedness. A person is considered to be right-handed when his or her value is higher than +50. Good validity and reliability of the scale has been established previously (Oldfield, 1971). In the present research, Cronbach's alpha was .89.

Second, to measure the participants' level of perceived pressure, we recorded competitive state anxiety using the Wettkampfangst-Inventar-State (WAI-S; Ehrlenspiel, Brand, & Graf, 2009). The WAI-S is the only published German instrument based on the multidimensional model of competitive state anxiety by Martens (Martens, Vealey, & Burton, 1990). Similar to the Competitive State Anxiety Inventory-2 (Martens, Burton, Vealey, Bump, & Smith, 1990), which has often been used to check the effectiveness of pressure induction (cf. Liao & Masters, 2002), it consists of three subscales with four items each that have to be answered on a 4-point scale (1 = *not at all*, 4 = *very much so*): somatic state anxiety; cognitive state anxiety; and, as a positive component, self-confidence. We used only the somatic and the cognitive subscales for the analyses because they represent the central aspects of anxiety. The WAI-S has sufficient internal consistency ranging from Cronbach's $\alpha = .72$ for cognitive state anxiety to $\alpha = .88$ for somatic state anxiety; its validity has also been well established (Ehrlenspiel et al., 2009; Strahler, Ehrlenspiel, Heene, & Brand, 2010). In the present research, internal consistency satisfied traditional standards (Cronbach's $\alpha > .73$).

Procedure. The experiment was performed in the auditorium of the Faculty of Sport Science. The auditorium contains a large stage where various events. such as exams in synchronized dancing, are organized. We set up a goal wall on the stage. Upon arrival in the auditorium, participants completed the Edinburgh Handedness Inventory (Oldfield, 1971) and warmed up. Thereafter, we called participants to the goal wall and tested their baseline performance (i.e., the pre-pressure phase). Each participant completed the WAI-S for the first time and then performed two practice shots (one for each goal hole), followed by six test shots (three shots into the lower right hole followed by three shots into the upper left hole). There were no persons present in the auditorium except the researcher, his assistant, and the participants.

The test phase was performed the next day starting at approximately the same time as the pre-pressure phase had (i.e., late afternoon). After all participants appeared and warmed up, pressure was induced. Participants were randomly arranged into two teams and told to compete against each other in a penalty shootout. We told them that the team that scores more goals[1] wins and would be rewarded with small gifts (e.g., energy drinks). As in the pre-pressure phase, all participants performed six shots. To enhance the pressure, the teams performed the task on a rotating basis; after a player from one team finished his six shots, the task changed to a player from the rival team. Moreover, the players performed their shots in the presence of a large audience. The shoot-out started about 1 hr before an international soccer match between Germany and Austria (UEFA EURO 2008 cup) was going to be telecast in the auditorium. At this time, the auditorium was already completely filled with people (approximately 300 students) waiting for the match. In addition, participants were specifically instructed to be aware of what they were doing and to pay close attention to their shooting technique (cf. Liao & Masters, 2002).

After the instructions, the competition started. Each participant completed the WAI-S for the second time. Immediately prior to his turn, the participant squeezed a soft ball for about 30 s. On a random basis, half the players squeezed the ball with their left hand (i.e., *left-hand squeezing condition*), whereas the other half used their right hand (i.e., *right-hand squeezing condition*). Although we did not provide spectators with any instructions, the audience spontaneously began to support participants with applause, whistling, trumpets, and Mexican waves. After all players had performed their shots, the competition was evaluated and the winning team rewarded. Participants were then debriefed and thanked for their participation.

Results

Pressure induction. We examined the data by using analysis of variance (ANOVA) with repeated measures. Effect sizes (*f*) are reported for all analyses.[2] As shown in Table 1, participants exhibited higher somatic anxiety after pressure induction than they did in the pressure-free phase, $F(1, 28) = 16.87, p < .001, f = .78$. Cognitive anxiety increased as well, $F(1, 28) = 7.40, p < .05, f = .51$. The right-hand and left-hand squeezing groups did not differ from each other in the anxiety levels in either the pre-pressure or post-pressure phase. These results suggest that the pressure induction effectively increased the participants' anxiety in both groups.

Table 1
Means (and Standard Deviations) of Cognitive and Somatic Anxiety Scores Pre- and Post-Pressure: Experiment 1

	Cognitive anxiety		Somatic anxiety	
Condition	Pre	Post	Pre	Post
Left-hand squeezing	6.43 (1.09)	7.21 (1.67)	6.14 (1.83)	7.86 (2.45)
Right-hand squeezing	6.73 (1.58)	7.33 (1.49)	6.33 (1.72)	8.20 (2.11)

Task performance. We conducted a 2 × 2 (Group × Phase) repeated measures ANOVA to examine the performance scores in both groups over the two phases. The overall performance significantly decreased after pressure induction ($M = 23.72$, $SD = 2.62$) when compared with the pre-pressure phase ($M = 24.96$, $SD = 2.95$), $F(1, 27) = 6.54, p < .05, f = .49$. Moreover, there was a significant Group × Phase interaction, $F(1, 27) = 5.15, p < .05, f = .44$. The right-hand squeezing group reduced their performance post-pressure significantly more than the left-hand squeezing group had (see Table 2). Subsequent simple main effects analysis indicated no group differences pre-pressure, $F(1, 27) = 1.45, p = .24, f = .23$, but a significant group difference post-pressure, $F(1, 27) = 27.50, p < .001, f = 1.01$. This difference was due to a significant performance decrement in the right-hand squeezing group post-pressure, $F(1, 14) = 8.67, p < .02, f = .79$, but no performance change in the left-hand squeezing group, $F(1, 13) = 0.07, p = .80, f = .07$.

Discussion

Experiment 1 provided initial evidence that the increase of right-hemispheric activity through squeezing of the left hand may eliminate performance decrements under pressure. In the presence of situational pressure and enhanced self-focus, participants who squeezed their left hand showed relatively stable performance, whereas those who squeezed their right hand choked. The effect obtained was strong. An interesting question is whether this effect can be extended to different motor behaviors. Experiment 2 was designed to answer this question.

Experiment 2

In Experiment 2, we sought to extend the results of Experiments 1 by using different settings. We used different methods to induce pressure and self-focused attention than we did in the first experiment. We also chose a different motor task. We asked a sample of experienced tae kwon do athletes to kick a sandbag as fast and accurately as they could. They made five simple kicks followed by five 3-kick combinations in a pressure-free situation and performed the identical task under pressure. The pressure was induced by increasing ego relevance. We set up a video camera and told athletes that their performance would be evaluated. Videotaping has been previously found to successfully enhance self-focused attention (e.g., Beilock et al., 2004; Lewis & Linder, 1997) and pressure (e.g., Beilock & Carr, 2005; Jackson, Ashford, & Norsworthy, 2006) and has, in fact, been argued to induce a

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[1] Goals were used for the evaluation of the shoot-out competition only. For the data analyses, we scored each shot with the 6-point scale described earlier.

[2] By convention, *f* effect sizes of 0.10, 0.25, and 0.40 are small, medium, and large, respectively (Cohen, 1988).

Table 2

Means (and Standard Devations) of Performance Scores and Differences: Experiment 1

Condition	Pre-pressure	Post-pressure	Difference
Left-hand squeezing	25.64 (2.62)	25.50 (1.51)	−0.14
Right-hand squeezing	24.33 (3.18)	21.93 (2.09)	−2.40

Note. Positive difference values indicate a performance increase from pre-pressure to post-pressure, whereas negative values indicate a performance decrease.

"monitoring-pressure"situation (DeCaro, Thomas, Albert, & Beilock, 2011). In addition, participants were instructed to pay close attention to their kicking technique (cf. Liao & Masters, 2002). As in Experiment 1, half the athletes squeezed a soft ball with their left hand just before the kicks were performed under pressure; the other half squeezed the ball with their right hand. We examined whether or not athletes who squeezed their left hand would differ in kick accuracy from athletes who squeezed their right hand under pressure when compared with the pre-pressure performance. The former group was expected to show stable performance, whereas the latter was expected to choke.

Method

Participants. Twenty participants (six women and 14 men) who had reached at least the seventh rank (i.e., the red belt or 2nd kup) in the tae kwon do belt-ranking system were recruited from around the Bavarian Taekwondo Association. All of them were nationally or internationally experienced athletes. As indicated by the Edinburgh Handedness Inventory (Oldfield, 1971), one participant (male) was left-handed and therefore eliminated from analyses. The final sample consisted of 19 right-handed participants with a mean age of 15.6 years (range = 13–23 years). Their mean laterality quotient was +87.4 (range = +50−+100).

Task and apparatus. The participants' task was to kick a sandbag with five "Bandal-chagi" kicks (i.e., front crescent kick) followed by five 3-kick combinations consisting of double "Bandal-chagi" (involving both feet) and "Dwit-chagi" (i.e., reverse turning kick) as fast and accurately as possible. All participants were highly experienced with the task. The participants' performance was defined in terms of the accuracy of the kicks performed. A tae kwon do vest that defines zones where a kick must be hit to award it a point was fixed on the sandbag. Participants were videotaped from the right side of the performer. The video camera did not hinder participants in performing the task. Three independent experts (professional referees) who were not aware of the experimental condition rated the kicks performed by participants according to tae kwon do competition rules. A kick was awarded 1 point when at least two experts recognized it as a hit. In addition to accuracy, we also measured the time needed to complete the task to control for a participant's engagement.

Procedure. The experiment was performed at the Olympic training center in Dachau, Germany. Upon arrival at the training center, participants completed the Edinburgh Handedness Inventory (see Experiment 1), warmed up, and began an easy practice. During the practice, we called participants to the sandbag individually and tested their pre-pressure performance. Each participant completed the WAI-S (see Experiment 1) and then performed the kicks. Although a video camera was set up, we did not stress its importance. After the pre-pressure performance of all participants was obtained, they finished the practice and moved to the test phase. We told participants that we were going to test their kicking technique and that each individual's performance would be videotaped and evaluated by their coach. We further instructed them that it was important to perform well. Therefore, they would have to complete a half-minute pre-performance routine prior to beginning the kicks. The routine consisted of squeezing a soft ball in their hand while closing their eyes and imagining the mechanics of their kicking process. After the instructions, the testing started. Each participant completed the WAI-S and the pre-performance routine immediately before his or her turn. On a random basis, half the participants squeezed the ball with their left hand (i.e., left-hand squeezing condition), the other half with their right hand (i.e., right-hand squeezing condition). Using a stopwatch, we instructed each participant to start the kicks after the pre-performance routine time (i.e., 30 s) was up. He or she then performed the kicks while others watched. After all participants had performed the kicks, they were debriefed and thanked for their participation.

Results

Pressure induction. As shown in Table 3, participants exhibited marginally higher somatic anxiety after pressure induction than in the pressure-free phase, $F(1, 18) = 3.74$, $p = .07$, $f = .46$. Cognitive anxiety was not affected by pressure induction, $F(1, 18) = .16$, $p = .70$, $f = .10$. The right-hand and left-hand squeezing groups did not differ from each other in anxiety levels in either the pre-pressure or the post-pressure phase. Hence, the pressure induction only marginally increased the level of somatic anxiety.

Task duration. We conducted a 2 × 2 (Group × Phase) repeated measures ANOVA to examine the duration of the task execution in both groups over the two phases. The analysis revealed a significant main effect of phase, $F(1, 17) = 3.23$, $p = .09$, $f = .44$, but no interaction, $F(1, 17) = 0.18$, $p = .68$, $f = .10$. Hence, participants in both right-hand and left-hand squeezing groups performed somewhat faster post-pressure than pre-pressure (see Table 4). In addition, task duration was not correlated with performance either pre-pressure ($r = .07$, $p = .76$) or post-pressure ($r = .26$, $p = .29$). The results suggest that pressure marginally facilitated participants' engagement with the task in both groups, but the enhanced tempo was not detrimental to the kick accuracy.

Task performance. We applied a 2 × 2 (Group × Phase) repeated measures ANOVA on task performance, with right-hand squeezing versus left-hand squeezing condition as the between-subjects variable. The overall performance slightly decreased post-

Table 3

Means (and Standard Deviations) of Cognitive and Somatic Anxiety Scores Pre- and Post-Pressure: Experiment 2

	Cognitive anxiety		Somatic anxiety	
Condition	Pre	Post	Pre	Post
Left-hand squeezing	7.11 (2.37)	7.44 (2.51)	6.56 (2.35)	7.33 (2.83)
Right-hand squeezing	6.80 (1.48)	6.70 (1.34)	6.60 (1.35)	7.30 (1.95)

Table 4
Means (and Standard Deviations) of Task Duration (in Seconds), Performance Scores, and Differences: Experiment 2

Condition	Task duration		Task performance		
	Pre-pressure	Post-pressure	Pre-pressure	Post-pressure	Difference
Left-hand squeezing	13.77 (2.50)	13.07 (2.37)	17.22 (1.39)	18.44 (1.24)	+1.22
Right-hand squeezing	13.07 (2.02)	12.63 (1.84)	17.70 (2.31)	16.10 (2.96)	−1.60

Note. Positive difference values indicate a performance increase from pre-pressure to test post-pressure, whereas negative values indicate a performance decrease.

pressure (M = 17.21, SD = 2.55) when compared with the pre-pressure phase (M = 17.47, SD = 1.89). This main effect was not significant, $F(1, 17) = 0.23$, $p = .64$, $f = .11$. However, there was a strong Group × Phase interaction. Whereas participants in the right-hand squeezing group choked, participants in the left-hand squeezing group improved their performance (see Table 4). This interaction effect was significant and strong, $F(1, 17) = 12.84$, $p < .01$, $f = .87$. Subsequent simple main effects analysis indicated no group differences pre-pressure, $F(1, 17) = 0.29$, $p = .60$, $f = .13$, but a significant group difference post-pressure, $F(1, 17) = 4.86$, $p < .05$, $f = .53$. This difference was due to a significant performance decrement in the right-hand squeezing group post-pressure, $F(1, 9) = 6.00$, $p < .05$, $f = .82$, and a significant performance improvement in the left-hand squeezing group, $F(1, 8) = 9.31$, $p < .05$, $f = 1.08$.

Discussion

The results of Experiment 2 support the beneficial effect of activating the right hemisphere through left-hand squeezing under enhanced pressure. We induced pressure through videotaping and controlled for participants' engagement with the motor task (i.e., making the kicks). After enhancing pressure, participants engaged somewhat more in performing the task. However, performing faster was not detrimental to the accuracy of the kicks made, although the pressure was. Participants in the right-hand squeezing condition choked. In contrast, participants who used hemisphere-specific priming to activate the right hemisphere (i.e., the left-hand squeezing condition) did not choke and even improved their performance.

The improved performance deserves mention. It is unlikely that contracting the left hand improved the level of participants' kicking skills in the experiment. Rather, hemisphere-specific priming had an optimizing effect on performance. As indicated by increased tempo, participants in both conditions were not as much activated pre-pressure as they were post-pressure. Hence, it seems plausible that the pressure enhanced the overall participants' activation and their strivings and that the subsequent left-hand squeezing facilitated the flow of well-learned behavior, which led to even better performance than pre-pressure.

Experiments 1 and 2 indicate that activating right-hemispheric processes through left-hand squeezing facilitates skilled performance under pressure. The right-hand squeezing did not show any beneficial effect. However, a substantial limitation is that we cannot be sure that the right-hand squeezing did not produce an additional detrimental effect on performance. Squeezing the right hand may stimulate left-hemispheric processes, including verbal-analytic thinking, which appear to be disadvantageous for performance (Crews, 2004; Kerick et al., 2004; Landers et al., 1994). Moreover, pressure is thought to enhance left-hemispheric activation, and additional stimulation may intensify its effect (Kuhl, 2001). Accordingly, right-hand squeezing might have amplified the impact of pressure on skilled performance in these studies. The findings that left-hand squeezing extenuates choking might therefore be weighted. Experiment 3 was designed to overcome this limitation. To test the effect of left-hand squeezing more directly, we incorporated one more test phase and examined first the detrimental effect of pressure and, in the next step, the effect of hemisphere-specific priming.

Experiment 3

Experiment 3 was an attempt to demonstrate directly that squeezing the left hand eliminates choking. The experiment consisted of three phases, a pretest pressure-free phase followed by two test phases under pressure. After the pre-pressure measurement, we induced pressure and examined the occurrence of choking (i.e., the first post-pressure phase). Thereafter, we included hand-squeezing manipulation (i.e., the second post-pressure phase) and tested whether left-hand squeezing extenuated choking. As in the previous experiments, right-hand squeezing was applied as the control condition. Although right-hand squeezing may amplify the effect of pressure, we could control for it by comparing the two post-pressure phases. In addition, as argued in Experiment 1, no-hand squeezing would not be an appropriate control condition because of the effects on concentration (Mesagno & Mullane-Grant, 2010) that we were unable to control for. We tested a sample of experienced badminton players, using their serving accuracy as the performance measure. We expected that the players would choke after pressure induction and that the participants assigned to the left-hand squeezing condition would not differ from the participants in the right-hand squeezing condition in the first post-pressure phase. However, we also expected that they would differ from each other after the hand-squeezing manipulation (i.e., the second post-pressure phase). Those squeezing their left hand would extenuate choking, whereas the others would not.

Method

Participants. Eighteen participants (six women and 12 men) who play badminton at least in the Bavarian league were recruited. Their mean age was 35.6 years (range = 24–47 years). All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Their mean laterality quotient was +98 (range = +82–+100).

Task and apparatus. The participants' task was to make 10 serves from the right service court diagonally to the opponent's court. The badminton net was fixed in the middle of the court in accordance with international badminton rules (1.55 m high at the edges and 1.52 m high in the center). In collaboration with a professional badminton coach, we defined an optimal field where the shuttlecock should be landed and depicted a target on the opponent's left service court (see Figure 1). The participants' performance was measured by scoring the accuracy of each serve with a 10-point system. The optimal serve (i.e., landed in the optimal field) was awarded 10 points. Points decreased with the distance from the optimal field. A serve outside of the target was awarded 0 points. A serve in the net was awarded 0 points as well.

Procedure. The experiment was performed on a regular badminton court and consisted of three phases, a pre-pressure phase followed by two test phases (i.e., post-pressure). Upon arrival at the court, participants completed the Edinburgh Handedness Inventory (see Experiment 1) and began easy warm-up training in neighboring courts. During the training, we called participants to the experiment court individually, informed them about the task, and tested their pre-pressure performance. Each participant completed the WAI-S (see Experiment 1) and performed two practice serves followed by 10 test serves. After the pre-pressure performance of all participants was obtained, they finished the training and moved to the first test phase.

In the first test phase, pressure was induced. Participants were randomly arranged into two teams (balanced for men and women) and instructed to compete against each other. We told them that the team with more precise serves wins and would be rewarded with small gifts (e.g., energy drinks). We further told them that the teams will perform the task on a rotating basis; after a server from one team finishes his or her serves, the task changes to a server from the rival team. The teams were encouraged to verbally support their coplayers and discourage the opponents during the task. In addition, a video camera was set up to the right side of the performer. We told participants that their serving technique would be videotaped and evaluated by their coach. Therefore, they should pay close attention to their serving technique (cf. Liao & Masters, 2002, p. 297). After the instructions, the competition started. Each participant completed the WAI-S for a second time and then performed the serves.

Next, the second test phase was introduced. Participants were informed that they were only at half-time of the competition and that the better team from the first test phase should now confirm its victory. We also informed them that we were going to test the effect of enhanced concentration on serving accuracy and introduced the hand-squeezing task as an easy exercise to facilitate it. After the instructions, the competition continued. Each participant completed the WAI-S for the third time and subsequently squeezed a soft ball for about 30 s immediately before his or her turn. On a random basis, half the participants were assigned to the right-hand squeezing condition, the other half to the left-hand squeezing condition. After all players performed their shots, the competition was evaluated and the winning team rewarded. Participants were then debriefed and thanked for their participation.

Results

Pressure induction. As reported in Table 5, participants exhibited marginally higher somatic anxiety post-pressure than pre-pressure, $F(1, 17) = 3.76$, $p = .07$, $f = .47$. Cognitive anxiety was not significantly affected by pressure induction, $F(1, 17) = 2.59$, $p = .13$, $f = .39$. The post-pressure anxiety levels also persisted during the second post-pressure phase. Neither somatic anxiety, $F(1, 17) = 0.01$, $p = .91$, $f = .03$, nor cognitive anxiety, $F(1, 17) = 0.09$, $p = .77$, $f = .07$, changed in the second post-pressure phase, as compared with the first post-pressure phase. In addition, we compared pre-pressure anxiety with the anxiety levels in the second post-pressure phase. Somatic anxiety was marginally higher in the second post-pressure phase than pre-pressure, $F(1, 17) = 3.91$, $p = .06$, $f = .48$. There was no difference between the pre-pressure and the second post-pressure phases in the level of cognitive anxiety, $F(1, 17) = 1.94$, $p = .18$, $f = .34$. The right-hand and left-hand squeezing groups did not differ from each other in somatic anxiety in either the pre-pressure, $F(1, 16) = 0.07$, $p = .79$, $f = .06$; or the first post-pressure, $F(1, 16) = 0.01$, $p = .91$, $f = .03$; or the second post-pressure phases, $F(1, 16) = 0.06$, $p = .81$, $f = .06$. Similarly, the right-hand and left-hand squeezing groups showed no difference in cognitive anxiety in either the pre-pressure, $F(1, 16) = 0.08$, $p = .78$, $f = .07$; or the first

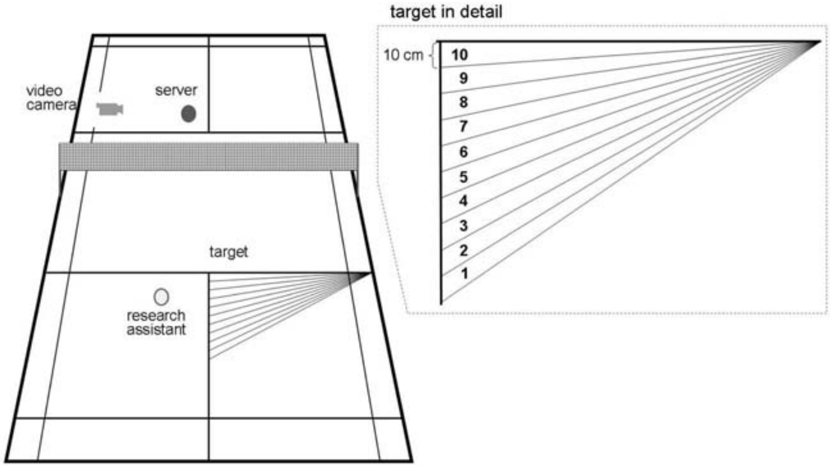

Figure 1. Details of an experimental setup in Experiment 3.

Table 5
Means (and Standard Deviations) of Cognitive and Somatic Anxiety Scores Pre- and Post-Pressure: Experiment 3

	Cognitive anxiety			Somatic anxiety		
Condition	Pre	Post 1	Post 2	Pre	Post 1	Post 2
Left-hand squeezing	6.56 (2.01)	7.00 (1.94)	7.22 (1.72)	6.00 (1.50)	6.89 (1.76)	7.11 (1.62)
Right-hand squeezing	6.78 (1.23)	7.44 (2.24)	7.44 (2.65)	6.22 (1.98)	7.00 (2.69)	6.89 (2.15)

post-pressure, $F(1, 16) = 0.20$, $p = .66$, $f = .11$; or the second post-pressure phases, $F(1, 16) = 0.05$, $p = .84$, $f = .05$. These results indicate that the pressure induction marginally increased the level of somatic anxiety in both groups.

Task performance. We applied a 2 × 3 (Group × Phase) repeated measures ANOVA on task performance with right-hand squeezing versus left-hand squeezing condition as the between-subjects variable. This analysis yielded a nonsignificant main effect of condition, $F(1, 16) = 0.02$, $p = .88$, $f = .03$; a nonsignificant main effect of phase, $F(2, 15) = 2.59$, $p = .11$, $f = .59$; but a significant Group × Phase interaction, $F(2, 15) = 4.05$, $p < .05$, $f = .73$. Table 6 shows the mean performance for both conditions.

The origin of the interaction was revealed from further analyses as follows. A significant performance decrease was found after pressure induction (i.e., the first post-pressure phase) when compared with the pre-pressure phase, $F(1, 16) = 4.58$, $p < .05$, $f = .54$. However, changes in performance were not systematically related to hand-squeezing conditions, $F(1, 16) = 0.48$, $p = .50$, $f = .17$. Subsequent simple main effects analysis indicated no group differences in either the pre-pressure, $F(1, 16) = 0.15$, $p = .70$, $f = .10$, or in the first post-pressure phase, $F(1, 16) = 1.13$, $p = .31$, $f = .26$. Hence, pressure led to choking in both groups.

However, a significant interaction was found after hand-squeezing manipulation (i.e., in the second post-pressure phase) when compared with the first post-pressure phase, $F(1, 16) = 6.58$, $p < .03$, $f = .64$. Participants in the right-hand squeezing group continued to choke, whereas participants in the left-hand squeezing group increased their performance. Subsequent simple main effects analysis indicated no group differences in the first post-pressure phase, $F(1, 16) = 1.13$, $p = .31$, $f = .26$, but a marginally significant group difference in the second post-pressure phase, $F(1, 16) = 3.37$, $p = .09$, $f = .46$. This difference was due to a significant performance improvement in the left-hand squeezing group in the second post-pressure phase, $F(1, 8) = 5.64$, $p < .05$, $f = .84$, but no performance change in the right-hand squeezing group, $F(1, 8) = 1.61$, $p = .24$, $f = .45$.

In addition, we compared participants' performance in the second post-pressure phase with their pre-pressure performance. A significant interaction effect was found, $F(1, 16) = 6.14$, $p < .03$, $f = .62$. This interaction was due to a significant performance decrement in the right-hand squeezing group, $F(1, 8) = 7.52$, $p < .03$, $f = .97$, but no performance change in the left-hand squeezing group, $F(1, 8) = 0.43$, $p = .53$, $f = .23$.

Table 6
Means (and Standard Devations) of Performance Scores: Experiment 3

Condition	Pre-pressure	Post-pressure 1	Post-pressure 2
Left-hand squeezing	47.00 (9.77)	38.33 (9.86)	49.22 (10.27)
Right-hand squeezing	49.11 (13.00)	44.67 (14.92)	38.67 (13.85)

Note. High scores represent good performances.

Discussion

Experiment 3 aimed to demonstrate that activating the right hemisphere through hemisphere-specific priming would extenuate the previous occurrence of choking and optimize performance. We arranged participants into two groups and let them compete against each other. Under this pressure situation, we found the expected decrease in skilled performance. Thereafter, we kept participants under pressure but instructed them to squeeze either their left or their right hand before performing again. After this manipulation, the participants who squeezed their left hand enhanced their performance, whereas the other group continued to choke. The results directly support the beneficial effect of activating the right hemisphere for optimization of skilled motor performance and elimination of choking.

In addition, we asked whether the activation of the left hemisphere through contracting the right hand may amplify the effect of pressure and, in turn, show an additional detrimental effect on performance. Although participants in the right-hand squeezing condition decreased their performance after they squeezed their right hand, the effect fell short on significance. Hence, under pressure, increased right-hemispheric activation rather than left-hemispheric activation affects the skilled motor performance.

General Discussion

The present research was based on a model of motor skill failure as mediated by enhanced self-focus and underlying hemispheric asymmetries. This model was tested using the choking under pressure paradigm (Baumeister, 1984). It is assumed that pressure engenders conscious control of automated behavior, which disrupts the execution of that behavior, leading to inferior performance (e.g., Baumeister, 1984; Beilock & Carr, 2001). Enhanced left-hemispheric activity underlies conscious control, whereas right-hemispheric activity underlies the execution of automated behavior. We hypothesized that activating the right hemisphere through squeezing the left hand extenuates choking under pressure. The results of the present research were consistent with that model and supported the hypothesis. All three experiments found that applying the left-hand squeezing manipulation before performing a task under pressure prevented choking when compared with the right-hand squeezing. Experiments 1 and 2 suggested that squeezing the left hand eliminates the decrease in performance after pressure induction. In a more direct test, Experiment 3 first compared the execution of a skilled behavior in a pressure-free situation with that under pressure. As expected, choking occurred. However, the performance improved after participants squeezed the left hand, whereas participants who squeezed their right hand continued to choke.

Alternative explanations for the extenuation of choking under pressure in our experiments may include enhanced concentration or reduced anxiety as affected by the hand-squeezing manipulation because of its behavioral components. Indeed, Mesagno and Mullane-Grant (2010) found that the execution of simple behavioral steps optimized concentration. These authors also proposed that such behavioral steps may modify the arousal level because they act as a coping strategy to the athletes without a coping repertoire. Although concentration or calming-down effects cannot be ruled out, they are nonetheless unlikely to account for our results for one reason. In all experiments, we used the hand-squeezing manipulation as the control condition as well. Half of participants squeezed the left hand, whereas the other half squeezed the right hand. However, only the left-hand squeezing showed a beneficial effect on performance. We propose that this occurred because of the activation of right-hemispheric processes related to skilled performance. A large amount of research evidence shows that unilateral muscle contractions in the upper limbs activate contralateral brain hemispheres and the functions associated with them (e.g., Baumann et al., 2005; Kim et al., 1993; Schiff et al., 1998; Schiff & Lamon, 1994). Furthermore, a large body of research shows that enhanced right-hemispheric activity facilitates skilled performance (e.g., Hatfield et al., 1984; Hillman et al., 2000; Landers et al., 1991; Salazar et al., 1990). Pressure situations seem to reverse this optimal pattern. The left hemisphere becomes dominant. Hence, left-hand squeezing could have been effective because it restored the optimal functioning, triggering right-hemispheric processes associated with the appropriate motor program, thereby enabling more accurate skill execution. In contrast, right-hand squeezing might activate left-hemispheric processes that were found to impair skilled behavior (e.g., Crews, 2004; Kerick et al., 2004; Landers et al., 1994).

Some limitations deserve mention. In the present research, participants were told to pay close attention to their behavior in addition to pressure induction. We stressed the monitoring of movements during the tasks execution because of our interest in self-focus as a mechanism of choking. Moreover, the self-focus instruction was aimed to direct participants' attention toward tasks execution rather than to task-irrelevant stimuli under pressure. This way we were able to more precisely test the effect of hemisphere-specific priming on preventing motor skill failure, as based on self-focus mechanism. However, in a true pressure situation such as an important competition, individuals are not necessarily given such self-focused instructions before performing a motor task. An inferior performance may result from increased self-focus as well as from focusing attention on task-irrelevant stimuli (Mesagno & Mullane-Grant, 2010). The effect of hemisphere-specific priming is limited to alleviating self-focus only, but it would probably not prevent the distraction-based performance decline.

Furthermore, the effect of hemisphere-specific priming would probably not apply to performance based on strength or stamina. Such performances are based on rather simple motor action, which does not necessarily comprise complex motor sequences that have become automated (Baumeister, 1984). Therefore, pressure need not be detrimental to such performances. According to a meta-analysis performed by Bond and Titus (1983), performance based on strength and stamina was not worse, but even better under pressure. The effect of hemisphere-specific priming therefore applies to performances based on accuracy, as shown in the present research. Such performances reflect more complex motor sequences (Ehrlenspiel, 2006) and have been found to be performed less well under pressure (Bond & Titus, 1983). Hence, enhancing right-hemispheric activity through squeezing the left hand brings benefits to the performance of complex motor tasks. Performance of simple motor action need not be affected.

The exact mechanism underlying the effect of hemisphere-specific priming is still unknown. As found in Experiment 3, activating the left hemisphere through contracting the right hand did not significantly amplify the effect of pressure. Rather, increasing right-hemispheric activity through the left-hand squeezing affected skilled performance under pressure. However, did the athletes who squeezed their left hand extenuate choking because of *activating* the right-hemispheric processes associated with well-learned behavioral patterns or because of *suppressing* conscious control in the left hemisphere, which is likely to interrupt the flow of behavior? Future research is needed to substantiate the effects of hemisphere-specific priming by using a direct test of hemispheric activity in addition to behavioral measures. For example, a series of experiments with the use of EEG should be designed to test (a) the effect of pressure on hemispheric asymmetry, (b) the effects of right- and left-hand squeezing on hemispheric activity under pressure, and (c) their mediating effect on performance.

The results of the present research suggest practical implications. Pre-performance routines such as use of the imagination, deep breathing, or cue words are often used to facilitate concentration and optimize arousal level (cf. Mesagno & Mullane-Grant, 2010). During debriefing after the experiments, we asked athletes about how they had perceived the hand-squeezing exercise. In general, they reported that it was helpful, not disturbing, and, for those with pre-performance routines, easily integratable into their routines. Hence, squeezing the left hand before performing a task under pressure may become a useful part of pre-performance routines in addition to imagination, deep breathing, or cue words. Future research should examine this additional benefit of hemisphere-specific priming in the field more deeply.

Furthermore, future research should identify individual differences related to that benefit. People differ in their vulnerability to motor skill failure according to their levels of trait anxiety (Wang, Marchant, Morris, & Gibbs, 2004) and self-consciousness (Baumeister, 1984), or their tendency to turn their attention inward (Masters, Polman, & Hammond, 1993). Individuals with higher trait anxiety and persons low in self-consciousness appear to be more vulnerable. Hence, those individuals may especially benefit from the use of hemisphere-specific priming.

Although tested in the area of choking under pressure, the conclusions and implications of the present research are not limited to this area of interest. The same principles may be applied to other areas of motor skill failure, for example, to elderly people who have problems maintaining balance. Attempts to consciously control balance involving a dominant activation of the left-brain hemisphere is doomed to fail. Shifting dominance of activation to the right hemisphere should help people to maintain balance. Hence, hemisphere-specific priming also has the potential to act as a therapeutic or remedial manipulation and could have wide applications in situations believed to be related to enhanced self-focus attention.

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