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Relation	

The influence of monetary reward and punishment on psychological, physiological, behavioral, and performance aspects of a golf putting task

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Abstract

The first purpose of the present study was to examine kinematic characteristics and force control during a golf-putting task under a pressure condition. The secondary purpose was to provide an exploratory investigation of the relationship between changes in behavior (kinematics and force control) and performance on the one hand, and psychological (attention and affect) and physiological (arousal level) changes on the other. Twenty male novices performed 150 acquisition trials, followed by 10 test trials during a pressure condition induced by performance-contingent distracters: a cash reward or punishment. A three-dimensional motion analysis revealed that, during the pressure test, angular displacements of rotational movements at the horizontal plane and movement time of the arms and club during the backswing and downswing phases all decreased, while acceleration of the elbows during the downswing phase increased. Mean performance indices in all participants' were unchanged in spite of the kinematic changes under the pressure condition. Multiple regression analyses indicated that the decrement in performance, as well as increased variability of movement time and speed, were more likely to increase when participants shifted their attention to movements. Furthermore, changes in heart rate and negative affect were related to both the increase in movement acceleration and a decrease in grip force. These findings suggest that performance and behavioral changes during golf-putting under pressure can be associated with attentional changes, along with the influences of physiological-emotional responses.

Keywords: stress, motion analysis, force control, attention, arousal, affect.

1. Introduction

Various kinds of psychological stressors occur in a competitive sports context, including presence of an audience, potential acquisition of prize money, and evaluation of one's performance by others. One such psychological stressor is pressure. Pressure is defined as "any factor, or combination of factors that increases the importance of performing well on a particular occasion (Baumeister, 1984, p.610)." Baumeister also defined choking under pressure as "performance decrements under pressure circumstances." Overcoming performance decrements under pressure is a serious challenge faced by many athletes.

Many previous studies have examined motor behavior under pressure. These studies evaluated motor performance as well as stress responses across three different dimensions: psychological, physiological and behavioral. In terms of the psychological dimension of the stress response, it has been reported that changes in attention are observed under pressure, including increased self-awareness (Liao & Masters, 2002) and increased mental effort directed toward completion of tasks (Williams, Vickers, & Rodrigues, 2002; Wilson, Smith, Chattigton, Ford, & Marple-Horvat, 2006), along with emotional changes such as increased state anxiety (e.g., Weinberg & Hunt, 1976). As for the physiological dimension, changes in autonomic nervous and endocrine system functioning have been observed, including increased heart rate (HR) (e.g., Beuter, Duda, & Widule, 1989), decreased percentage of high-frequency sub-band in HR variability (Mullen, Hardy, & Tattersall, 2005), and increased production of cortisol (Salvador, Suay, González-Bono, & Serrano, 2003), indicating that physiological arousal tends to increase under pressure.

The behavioral dimension of motor performance under pressure has been studied from both the kinematics and kinetics points of view. Previous studies that examined kinematic characteristics using two-dimensional motion analysis found decreased movement displacement (Beuter et al., 1989; Tanaka & Sekiya, 2010a), movement speed (Tanaka & Sekiya, 2010a), and movement coordination (Tanaka, Urimoto, Murayama, & Sekiya, 2009) under pressure. Previous studies of variability in kinematic functions under pressure have reported contradictory results, including both increases (Higuchi, 2000; Gray, 2004; Tanaka & Sekiya, 2006) and decreases (Court, Bennett, Williams, & Davids, 2005; Tanaka et al., 2009; Tanaka, Yamamoto, & Sekiya, 2010). These contradictory findings might pertain to optimal control theory. In this theory, increased variability in task-irrelevant movement parameters is considered to be a positive factor in terms of performance outcomes, whereas increased variability of task-relevant movement leads to poor motor performance (Diedrichsen, Shadmehr, & Ivry, 2010; Todorov & Jordan, 2002).

These studies employed two-dimensional motion analysis. Two-dimensional motion analysis can be used to calculate kinematic variables pertaining to translational movements on one dimension. However, this approach cannot be used to calculate many other kinds of variables, including those pertaining to rotational movements. It is therefore necessary to use three-dimensional motion analysis to calculate kinematic variables such as movement displacement, movement speed and movement time, including both translational and rotational movements, and this approach should therefore prove more useful in the evaluation of the effects of pressure on motor behavior. Williams et al. (2002) examined motor behavior during table tennis and provide the only study to date that has used three-dimensional motion analysis to examine kinematic variables under pressure. While Williams et al. observed some behavioral changes under pressure, including decreases in performance accuracy and increases in gaze frequency, they did not identify any kinematic changes.

Previous studies that measured electromyograms (EMG) report that pressure causes kinetic changes such as prolonged EMG dwell time (Weinberg & Hunt, 1976), higher EMG amplitude (Tanaka, Funase, Sekiya, Sasaki, & Takemoto, 2011; Yoshie, Kudo, Murakoshi, & Ohtsuki, 2009; Yoshie, Kudo, & Ohtsuki, 2008), and increased co-contraction between prime movers (agonists) and antagonists (Weinberg & Hunt, 1976; Yoshie et al., 2008; Yoshie et al., 2009). In contrast, other studies report no changes in these measurements under pressure (Tanaka & Sekiya, 2006; Tanaka et al., 2009). These EMG studies evaluated force control in body parts that are involved in the execution of given motor skills. In studies that evaluated kinetic characteristics under conditions of psychological stress incurred by performing mental arithmetic (van Loon, Masters, Ring, & Mclntyre, 2001) and exposure to auditory stimuli (Coombes, Gamble, Cauraugh, & Janelle, 2008), force control of net forces generated by muscular activities in each of the body parts was evaluated using a force-sensor. As was done in these studies, evaluation of force control of net forces during execution of motor skills may also be necessary when examining kinetic characteristics of motor skills under pressure.

Many previous studies indicate that attentional shift, a psychological dimension, is a cause of poor performance under pressure. According to previous studies, there are two types of attentional shifts that cause decreased performance. First, by using instructions to experimentally manipulate participants' attentional focus, it has been reported that increased attention toward movements leads to poor performance (Baumeister, 1984; Masters, 1992). Second, some theoretical perspectives suggest that reduced attention paid to the execution of motor skills is related to poor performance under pressure (Wine, 1971; Eysenck, 1979). The former view is called the conscious processing hypothesis, while the latter is dubbed the distraction hypothesis. Eysenck and Calvo (1992) extended the distraction hypothesis to include the processing efficiency theory. This theory explains the relationship between *processing efficiency,* defined as the invested amount of processing resources, and *performance effectiveness,* defined as the subsequent performance outcome. Furthermore, Eysenck, Derakshan, Santos, and Calvo (2007) integrated the processing efficiency theory with the attentional control theory. The attentional control theory refers to the underlying mechanisms of processing efficiency from the perspective of balance between stimulus-driven and goal-directed attentional systems in central executive functions that involves inhibition, shifting, and updating. There have been many debates over which of these hypotheses are correct when it comes to identifying the primary cause of decreased performance under pressure. Whereas some studies support the conscious processing hypothesis (e.g., Lewis & Linder, 1997; Beilock & Carr, 2001), others support the distraction view (e.g., Williams et al., 2002; Wilson et al., 2006).

Recently, a few studies have examined the underlying behavioral mechanism of internal and external foci of attention for motor performance in non-pressure situations (Lohse, Sherwood, & Healy, 2010; Wulf, Dufek, Lozano, & Pettigrew, 2010). Lohse et al. (2010) found that better performance on a dart-throwing task was associated with less EMG activity and increases in functional inter-trial variability under conditions of an external focus of attention, as compared to an internal focus. Wulf et al. (2010) also found that this economical motor control associated with an external focus of attention was related to increased jump height during a vertical jump-and-reach task. These studies have examined the relationships between attentional shifts and behavioral characteristics in non-pressure situations. However, only a few studies have investigated the behavioral characteristics that might intervene between attentional shifts and ultimate motor performance under pressure. By examining such behavioral characteristics, one can approach the issue of what causes a decline in performance under pressure from a new behavioral angle.

In addition, previous studies have also addressed the relationship between affect and physiological arousal on the one hand and motor performance on the other. For instance, Yerkes and Dodson (1908) suggest that there is an inverted-U shaped relationship between physiological arousal and motor performance, and it has been reported that an inverted-U pattern also holds for the relationship between physiological arousal under pressure and performance accuracy on a tracking task (Martens & Landers, 1970). Several theoretical models have been proposed to account for the relationship between motor performance and both psychological and physiological changes under pressure. These include the “catastrophe model”, which seeks to estimate motor performance using the interactions between cognitive anxiety and physiological arousal (Hardy, 1990), and the multi-dimensional theory of anxiety, which accounts for the relationship between motor performance and three measures: cognitive anxiety, somatic anxiety, and self-confidence (Martens, Burton, Vealey, Bump, & Smith, 1990). However, studies of these models fail to address the behavioral dimension, which includes kinematic and kinetic functions intervening along with psychological factors, physiological factors, and final motor performance under pressure.

Given the aforementioned background, the primary purpose of the present study was to use three-dimensional motion analysis to evaluate kinematic characteristics during execution of motor skills under pressure, and to use a force sensor to examine force control under pressure.

The secondary purpose was to examine the relationship between psychological (attention and affect) / physiological (arousal level) aspects of experience on the one hand, and performance / behavioral aspects (kinematics and force control) of a motor skill conducted under pressure on the other. Golf putting was used as an experimental task in this study because it has been used in many previous studies that examined human motor behavior under pressure (e.g., Beilock and Carr, 2001; Lewis and Linder, 1997; Masters, 1992; Mullen et al., 2005; Tanaka and Sekiya, 2010a).

It was predicted that pressure would influence not only the translational movement kinematics reported in some previous golf-putting studies (e.g., Tanaka & Sekiya, 2010a), but also that rotational movement and/or force control parameters would be affected. In previous studies, two different possibilities based on attentional shifts have been advanced as potential causes of poor performance under pressure. We predicted that some changes in movement kinematics or force control, along with changes in conscious control of movements, would lead to poor performance outcomes under a pressure condition. This is because many previous studies using a golf-putting task, which involves use of a discrete and closed motor skill, support the conscious processing view that internal focus of attention is related to poor motor performance under pressure (e.g., Lewis & Linder, 1997; Masters, 1992). In addition, physiological arousal changes would be expected to lead to some behavioral and/or performance changes, with several theoretical models being proposed to account for the relationship between motor performance and physiological changes under pressure (Hardy, 1990; Martens et al., 1990; Martens & Landers, 1970). We did not adopt a hypothesis verification approach but rather an exploratory one, in order to examine the relationship between psychological / physiological aspects and performance /

behavioral aspects of performance under pressure.

2. Method

2.1. *Participants*

Twenty right-handed male university students aged 19.7 ± 0.5 years who had no experience in playing golf participated. Informed consent was obtained from all participants.

2.2. *Task and apparatus*

The participants performed a golf-putting task in a laboratory. They hit a golf ball on artificial turf toward a target that was 1.5 m from the putting point. Each target comprised nine concentric circles. The outermost circle had a diameter of 90 cm, and each consecutive circle was reduced by 10 cm, such that the innermost circle was 10 cm in diameter. For scoring purposes, areas between one circle and the next were assigned values of 9, 8, 7, 6, 5, 4, 3, 2, and 1 points (from inner to outer circle). No points were awarded for a putted ball that landed outside the outermost circle. All participants putted right-handed, and were told to score as many points as possible on each trial. All participants used the same standard golf putter and the same standard golf balls.

Putting movements were videotaped with three digital high-speed cameras (DKH B cam), with a sampling frequency of 100 Hz. These three cameras were placed in front of, to the left front of, and to the right side of participants. Movement kinematics was analyzed using a three-dimensional analysis (DKH Frame-DIAS for Windows). A digital video camera (Sony DCR-TRV70K) was placed above the target in order to videotape the golf ball locations on the target. A force-sensor was used to measure grip force, and an analog-to-digital converter (AD Instruments PowerLab/4st) with a sampling frequency of 1000 Hz was used to generate force signals. The State-Trait Anxiety Inventory-Form JYZ (STAI Y-1; Hidano, Fukuhara, Iwawaki, Soga, & Spielberger, 2000) was used to measure state anxiety. The Japanese version of Positive and Negative Affect Schedule (PANAS; Sato & Yasuda, 2001) was used to measure positive and negative affect. HR was measured during the golf-putting task with a HR monitor (Canon Bandage XL).

2.3.*Procedure*

Participants were tested individually. After each participant entered the laboratory, the transmitter of the HR monitor was attached to his chest, and a receiver was attached to his left wrist. Six reflecting markers for movement analysis were attached to the elbows (capitulum humeri), the hip (i.e. both ends of a bar that was attached to the back of participants), and two positions on the putter (between the shaft and the head, and at the tip of the head). Moreover, the force-sensor was attached to the right little finger phalanx distalis on the palm side, to measure grip force. The participant was instructed to hold the putter with a normal grip. The following three instructions, derived from the advice of two professional golf instructors from the Japan Professional Golf Association, were given to each participant: (1) Hold the putter with optimal force, (2) Keep the lower half of the body in a fixed position, keep the elbow and wrist straight, and swing the putter from the shoulder, and (3) Swing the putter back with precise speed and then swing it forward. If participants asked any further questions about the golf-putting task, the experimenter provided further instruction.

After receiving general instructions, the participants performed 150 acquisition trials (15 blocks of 10 trials each), in order to acquire the golf putting task and become familiarized with the experimental setting. State anxiety, positive and negative affect were measured before the last block of acquisition trials. During the last acquisition block, putting movements, ball location on the target, grip force, and HR were all recorded. The participants were provided with instructions designed to produce pressure in the following test session. Each participant was told that he would receive a cash reward of 10,000 JPY if his test score exceeded the highest score of any acquisition trial block. However, participants were also told that an electric shock would be administrated after the test if the putting scores for each of the 10 test trials were lower than the value calculated by subtracting the standard deviation of the 50 acquisition trials from the 11th to 15th blocks from the mean of the same 50 trials (if a participant marked 5.2 ± 1.1 points during the final 50 acquisition trials, he was instructed that a penalty is administrated when the scores for each of the 10 test trials were 4.1 points or lower). Moreover, they were told that the strength of electric shock would increase to two to ten times the strength of strong static electricity every time a lower score was recorded during each of the 10 test trials. These two different types of stressor were used in order to create psychological and physiological stress responses that were as strong as possible. Previous studies have also used compound stressors to induce greater stress responses under pressure conditions (e.g., Masters, 1992; Mullen & Hardy, 2000; Williams et al., 2002). In fact no shocks were administered, even if the test score was less than the score on the final 50 acquisition trials. This false instruction about punishment was created based on Higuchi, Imanaka, and Hatayama's (2002) study in which a similar false instruction produced a psychological stress. Following these instructions, participants answered the STAI Y-1 and the PANAS.

Next participants performed 10 trials in a final test block. During testing, putting movements, ball location on the target, grip force, and HR were all recorded. Putting scores were provided to each participant as feedback after each trial, for all acquisition and test trials. In addition, the scores for each block were provided after each block in both acquisition and test phases. Following the block of test trials, participants answered a questionnaire, comprising four questions (Q1-Q4), which was designed to measure attentional focus during test trials (see Table 1). In previous studies of attentional focus under pressure, conscious control of movements (e.g., Masters, 1992) and distraction (e.g., Wine, 1971) led to relatively poor motor performance. Q1 and Q2 were included in the present study to investigate conscious control of movements, while Q3 was intended to investigate the effect of distraction under pressure. Other attentional foci not asked about in Q1 through Q3 were asked about in Q4. This questionnaire was similar to those used in previous studies that measured participants' attentional focus (Tanaka and Sekiya, 2010a, 2010b), which provides some evidence for construct validity.

A structured interview was conducted in which an experimenter recorded participants' self-reported answers to the questionnaire. The participants could view the questions and response options during the structured interview. For Q1 and Q4, the participants were instructed to describe certain changes in attention that started in test trials relative to their experience in the final (15th) block of acquisition trials; using a 9-point scale, anchored between +4 (*I started paying a close attention*), 0 (*no effects*), and -4 (*I started paying no attention*). For Q2 and Q3, the participants were instructed to describe the degree to which their attention was directed to the test, also by using a 9-point scale, anchored between 8 (*my attention was very much directed to it*), 4 (*my attention was somewhat directed to it*), and 0 (*my attention was not directed to it at all*). In addition, for Q1, Q2 and Q4, the participants first gave a self-report regarding the specific object or focus of their attention (using multiple responses if necessary) before indicating this element on a point on the 9-point scale. After the participants provided their responses to the all questions, they were told that the section of the instructions regarding the electric shock was not true.

2.4.*Dependent Measures*

As indices of the emotional aspect of performance, state anxiety, positive and negative affect were measured via the STAI Y-1 and the PANAS before the last block of acquisition trials, and again before the test phase. These questionnaires have been widely used to assess emotional states under pressure (e.g., Weinberg and Hunt, 1976; Tanaka and Sekiya, 2010b). Answers to the questionnaire were taken as indices of attentional foci. As an index of physiological arousal, HR was measured during the last block of acquisition trials and during the test at 5-second intervals.

In order to analyze movement kinematics, reflective markers were videotaped during the last block of acquisition trials and during the test. The digitized data were smoothed with an every three points filter after time-domain waveforms at 6 Hz. The putting movements were classified into backswing (BS), downswing (DS), and follow-through (FT) phases, based on club movement.

The linear movement amplitudes of the right elbow and club head during the BS, DS, and FT phases were examined, as spatial aspects of the movement. The averaged velocities of the right elbow and club head during the BS, DS and FT phases were used to reflect the speed of the movement. The averaged accelerations of the right elbow and club during the BS, DS and FT phases were used to reflect acceleration. The movement times for the club during the BS, DS and FT phases were examined as temporal aspects. We analyzed these variables pertaining to the kinematic functions that were described using two markers attached to the club (the tip of the head) and right elbow, because the golf putting task required participants to control club head movement in the frontal plane. Previous studies that used a golf putting task also measured spatial and temporal aspects of club head movement (Coello, Delay, Nougier, & Orliaguet, 2000; Craig, Delay, Grealy, & Lee, 2000; Delay, Nougier, Orliaguet, & Coello, 1997; Mullen & Hardy, 2000). Furthermore, the upper-arms, forearms, hands, and club movements in the golf-putting task were produced by the abduction and adduction movements of shoulder joints with fixing the lower half of the body and trunk. The abduction and adduction movements of shoulder joints were measured by capturing the elbow kinematics. Therefore, in the present study, elbow kinematics were taken to represent the movement of the arm. In addition, angular displacements of rotational movements of the club, arm, and hip on the horizontal plane during the BS, DS and FT phases were calculated, to serve as indices for indicating spatial scale of rotational movements. The standard deviations (over trials) of these kinematic measures were used to reflect inter-trial variability within each participant's performance.

Grip force during the golf-putting task varied from trial to trial in each block. We therefore calculated the mean grip force during the BS, DS and FT phases in each trial during the 15th block of the acquisition trials and test trials, based on the waveforms of the right little finger's grip force. The mean of the 10 test trials and the 15th block of the acquisition trials (an index that indicates amplitude of grip force during each of the phases) and the standard deviation of the 10 test trials and the 15th block of the acquisition trials (an index that indicates variability in grip force during each of the phases) were also calculated. Also, with each of the trials in the 15th block and those in the test block, a signal indicating the start of filming with the high-speed cameras was entered into PowerLab/4st. The starting point of each trial was determined by this signal and marked on the waveforms of grip force.

As an index of performance, mean putting scores for each trial were obtained for each block of 10 trials. In addition, absolute error (AE(x)), absolute constant error (ACE(x)), and variable error (VE(x)) were measured to reflect width errors of golf ball locations on the target from the viewpoint of the initial ball position. The AE(y), ACE(y), and VE(y) were measured to reflect depth errors of golf ball locations.

2.5.*Data Analysis*

In order to examine the changes that occurred between the 15th acquisition block and the pressure test, paired *t*-tests were conducted with state anxiety, positive affect, negative affect, HR, kinematic variables, grip force, and performance indices as dependent variables. For grip force, the data from nineteen participants were analyzed, with data from one participant being excluded due to a recording error. With state anxiety, each of the participants' total points throughout the acquisition block and the test were converted to t-scores using the average and standard deviation of 1,088 male university students taken from the STAI manual (Hidano et al., 2000) and *t*-tests were performed with the standardized state anxiety. Moreover, in order to determine the level of acquisition of the task in the total 150 trials in the acquisition phase and to examine changes in putting points from the 15th block of the acquisition phase to the pressure test, one-factor repeated measures analysis of variance (ANOVA) was conducted on the putting points with blocks (16) as the factor. Since blocks were a repetitive factor, we used Bonferroni's method to determine the ranking.

In order to examine the changes in attention throughout the final acquisition block (15th block) and the test block (16th block), the average points for Q1 and Q4 from the questionnaire data of all the participants were compared with 0 using *t*-tests; we designated the null hypothesis as a neutral rating score of 0 (for a scale of -4~+4); this corresponds to the standard point of participants in evaluating changes in the degree of attention paid during the test. In addition, the average points of Q2 and Q3 of all the participants were also compared with 0 using *t*-tests; we also designated the null hypothesis as a neutral rating score of 0 (for a scale of 0-8); this corresponds to the standard point of participants in evaluating appearance of new attentional focus under pressure.

Percent changes between the 15th block and the test were calculated for the state anxiety, positive affect, and negative affect, which is a psychological index, for HR, which is a physiological index, and for kinematic and grip force variables (see footnote 1). In order to examine the relationship between changes in psychological and physiological aspects on the one hand and behavioral and performance aspect on the other, step-wise multiple regression analyses were performed with changes in the kinematics, grip force, and performance variables as response variables and changes in psychological and physiological variables as predictor variables. For these multiple regression analyses, only the main effects of each predictor variables on the response variables were tested, such that potential interactions among the predictor variables were not examined. Due to the exploratory nature of the present study, it was considered sufficient to examine only the main effects. The Kolmogorov-Smirnov test was used to examine whether these response variables in the stepwise multiple regression analyses were normally distributed. The variables with non-normal distributions were excluded from further analyses. Additionally, multicollinearity of predictor variables in the multiple regression analyses was examined, based on the variance inflation factor (VIF). The significance level for all the analyses was less than 5 %. The statistical significance level of regression analyses was not adjusted for multiplicity, given the exploratory approach adopted in this study.

3. Results

3.1. *Psychological and physiological aspects*

The top panel of table 2 shows the means and standard deviations of state anxiety, positive affect, and negative affect scores before the 15th block and the test, and HR during the 15th block and the test block. The *t*-test showed that HR (t (19) = 3.02, $p < .01$) increased significantly from the 15th block to the test. However, state anxiety, positive affect, and negative affect showed no significant change. Table 3 shows all self-reports of the various attentional foci, which were answered for Q1, Q2, and Q4. The *t*-test showed that mean score of Q3 (t (19) = 13.10, $p < .001$) was significantly higher than 0, indicating that participants' attention was directed to the distracters in the test. The mean score of Q4 (t (19) = 3.26, $p <.01$) was also significantly higher than 0, indicating that their attention was directed to other things, such as the putting scores and imagery of ball rotation.

3.2. *Behavioral aspect*

Table 4 shows the means and standard deviations of behavioral variables that showed significant t-values between the 15th block and the test. The *t*-test showed that the averaged acceleration of club in DS increased significantly from the 15th block to the test (t (19) = 4.39, $p < .001$). The angular displacement of club in BS (t (19) = 2.69, $p < .05$), arm in BS (t (19) = 2.64, $p < .05$), club in DS (t (19) = 3.09, $p < .01$), and arm in DS (t (19) = 2.16, $p < .05$) decreased significantly from the 15th block to the test. The movement time of club in BS (t (19) = 4.03, $p < .01$) and DS (t (19) = 3.58, $p < .01$) also decreased significantly from the 15th block to the test. The *t*-tests for the inter-trial variability showed that the variability of the averaged velocities of elbow in BS (t (19) = 3.72, $p < .01$) and DS (t (19) = 3.62, $p < .01$) decreased significantly from the 15th block to the test. The variability of the angular displacement of club in FT also showed a significant decrease from the 15th block to the test (t (19) = 2.12, $p < .05$).

3.3.*Performance*

The bottom panel of table 2 shows the means and standard deviations of performance variables in the 15th block and the test. The *t*-tests for all performance variables showed no significant changes. The ANOVA for the putting scores showed a significant main effect for block, F (15, 225) = 5.89, $p < .001$. The post-hoc test showed that the putting score in the 1st block of acquisition trials was significantly lower than the 3rd through 14th blocks. Moreover, the putting score in the 2nd block was significantly lower than the 10th and 12th blocks, and the score in the 3rd block was significantly lower than the12th block. Only one participant earned the cash reward.

3.4.*Relationships between psychological / physiological aspects and behavioral / performance aspects*

Table 5 shows significant predictors in the multiple regression analyses of psychological / physiological variables on behavioral / performance variables. The standardized regression coefficient of Q1 (β = -.521, $p < .05$) was negative for putting scores. The standardized regression coefficients of Q1 were also positive for variability of velocity of elbow in DS (β = .452, $p < .05$) and variability of movement time of club in BS (β = .522, $p < .05$). The coefficient of Q3 was significant for variability of movement time of club in DS (β = .622, $p < .01$). The standardized regression coefficient of Q4 (β = .457, $p < .05$) was positive for variability of velocity of elbow in FT.

The standardized regression coefficients of HR were positive for variability of amplitude of club in FT (β = .640, p < .01), acceleration of elbow in DS (β = .559, p < .05), angular displacement of club in BS (β = .482, p < .05), variability of angular displacement of club in BS (β = .501, p < .05), and variability of movement time of club in FT (β = .619, p < .01). The coefficients of negative affect (β = -.867, p <.01) and HR (β = -.351, p <.01) were significant for grip force in BS. The coefficients of negative affect (β = -.686, p <.01) and Q4 (β = -.354, p <.05) were also significant for grip force in DS. The coefficients of negative affect (β = -.828, p <.01) and Q4 (β = -.317, p <.05) were also significant for grip force in FT. Lastly, multicollinearity was not observed between the predictor variables in these multiple regression analyses (VIF < 2.0).

4. Discussion

This study examined psychological and physiological stress that arose as a result of a performance-contingent cash reward or punishment, and found that HR significantly increased from the 15th block to the pressure test. However, the average state anxiety T-score during the pressure test was approximately 48 points, and no significant difference on this measure was observed between the 15th block and the pressure test. Therefore, it can be concluded that the type of pressure used in this study was effective, based on physiological stress reactions. Previous studies that evaluated HR changes under pressure report that the HR of sprinters, who need to perform well at the start of races, were approximately 40 bpm higher than the HR of long distance runners at the starting point of races (McArdle, Foglia, & Patti, 1967), and that the HR of piano players is approximately 35 bpm higher when performing in front of audience (Yoshie et al., 2009). In the present study, the mean HR increase for participants between the 15th block and the pressure test was approximately 9 bpm. Therefore, the physiological stress created during this study was of a lower intensity than that experienced by athletes during athletic competitions.

The primary purpose of this study was to use three-dimensional analysis to evaluate kinematic characteristics, as well as examine force control using a force-sensor during a pressure test. One of the kinematic change differences observed from the 15th block of acquisition trials to the test trials was a decrease in angular displacement of rotational movements of the arms and club at the horizontal plane, during the BS and DS phases. Since no change in angular displacement of rotational movements was observed for participants' hips, the decrease observed here must have been due to decreased pronation-supination movements of the wrists during the putting motion. Previous studies using two-dimensional motion analyses show that movement displacements decrease under pressure for transitional movements during putting tasks (Tanaka & Sekiya, 2010a), and during a task in which participants step over obstacles (Beuter et al., 1989). The present study shows that decreased movement displacements are also observed during rotational movements.

In addition to the decrease in angular displacements of rotational movements of the arms and club at the horizontal plane, the present study also found increased acceleration of the elbows during the DS phase, and decreased movement time during the BS and DS phases of the pressure test. Since increased force as a result of psychological stress caused by mental calculation (van Loon et al., 2001) and unpleasant auditory stimuli (Coombes et al., 2008) has been previously reported, it was thought that increased force during the task under pressure would lead to the increased movement acceleration. However, as far as force control during putting movements is concerned, no change in grip force during the pressure test was observed. Grip force (as measured via mechanical indices) is considered to reflect force control in the hands and forearms during the putting movement, and (arguably) this is why the pressure manipulation used in this study did not affect force control in these muscles. Nonetheless, golf putting involves force control of muscular activities in various body parts, including the trunk, lower half of the body, shoulders, and upper arms. As such, future studies should examine force control in these body areas.

Significant kinematic changes that were observed in the pressure condition included decreased angular displacements of rotational movements, decreased movement time, and increased acceleration of movements. Additionally, responses to the questionnaire that inquired about distractions, demonstrated that the attention of participants was significantly shifted toward the distracters during the test phases. According to the attentional control theory (Eysenck et al., 2007), processing efficiency declines under stress, because of increases in the stimulus-driven attentional system. Current results support this account, because distractions increased under the pressure condition. However, none of the performance related variables showed significant decreases from the 15th block to the test, indicating that performance effectiveness was not impaired. Therefore, it is suggested that attentional shifts toward distracters and kinematic changes could have occurred under a relatively low level of pressure that does not result in performance decrements.

The secondary purpose of this study was to provide an exploratory investigation of the relationship between changes in behavior and performance on the one hand and psychological / physiological changes on the other. Putting scores tended to decrease under pressure in those participants whose Q1 score was relatively high. This finding supports the conscious processing hypothesis, according to which performance suffers as attention toward movements increases under pressure (Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992). In addition, the greater the increase of attention to movements during the pressure test, the greater the changes in variability of club movement time during the BS phase, and the greater the changes in variability of elbow speed during the DS phase. Many previous studies report increases in variability of movements under pressure (Higuchi, 2000; Gray, 2004; Tanaka & Sekiya, 2006), and there are also reports that increased attention to movements leads to increased variability of movements even when athletes are not under pressure (e.g., Perkins-Ceccato, Passmore, & Lee, 2003). From these findings, it may be possible to argue that kinematic changes, namely variability in movements, lie between increased attention to movements under pressure and resulting decrements in performance.

Two possible interpretations have been proposed in previous studies with regards to movement variability. Traditionally, movement variability has been thought to reflect "noise" in the output of neural and physiological mechanisms underlying motor control (e.g., Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). This interpretation considers movement variability to be a dysfunctional aspect of performance outcomes. Conversely, some motor control theorists, such as proponents of dynamical system theory, have emphasized a functional role of movement variability. For example, it has been found that compensatory movements resulting from variability in joint coordination are associated with heightened performance of a variety of motor skills, involving pistol shooting (Arutyuyan, Gurfinkel, & Mirskii, 1968) and treadmill running (Hamill, van Emmerick, Heiderscheit, & Li, 1999; Heiderscheit, Hamill, & van Emmerik, 2002). In the present study, increases in task-relevant movement variability (along with conscious control of movement) were associated with relatively poor motor performance during the golf-putting task in the pressure condition. It might therefore be suggested that the increased variability of movements under pressure was caused by increased neurophysiological noise at both central and peripheral levels of motor control. In addition, based on optimal control theory, such increases in task-relevant movement variability should be associated with poor motor performance (Diedrichsen et al., 2010; Todorov & Jordan, 2002). Therefore, it might be emphasized that the relationships amongst internal focus of attention, increased variability of task-relevant movement parameters, and decreased performance under pressure conditions in the present study supports the optimal control theory account of movement variability.

In addition, multiple regression analyses also revealed that there are relationships between kinematic changes and changes in physiological arousal and emotions during the pressure test. For instance, the greater the increase in negative emotions, the greater the decrease in grip force during the BS, DS and FT phases. Moreover, the participants who showed greater increases in HR showed increased angular displacement of rotational movements of the club during the BS phase, as well as increased acceleration of the elbow during the DS phase. Previous studies that have examined the effects of emotional changes on motor skills report that motor speed is increased by stimuli that elicit negative emotions (Chen & Bargh, 1999; Coombes, Janelle, & Duley, 2005). More recent studies suggest that behavioral changes under pressure may be caused by physiological emotional responses along with changes in attention (Harfield, 2007). The results of the present study also suggest that changes in emotion and physiological arousal under pressure affect motor behavior. As such, future studies should examine the effects of physiological emotional responses on motor behavior and performance under pressure. In addition, we must concede the possibility that the large number of variables analyzed in the regression analyses of the present study has led to an increased likelihood of committing Type I errors. As described previously, adjustments to significance level were not made, as the present study was considered to be exploratory. Future focused studies are required to confirm the validity of our results.

5. Conclusion

The main purpose of this study was to examine kinematic characteristics and force control during a golf putting task, under a pressure condition produced by a combination of performance-contingent cash reward and threat of punishment. Decreases in angular displacements of arms and club rotational movements at the horizontal plane during the BS and DS phases were demonstrated in the pressure condition. Increased acceleration of the elbow during the DS phase and decreased movement time during the BS and DS phases were also found in the pressure condition. The secondary purpose was to investigate the relationship between changes in behavior (kinematics and force control) / performance and psychological (attention and affect) / physiological (arousal level) changes. Positive correlations were observed between the conscious control of movements and changes in putting scores, variability of club movement times during the BS phase, and variability in elbow speed during the DS phase form the acquisition phase to the pressure test. In addition, an increase in negative emotionality was associated with decreased grip force during the BS, DS and FT phrases. The participants who showed increased HR also showed increased angular displacement of rotational movements of the club at the horizontal plane during the BS phase, and increased acceleration of the elbow during the DS phase.

Footnote 1

For each of the measurements, we used (the average of 10 trials in the test) / (the average of the 10 trials in the 15th block) × 100 as an index of percent changes between the 15th block and the pressure test.

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Table 1

Questionnaire items and response options measuring participant's attentional focus

Items	Response options using the 9-point scale based on the structured interview
1. During the test, how much attention did you pay to movement (i.e., strength to hit the ball, timing to hit, golf putting form) that you were consciously aware of during the last block of acquisition trials?	Between +4 (I started paying a close attention), 0 (no effects), and -4 (I started paying no attention)
2. During the test, how much attention did you pay to movement that you were not consciously aware of during the last block of acquisition trials?	Between 8 (my attention was very much directed to it), 4 (my attention was somewhat directed to it), and 0 (my attention was not directed to it at all)
3. How much attention did you pay to distracters (i.e., prize, electric shock, anxiety) during the test?	Between 8 (my attention was very much directed to it), 4 (my attention was somewhat directed to it), and 0 (my attention was not directed to it at all)
4. During the test, how much attention did you pay to other things that were not answered in Q1 through Q3?	Between +4 (I started paying a close attention), 0 (no effects), and -4 (I started paying no attention)

Table 2

Means and standard deviations of psychological, physiological, and performance variables in the 15th block of acquisition trials and the test

	Acquisition	Test
Psychological and physiological aspects		
State anxiety score (T-score)	44.61± 3.80	47.90± 4.39
Positive affect score	35.90± 7.22	37.68± 7.86
Negative affect score	24.10± 8.92	24.87± 9.51
Q1	—	.40± 1.07
Q2	—	.75± .96
Q3	—	5.30± .90
Q4	—	1.25± .86
HR (bpm)	86.97± 5.50	95.28± 9.08
Performance		
Putting scores for each trial	6.31± 1.25	6.52± 1.06
AE(x) (cm)	2.81± 1.63	3.30± 1.85
AE(y) (cm)	16.32± 7.26	14.30± 5.74
ACE(x) (cm)	1.25± 1.56	1.98± 1.56
ACE(y) (cm)	3.56± 3.22	4.69± 3.91
VE(x) (cm)	3.44± 2.23	4.25± 2.32
VE(y) (cm)	19.15± 8.84	16.39± 7.38

Note . Acquisition = the 15th block of acquisition; Test = the 10 trials in the pressure condition.

Table 3

Self-reports concerning attentional focus

	Points of attentional foci (number of participants)
Q1	Force control during putting (12)
	Amplitude of BS or FT (9)
	Upper limb movement (4)
	Direction of swinging the club and arm (3)
	Posture before swinging the club (2)
	Timing to start the BS (2)
	Temporal aspect of DS (1)
	Knee movement (1)
	Eye movement (1)
	Position of the gripping hand (1)
Q2	Amplitude of BS (1)
	Direction of the club before swinging the club (1)
	Position of participant's head during putting (1)
Q4	Scores in trials (2)
	Image of the ball rotation (2)
	Coping strategy for the stress response (2)
	Lack of conscious awareness of the movement or target (2)
	Physical state (1)
	Eye movement (1)
	Miss to hit (1)

Table 4

Means and standard deviations of behavioral variables that showed significant t-values between the 15th block of acquisition trials and the test

	Acquisition	Test
Averaged acceleration		
Club in DS (cm/s^2)	312.56±31.71	327.60±33.50
Angular displacement		
Club in BS (deg)	4.43± .81	3.59± .71
Arm in BS (deg)	8.19± 1.27	7.46± 1.06
Club in DS (deg)	2.97± .64	2.34± .63
Arm in DS (deg)	8.60± 1.03	8.04± 1.05
Movement time		
Club in BS (ms)	819.35±64.38	785.40±63.61
Club in DS (ms)	433.55±40.82	412.35±35.89
Variability of averaged velocity		
Elbow in BS (cm/s)	1.14± .13	.93± .14
Elbow in DS (cm/s)	1.64± .25	1.34± .24
Variability of angular displacement		
Club in FT (deg)	1.87± .22	1.60± .32

Note . Acquisition = the 15th block of acquisition; Test = the 10 trials in the pressure condition.

Table 5

Results of stepwise multiple regression analyses with the psychological and physiological changes as predictor variables and the behavioral and performance changes as response variables

Response variables	Predictor variables (β)	adjusted R^2
Change of performance	**Change of psychological / physiological variables**	
Putting scores	Q1 (-.521*)	.230*
Change of variability of linear amplitude		
Club in FT	HR (.640**)	.377**
Change of variability of averaged velocity		
Right elbow in DS	Q1 (.452*)	.160*
Right elbow in FT	Q4 (.457*)	.164*
Change of acceleration		
Right elbow in DS	HR (.559*)	274*
Change of angular displacement		
Club in BS	HR (.482*)	.190*
Change of variability of anglar displacement		
Club in BS	HR (.501*)	.209*
Change of variability of movement time		
Club in BS	Q1 (.522*)	.233*
Club in DS	Q3 (.622**)	.352**
Club in FT	HR (.619**)	.348**
Change of grip force		
BS	negative affect (-.867**), HR (-.351**)	.805**
DS	negative affect (-.686**), Q4 (-.354*)	.550**
FT	negative affect (-.828**), Q4 (-.317*)	.764**

Note. These multiple regression analyses included eight predictor variables. In this table, only significant predictors of psychological / physiological variables on behavioral / performance variables are shown; β = standardized regression coefficient; adjusted R^2 = squared multiple correlation coefficient adjusted for the degrees of freedom; ** p <.01, * p <.05