Running head: SKILL LEVEL AND CARDIAC ACTIVITY

The relationship between skill level and patterns in cardiac and respiratory activity during
golf putting

David L. Neumann^{1,3}, Patrick R. Thomas^{2,3}

¹School of Psychology, Griffith University, Australia

²School of Education and Professional Studies, Griffith University, Australia

³Centre of Excellence for Applied Sport Science Research, Queensland Academy of Sport,
Australia

Number of text pages (including tables and figures): 29

Number of tables: 2

Number of figures: 3

Corresponding author and address: David Neumann, School of Psychology, Griffith
University (Gold Coast Campus), Mail: GRIFFITH UNIVERSITY QLD, Queensland, 4222,
Australia, E-mail D.Neumann@griffith.edu.au, Facsimile +61(0)7 5552 8291, Telephone
+61(0)7 5552 8052

Abstract

Individual differences in skill level during sport-related motor tasks, such as golf putting, can be related to not only performance, but also patterns in psychophysiological activity. The present study examined the similarities and differences in cardiac and respiratory activity among elite, experienced, and novice golfers. Participants attempted flat putts 2.4 m from the hole. Performance was better in elite and experienced golfers than in novice golfers.

Compared to novice golfers, the experienced and elite golfers showed a pronounced phasic deceleration in heart rate immediately prior to the putt, greater heart rate variability in the very low frequency band, and a greater tendency to show a respiratory pattern of exhaling immediately prior to the putt. The psychophysiological patterns may be related to differences in attentional processes or task familiarity between the groups. The implications of the results for the assessment and training of athletes in precision sports is discussed.

Keywords: heart rate, respiration, heart rate variability, attention, golf, sport

1. Introduction

Many people seek to attain an expert level in the performance of complex motor skills, such as those required during sport. The fact that not all people are able to attain this level has led researchers to investigate what factors are associated with the development of expertise. Attentional processes have emerged as a key psychological factor important for skill learning (Abernethy et al., 2007). One method by which attentional processes can be correlated to expert performance is to examine the similarities and differences between elite and novice athletes on measures sensitive to attention. Psychophysiological methodology provides an ideal avenue to progress such research because it can index a range of processes related to attention and can be measured relatively unobtrusively and continuously during concurrent performance (Abernethy et al., 2007; Collins, 2002). The present research examined patterns in cardiac and respiratory activity in athletes during the skill of golf putting.

Phasic changes in heart rate (HR) have most commonly been examined immediately prior to putting a golf ball. Elite golfers have shown HR deceleration across the five interbeat intervals preceding the putt, with the execution of the putt coinciding with the time at which HR was slowest (Boutcher and Zinsser, 1990; Hassmén and Koivula, 2001; Molander and Backman, 1989). The deceleration in HR can also be found prior to other types of golf shots (Cotterill and Collins, 2005). It is also more pronounced in elite athletes who show low trait anxiety scores when there is noise presented while putting (Hassmén and Koivula, 2001). Boutcher and Zinsser (1990) showed that both elite and novice golfers can exhibit HR deceleration, although the deceleration was more pronounced for elite golfers. The observation of more pronounced HR deceleration at higher skill levels has also been found in other sports, such as pistol shooting (Tremayne and Barry, 2001), and rifle shooting (Hatfield et al., 1987), although it was not found in one study on archery (Salazar et al., 1990).

Lacey and Lacey's (1974, 1980) intake-rejection hypothesis provides a framework to explain the relationship between HR changes and motor skill performance. According to this hypothesis, a deceleration in HR is associated with decreased feedback to the brain and results in a more effective external focusing of attention and superior performance. Laboratory-based studies have supported this conceptualization (Lacey and Lacey, 1974). Support has also been found during self-paced sporting tasks. For example, Radlo et al. (2002) asked novices to throw darts at a target while focusing attention externally at the target or internally on their movements. The external focus condition was associated with a pronounced deceleration in HR immediately before the throw, whereas the internal focus condition was associated with an acceleration of HR. Moreover, performance was better in the external focus condition than in the internal focus condition. The authors interpreted the results as indicating that the HR deceleration reflected a more effective focusing of attention during the task.

Tonic measures of HR can also provide information regarding attentional demands. Abernethy et al. (2007) noted that heart rate variability (HRV) might provide a particularly promising physiological indicator of attentional workload during sport, although it has received little application to date. This measure aims to quantify the variations in HR across time. Spectral power analysis can decompose variability into different frequency components: a very low frequency (VLF) component from 0.03 to 0.05 Hz thought to reflect temperature regulation; a low frequency (LF) component from 0.05 to 0.15 Hz thought to reflect blood pressure regulation; and a high frequency (HF) component from 0.15 to 0.4 Hz thought to reflect respiratory influences or respiratory sinus arrhythmia (Grossman, 1992). HRV also reflects the balance between the sympathetic and parasympathetic nervous systems, which adapt to changing external and internal stimulation. Heart rate at any one time is thus the net effect of sympathetic influences, which accelerate HR, and parasympathetic influences, which slow HR. The variation in HR over time reflects the individual's ability to adapt to internal

and external demands. Increasing attentional demands tend to reduce power in all HRV frequency components (Egelund 1982; Neumann, 2002; Veltman and Gaillard 1998), although it can have a larger effect on the LF component (Aasman et al., 1987).

The attainment of a higher skill level is suggested to be associated with greater automaticity in performing motor acts, and thus reduced attentional demands (Abernethy et al., 2007; Wulf, 2007). Based on this suggestion, it would be expected that elite golfers will show reduced HRV relative to novice golfers. However, research has yet to test this hypothesis. Mullen et al. (2005) provided the first examination of HRV during golf putting in which amateurs putted under single or dual-task conditions. The HF component was higher during the dual-task conditions than during the single-task (putting only) condition. It was suggested that participants may have adapted to the increased attentional demands of the dual-task condition by adopting a breathing-based relaxation strategy. Although respiratory activity was not examined in their study, it would provide a mechanism by which an increase in the spectral power of the HF component occurred.

The present report is part of a larger study in which golfers attempted flat putts under single and dual-task conditions. We report here the component that examined the relationship between skill level and patterns in HR deceleration, absolute HR, HRV, and respiratory activity during the single putting task. Whereas previous research has tended to examine differences between elite and novice golfers, a third group of experienced golfers was included. For the experienced golfers, putting is a well-practiced skill, although it might not be performed at the same level as the elite golfers. It was hypothesized that elite golfers would show superior performance to novice golfers. Elite golfers were also expected to show more pronounced phasic HR deceleration, indicating a more effective external focusing of attention, prior to the putt than novice golfers. In addition, elite golfers were hypothesized to show lower overall HR and higher HRV than novice golfers, indicating an overall lower level

of attentional demands. The experienced golfers were expected to show performance and psychophysiological patterns between the elite and novice golfers on most measures.

However, those instances in which there were similarities between the experienced golfers and the other groups would indicate what cardiac and respiratory patterns are associated with an elite level of performance over and above that due to experience with the task.

2. Materials and Methods

2.1. Participants

Elite, experienced, and novice golfers were recruited (see Table 1). The 19 elite golfers aged from 16 to 34 years were either amateurs who had recently competed at national or international golf competitions or were professional golfers. The 16 experienced golfers aged from 19 to 41 years were recruited from local clubs and had competed up to regional or state level competitions. The 17 novice golfers aged from 17 to 41 years were recruited from a first-year psychology participation scheme and had no prior experience in playing golf or minigolf. The three groups did not differ in mean age or the ratio of males to females, both $p > .05$. The elite and experienced groups did not differ in mean years of playing experience, $p > .05$. As expected, the elite golfers had a significantly lower handicap, $t(33) = 4.62$, $p = .001$, and played more frequently, $t(33) = 2.24$, $p = .03$, than the experienced golfers. The elite and experienced golfers were reimbursed AUD\$15 and the novice golfers received partial course credit for participation. All golfers provided informed consent to a protocol approved by the institutional Human Research Ethics Committee prior to participation.

 Insert Table 1 about here

2.2. Apparatus

The experiment was conducted on an outdoor synthetic grass surface measuring 8.3 m

x 11 m. A flat section of the surface was selected for the putting task. A dot was placed 2.4 m from a standard cup 108 mm in diameter to mark the place from where each putt was to be attempted. Participants used their own putter or an Odyssey #2 centre-shafted putter (left or right-handed, as appropriate) and Optima TS golf balls. Performance (number of putts holed) was recorded via a Sony Model DCRHC42 Mini DV Handycam suspended 3.4 m above the cup (for details, see Neumann and Thomas, 2008).

Recordings of electrocardiogram (ECG) and respiratory effort were taken via a PowerLab (ADInstruments, Sydney) Model 4/20 physiological data acquisition system in conjunction with a Dell Latitude D800 computer. The ECG was recorded via disposable ADInstruments MLA1010B Ag/AgCl electrodes applied to three chest sites: the manubrium, the xiphoid process, and over the 6th rib (ground). Signals were acquired via an ADInstruments ML132 Bio Amp. Respiration was recorded via an ADInstruments MLT1132 Piezo Respiratory Belt Transducer applied around the lower chest. The data acquisition system was used to detect the onset of the putting stroke in two ways. The first used an ADInstruments MLA92 push button switch that was depressed by the experimenter when the participant's putter made contact with the ball. The second employed RadioShack 49-312 Invisible Beam Entry Alert that placed a mark on the data acquisition channel when the beam was broken by the putter during the backswing of the shot. However, as this latter method proved unreliable because several participants did not have a large enough backswing to break the beam, the pressing of the button upon ball contact was used as the reference point for all participants. All signals were sampled at 400 Hz and saved to computer for later processing.

2.3. Procedure

After obtaining informed consent, the electrodes and transducers for the psychophysiological recordings were attached. Although it was not a focus of the present experiment, the participants also completed a reaction time task in which they had to respond

by repeating the target word *boat* that was played among a string of 75 distracter words. Physiological recordings were taken across the 3 min it took to complete this task. Each participant was then allowed 10 practice shots at the hole for familiarization. Finally, participants attempted 20 putts at the hole. The putting task was self-paced with the participant determining when to strike the ball and how long to rest or prepare between each putt. The ball was collected after each putt and the participant was encouraged to begin preparing for the next shot during this time. Participants took approximately 5 min to complete the set of 20 putts, with approximately 15 s between each putt.

2.4. Response quantification

Three measures of cardiac activity were taken from the ECG recordings. The first was the mean HR and was calculated by the Chart software package (ADInstruments, Sydney) through the identification of the ECG R-peaks. The second measure was the change in HR around each putt and spanned from 11 s prior to putt onset and 11 s following putt onset. Putt onset was defined as the time at which contact was made between the putter and ball, similar to Boutcher and Zinsser (1990). Heart rate change was processed via a custom-written program that used a peak detector for the identification of R-peaks. The interbeat intervals were screened for artifacts and the HR was calculated using time-based methods (Graham, 1978) to derive a value for each successive 0.5 s epoch. Heart rate change was calculated by taking the HR in each 0.5 s epoch and subtracting from that the HR at 11.5 s prior to putt onset. A negative change indicates a deceleration in HR. Finally, HRV was calculated by using the HRV module extension for the Chart software package (ADInstruments, Sydney). The R-peaks in the ECG signal were initially detected and screened for artifacts. The HRV analysis was next conducted using a cosine taper with 0.5 overlap. Spectral power was calculated across three bands to represent the VLF (0 to 0.04 Hz), LF (0.04 to 0.15 Hz), and HF (0.15 to 0.4 Hz) frequency components.

Respiration could not be recorded for two participants in the novice group and one participant in the elite group due to equipment problems. Respiration frequency was scored using the cyclic measurements function of the Chart (ADInstruments, Sydney) software package. The scoring parameters used the preset detection settings for the respiration transducer and a 0.9 standard deviation threshold for detecting the minimum peak height. The phasic changes in respiratory activity around the time of putt onset were scored by first converting the respiratory trace to z-scores for each participant for each putt to standardize the magnitude of the fluctuations across participants (negative z-scores indicate exhalation). The level of the respiratory trace in each 0.5 s epoch in the 11 s prior to putt onset and 11 s following putt onset was next calculated. In addition the respiratory pattern immediately prior to the putt was classified as inhaling, holding, or exhaling for each individual (Boutcher and Zinsser, 1990). A pattern of inhaling was defined as those in which a peak occurred in the respiratory trace within 2 s prior to the putt onset, and a pattern of exhaling was defined as those in which a trough occurred within the same window. Patterns of inhaling and exhaling showed variable oscillations leading up to the putt. A pattern of holding, by contrast, showed no oscillation immediately prior to the putt and was followed by a large change after the putt. Two raters who were blind to the participant group membership classified the respiratory patterns. The raters initially showed 94% agreement and were in 100% agreement following discussion.

Prior research investigating cardiac and respiratory patterns during golf putting have either not reported or not found gender differences (e.g., Boutcher and Zinsser, 1990). Nevertheless, preliminary statistical analyses were conducted to test for gender differences in the dependent measures. No main effects or interactions involving gender were found, all F s < 2.05 , $p > .05$. For this reason, subsequent analyses were collapsed across all participants in each group. A two-tailed significance level of .05 was used to evaluate all analyses. Post hoc

analyses employed *t*-tests that were adjusted for the accumulation of Type I error by using Šidák's multiplicative inequality (Games, 1977). Greenhouse-Geisser adjusted degrees of freedom were used for within-subjects factors of more than two levels.

3. Results

3.1. Putting performance

Performance, quantified as the number of putts holed, was compared across groups with a one-way ANOVA. Performance differed across groups, $F(2, 49) = 6.10, p < .01$. Post hoc comparisons showed that the elite ($M = 14.38, SD = 3.64$) and experienced golfers ($M = 13.31, SD = 3.21$) holed significantly more putts than novices ($M = 10.87, SD = 2.05$), both $t_s > 2.61, p < .05$. The elite and experienced golfers did not differ, $t < 1$.

3.2. Heart rate measures

The VLF, LF, and HF HRV measures were log transformed due to high positive skewness. Initial analyses showed that these measures, in addition to mean HR, were highly correlated (most $r > .64, p < .001$). As a result, a MANOVA was used for the analyses of these measures. The first set of analyses compared across groups when participants performed the reaction time task on its own to provide an indication of any differences between groups independent of the putting task. The multivariate effect was significant, $F(8, 92) = 2.41, p = .02, \lambda = .68$. Univariate ANOVAs were used to examine the differences between the groups in each measure. Groups differed in HR, $F(2, 49) = 8.96, p < .001$, the LF HRV component, $F(2, 49) = 4.39, p = .02$, the HF HRV component, $F(2, 49) = 5.14, p = .009$, but not the VLF HRV component, $F(2, 49) = 2.16, p = .13$. Post hoc analyses showed that HR in the novice group ($M = 105.08, SD = 12.34$) was higher than in the experienced group ($M = 88.82, SD = 15.67$) and elite group ($M = 89.25, SD = 10.33$), both $t_s > 3.38, p < .001$. The LF component was lower in the novice group ($M = 2.66, SD = .44$) than in the experienced group ($M = 3.09, SD = .52$), $t(49) = 2.73, p = .009$, but not the elite group ($M = 2.95, SD = .33$). The HF

component was also lower in the novice group ($M = 1.98$, $SD = .43$) than in the experienced group ($M = 2.48$, $SD = .63$), $t(49) = 2.86$, $p = .006$, but not the elite group ($M = 2.37$, $SD = .37$). The experienced and elite groups did not differ on any comparison, all $ts < 1$. Groups did not differ in mean respiratory frequency as assessed by a one-way ANOVA, $F(2, 45) = 0.08$, $p = .92$.

Due to the differences between groups in the HR measures independent of the putting task, a MANCOVA was used in the analyses of mean HR, VLF, LF, and HF HRV components during the putting task. The multivariate effect was significant, $F(8, 84) = 3.45$, $p = .002$, $\lambda = .57$. As shown in Figure 1, a pattern emerged in which groups did not differ in mean HR, but did differ in some components of HRV. Univariate covariate analyses confirmed these impressions with a difference across groups for the LF HRV component, $F(2, 45) = 6.19$, $p = .004$, whereas the difference across groups for the HF HRV component was not significant, $F(2, 45) = 2.45$, $p = .09$. Post hoc analyses confirmed that the LF HRV component was lower in the novice group than in the experienced and elite groups, both $ts > 2.52$, $p < .016$, which themselves did not differ, $t < 1$. Groups did not differ in HR or the VLF HRV component, both $Fs < 1.54$, $p > .05$.

 Insert Figure 1 about here

Heart rate change prior to and following the putt is shown in Figure 2. The participants showed an initial acceleration in HR followed by a deceleration near putt onset and an acceleratory component following putt onset. However, the groups differed in both the timing and magnitude of these components. A 3×44 (Group $\times$ Epoch) ANOVA confirmed these impressions with a main effect for Epoch, $F(43, 2150) = 28.46$, $\epsilon = .09$, $p < .0001$, and a Group $\times$ Epoch interaction, $F(86, 2150) = 5.82$, $\epsilon = .09$, $p < .0001$. The main effect for Group

was not significant, $F = 1.47, p > .05$.

 Insert Figure 2 about here

The Group x Epoch interaction was investigated further in two ways. The first strategy examined the 95% confidence intervals for the change in HR at each epoch. Heart rate change was deemed to be significantly different from the baseline if zero was outside the confidence interval. In the elite group, the initial HR acceleration was significant from 11 s to 6.5 s prior to putt onset and the subsequent deceleration was significant from 1.5 s prior until 3 s following putt onset. The later acceleration was significant from 4.5 s to 9.5 s following putt onset. In the experienced group, the initial acceleration was significantly different from zero only at 4.5 s prior to putt onset. The deceleration was significant from 1.5 s prior until 2.5 s following putt onset and the subsequent acceleration was significant from 4.5 s to 9.5 s following putt onset. In the novice group, no significant acceleration relative to baseline was evident either before or following putt onset. Deceleration was significant at putt onset until 3.5 s following putt onset. In sum, the elite and experienced groups showed more fluctuation in HR, with a significant deceleration that began prior to putt onset. In contrast, the novice group showed less variation in HR across the putt and a deceleration that began at putt onset.

The second strategy focused on the HR deceleration by using α -protected t -tests to compare between the three groups at each epoch from 1.5 s prior to until 3 s following putt onset. The analyses showed that HR differed between the elite and novice groups from 1.5 s prior until putt onset, all $ts > 3.53, p < .05$. The experienced and novice groups differed only at 1 and 0.5 s prior to putt onset, both $ts > 3.63, p < .05$. The elite and experienced groups did not differ at any epoch, all $ts < 1.31, p > .05$. The HR deceleration was thus more pronounced in the experienced and elite groups than in the novice group prior to the putt onset.

3.3. Respiration measures

The mean respiration rate across the 20 putts was 0.40 Hz ($SD = 0.08$) for the elite group, 0.44 Hz ($SD = 0.09$) for the experienced group, and 0.41 Hz ($SD = 0.11$) for the novice group. A one-way ANOVA did not find any significant differences between groups, $F < 1$.

The mean breathing frequency across all participants of 0.42 Hz ($SD = .09$) corresponds to 25 cycles per minute or one cycle approximately every 2.5 s.

The averaged pattern in respiratory activity around putt onset for each group is shown in Figure 3. A 3 x 44 (Group x Epoch) ANOVA resulted in a main effect for Epoch, $F(43, 2021) = 4.33$, $\epsilon = .20$, $p < .0001$, whereas all other main effects and interactions were not significant, all other $F_s < 1.37$, $p > .05$. As can be seen in Figure 3, the main source of variation was evident at the time interval between 2 s prior to putt onset until 2 s following putt onset. Examination of the 95% confidence intervals during this interval indicated that respiratory effort was significantly above zero (indicating inhalation) at 1 s prior and at putt onset in the novice group, whereas respiratory effort was significantly below zero (indicating exhalation) in the elite group between 1 and 0.5 s prior to the putt and in the experienced group between 4 and 3 s and at 1.5 s prior to the putt. The elite and experienced groups showed respiratory effort significantly above zero following putt onset. This occurred between 0.5 and 1 s and at 4.5 s for the elite group, and between 0.5 and 1.5 s and 4 and 4.5 s for the experienced group.

Insert Figure 3 about here

The classification of the respiratory state of the participants immediately prior to the putt is shown in Table 2. The dominant pattern tended to differ between the groups, as

confirmed by chi-square analysis, $\chi^2(4) = 17.63, p = .001$. Further analyses were conducted by examining the adjusted standardised residuals in each cell (MacDonald and Gardner, 2000) with an α -value adjusted for inflated Type I error using Šidák's correction. More elite golfers (72%) showed a pattern of exhaling immediately prior to the putt than expected by chance, $z_{\text{adj}} = 3.2, p < .05$. In contrast, more novice golfers (69%) showed a pattern of inhaling, $z_{\text{adj}} = 3.3, p < .05$, and fewer novice golfers (7%) showed a pattern of exhaling, $z_{\text{adj}} = -3.5, p < .05$, immediately prior to the putt than expected by chance. Although most experienced golfers tended to show a pattern of exhaling (44%), examination of the residuals indicated that there was no dominant pattern in this group, all $p > .05$.

 Insert Table 2 about here

4. Discussion

The present study showed that elite, experienced, and novice golfers show some similarities, but also important differences in their patterns of cardiac and respiratory activity during a putting task. Making a 2.4 m putt along a level surface was a relatively easy task as shown by novices being able to hole approximately half their putts. The elite and experienced golfers performed significantly better in that they holed approximately 72% and 67% of putts, respectively. The similar scores for the elite and experienced golfers suggest that performance was most closely associated with practice on the task of putting, rather than attaining an elite level in the sport. The group differences in cardiac and respiratory activity were largely consistent with the performance measures in that elite and experienced golfers together showed higher power in the LF HRV component, more pronounced deceleration of HR immediately prior to the putt, and a greater tendency to show a respiratory pattern of exhaling prior to the putt than novice golfers. However, some subtle differences also emerged between

the elite and experienced golfers in HR deceleration and breathing patterns immediately prior to the putt.

The tonic measures derived from cardiac activity indicated that a higher skill level was associated with increased HRV in the LF frequency band. This difference is consistent with the notion that the attainment of a proficient level of expertise in sport is associated with increased automaticity and reduced attentional demands (Abernethy et al., 2007; Wulf, 2007). An increase in mental workload demands during computer-based tasks or simulated human-machine interactions (e.g., flight simulators) has been associated with reduced power in the LF component of HRV (Egelund 1982; Neumann, 2002; Veltman and Gaillard 1998). When applied to the present results, it would appear that the novice golfers were investing greater attentional effort into the putting task than elite and experienced golfers, despite the fact that this did not result in a similar level of performance. The novelty of the putting task may have contributed to the increased attentional demands in the novice participants. Alternatively, the novelty of the task could have induced some degree of stress due to performance scrutiny in the novices and this may have influenced the psychophysiological measures.

The results obtained for the phasic change in HR around the time of putt onset replicated previous findings of a marked deceleration in highly skilled golfers (Boutcher and Zinsser, 1990; Hassmén and Koivula, 2001; Molander and Backman, 1989) that was more pronounced than in novice golfers (Boutcher and Zinsser, 1990). However, Boutcher and Zinsser (1990) concluded that novice golfers showed a significant deceleration in HR, which contrasts to the present results in which the deceleration was not statistically different from a baseline taken at 11 s prior to putt onset. The different interpretations may reflect the ways in which the data were examined. For instance, we examined HR as a function of the change from the level of HR that was present at 11.5 s prior to putt onset, whereas Boutcher and Zinsser (1990) concluded HR deceleration on the basis of a comparison between the fourth

interbeat interval before ball contact and the interbeat interval at ball contact. The authors concluded that HR decelerated from 93 bpm to 78 bpm between these time periods for a 3.6 m putt. A similar analysis extended to the present data in the novice group showed that mean HR was 110.76 bpm ($SD = 12.31$) at the epoch starting 2.5 s prior to putt onset and 106.71 bpm ($SD = 11.64$) at the epoch starting at putt onset. The difference of 4.05 bpm is consistent with a deceleration across the same time period, although it is considerably more modest than that reported by Boutcher and Zinsser (1990).

The elite and experienced golfers also differed from the novice golfers in that the HR deceleration began earlier and was greatest at a time that coincided with the contact between the putter and the ball. In contrast, the HR deceleration for novice golfers was greatest at 1.5 s following putt onset. The earlier onset of the HR deceleration in the elite and experienced golfers may indicate a more effective preparatory routine than the novice golfers based on the interpretation of HR change offered by Lacey and Lacey (1974, 1980). The higher skilled golfers may have been more effective in encoding information about the external environment and focusing on external cues related to the shot (e.g., ball, line, and hole) early on in the routine. In contrast, the novice golfers may have adopted a preshot routine in which attention initially focused on internal cues as shown by the small acceleration observed between 3 and 1 s prior to putt onset. They subsequently focused attention on external cues, although this external focusing was most apparent after the putter contacted the ball.

The present results support the intake-rejection hypothesis of Lacey and Lacey (1974, 1980) and suggest that superior putting performance was associated with a more effective external focusing of attention. An alternative hypothesis, the cardiac-coupling hypothesis of Obrist (1968), suggests that the deceleration of HR is associated with an external focusing of attention because of the reduced muscle and metabolic activity that is associated with external tasks. However, the present results do not seem to support this explanation because the HR

deceleration in elite and experienced golfers was observed to occur between putt onset and up to 5 s prior to putt onset. During this time, the golfers engaged in practice strokes and movements that would have had the effect of increasing muscle and metabolic activity. The fact that HR deceleration was observed in spite of these preparatory actions is thus better accounted for by Lacey and Lacey's (1974, 1980) intake-rejection hypothesis.

A second alternative explanation could be that the HR deceleration reflects respiratory influences rather than attentional effects due to the relationship between breathing and heart rate. Respiratory sinus arrhythmia corresponds to the slowing down of heart rate during exhalation and an increase in heart rate during inhalation. An examination of the breathing patterns for the elite golfers indicated that 72% showed a pattern of exhaling immediately prior to the putt and this may explain the associated deceleration in HR. However, additional evidence suggests that it does not provide a full explanation of the HR pattern. First, the HR deceleration in elite golfers began approximately 7 s prior to putt onset. Inspection of the respiratory patterns indicated that elite participants did not begin their final preputt exhale until closer to putt onset. Second, experienced golfers showed a similar deceleration in HR as that observed in elite golfers. However, the experienced golfers as a group exhibited a more diverse range of respiratory patterns. The fact that there was no clear dominant pattern in this group, despite the finding of significant HR deceleration, further suggests that the HR change was largely due to attentional factors.

The elite and experienced groups were similar in many indices of cardiac and respiratory activity as might be expected based on the similar performance between these two groups. However, there were some notable exceptions. The elite group showed a dominant pattern of exhaling (72%) with few elite golfers showing a pattern of inhaling (17%) or holding (11%). Although a pattern of exhaling was the most common in the experienced group, fewer golfers (44%) adopted this pattern than in the elite group. Instead, the

experienced golfers showed a more even distribution across the different respiratory patterns. The deceleration in HR also appeared to begin earlier and last longer in the elite group than in the experienced group. The differences may reflect that elite golfers showed a tendency to adopt an external focus of attention earlier during the preshot routine than experienced golfers. Taking the results together, it would appear that the attainment of an elite level within a sport might be associated with more subtle differences in physiological patterning over that achieved through extensive experience. Further research could use more challenging tasks, such as difficult putts or realistic competition conditions, to determine if increased difficulty enhances the psychophysiological differences between elite and experienced golfers.

In differential research that compares groups based on pre-existing characteristics, non-psychological factors may contribute to the differences that are found. The three groups in the present experiment were matched on age and gender and the elite and experienced groups were matched on playing experience. However, a possible limitation is that the use of medications, consumption of caffeine, tobacco smoking, or heavy exercise prior to the test session was not compared across groups. Each of these factors can influence cardiovascular activity. Future research could control for these variables by, for example, giving participants instructions to avoid consuming drinks containing caffeine or smoking tobacco in the 24 hours prior to the test session. In addition, we did not take a baseline measurement of physiological activity that was independent of any tasks. Our baseline measurement was taken when participants performed a reaction time task and as such was a novel task for all participants. However, a resting or no-task baseline would be preferable.

The present research also presented methodological challenges due to the physical nature of the task. As noted above, heart rate is sensitive to both psychological and physical aspects of the putting task. Likewise, the physical aspects of putting may have influenced the observed respiratory patterns. For instance, a relatively large positive change in the

respiratory pattern (indicating an inhalation) was observed immediately following putt onset. The respiratory pattern was recorded by a transducer placed around the participants' chest and as such this apparent change may reflect, at least in part, the upper-torso movement in the putting action. An alternative approach to measuring respiration, such as using a sensor that detects nasal inhalation and exhalation, could be used to examine this possibility in future research. A final methodological note is that it was difficult to obtain an accurate registration of the onset of the back lift prior to the putting stroke. The infrared beam that was used proved to be unreliable due to the small or absent backswings in several participants. The contact between the putter and ball was thus used, similar to Boutcher and Zinsser (1990). Crews and Landers (1993) noted that from a psychological perspective, the putt onset may be more appropriately defined by the onset of the putting movement. To measure back lift onset in a more reliable manner may require alternative technology, and we have begun to explore other methods including the use of accelerometers or a reed switch. Alternatively, a video camera that is placed side-on and is time-locked to the other recording equipment could be used. A video camera would allow researchers to detect the onset of multiple aspects of the putt (e.g., back lift, contact with ball) and measure other aspects of the putting action (e.g., velocity of swing, amount of back lift).

In summary, the present results suggest that there are certain psychophysiological patterns that are associated with the attainment of skilled performance in golf putting and some that are unique to attaining an elite level in the sport. Further research is required to determine the extent to which the present results, particularly those obtained with HRV, are applicable to other self-paced sports such as archery, pistol shooting, and rifle shooting. Moreover, it remains to be determined whether the information gained can be applied in developing psychophysiological training programs for golfers at different levels of ability. For instance, cardiac and respiratory activity might be assessed while golfers attempt putts. A

comparison between the individual's profile and the typical patterns shown by elite athletes would indicate what aspects of performance require further training. Such training programs, however, would hinge on identifying the causal mechanisms by which the differences between athletes at different skills levels occur. A training program based on the goal of increasing HR deceleration immediately prior to the putt may be best served by using techniques that enhance the individual's ability to focus attention on external cues related to the task.

References

- Aasman, J., Mulder, G., & Mulder, L.J.M. 1987. Operator effort and the measurement of heart rate variability. *Hum. Factors* 29, 161-170.
- Abernethy, B., Maxwell, J.P., Masters, R.S.W., Van Der Kamp, J., Jackson, R.C. 2007. Attentional processes in skill learning and expert performance. In: Tenenbaum, G., Eklund, R.C. (Eds.), *Handbook of Sport Psychology*, 3rd edn., John Wiley & Sons, Hoboken, pp. 245-283.
- Boutcher, S.H., Zinsser, N.W. 1990. Cardiac deceleration of elite and beginning golfers during putting. *J. Sport Exercise Psy.* 12, 37-47.
- Collins, D. 2002. Psychophysiology and athletic performance. In: Blumenstein, B., Bar-Eli, M., Tenenbaum, G. (Eds.), *Brain and Body in Sport and Exercise: Biofeedback Applications in Performance Enhancement*, John Wiley & Sons, New York, pp. 15-36.
- Cotterill, S. Collins, D. 2005. Heart rate deceleration characteristics across shot types in golf. *J. of Sports Sci.* 23, 173-174.
- Crews, D.J. Landers, D.M. 1993. Electroencephalographic measures of attentional patterns prior to the golf putt. *Med. Sci. in Sports and Exer.* 25, 116-126.
- Egelund, N. 1982. Spectral analysis of heart rate variability as an indicator of driver fatigue. *Ergonomics* 25, 663-672.
- Games, P.A. 1977. An improved t table for simultaneous control on g contrasts. *J. Am. Stat. Assoc.* 72, 531-534.
- Graham, F.K. 1978. Constraints on measuring heart rate and period sequentially through real and cardiac time. *Psychophysiology* 15, 492-495.
- Grossman, P. 1992. Respiratory and cardiac rhythms as windows to central and autonomic biobehavioral regulation: Selection of window frames, keeping the panes clean and viewing the neural topography. *Biol. Psychol.* 34, 131-161.

- Hassmén, P., Koivula, N. 2001. Cardiac deceleration in elite golfers as modified by noise and anxiety during putting. *Percept. Motor Skill*. 92, 947-957.
- Hatfield, B.D., Landers, D.M., Ray, W.J. 1987. Cardiovascular-CNS interactions during a self-paced, intentional attentive state. *Psychophysiology* 24, 542-549.
- Lacey, B.C., Lacey, J.I. 1974. Studies of heart rate and other bodily processes in sensorimotor behavior. In: Obrist, P.A., Black, A.H., Bener, J., DiCara, L.V. (Eds.), *Cardiovascular Psychophysiology*, Aldine, Chicago, pp. 538-564.
- Lacey, B.C., Lacey, J.I. 1980. Cognitive modulation of time-dependent primary bradycardia. *Psychophysiology* 17, 209-221.
- MacDonald, P.L., Gardner, R.C. 2000. Type I error rate comparisons of post hoc procedures for I x J chi-square tables. *Educ. Psychol. Meas.* 60, 735-754.
- Molander, B., Backman, L. 1989. Age differences in heart rate patterns during concentration in a precision sport: implications for attentional functioning. *J. Gerontol.: Psychol. Sci.* 44, 80-87.
- Mullen, R., Hardy, L., Tattersall, A. 2005. The effects of anxiety on motor performance: A test of the conscious processing hypothesis. *J. Sport Exercise Psy.* 27, 212-225.
- Neumann, D.L. 2002. Effect of varying levels of mental workload on startle eyeblink modulation. *Ergonomics*, 45, 583-602.
- Neumann, D.L., Thomas, P.R. 2008. A camera-based scoring system for evaluating performance accuracy during a golf putting task. *Behav. Res. Methods* 40, 892-897.
- Obrist, P.A. 1968. Heart rate and somatic-motor coupling during classical aversive conditioning in humans. *J. Exp. Psychol.* 77, 180-193.
- Radlo, S.J., Steinberg, G.M., Singer, R.N., Barba, D.A., Melnikov, A. 2002. The influence of an attentional focus strategy on alpha brain wave activity, heart rate, and dart-throwing performance. *Int. J. Sport Psychol.* 33, 205-217.

- Salazar, W., Landers, D., Petruzzello, S., Han, M., Crews, D., Kubitz, K. 1990. Hemispheric asymmetry, cardiac response and performance in elite archers. *Res. Q. Exercise Sport* 61, 351-359.
- Tremayne, P., Barry, R.J. 2001. Elite pistol shooters: physiological patterning of best vs. worst shots. *Int. J. Psychophysiol.* 41, 19-29.
- Veltman, J.A., Gaillard, A.W.K. 1998. Physiological workload reactions to increasing levels of task difficulty. *Ergonomics* 41, 656-669.
- Wulf, G. 2007. Attention and motor skill learning. Human Kinetics, Champaign.

Author Notes

This research was supported under Australian Research Council's Linkage Projects Funding Scheme (Project Number LP0667727). Thanks to Minhtri Pham and Xuesong Le for computer programming assistance, Martin Hampson for data collection assistance, and Michelle Neumann for data scoring assistance.

Table 1. Demographic characteristics of the novice, experienced, and elite golfers (mean values given with standard deviations in parentheses)

Measure	Group		
	Novice	Experienced	Elite
Male:Female ratio	11:6	11:5	13:6
Age (years)	21.35 (6.02)	25.94 (6.46)	22.58 (4.14)
Handicap	-	8.00 (7.04)	0.32 (1.67)
Experience (years)	0	11.94 (7.10)	10.63 (4.41)
Playing frequency (per month)	0	7.88 (7.01)	13.74 (8.26)

Table 2. Classification of the respiratory patterns immediately prior to the putt for the novice, experienced, and elite groups averaged across all putting conditions

Respiratory Pattern	Group		
	Novice	Experienced	Elite
Inhaling	69%	25%	17%
Holding	25%	31%	11%
Exhaling	6%	44%	72%
Total	100%	100%	100%

Figures

Figure 1. Mean heart rate (left panel) and mean spectral power for the very low frequency (VLF), low frequency (LF), and high frequency (HF) components for heart rate variability (right panel) in the novice, experienced, and elite groups. The means shown are adjusted against the covariates in the model. Error bars depict the standard error of the mean.

Figure 2. Mean heart rate (HR) change in the novice, experienced, and elite groups. The minimum time value for each epoch is indicated and negative values indicate epochs prior to putt onset (e.g., -1 s is the epoch that spanned from 1 to 0.5 s prior to the putt). Error bars are omitted to maintain clarity in the figure.

Figure 3. The mean pattern in respiratory activity prior to and following putt onset in the novice, experienced, and elite groups. Positive values indicate inhalation and negative scores indicate exhalation. The minimum time value for each epoch is indicated and negative values indicate epochs prior to putt onset (e.g., -1 s is the epoch that spanned from 1 to 0.5 s prior to putt onset). Error bars are omitted to maintain clarity in the figure.