State Anxiety and Low-Frequency Heart Rate Variability in High-Level Amateur Golfers While Putting under Pressure

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The present study investigated the relationship between psychophysiological state and clutch or choking performance during golf putting under pressure. Ten males and 13 females who were high-level competitive amateur golfers performed 25 putts under control and pressure conditions. State-Trait Anxiety Inventory-Y1 (STAI-Y1), heart rate variability (HRV), and putting scores were measured. Participants whose performance improved under the pressure condition compared to the control condition were defined as clutch performers and all others were defined as choking performers. Change ratios between the pressure and control conditions for each variable were calculated and compared between clutch and choking performers. There was a significant difference in the change ratio of the low frequency (LF) component of HRV such that LF HRV decreased under the pressure condition compared with the control condition only in choking performers. Thus, LF HRV may be associated with improved fine motor control, such as golf putting, under pressure circumstances.

Keywords: fine motor control, attentional focus, maximum entropy method, choking performance

1. Introduction

Many individuals experience a decrease in performance when under pressure, known as a choking performance, due to psychophysiological changes, such as anxiety (e.g., Beilock and Gray, 2007; Gray and Cañal-Bruland, 2015). In contrast, others are able to achieve high performance levels despite being under pressure (e.g., Gray and Cañal-Bruland, 2015; Hasegawa et al., 2013); this type of performance is known as a clutch performance, which can be defined as superior performance under pressure (Otten, 2009). Although many of the variables associated with a choking performance have been well documented, the psychophysiological factors involved in choking and clutch performances, including those originating in the peripheral and central nervous systems, are less understood (e.g., Reyes Del Paso et al., 2013).

Heart rate variability (HRV) has been used extensively as a non-invasive and time-saving tool to monitor training status and physiological adaptations in both moderately trained individuals and athletes (e.g., Bellenger et al., 2016). Time-series changes in HRV are thought to be an exact reflection of the ability to adapt to the body’s internal and external environments (Neumann and Thomas, 2009). HRV is sensitive to changes in emotional states, such as anxiety (e.g., Appelhans and Luecken, 2006), and is useful as a field-based assessment tool that reflects the interaction between the heart and the brain (e.g., Berntson et al., 1997; Riganello et al., 2018). Mateo et al. (2012) reported that an HRV analysis provides a complementary tool for assessing competitive pressure. Thus, we focused on the anxiety evoked by pressure and investigated the psychophysiological changes in performers in terms of HRV. Golf putting was employed as a motor task because it is a very low-intensity activity that is primarily cognitive, as it involves concentrating on aim (Neumann and Thomas, 2009).

The power of the HF component has been considered an index of cardiac parasympathetic tone, the LF component as an index of cardiac sympathetic outflow, and the LF/HF ratio is usually interpreted as reflecting...
the relative sympathetic contribution to the control of heart rate (HR) as sympathovagal balance (Reyes Del Paso et al., 2013). However, it has been proposed that the framework to associate the HRV frequency components (LF and HF) with division of the autonomic nervous system (sympathetic and parasympathetic) is too simplistic (Hayano and Yuda, 2019). According to a review by Reyes Del Paso et al. (2013), the HRV spectrum including LF HRV is predominantly determined by vagal activity, emphasizing the vast importance of the parasympathetic system in cardiac regulation.

On the other hand, assessing HRV has been reported to help elucidate the problem of the attentional focus of performers in motor learning (Bell and Hardy, 2009; Mullen et al., 2012). Furthermore, the problem of deterioration in performance due to anxiety has been described in terms of the performer’s attention. Movement kinematics change when state anxiety is evoked due to pressure, which affects movement accuracy (e.g., Cooke et al., 2010; Tanaka and Sekiya, 2010). Two theories have been proposed to explain a deterioration in performance under pressure: the distraction theory (Wine, 1971) and the explicit monitoring theory (Beilock and Gray, 2007). The distraction theory proposes that pressure influences task performance by creating a distracting environment that compromises one’s working memory capacity resources. If the ability of working memory to maintain task focus is disrupted, performance may deteriorate (Wine, 1971). On the other hand, the explicit monitoring theory states that performance anxiety enhances self-consciousness about performance, and this focus on self is thought to prompt the turning of attention towards specific performance processes in an attempt to achieve more explicit monitoring and control than would be applied under a non-pressure situation (Beilock and Gray, 2007). Choking performers pay attention to their own motor control processes and this prevents smooth motor execution and decreases performance, a process referred to as step-by-step control (Masters, 1992).

The theory that best describes deterioration in performance under pressure depends on the type of task (Beilock and Gray, 2007). Distraction theory (Wine, 1971) is used to explain deterioration in performance under pressure during sports skills that rely heavily on working memory, such as strategizing, problem solving, and decision making (i.e., skills that require considering multiple options simultaneously and updating information in real time). These kinds of tasks will be likely fail as a result of pressure-induced working memory, similar to a working-memory-dependent academic task. In contrast, explicit monitoring theory is used to explain motor skills that run largely outside of the working memory (e.g., a highly practiced golf putt or baseball swing). Such tasks fail when pressure-induced attention disrupts automated control processes. As suggested by Gray and Beilock (2007), we recruited high-level golfers and focused on explicit monitoring theory in the present study.

Furthermore, the explicit monitoring theory explains that focusing on motor control processes under pressure, that is, increased internal attention, causes choking performance. In fact, Bell and Hardy (2009) suggested that performers should maintain their attention on an external focus while golf putting under pressure circumstances. According to Abernethy et al. (2007), HRV is a psychophysiological indicator of attentional workload during motor acts. Increased attentional demand that occurs when a subject strives to perform better during a fine motor control task have a tendency to reduce the power of all HRV frequency components (Egelund, 1982; Veltman and Gaillard, 1998), which can have a larger effect on the LF component (Aasman et al., 1987). Therefore, from the viewpoint of attention, it was hypothesized that the LF HRV of a choking performer would decrease and the LF HRV of a clutch performer would not change.

However, previous findings regarding the relationship between HRV and performance during golf played under pressure conditions are inconsistent (Cooke et al., 2010; Mullen et al., 2005). For example, Mullen et al. (2005) reported that HF HRV values partially reflected putting scores when playing under dual-task conditions, in which more of an individual’s attentional resources were used. Cooke et al. (2010) found that participants exhibited increases in both HR and LF HRV under pressure situations, but they could not demonstrate the relationship between LF HRV and putting score. These inconsistencies may be due to oversights regarding the different psychophysiological responses of clutch and choking performers, as mentioned above. If the psychophysiological responses of these groups were confused, the results may have been misleading. Thus, in the present study, clutch and choking performers were categorized according to their putting scores, and the psychophysiological responses of the groups were compared under a pressure situation.
The purpose of this study was to investigate the relationship between clutch/choking performance and psychophysiological state (i.e., HRV) during golf putting under pressure. A better understanding of the differences between clutch and choking performances will contribute to improved performance, training, and/or psychological control in players and other individuals who perform under pressure.

2. Methods

2.1. Participants

The participants included 23 high-level amateur golfers (10 males and 13 females) who performed in competitions. The average age of the males was 37.3 ± 11.7 years (average handicap; 5.7 ± 3.2). The average age of the females was 39.6 ± 14.8 years (average handicap; 5.8 ± 2.6). All participants gave written informed consent after a complete explanation of this study before participating in the study. This study was performed in accordance with the guidelines of the Declaration of Helsinki and was approved by the Internal Review Board of the Chukyo University.

2.2. Questionnaire and Apparatus

The State-Trait Anxiety Inventory Form JYZ Y-1 ([STAI Y-1]; Hidano et al., 2000) was used to measure the cognitive state anxiety of the participants. An electrode was placed on the chest of each participant to measure the R-R interval using an HR monitor (LRR-03; Arm Electronics Corp., Tokyo, Japan). The R-R interval sequence data were obtained at a sampling frequency of 1,000 Hz and analyzed using the MemCalc computer program (MemCalc/Tarawa; Suwa Trust, Tokyo, Japan). The MemCalc program was used to calculate the HRV spectrum based on the maximum entropy method, which overcomes the disadvantages in the frequency domain associated with conventional spectral analyses, including poor resolution and insufficient estimates of short time-series data using the fast Fourier transform and autoregressive methods (Ohtomo et al., 1994; Radoski et al., 1976). MemCalc is able to detect the proper frequency using data with a length corresponding to a single R-R interval (Ohtomo et al., 1994; Tsuchida et al., 1998). Noise was automatically deleted by the program, and a linear interpolation was performed. The LF and HF activities were calculated based on the R-R data at 2-s intervals within a 30-s window and then averaged over the time course of each condition. Although MemCalc is a relatively new program, it has been validated in many studies (e.g., Sumi et al., 2006).

For the putting task, a single layer of artificial turf manufactured specifically for golf putting (K-80; Kiitos Co., Ltd., Tokyo, Japan) was stretched across a platform made of wood (5.00 m long × 1.82 m wide × 0.30 m high). A hole with the same dimensions as those on a real golf course (10.8 cm in diameter and approximately 15 cm in depth) was used; the center of the hole was 1.80 m in length and 0.91 m in width from the edge of the putting platform.

2.3. Task and procedure

All participants performed the golf-putting task under control and pressure conditions using five putting distances: 0.75, 1.25, 1.50, 1.75, and 2.25 m. The participants hit one shot from each distance; a total of five shots were included in one set and the participants completed five sets under each condition, yielding a total of 25 shots. Five distances were set because it was assumed that changing the distance of the putt would require a greater degree of attentional effort. As for the putting score, one point was awarded when sinking a putt on the first try, and 0 points were given when the putt was not sunk on the first try. That is, if the participant sank all putts on the first try, they would get 25 points under each condition. The ball was placed on the mat in a random order by the experimenter. Each participant was allowed to putt using their own routine (no time limit) and they were required to continue putting until a putt was made in each trial.

All participants performed all of the experimental tasks in a single day. The participants were instructed to obtain a normal and appropriate amount of sleep the night before the experiment, to refrain from particularly strenuous exercise on the day of the experiment, and to eat a meal 3 h prior to the experiment. Upon arrival, all participants were required to rest for 30 min prior to attachment of the HR monitor to the chest. Then, the participants were taken to the laboratory, where they practiced putting for 5 min. After that, the participants returned to the waiting room and rested for an additional 10 min. Then, they moved to the laboratory and began the experimental trials.

In the control condition, participants completed the STAI Y-1, performed the putting task, and then re-
turn to the waiting room. Under the pressure condition, the participant practiced putting in a manner similar to that under the control condition. They re-entered the laboratory containing a 12-person gallery, which was located toward the hitting direction, and thus opposite the hitting direction of the participant. Moreover, the participants were told that if they completed the task at 80% or better proficiency (i.e., if they sank 20 or more putts), they would be given 2,000 Japanese yen. If their performance was poorer than 80%, they would have to pay a penalty of 2,000 Japanese yen. Then, the participant completed the STAI Y-1, performed the putting and returned to the waiting room. The order of the control and pressure conditions was counterbalanced. The rest period between the two conditions was 30 min. Also, the participants were paid the reward when the goal was achieved but they were not actually required to pay the penalty when they did not achieve the goal.

2.4. Data analysis

The power spectrum indices of the spectral components of the HRV analysis were determined based on the following fundamental framework: LF HRV was the sum of the power from 0.04 to 0.15 Hz, HF HRV was the sum of the power from 0.15 to 0.4 Hz, and the LF/HF ratio was the ratio of those values (e.g., Hayano and Yuda, 2019; Reyes Del Paso et al., 2013). The putting distance factor was omitted from the analysis because the participants were allowed to play using their own routines with no time limitations; thus, we could not separate out the data for each strike from those associated with technical problems. Therefore, the HRV values were averaged across all distances for each condition.

Participants who improved their performance under the pressure condition compared to the control condition were defined as clutch performers (n = 11; including one participant whose score was the same in both the control and pressure conditions), whereas the others were defined as choking performers (n = 12). We investigated the effect of condition on group classification. Among those who completed the control condition first, six participants were classified into the clutch group and five into the choking group. Among those who completed the pressure condition first, five participants were classified into the clutch group and seven into the choking group. A chi-square test confirmed ($\chi^2(1)=0.057$, n.s.) that there was no order effect of condition on group classification.

The average values on each variable were calculated for each participant, and the differences between clutch and choking performers were assessed based on the change ratio between the control and pressure conditions, as follows:

Change ratio (%) = \frac{(\text{measurement in the pressure condition}) - (\text{measurement in the control condition})}{100}

This is because considerable individual differences in HRV (Kobayashi, 2007) can occur due to interactions among physiological influences, such as age, sex, and/or body mass index (e.g., Agelink et al., 2001; Koenig et al., 2014) in conjunction with cognitive awareness of the environment. Normalizing the measured physiological variables within an individual, and suppressing inter-individual variability, is a method used to address these issues (Lamichhane et al., 2016).

2.5. Statistical analysis

To determine whether the experience of pressure was properly induced, the change ratio of HR and the STAI Y-1 scores in each group were compared to 100 using a one-sample t-test. In addition, for the change ratio of LF, HF, and LF/HF in each group, the one-sample t-test was performed to compare the value with 100, similar to the STAIY-1 and HR. Welch’s t-test was also performed to confirm that the putting scores of two groups were significantly different.

Psychophysiological differences between the two groups were evaluated using Welch’s t-test with respect to the change ratio of the STAI Y-1 scores, mean HR, all HRV parameters. All data were analyzed using PASW Statistics (ver. 18.0; IBM Japan, Ltd., Tokyo, Japan) and P-values < .05 were considered significant. Additionally, d effect size indices were calculated using G*power 3.1.9.4 (Faul et al., 2007).

3. Results

3.1. Pressure manipulation check

Table 1 shows the average STAI Y-1 score and HR values in both groups. Figure 1(a) shows the change ratio of the STAI Y-1, and Figure 1(b) the change ratio of HR, in both groups. A one sample t-test of the STAI Y-1 scores revealed that both the clutch group ($t_{10}=3.84$, p = .003, d = 1.15) and the choking group ($t_{11}=3.96$, p = .002, d = 1.14) exhibited a significant
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increase in state anxiety under the pressure condition. One sample t-test of HR revealed that both the clutch group \((t_{10} = 2.33, p = .042, d = 0.70)\) and the choking group \((t_{11} = 6.25, p = .000, d = 1.80)\) exhibited a significant increase in HR under the pressure condition. Therefore, both groups experienced an increase in anxiety and HR under the pressure condition.

### 3.2. Manipulation check of the classification of two groups

**Figure 2** shows the change ratios of the putting scores of the two groups. Welch’s t-test was performed to compare the mean putting score of the clutch group with that of the choking group; the change ratio of the clutch group was significantly higher than that of the choking group \((t_{16} = 7.70, p = .000, d = 0.99)\). Welch’s t-tests assessing the change ratios of the STAI Y-1 scores \((t_{16} = -0.47, p = .640, d = 0.02)\) and HR values \((t_{12} = -0.88, p = .395, d = 0.04)\) showed no differences between the clutch and choking groups.

### 3.3. Differences of the HRV indices between the pressure and control conditions

**Table 2** shows the HRV parameters for all participants. **Figure 3** shows change ratios for the LF, HF, and LF/HF of the HRV in each group. The one sample t-test of the change ratios of LF HRV in the clutch group indicated no significant difference in LF HRV under the pressure condition \((t_{10} = 0.03, p = .97, d = 0.01)\). However, the one sample t-test of the change ratios of LF HRV in the choking group exhibited a significant decrease in LF HRV under the pressure condition \((t_{11} = 4.40, p = .001, d = 1.27)\). The one sample t-test of the change ratios of HF HRV revealed that both the clutch group \((t_{10} = 0.97, p = .36, d = 0.29)\) and the choking group \((t_{11} = 0.19, p = .85, d = 0.06)\) were not significantly different in HF HRV under the pressure condition. The one sample t-test of the change ratios of LF/HF in the clutch group indicated no significant difference in LF/HF under the pressure condition \((t_{10} = 0.97, p = .35, d = 0.29)\). In contrast, the one sample t-test of the change ratios of LF/HF in the

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**Table 1** Average STAI Y-1 score and HR value in each group.

|            | STAI Y-1 |            | HR (bpm) |
|------------|----------|------------|----------|
|            | Clutch   | Choking    | Clutch   | Choking |
| Control    | 39.0 ± 10.3 | 38.9 ± 6.4 | 84.2 ± 8.9 | 82.6 ± 10.0 |
| Pressure   | 51.1 ± 10.1 | 54.4 ± 11.1 | 93.7 ± 18.9 | 95.7 ± 14.3 |

Note. ± ** indicates the between-subjects standard deviation for each condition.

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**Figure 1** Change ratio for the STAI Y-1 scores and HR values in each group. The vertical bar represents the between-subjects standard deviation.

**Figure 2** Change ratio for the putting scores in each group. The vertical bar represents the between-subjects standard deviation. ***p < 0.001.

**Figure 3** Change ratio for the HF HRV in each group. The vertical bar represents the between-subjects standard deviation. ***p < 0.001.
| Player | Gender | Total power (ms²) | LF power (ms²) | HF power (ms²) | LF/HF ratio |
|--------|--------|------------------|----------------|---------------|-------------|
|        |        | Control | Pressure | Control | Pressure | Control | Pressure | Control | Pressure | Control | Pressure |
| 1 M    |        | 1625.90 ± 403.24 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 2 M    |        | 1277.37 ± 590.28 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 3 M    |        | 1893.01 ± 1206.24 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 4 M    |        | 1953.01 ± 1206.24 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 5 M    |        | 2377.37 ± 2144.54 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 6 M    |        | 2227.37 ± 2144.54 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 7 M    |        | 1953.01 ± 1206.24 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 8 M    |        | 1953.01 ± 1206.24 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 9 M    |        | 2977.37 ± 2144.54 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |
| 10 M   |        | 2227.37 ± 2144.54 | 244.44 ± 35.15 | 57.86 ± 12.94 |        |        |        |        |        |        |        |

Note: ** indicates the within-subject standard deviation for each condition, and * indicates male.
3.4. Differences of the HRV indices between the clutch and choking groups

Welch’s t-test of the change ratios of LF HRV revealed that the change ratio of the choking group was significantly lower than that of the clutch group ($t_{16} = 2.13$, $p = .049$, $d = 0.90$), indicating that the choking group exhibited a decrease in LF HRV under the pressure condition [Figure 3(a)]. Welch’s t-test of the change ratios of HF HRV showed no differences between the clutch and choking groups ($t_{16} = 0.70$, $p = .493$, $d = 0.29$) on this measure [Figure 3(b)]. Welch’s t-test of the LF/HF change ratios revealed no differences between the clutch and choking groups ($t_{16} = 1.55$, $p = .135$, $d = 0.64$) on this measure [Figure 3(c)].

4. Discussion

To determine whether pressure was properly induced, the change ratio of HR and the STAI Y-1 scores of each group was compared to 100 using a one-sample t-test. Both groups exhibited increases in anxiety and HR under the pressure condition, but Welch’s t-tests of the change ratios of the STAI Y-1 and HR variables revealed no differences between the clutch and choking groups. Therefore, pressure was effectively induced in both choking and clutch performers (Table 1).

By categorizing the choking and clutch performers based on their putting scores in both conditions, we clarified the relationship between LF HRV and a low level of sporting activity (golf putting task), which has shown inconsistency among previous studies (Cooke et al., 2010; Mullen et al., 2005). The one sample t-test was also performed for the change ratio of LF, HF, and LF/HF in each group. As results, none of the HRV components under pressure in the clutch group increased or decreased significantly from baseline. On the other hand, the change ratio of LF HRV and LF/HF in the choking group were significantly lower than the baseline. Furthermore, a significant difference was found in the change ratio of LF HRV between the two groups [Figure 3(a)]. We discuss these results in terms of attention rather than autonomic nervous system activity because recent studies on the mechanisms underpinning HRV have underscored the inappropriateness of directly associating HRV frequency compo-
The explicit monitoring theory seems to be the better theory to explain a deterioration in performance under pressure in skilled golf putting. This is because the highly practiced golf putt run largely outside of the working memory (Beilock and Gray, 2007). According to explicit monitoring theory, pressure-induced anxiety evokes conscious awareness of an attempt to achieve higher accuracy during a task (Beilock and Gray, 2007). Due to this change in cognition, performers re-invest attention back to movements that they usually perform unconsciously (i.e., automaticity; Beilock and Gray, 2007). That is, performers revert back to step-by-step control processes that demand greater attentional effort under pressure, which is also referred to as deautomatization of motor skills (Deikman, 1966), and performance decreases due to changes in the focus of attention (Beilock and Gray, 2007; Masters, 1992). That is, these theories state that the performer’s attention shifts to an internal focus in a pressure situation. Also, a study that investigated the relationship between participants’ attentional focus and HRV during motor learning reported that LF HRV was lower in the internal focus group than in the external focus group (Mullen et al., 2012). Based on these reports, it is presumed that the choking performers in the present study may have increased their internal attentional focus to their motor control processes under pressure, and that clutch performers who improved under the pressure condition did not exhibit this change in attention.

In the present study, we focused on LF HRV because LF HRV is thought to reflect mental workload (e.g., de Waard et al., 1999; Veltman, 2002) and attentional focus of performers (Mullen et al., 2012; Wilson et al., 2007) in previous studies. As predicted, there were no significant differences in HF HRV or LF/HF between the two groups under pressure. Considering previous studies reporting that HF HRV is related to respiratory effects, reflects emotion regulation, and links coping-related variables (Laborde et al., 2015), there was a possibility that a significant difference between HF HRV of the choking group and that of the clutch group would be found, which were not found in our experiment. Also, we found that the choking group showed reduced LF/HF under pressure as a result of decreased LF HRV. According to the review by Reyes Del Paso et al. (2013), stress reduces the HRV all-frequency band, and the findings of the present study partially support their statements.

Our results were opposite to those of Murray and Raedeke (2008) where their participants showed that LF HRV increased, HF HRV decreased, and LF/HF increased under the pressure situation during golf putting. The pressure condition (i.e., audience) and the division of the power frequency band in our experiment were similar to those in the previous study. We speculate that there are two reasons for this inconsistency. First, their research did not distinguish choking performers from clutch performers. Second, the participants of the present study and their participants had different skill levels. We also need to confirm these issues in future research.

The results of this study suggest that LF HRV may differentiate choking and clutch performers. However, the relationship between the attentional focus (i.e., internal vs. external), HRV, and pressure are issues that should be considered in future, more controlled studies. Also, our results did not rule out the possibility that the differences between choking and clutch performers were also due to variations in how the situation was interpreted (Brooks, 2014), the personality of the performers, and/or confidence of play. The generalizability of our findings requires further data to obtain more reliable results (e.g., a greater number of golfers).

We conclude that clutch performers did not exhibit changes in LF HRV under the pressure condition, while choking performers exhibited a decrease. The other HRV parameters did not distinguish clutch performers from choking performers. LF HRV may be associated with improved fine motor control under pressure, such as golf putting in front of an audience. Our findings may be applied to biofeedback training (Lagos et al., 2008) in the future.

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• Hasegawa, Y., Miura, A., Fujii, K., Yokoyama, K., and Yamamoto, Y. (2019). Motor control of practice and actual strokes by professional and amateur golfers differ but feature a distance-dependent control strategy. Eur. J. Sport Sci., 19: 1204-1213.
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