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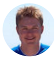

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Some pressures are more equal than others: Effects of isolated pressure on performance

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A B S T R A C T

It is commonly assumed that performance is impaired by pressure and that different types of individual situational factors can produce equivalent pressure. Our aim was to explore the psychophysiological effects of pressure to test this assumption. Eighty-one novices completed a golf putting task under control and eight individual pressure conditions: time, difficulty, video, team, goal, fame, shame, and distraction. Performance was measured by the number of holed putts and ball-hole distance. Psychological, physiological and kinematic measures were collected. Performance was impaired by time and difficulty conditions but improved by team, goal and shame conditions compared to control. Perceived pressure and effort were higher than control in all conditions except distraction. Conscious processing was greater than control in all conditions except distraction and time constraint. Heart rate was faster with time, team, fame and shame. Heart rate variability and muscle activity were largely unaffected. Putter kinematics provided evidence of swing profiles slowing and/or becoming constrained in conditions where conscious processing increased, while the swing became faster in the time-pressure condition where conscious processing was decreased. Taken together, these results reveal heterogenous effects of pressure on performance, with performance impaired, unaffected, and improved by individual pressure situations. Similarly, heterogeneity characterized the effects of pressure on psychological, physiological and kinematic responses associated with task performance. In sum, the evidence challenges the standard tacit assumptions about the pressure-performance relationship in sport.

1. Introduction

The ability to perform under pressure is key to sporting success (Jones & Hardy, 1990). It has been argued that pressure can stem from *'any factor or combination of factors that increases the importance of performing well on a particular occasion'* (Baumeister, 1984). However, this definition and the associated seminal work by Baumeister and colleagues (e.g., Baumeister, 1984; Baumeister & Showers, 1986) may have inadvertently led some researchers to an assumption that all pressure-inducing factors or combinations of factors create similar and/or additive effects on performance. Research evidence on the effects of isolated pressure manipulations on performance (Mesagno *et al.*, 2011; Stoker et al., 2017, 2019), questions this tacit assumption. Baumeister's (1984) definition also excludes factors such as elevated task difficulty or auditory distractions, which may not increase importance of performing well per se, but which are routinely used to induce pressure in athletes (Stoker et al., 2016). The current experiment aims to shed light on what constitutes pressure, and on the intricate relationships between different kinds of pressures and performance to yield important implications for researchers and practitioners alike.

1.1. Effects of pressures on performance

From world record performances (e.g., Usain Bolt in the 100 and 200 m finals at the 2009 World Athletics Championship) to spectacular performance breakdowns (e.g., Jana Novotna failing to capitalize on a seemingly unassailable lead to lose tennis' 1993 Wimbledon final) the most pressure-filled finals of elite sport's blue riband events yield the full spectra of performance effects. Anecdotally then, it seems clear that pressure has the potential to provoke a wide range of impacts. In an attempt to model and understand the effects of pressure on performance, researchers have sought to create pressure in laboratory settings by manipulating combinations of the task, performer, and environment. The task may be manipulated, for example, by altering target size, distance from target, and trial randomization/blocking (Stoker et al., 2017, 2019). The performer may be manipulated by secondary tasks that impair normal cognitive function and create mental fatigue (Provost & Woodward, 1991). The environment may be manipulated by elevating the performer (Oudejans & Pijpers, 2009) and making noise (Driskell *et al.*, 2001). Other well-used environmental manipulations of pressure include performance-based consequences, such as reward and punishment (e.g., Beilock & Carr, 2001; Bell *et al.*, 2013; Driskell *et al.*, 2014;

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Oudejans & Pijpers, 2009, 2010; Stoker et al., 2017, 2019), evaluations by audiences, coaches and peers (e.g., Driskell *et al.*, 2014; Masters, 1992; Mesagno *et al.*, 2011) and various forms of competition (e.g., Kavussanu et al., 2023).

Because pressure manipulations in the laboratory are less provocative than those experienced by athletes in their sporting competitions, studies often combine two or more manipulations with the aim of amplifying the amount of pressure experienced by participants (e.g., Cooke et al., 2010, 2011, 2014). The rationale for this approach is intuitive and this hybrid approach could be viewed as advantageous, especially if the manipulation succeeds in provoking higher levels of pressure than would otherwise have been achieved by isolated pressure. However, a counter-position would argue that the hybrid approach is disadvantageous on the basis that different aspects of hybrid manipulations could elicit conflicting effects that make it more difficult for researchers to understand the nuanced-relationship between pressure and performance. In support of both positions, we have noted that on the one hand, the incremental addition of new elements of hybrid pressure manipulations can serve to amplify perceived pressure (e.g., Cooke et al., 2010, 2011), but on the other hand, hybrid pressure manipulations consistently reveal inconsistent effects on performance. For example, research from the same laboratory shows that hybrid pressure manipulations combining evaluation, competition, reward and punishment have yielded positive effects (Cooke et al., 2011), negative effects (Cooke et al., 2010), and null effects (Cooke et al., 2014) on golf putting performance.

The use of hybrid and/or inconsistent pressure manipulations across studies could present particular challenges for theories of performance under pressure. Currently, most incidents of impaired under pressure are interpreted by so-called distraction theories or self-focus theories (Roberts, Cooke, et al., 2019). In brief, distraction theories posit that pressure impairs performance by causing performers to become overwhelmed by stimulus-driven processes (e.g., environmental distractions, internal worries) and thus, unable to focus appropriately on the task at hand (see for an example attentional control theory – Eysenck et al., 2007). Meanwhile, self-focus theories argue that pressure-induced performance breakdowns result from performers engaging in conscious motor processing and thereby disrupting automatic movement processes (see for an example reinvestment theory – Masters & Maxwell, 2008). When considering the variety of pressure manipulations at the disposal of researchers, it is easy to imagine how the nature of the pressure manipulation employed could have a direct impact (deliberately in some cases, inadvertently in others) on the types of pressure-performance theories and mechanisms that are being supported and developed. For example, it has been shown that lapses in goal-driven attention are more likely to occur during pressures that divert attention away from the primary task (e.g., counting external tones), whereas conscious motor processing is more likely to be provoked by self-focus pressures (e.g., video recording) (DeCaro *et al.*, 2011). In the case of hybrid manipulations, it is possible that both distraction and self-focus mechanisms could be activated, yielding conflicting results.

In sum, it is important for researchers to pay careful attention to how pressure manipulations are constructed when interpreting previous research and designing new performance under pressure studies. A more detailed understanding of how isolated pressures impact performance should help researchers to develop more informed manipulations and facilitate more targeted tests of theories and interventions.

1.2. *Effects of isolated pressures*

A few studies have begun to investigate how isolated pressures affect performance. Mesagno *et al.* (2011) reported one of the first sport psychology studies of isolated pressure manipulations. They compared the effects of various pressures on a field hockey task and found that performance declined in self-presentation conditions (audience, video camera) but improved in performance-contingent monetary incentive conditions. Next, Stoker et al. (2017) compared control demands (visual occlusion, time constraint, noise distraction) and consequences (evaluation, reward, forfeit) to reveal that consequence conditions were most potent at increasing perceived pressure, but had no impact on performance, whereas demand and demand plus consequence conditions impaired performance relative to the control. Finally, Stoker et al. (2019) confirmed that consequences created pressure, and, moreover, showed that a forfeit condition improved performance compared to a mental fatigue condition. Collectively, these studies provide further evidence that isolated pressures produce unequal effects on performance.

In addition to understanding the effects of isolated pressures on performance, it would be useful for researchers and practitioners to be aware of the effects of isolated pressures on the psychophysiological and kinematic processes that govern performance. A multi-measure approach (Cooke & Ring, 2019), with concurrent recordings of physiological and kinematic responses during tasks, can be used to help understand how pressure might affect the performer and their task execution. For instance, heart rate and heart rate variability, putative indices of anxiety (e.g., Oudejans & Pijpers, 2009, 2010; Stoker et al., 2017, 2019; Veldhuijzen van Zanten *et al.*, 2002), and effort (e.g., Cooke *et al.*, 2010; Roberts, Cooke, et al., 2019), muscle activity, a reflection of neuromuscular efficiency (e.g., Cooke *et al.*, 2010; Roberts, Cooke, et al., 2019; Weinberg & Hunt, 1976), and movement velocity/acceleration, indices of motor control (Cooke et al., 2010, 2011; Maxwell *et al.*, 2003; Nieuwenhuys *et al.*, 2008; Pijpers *et al.*, 2005), are sensitive to the effects of pressure manipulations on motor tasks. Although the pressure-performance relationship has received much research attention, there is little evidence on the mechanisms underlying the effects of isolated pressure on performance. The present study adopts a multi-measure approach to shed light on this important issue.

1.3. *Current experiment*

This experiment sought to examine the effects of isolated pressures on performance, and, importantly, on the physiological and kinematic antecedents of performance. It is, to our knowledge, the first study to adopt a multi-measure approach to address this important issue. We hope that the findings will provide a useful point of reference for future researchers wishing to employ targeted, pure and impactful pressure manipulations to shed new light on pressure-performance relations. Our objectives were two-fold. First, we determined the effects of isolated pressure manipulations on perceived pressure and task performance. Second, we determined the effects of these pressure manipulations on task-related psychological, physiological, and kinematic responses. Participants completed a golf putting task under isolated pressure conditions that manipulated task demands (difficulty, time-constraint), the performance climate and consequences (goal, team, reward, punishment, video), and the performer (external distractions). Following Baumeister's seminal research, we were confident that our consequence conditions would heighten perceived pressure beyond the levels reported during the control (Baumeister, 1984; Baumeister & Showers, 1986). Our demands and distraction conditions do not as obviously raise the importance of doing well, but anecdotal evidence of their pressure-inducing potential (e.g., Stoker et al., 2016) led us to predict that they would also elicit more perceived pressure than control. Importantly, we expected that the subsequent effects of the pressure manipulations on our primary (performance) and secondary (time, psychology, physiology, kinematics) outcome measures would be mixed. For example, we expected demand pressures to impair performance relative to control conditions, while the performance effects of consequence pressures were less certain (Stoker et al., 2017, 2019). Concerning our secondary measures, we expected that pressures likely to draw attention away from the performer (e.g., time-pressure; distracting sounds) would decrease conscious processing while pressures likely to induce self-focus (e.g., video camera, increased difficulty) were expected to increase conscious processing (DeCaro et al., 2011) and prompt associated changes in physiological (e.g., increased heart rate) and kinematic processes (e.g., slower swing) indicative of a more effortful and constrained technique.

2. Method

2.1. Participants

Eighty-one right-handed sport and exercise sciences students ($N_{male} = 20$; $N_{female} = 61$; $M_{age} = 20.0$, $SD = 1.1$ years), participated in exchange for course credit. All were golf novices, with no previous golf training. Power calculations using GPower 3.1.9.7 (Faul, et al., 2007) software indicated that with a sample size of 81 the current study was powered at .80 to detect significant ($p < .05$) differences among the conditions using repeated measures analyses of variance corresponding to a small ($f = 0.15$, $\eta_p^2 = 0.02$) effect size (Cohen, 1992). The current sample size also exceeded those recruited for previous experiments that compared the effects of pressure manipulations on various outcome measures in this context (see Introduction). Participants were asked to refrain from consuming alcohol and caffeine for 12 and 4 h before visiting the laboratory respectively and avoid vigorous exercise for 4 h prior to testing.

2.2. Design and task

We asked participants to complete a golf putting task in a repeated measures design that involved completing five putts in a no pressure control condition and each of eight isolated pressure conditions (difficulty; video; time; team; goal; fame; shame; distraction – see Experimental Conditions section below). We designed and manufactured a bespoke putter for use in the experiment, comprising of an 81 cm long completely upright shaft that was centred in a semi-circular aluminium club head (height = 2.5 cm; face width = 7.5 cm; radius = 3.5 cm). Putts were struck using the flat face unless otherwise stated. Participants putted with standard sized golf balls (Ultra, Wilson) 2 m to a target hole, located centrally 1.25 m from the end of a 1.5 m × 5 m indoor artificial putting surface (Augin Turftiles), with a Stimpmeter reading of 4.27 m. The hole was modified (depth = 1.5 cm; width = 7 cm) to form a shallow, straight sided aperture. The depth of a standard golf hole often means that despite a ball travelling at a speed which would result in it finishing past the hole, some putts are successfully holed. Furthermore, the circular lip of a traditional golf hole means that in instances where a ball is travelling along the edge of the hole, if it does not 'drop-in' or run past the hole, it may 'lip' around the back of the hole and come to rest on the opposite side of the hole. The hole was designed to have straight edges in line with direction travel of the ball, and only a putt travelling at a speed of 10–15 cm past the hole (the pace recommended by most professional golfers) was likely to be holed. The experimenter placed each new ball in the same position after every putt to ensure consistency and avoid any physiological interference from participants bending down during placement.

2.3. Experimental Conditions

Control. Participants were instructed to putt each ball to the hole.

Time. Participants were given 15 s to putt all five balls. A countdown timer was placed in the participant's line of sight, which visually and audibly signified time elapsing. The timer was started by the experimenter when participants struck their first putt; it stopped automatically. Participants could see where their ball terminated before hitting the next putt. The set duration was established in pilot testing. Novice performers in the declarative stage of skill acquisition require the opportunity for conscious monitoring and control (Beilock *et al.*, 2004; Masters, 1992), and, therefore, reducing the time available to plan and process movement was expected to impair performance.

Difficulty. Participants were instructed to putt using the rounded side of the semi-circular headed putter (i.e., reverse side). The rounded face was designed to test accuracy, with inaccurate swing planes and inconsistent strike patterns exaggerating any off-centre miss-hit. Stoker *et al.* (2016) noted that coaches increase task difficulty to generate pressure during training, whilst laboratory studies have confirmed that manipulating difficulty can influence performance (Oudejans & Pijpers, 2009, 2010).

Video. Participants were filmed by the experimenter holding a video camera with a lighting attachment. They were told that the footage would be used during an upcoming golf professionals conference, implying that their putting performance would be viewed and evaluated by a large audience of experts (Geukes et al., 2012). Videotaping was expected to increase self-evaluation (Buss, 1980), self-consciousness (Lewis & Linder, 1997), and self-presentation concerns (Mesagno *et al.*, 2011). To reduce the likelihood of participants becoming acclimatised to videotaping, the experimenter changed position of filming every other putt, gradually becoming more obtrusive and increasingly present in the participant's line of sight.

Team. Participants were told that they had been randomly paired with another participant to form a team. Using number of holed putts from the pre-test control condition, an achievable target was calculated to give the impression that the competition against another team was close. When faced with a scenario that will directly affect other team members, it is thought that pressure stemming from ego-threat may cause athletes to perform poorly (Baumeister, 1997).

Goal. Participants were given the goal of beating their initial control performance (i.e., number of holed putts). Pressure is expected when performers want to do well and are set a clear target to beat, especially if the target is close to their current performance level (Baumeister, 1984). Basing the target on their control performance ensured the latter clause was satisfied.

Fame. Participants were presented with a leader board entitled the "*wall of fame*", containing names and photos of the supposed best performers. Moreover, participants were awarded £1 for every putt holed (with coin(s) stacked in line of sight). Monetary rewards and social evaluation are common features in studies of pressure (e.g., Beilock & Carr, 2001; Cooke et al., 2011; Wilson et al., 2007; Wilson, 2008).

Shame. A "*wall of shame*" was fabricated to create the illusion of a worst performance loser board. Participants were informed that they had been granted £5 for volunteering for the study; however, for every putt they missed, they would lose £1. The £5 stack coins was placed in the participant's direct sight, with a £1 coin removed following every missed putt. The potential for losing money as a consequence of poor performance should increase pressure (Cooke *et al.*, 2011).

Distraction. Whilst participants performed under control instructions, increasingly audible noises (running tap, chatter, slamming metal bin lid) were made by the experimenter. Previous findings indicate that pressure can stem from the performance environment, and distractions such as noise can impair performance (Driskell *et al.*, 2001; Stoker et al., 2017, 2019).

2.4. Measures

Performance Outcome Measures. The total number of holed putts in each condition was the performance outcome measure. Mean radial error (distance from the centre of the hole to the closest point of the ball) in each condition was also calculated as a performance accuracy measure.

Time Measure. We recorded task completion time as the number of seconds between hitting the first and last putt.

Self-report Measures. Conscious processing was measured using the 6-item putting-specific conscious motor processing scale (Cooke *et al.*, 2011). Participants were asked to indicate how they felt about the previous 5 putts (e.g., "*I thought about my putting stroke*", "*I tried to figure out why I missed putts*") on a 5-point Likert scale, anchored by 1 ("*never*") and 5 ("*always*"). In line with past research (Cooke *et al.*, 2011) the internal consistency of the scale was very good (α = 0.81 to 0.92) across conditions. Pressure and effort were measured using the 5-item pressure/tension and effort/interest subscales of the Intrinsic Motivation Inventory (Ryan, 1982). Participants were instructed to rate each item (e.g., "*I felt pressured*", "*I tried very hard to do well*") on a 7-point Likert scale anchored by 1 "*not at all true*" and 7 "*very true*". The internal consistency of the pressure (α = 0.89 to 0.94) and effort (α = 0.92 to 0.95) subscales were very good across conditions.

Physiological Measures. An electrocardiogram (ECG) was recorded using three silver/silver chloride spot electrodes (Cleartrace, ConMed, Utica, NY) in a modified chest configuration. The signal was amplified (Delsys Bagnoli-4 EMG system, Boston, MA), filtered (1–100 Hz), and digitalized at 2500Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design, Cambridge, UK) using Spike2 software (Cambridge Electronic Design). Mean heart rate and heart rate variability (SDNN; standard deviation of R–R intervals, RMSSD; root mean square of successive differences in R–R intervals) were calculated from the ECG for each condition. We expected pressure to be positively related to heart rate and negatively related to heart rate variability (e.g., Cooke et al, 2010, 2011, 2014).

Electromyographic (EMG) activity of the left flexor carpi radialis and left biceps brachii muscles were measured continuously. Muscle activity (μV) was recorded via single differential surface electrodes (DE 2.1, Delsys, Boston, MA) and amplifier (Bagnoli-4, Delsys, Boston, MA), with a ground electrode attached on the collar bone. EMG signals were amplified, filtered (20–450 Hz), digitalized (2500 Hz), and recorded. Mean muscle activity for each muscle was calculated for each condition. We expected pressure to be positively related to muscle activity (e.g., Cooke et al, 2010, 2011, 2014).

Kinematic Measures. A tri-axial accelerometer (ADXL337 Breakout, Cool Components, UK) recorded clubhead acceleration in three planes. Lateral, vertical, and back-and-forth movements were calculated via X, Y, and Z acceleration axes respectively. An impact sensor (Piezo Vibration Sensor, Measurement Specialties Inc, USA) was used to detect when contact between the putter and ball occurred. The impact sensor and accelerometer were both recessed into the underside of the putter clubhead. Movement kinematics for each putt was assessed from the onset of the downswing phase to the point of impact with the ball. The average X, Y, and Z acceleration was calculated. Mean kinematic measures were computed for each condition.

2.5. Procedure

The protocol was approved by the local research ethics committee. Participants completed five practice putts to familiarise them with the putting surface and equipment. Using a within-participant design, participants then completed the "*pre-test*" control, eight pressure conditions, counterbalanced using a Latin square design (Williams, 1949), and a "*post-test*" control condition. The data from the *pre-test* and *post-test* control conditions were averaged (i.e., computed the mean of *pre-* and *post-*values) to create an overall control condition to take account of any practice effects during the session. No instructions or suggestions were given prior to or during the experiment regarding putting technique. Participants were informed repeatedly throughout the experiment to complete putts at their own pace and reminded that performance would be assessed in terms of number of holed putts and mean radial error; therefore, they should not only aim to get the ball in the hole, but to finish it as close to hole as possible. Participants were told at the start of the session, that a £20 reward was offered for the best overall performer (computed across all conditions, including control). This was expected to encourage task engagement. Each pressure condition was explained and administered by the experimenter using a script, and before each putt the ball was placed in the designated spot by the experimenter to avoid any recording artefacts due to changes in posture. Physiological and kinematic measures were recorded continuously during each condition. Immediately after participants had finished the five putts in each condition, they completed self-report measures for pressure, effort, and conscious processing using a tablet computer. This allowed participants a 3-min rest between conditions.

2.6. Data analysis

We performed a series of 9 pressure condition (control, difficulty, video, time, team, goal, fame, shame, distraction) repeated measures analysis of variance (ANOVAs) on the performance, psychological, physiological and kinematic measures. We report the multivariate solution to reduce the risk of violating sphericity and compound symmetry assumptions (Vasey & Thayer, 1987). Partial eta squared (η_p^2) indicates the effect size, with small, medium and large effects sizes corresponding to values of 0.02, 0.13, and 0.26, respectively (Cohen, 1992). A series of 2 condition (control, pressure) pairwise comparisons determined whether each isolated pressure condition differed from control. Significant differences were evident when the mean value of a pressure condition fell outside the 95 % confidence intervals of the control condition.

3. Results

3.1. Pressure

The 9 condition repeated measures ANOVA confirmed a large effect of condition on perceived pressure (Table 1). Perceived pressure was greater in each of the consequence and demand pressure conditions compared to the control but did not differ between control and distraction.

3.2. Performance

The repeated measures ANOVAs confirmed large effects of pressure condition on putts holed and radial error (Table 1). In brief, fewer putts were holed in the difficulty, time, and video conditions compared to control. In terms of radial error, putting was less accurate in the difficulty and time conditions, but more accurate in the team, goal, and shame conditions compared to control.

3.3. Time

The 9 condition ANOVA found a large effect of pressure condition on the time to complete putting the five balls (Table 1). Specifically, less time was spent putting in the time and difficulty conditions, but more time was spent in the other pressure conditions relative to control.

3.4. Psychological measures

The ANOVAs yielded large condition effects on effort and conscious processing (Table 1). Effort was greater in seven out of the eight pressure conditions relative to control; the exception was distraction, which did not differ. Conscious processing increased in six conditions, decreased in one condition (time), and was unchanged in one condition (distraction).

3.5. Physiological measures

The ANOVAs indicated large pressure condition effects for heart rate, SDNN and left flexor carpi radialis EMG, but not for RMSSD and left biceps brachii EMG (Table 1). Heart rate was faster than control in the time, team, fame, and shame conditions. Heart rate variability, indexed by SDNN, was higher in the goal condition, but lower in the time condition compared to control. Muscle activity, indicating a tighter grip, was greater in the time condition compared to control.

Table 1
Mean *(SD)* pressure, performance, psychological, physiological and kinematic measures in each condition.

Measure	Control	Time	Difficulty	Video	Team	Goal	Fame	Shame	Distraction	$F(8, 73)$	η_p^2
Perceived Pressure	2.55	3.68 ^{c}	2.81 ^{c}	3.17 ^{c}	3.25 ^{c}	2.99 ^{c}	3.44 ^{c}	3.68 ^{c}	2.59	15.83***	.63
(1–7)	(1.07)	(1.50)	(1.21)	(1.37)	(1.33)	(1.23)	(1.36)	(1.44)	(1.22)		
Radial Error	34.13	45.97 ^{c}	42.14 ^{c}	33.38	27.90 ^{c}	28.94 ^{c}	30.14	29.37 ^{c}	31.56	8.60***	.49
(cm)	(15.67)	(28.35)	(17.87)	(18.11)	(15.02)	(12.65)	(15.56)	(14.28)	(19.19)		
Holed Putts	0.79	0.44 ^{c}	0.30 ^{c}	0.53 ^{c}	0.91	0.75	0.64	0.63	0.72	5.55***	.38
(0–5)	(0.66)	(0.72)	(0.49)	(0.69)	(0.85)	(0.99)	(0.93)	(0.91)	(0.91)		
Completion Time	23.36	11.29 ^{c}	22.39 ^{c}	24.64 ^{c}	24.60 ^{c}	24.21^{c}	25.14 ^{c}	26.94 ^{c}	26.04 ^{c}	86.03***	.90
(s)	(3.74)	(2.83)	(4.21)	(6.45)	(5.65)	(4.64)	(5.06)	(7.14)	(5.77)		
Effort	4.59	4.88 ^{c}	4.87 ^{c}	4.89 ^{c}	5.41 ^{c}	5.16 ^{c}	5.41 ^{c}	5.36 ^{c}	4.73	14.42***	.61
(1–7)	(1.24)	(1.42)	(1.37)	(1.37)	(1.30)	(1.28)	(1.24)	(1.37)	(1.32)		
Conscious Processing	3.37	2.77 ^{c}	3.66 ^{c}	3.63 ^{c}	3.71 ^{c}	3.65 ^{c}	3.71 ^{c}	3.64 ^{c}	3.47	15.26***	.63
(1–6)	(0.65)	(0.83)	(0.76)	(0.75)	(0.70)	(0.77)	(0.76)	(0.78)	(0.75)		
Heart Rate	83.59	85.72 ^{c}	82.82	84.01	85.34 ^{c}	83.77	86.48 ^{c}	87.00 ^{c}	82.54	5.73***	.39
(bpm)	(10.47)	(10.97)	(11.65)	(12.50)	(10.50)	(11.15)	(11.92)	(12.72)	(11.25)		
SDNN	59.24	46.51 ^{c}	61.36	60.64	65.73	68.17 ^{c}	58.48	64.27	61.57	4.39***	.33
(ms)	(1.76)	(2.72)	(2.99)	(2.95)	(3.44)	(3.57)	(2.43)	(2.71)	(2.56)		
RMSSD	39.90	35.99	44.22	42.93	43.64	46.16	38.45	42.26	40.07	1.17	.11
(ms)	(22.23)	(29.29)	(43.82)	(34.16)	(36.46)	(40.81)	(29.16)	(32.67)	(25.38)		
Extensor EMG	9.05	11.37 ^{c}	9.36	9.30	8.75	8.76	8.84	8.92	10.21	6.66***	.42
(μV)	(4.28)	(5.78)	(4.55)	(5.35)	(4.21)	(4.09)	(3.95)	(4.32)	(14.58)		
Biceps EMG	22.36	23.29	33.17	28.39	18.93	25.05	24.15	22.86	25.33	1.13	.11
(μV)	(21.92)	(30.76)	(52.21)	(46.68)	(26.53)	(38.95)	(29.51)	(30.94)	(35.93)		
X-axis acceleration	2.26	2.31	1.10 ^{c}	2.10 ^{c}	2.10 ^{c}	2.14 ^{c}	2.18	2.09 ^{c}	2.16	140.33***	.94
($m.s^{-2}$)	(0.52)	(0.66)	(0.24)	(0.56)	0.54)	(0.52)	(0.56)	(0.49)	(0.56)		
Y-axis acceleration	1.32	1.57 ^{c}	0.98 ^{c}	1.27	1.22 ^{c}	1.25	1.19 ^{c}	1.15 ^{c}	1.23	17.58***	.66
($m.s^{-2}$)	(0.49)	(0.74)	(0.37)	(0.53)	(0.55)	(0.52)	(0.46)	(0.57)	(0.60)		
Z-axis acceleration	10.80	11.99 ^{c}	6.67 ^{c}	9.60 ^{c}	10.38	10.59	10.68	10.36	10.13 ^{c}	37.85***	.81
($m.s^{-2}$)	(3.79)	(4.72)	(1.82)	(3.35)	(3.41)	(3.66)	(3.75)	(3.78)	(3.59)		

Note: Superscript ^{c} indicates significant difference from control condition. $**p < .01$, $***p < .001$

3.6. Kinematic measures

Separate ANOVAs yielded large effects of pressure condition on movement acceleration (Table 1). The X-axis acceleration revealed less lateral movement during the increased difficulty, video, team, goal, and shame conditions compared to control. The Y-axis acceleration showed that club head was swung closer to the putting surface in the increased difficulty, team, fame, and shame conditions, but further away in the time condition, compared to control. The Z-axis acceleration indicated that the putter was swung slower in the increased difficulty and video conditions compared to control whereas the putter was swung faster in the time condition.

4. Discussion

This experiment was designed to generate evidence regarding the effects of different isolated pressures on perceived pressure, task performance and task-related time, psychological, physiological and kinematic processes. We created eight distinct pressure conditions and revealed that more pressure than control was experienced in all but one of the manipulated conditions (distraction), thereby confirming our expectation that a diverse range of isolated factors can augment perceived pressure. We also confirmed expectations that the isolated pressures would yield a range of effects on our primary (performance) and our secondary (time, psychological, physiological, kinematic) outcome measures. The pattern of effects for each pressure manipulation are discussed in the subsections below.

4.1. Effects of pressures evoked by changes to task demands

We created two pressure conditions by manipulating task demands, namely, the increased difficulty condition (rounded putter head) and the time-constrained condition (15 s time limit). Baumeister (1984) theorized that pressure is induced by factors that increase importance of performing well. The extent to which changes to task demands can be expected to increase importance of doing well is often unclear.[1] In spite of this, both of our demand conditions elevated the pressure that participants felt beyond the levels reported during the control putts. Our data concur with anecdotal evidence that time-restricted and more difficult tasks can be effective ways of inducing pressure in sport (Stoker *et al.*, 2016) and indicate that sources of felt pressure can be wider than those identified in Baumeister's seminal works.

In addition to augmenting pressure, both demand conditions impaired putting performance compared to the control condition, and both elevated self-reported effort. However, these isolated demand pressures yielded different effects on the remaining psychological, physiological and kinematic measures. As hypothesised, conscious processing was elevated during the difficulty condition, but reduced during the time-constrained condition. Conscious processing requires time (Meier et al., 2003), so it follows that this measure decreased when time was limited. In contrast, the requirement for a more precise putter-ball contact point due to the rounded putter face (compared to the standard flat putter face) in the difficulty condition, may have invoked more conscious control as a well-intentioned coping strategy (Beilock & Gray, 2007). Kinematic data from the difficulty condition revealed that putter acceleration was reduced on all three axes, resulting in a slower, flatter and more linear swing, compared to the control putts.

[1] An exception would be where an increase in demand also increases consequences – for example if the increased demand was to perform a skill at elevated height (Oudejans, 2008), an increased consequence (i.e., elevated risk of injury) might co-occur to heighten the importance of careful and precise motor execution. The rounded putter and the time-pressure conditions used in this experiment are unlikely to have increased importance in this way.

This reflects a more constrained swing, as would be expected for a more consciously controlled movement that prioritized contact-point accuracy (Higuchi *et al.*, 2002). While a more linear swing (i.e., reduction in X-axis acceleration) should help ensure more putts on the target line (Cooke *et al.*, 2010), the accompanying reduction in acceleration on the primary back-and-forth axis (Z-axis) increases the likelihood of putts being under-hit, and this could account for the reduction in accuracy in the difficulty condition. In the time-constrained condition, putter-head acceleration on the back-and-forth and the vertical axes were increased, indicating a faster and steeper swing and increasing the likelihood of putts being over-hit. Therefore, putts were missed in a different way, being over-hit rather than under-hit, in the time-pressure condition. We interpret this evidence of impaired performance in the time condition as confirmation that sometimes "haste makes waste" within a novice participant cohort.

Finally, in terms of the physiological measures, the time condition elevated heart rate and forearm muscle tension and reduced SDNN heart rate variability. Given the increased swing speed evident in the time condition, the observed physiological effects of the time pressure most likely reflect the additional physical demands of this condition. The difficulty condition did not impact the physiological measures. In sum, both conditions impaired performance, yet had varied effects on the secondary outcome measures. We suggest that the reasons for impaired performance in these conditions were principally due to increased physical demands (time condition) and the contrasting impact that the manipulations of task demands had on technique.

4.2. Effects of pressures evoked by changes to the performance climate

We created five pressure conditions focused on manipulating the climate, via competition, consequences, and video-recording. All these pressures contained a degree of ego-threat due to being evaluated and/or compared with others (Baumeister & Showers, 1986) which is likely to increase the importance of performing well and induce pressure in the manner expected by traditional pressure definitions (Baumeister, 1984). Our hypothesis that all these conditions would elevate perceived pressure beyond levels reported during the control putts was duly supported.

Overall, these pressures had negligible effects on number of holed putts, but tended to improve performance (team, goal, shame), relative to the control condition, in terms of radial error (i.e., balls came to rest closer to the target). An exception was the video condition, which had no impact on radial error, but which was associated with a slight reduction in holed putts compared to the control. This discrepancy between the performance outcome variables may be explained by greater sensitivity of distance from the hole compared to putts holed (see Cooke et al., 2010, 2011). These findings add evidence that competition and consequences reliably evoke perceived pressure, but alternative pressures that increase demands (difficulty, time) appear the most likely to impair performance (Stoker *et al.*, 2017). Of the various consequence pressures, those that involve video-recording of movements, possibly increasing self-presentation concerns (Mesagno *et al.*, 2011), possess the greatest potential to yield adverse effects, at least to crude outcome measures of performance.

Turning to the secondary outcome measures, our results confirmed that all of the competition and consequence pressures increased self-reported effort and conscious processing while also elongating task completion times, compared to control. These findings can be interpreted to reflect that all of these pressures were similarly effective in provoking performers to devote more conscious attention to the task compared to no-pressure control condition. This interpretation of the data is further supported by the physiological measures, with all of these pressure conditions provoking marginal (video, goal) to clear (fame, shame, team) increases in heart rate. Importantly, these cardiac changes occurred in the absence of any changes in muscle activity. Accordingly, the increases in heart rate appear psychologically-driven and could reflect elevations in anxiety and/or effort (Oudejans & Pijpers, 2009; Roberts, Cooke, et al., 2019). One would expect mild anxiety, increased effort and increased conscious processing to all have the potential to benefit the performance of novices, due to novices being somewhat reliant on conscious motor processes for successful skill execution (Beilock *et al.*, 2004; Masters & Maxwell, 2008) and due to mild anxiety and effort serving to motivate engagement in tasks (e.g., Shi *et al.*, 2021).

In keeping with the interpretation that competition and consequence pressures tended to elevate conscious processing to facilitate beneficial changes in performance, the kinematic data revealed that compared to control, all five of these pressure conditions were associated with reduced lateral acceleration, characteristic of a more linear (superior) swing plane (Peltz, 2000). The kinematic data also revealed a reduction in forward acceleration that was unique to the video pressure condition. This can explain the slight reduction in putts holed that occurred in this condition (i.e., putts were under-hit). As no physical observers, apart from the experimenter, were present in any of the pressure conditions, the presence of the video camera in addition to the experimenter in the video condition may have elevated self-awareness and prompted the participants to constrain movements uniquely to the video pressure (Lohse et al., 2010). This suggestion could be further investigated by future research.

4.3. Effects of pressure evoked by changes in attentional demands

We created one performer-focused pressure condition, namely, the distraction condition. This was the least impactful of the eight isolated pressure conditions that we created. The random noises that were made while putting during this condition did not impact perceived pressure, performance, or any of the other self-report or physiological measures, when compared to the no pressure control condition. It should be noted that task completion time was elongated slightly in this condition, providing some tentative evidence of the noises being disruptive to the putting routine of some performers. This condition also yielded a slightly slower forward acceleration of the putter, albeit not sufficiently to impact putting performance. More obtrusive distractions or distractions that require participants to engage with them (e.g., explicitly counting tones) could impact more strongly on performance and the processes that underpin performance (e.g., Beilock & Gray, 2007) and could be investigated by future studies. Importantly, our unexpected finding that distraction was ineffective at increasing pressure may help clarify the necessary features of pressure. While consequences that increase the importance of doing well, and some types of demand evidently can evoke pressure, distraction may be better viewed as a downstream mechanism through which pressure can impact performance (e.g., Eysenck & Calvo, 1992) rather than a source of pressure on its own. This finding is in broad agreement with previous research showing: a) the ineffectiveness of manipulated (i.e., artificial) distraction conditions on performance (Stoker *et al.*, 2017); and b) that consequence pressures can organically provoke distractions (e.g., increased tendency to fixate on threats in the environment rather than the task at hand) and those (naturally occurring) visual distractions can mediate detrimental effects of pressure on performance (Wilson, 2008).

4.4. Implications

Our findings should help researchers when interpretating past and future studies, designing studies, and developing theories about performance under pressure. It was clear that different isolated pressures elevated perceived pressure similarly yet had diverse effects on performance and on the timing, psychological, physiological, and kinematic processes that govern performance. Indeed, even different pressures within the same broad class sometimes yielded markedly different effects. Given our varied findings, we would caution against referring to classes of pressure as we have done here, and instead recommend researchers simply and precisely describe each individual pressure manipulation.

By investigating the effects of isolated pressures, our findings highlight potential complications of hybrid pressure manipulations. For example, had we combined our time, video, and shame conditions to create the sort of hybrid manipulation that is sometimes deployed by studies in this context, there would likely have been conflicting impacts on the performance and the process measures that would make the outcomes difficult to interpret. The solution is not straightforward as it is acknowledged that real-life pressure settings may include a combination of pressure-inducing factors. Indeed, there may be a place for hybrid manipulations in the research literature where the goal is to model highly ecologically valid scenarios. In such instances, we would recommend the use of analyses, such as mediation path models, to try and uncover which of the competing pressures and associated processes activated by those pressures are yielding the biggest impact on behaviour (see Shi *et al.*, 2021). However, if the goal of laboratory research is to provide clean tests of *a priori* specified theories and mechanisms then isolated and pure pressure manipulations are preferable. For example, our time-pressure manipulation would be less suitable than our difficulty, video, team, goal, fame or shame manipulations for researchers wishing to examine the effects of pressure-induced increases in conscious processing, whereas our distraction manipulation may be of limited use, in its current form, to yield insights on any aspects of pressure and performance.

4.5. Limitations and future directions

It should be recognised that the current findings are somewhat limited by the homogenous sample of novice golfers used. While we do not anticipate the general principle that isolated pressures have different effects on performance and process measures would change if we conducted the study with a different sample (e.g., experts), some of the specific patterns that emerge may change. Principally, the conditions that provoked high conscious processing in the current study tended to improve the performance of our novices. Had we recruited expert golfers who are towards the autonomous end of the skill acquisition continuum and less reliant on conscious rules to govern their movements, we might expect pressure-induced increases in conscious processing to prompt adverse performance effects (e.g., Beilock *et al.*, 2004). A future study of isolated pressures involving a wide range of expert and novice participants would help shed light on this issue.

Second, we revealed limited effects of pressure on heart rate variability. Since RMSSD and SDNN have been respectively proposed as corollary indices of anxiety and effort (Cooke *et al.*, 2010; Mateo *et al.*, 2012), the overall lack of effects could somewhat dilute our interpretations concerning anxiety and effort. SDNN did increase slightly in the goal condition only, but it decreased in the time condition, and both of these conditions were characterised by elevated self-reported effort. This observation questions the utility of the heart rate variability measures as indices of effort in this context. Phasic changes in heart rate that occur with individual golf putts (e.g., Cooke & Ring, 2019; Cooke *et al.*, 2014) are likely to cloud any effects of anxiety and effort on tonic heart rate variability and could limit the ability of these measures to reflect anxiety and effort in golf putting research.

Third, it is possible that performance was influenced by a state of fatigue elicited by the pressure manipulations, either immediately or residually. We counterbalanced conditions across participants and included a 3-min rest between conditions to account for this latter possibility. Future studies could collect any measures of fatigue to address these potential effects of fatigue on performance.

Fourth, it is possible that performance was influenced by the opportunity to win £20 for best overall performance. We do not know its impact on participants. This reward may have affected perceived pressure and/or task motivation. Future studies could avoid offering such a reward.

Finally, future research would do well to consider the role of personality as a moderator of the relation between isolated pressures and performance. The extent to which isolated pressures activate specific thoughts, feelings or behaviours is very likely to be impacted by the personality of the performer. Example traits that are of particular relevance to performance under pressure include sensitivity to reward and punishment (Bell *et al.*, 2013), narcissism (Roberts *et al.*, 2018), and reinvestment (Masters et al., 1993). For example, participants who are highly sensitive to reward might be more aroused and engaged by our fame condition, than our shame condition, whereas the oppositive might be expected for participants who are more sensitive to punishment. Participants who are sensitive to both reward and punishment might react to both fame and shame conditions, while participants who are insensitive to reward and punishment might react to neither condition. Participants who score high in grandiose narcissism might be expected to respond well to pressures that present an opportunity for glory (e.g., fame, difficulty) and less well to pressures that present fewer such opportunities to shine (e.g., distraction) (Roberts et al., 2018). Finally, participants who are high in reinvestment might be more likely to react to any form of pressure with increases in conscious processing, compared to their low trait reinvestment counterparts (Masters et al., 1993). The outcomes of any future personality-pressure-performance studies could be particularly beneficial for applied practitioners who may use personality assessments with their athletes to gain insight into what sorts of pressure-inducing factors are likely to be potent, or create the conditions likely to augment or impair, their individual performance.

4.6. Conclusion

Our findings shed new light on factors that constitute pressure, and they reveal that different isolated pressures exert different effects on skilled motor performance and task-related processes. This evidence challenges the tacit assumptions adopted by some studies of performance under pressure that all pressures are equal and additive (Baumeister, 1984). Adopting the "*less is more*" and "*simple is better*" principles (Cohen, 1990), we suggest that in most circumstances researchers shy away from unvalidated combined pressure manipulations and instead favour isolated pressure manipulations. We acknowledge that we have muddied the empirical and conceptual waters by previously ignoring these principles, but offer this recommendation as another example of one of those things that we have belatedly learned so far.

CRediT authorship contribution statement

Jennifer Henderson: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Maria Kavussanu:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. **Andrew Cooke:** Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Christopher Ring:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

We declare no conflicts of interest.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2024.102592.

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