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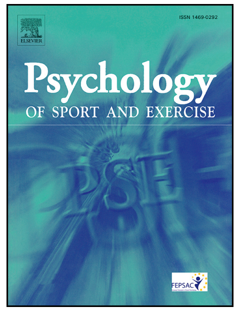

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Effects of task difficulty on performance and event-related bradycardia during preparation for action

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Abstract

The slowing of heart rate prior to movement onset has been presented as a marker of task-related cognitive processing and linked with performance accuracy. Here we examined this event-related bradycardia and task performance as a function of task difficulty. Forty experienced golfers completed a series of golf putting conditions that manipulated task difficulty by varying target distance, target size, and surface contour. Performance was measured by the number of holed putts and finishing distance from the hole. Physiological activity was recorded throughout. Analyses confirmed that performance varied as a function of task difficulty, worsening with longer distances to target, smaller targets, and sloping paths to target. Task difficulty also impacted the cardiac response, including the rate of heart rate deceleration, change in heart rate, and heart rate at impact. These heart rate metrics were found to correlate with performance strongly, moderately, and weakly, respectively. In conclusion, heart rate deceleration in the moments preceding movement onset was affected by task difficulty. Features of this cardiac deceleration pattern were characteristic of successful performance. Our findings are discussed in terms of the role of cognitive and motor processes during the execution of complex motor skills.

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Introduction

The sufficient and necessary allocation of attentional resources is a key feature of expertise and performance excellence in self-paced sport skills (Abernethy *et al*., 2007; Wulf, 2007). Physiological recordings can tell us about preparatory cognitive and motor processes and thereby serve as markers of movement preparation when executing and learning motor skills (Cooke, 2013). One such marker is the transient bradycardia that can be observed before cued and uncued (self-paced) movements. A short-term phasic pattern of heart rate deceleration is typical in the seconds preceding self-paced acts, such as golf (Cooke *et al*., 2010, 2011; 2014; Cotterill & Collins, 2005; Moore *et al*., 2012; Neumann & Thomas, 2009), pistol (Tremayne & Barry, 2001), and rifle (Hatfield *et al*., 1987; Hoffman & Street, 1992) shots. Despite consensus on the reproducibility of this phenomenon, its interpretation remains open to debate. Preparatory bradycardia has been interpreted as a marker of somatic quiescence by some (Obrist, 1968; Obrist *et al*., 1969, 1972, 1974) and a marker of attentional focus by others (Lacey & Lacey, 1970, 1974, 1980). The current study sought to contribute to this unresolved debate by examining cardiac activity and performance outcomes in relation to task difficulty for a self-paced motor task.

Lacey and Lacey's (1970, 1974, 1980) *intake-rejection hypothesis* argues that the event-related heart rate deceleration pattern reflects a relative shift in the allocation of attentional resources whereby individuals preferentially process (intake) external events and ignore (reject) internal events. In broad terms, it can be considered as representing a change in stimulus processing towards exteroception and away from interoception. For instance, the bradycardia before overt movement onset might be interpreted in terms of attentional focus, namely, a shift to external from internal focus of attention. The *intake-rejection hypothesis* is grounded in evidence from reaction time studies (Lacey, 1967; Lacey & Lacey, 1970) showing that heart rate decelerates in the fixed foreperiod between the presentation of the ready signal and the presentation of the imperative signal.

These original studies have been replicated and extended by studies of simple and complex motor skill tasks. Heart rate was shown to decelerate between the warning signal and imperative signal cueing participants to perform leg lifts, climb a flight of stairs, and pedal on a cycle ergometer (Chase *et al*., 1968; Stern, 1976). It is worth noting that the size of the heart rate deceleration was relatively small in these cued reaction time studies, generally averaging less than five beats per minute. In contrast, evidence from studies that examined self-paced sport skills have reported greater falls in heart rate (Cooke *et al*., 2010, 2011; 2014; Cotterill & Collins, 2005; Cottyn *et al*., 2008; Hatfield *et al*., 1987; Hoffman & Street, 1992; Moore *et al*., 2012; Neumann & Thomas, 2009; Tremayne & Barry, 2001). For instance, experts exhibited more substantial and profound heart rate deceleration (i.e., –12 bpm) before the onset of the backswing than novices (i.e., –4 bpm) while performing a golf putting task (Neumann & Thomas, 2009). It has been suggested that the superior performance of experts compared to novices may reflect differences in the extent to which performers pay attention to their external environment (e.g., the hole, the ball, and the path between the ball and hole) that may inform the programming of the movement (i.e., the direction and extent of the swing of the putter), and, that this contributes to the more pronounced drop in heart rate.

Obrist and colleagues (e.g., Obrist, 1968; Obrist *et al*., 1970; 1974; 1969) challenged the cognitive interpretation of the movement-related heart rate deceleration pattern. Instead, they offered an interpretation based upon a *general inhibition hypothesis*, whereby decreases in heart rate are attributable to lower peripheral muscle activity/metabolism driven by diminished efferent central motor commands. Thus, cardiac-somatic coupling is considered an organising feature of the cardiovascular and motor systems of the body under standard conditions, and, therefore, it is likely that variations in heart rate are closely connected with variations in somatomotor activity. By way of illustration, Howard *et al*. (1974) observed that variations in heart rate in the context of classical aversive conditioning were closely related to peripheral (i.e., general activity) and central (i.e., pyramidal tract activity) movement-related activity, thereby demonstrating how physical demands can orchestrate the heart rate response to a motor task.

With the aim of contributing to the debate on the interpretation of heart rate deceleration during preparation for action, the present study adopted a multi-method approach to explore the effects of task difficulty on phasic heart rate during a golf putting task in experienced golfers. Based on the assumption that increased task difficulty requires increased cognitive processing (e.g., Henry & Rogers 1960; Walters-Symons, 2018), and that increased task difficulty is associated with greater heart rate deceleration (e.g., Coles, 1972; 1974; Coles & Duncan-Johnson, 1977), we manipulated task demands by altering distance from the hole (target), hole size, and putting surface curvature. Evidence that the degree of bradycardia preceding task-relevant movement onset (i.e., swinging the club) is related to task difficulty independently of muscle activity would provide support for the *intake-rejection hypothesis* (Lacey & Lacey, 1970, 1974, 1980). In contrast, evidence that the degree of bradycardia is related to task difficulty relative to changes in muscle activity would provide support for the *general inhibition* hypothesis (e.g., Obrist, 1968; Obrist *et al*., 1970; 1974; 1969).

Methods

Participants

Male (n = 31) and female (n = 9) right-handed sport and exercise science students participated in exchange for course credit. Participants (M = 20.18, SD = 1.34 years) were regular golfers with on-course playing experience (M = 17.34, SD = 14.39 golf handicap). The protocol was approved by the local research ethics committee and all participants provided informed consent. Power calculations using GPower 3.1.9.7 (Faul, et al., 2007) software indicated that with a sample size of 40 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-to-medium (f = .19 to .20) effect size (Cohen, 1992). The current sample size also exceeded those recruited for previous experiments that compared the effects of task manipulations on various outcome measures in this context (see Introduction).

Measures

Perceived difficulty. Participants rated task difficultly on a 7-point Likert scale, anchored by 1 "not at all difficult" and 7 "very difficult".

Performance. The primary measure of performance was number of holed putts (out of 9). A secondary measure of performance, mean radial error (i.e., arithmetic mean of the distances the ball finished from the hole), indexed putting accuracy (Hancock et al., 1995). Distance of the ball from the hole was recorded as the distance (cm) from the centre of the hole to the closest point of the ball. The number of putts per condition was a compromise between the effectiveness of each experimental manipulation (Cooke et al., 2011) and the reliability of the measurements (Schweizer et al., 2020). On the one hand, on a one-off trial, the impact of a manipulation on the performer has high effectiveness and high ecological validity whereas measurements have low reliability and high variability (e.g., Woodman & Davis, 2008). On the other hand, with large numbers of trials, the impact of a manipulation on the performer has low effectiveness and low ecological validity whereas measurements have high reliability and low variability (e.g., Cooke et al., 2014). Mindful of the influence of consecutive repetitions on the attenuation of motor preparatory and control processes (Gallicchio & Ring, 2019), we designed 9 trials per condition.

Kinematics. A tri-axial accelerometer (ADXL337 Breakout, Cool Components) recorded putter head acceleration in three planes: X, Y, and Z acceleration measured lateral, vertical, and back-and-forth clubhead movements. Contact between the ball and putter was measured by an impact sensor (Piezo Vibration Sensor, Measurement Specialties). The accelerometer and impact sensor were attached to the bottom of the putter shaft. Movement kinematics were determined during the time between the initiation of the downswing and impact with the ball. The Z-axis (mediolateral), which is the primary movement in putting (Cooke *et al*., 2010, 2011; Maxwell *et al*., 2003), was used to calculate measures of kinematic proficiency (Nelson, 1983; Stelmach *et al*., 1989), namely, root mean square jerk (i.e., rate of change of acceleration) and smoothness (i.e., number of sign changes in jerk signal). Mean values for each kinematic variable were computed by averaging values across all putts in each condition.

Muscular activity. Left forearm and right upper arm muscle activity was recorded using single differential surface electrodes (DE 2.1, Delsys) and amplifier (Bagnoli-4, Delsys), with a ground electrode attached on the collar bone. The left flexor carpi radialis and right biceps brachii muscles have been implicated in putting (Smith *et al*., 2000; Stinear *et al.,* 2006). EMG signals were amplified, (Power 1401, CED), filtered (20-450 Hz), digitalized (2500 Hz), and recorded using Spike 2 software. Mean EMG amplitude (μV) was calculated during the entire condition (i.e., mostly resting muscle activity between the first and nineth ball strike) and during the brief window (c. 500 ms) just before the initiation of the upswing of the putter stroke (see Cooke *et al*., 2010). We computed the change in EMG (i.e., pre-initiation minus overall resting activity) to capture the characteristic increase in muscle activity in the preparatory period (see Moore et al., 2012).

Cardiac activity. An electrocardiogram was recorded using three silver/silver chloride spot electrodes (Cleartrace, ConMed) in a modified chest configuration. The signal was amplified (Bagnoli-4 Delsys), filtered (1-100 Hz), and digitalized at 2500 Hz with 16-bit resolution (Power 1401, CED) using bespoke software (Spike2, CED). R-wave peaks were identified and verified by an interactive program. The R-R intervals were used to compute heart rate (bpm) for each 0.5 s epoch, from 10 s before impact with the ball to 5 s post-impact to capture the heart rate deceleration profile (Cooke *et al*., 2014; Neuman & Thomas, 2009, 2011). T tests were used to confirm the highest and lowest heart rate in the 10 s before impact for the group in each condition. Heart rate at putter-ball impact corresponded with the lowest point of the heart rate deceleration response. The heart rate change was computed as the difference between the mean highest heart rate and mean lowest heart rate per condition for each participant. The rate of heart rate deceleration was computed as the heart rate change described above divided by the time between the two heart rate epochs.

Task and conditions

Participants performed a golf putting task. Similar tasks have been used in previous preparation for action studies (e.g., Cooke *et al.,* 2014; Neuman & Thomas, 2009, 2011). To be successful in this task, participants were expected to accurately plan and program both movement force and direction. Accordingly, cognitive processes, such as external focus of attention, were likely in the seconds before movement execution.

In the control condition, participants putted nine standard sized golf balls (Pro V1, Titleist) to a standard sized golf hole (10.8 cm diameter), located 2 m away using a standard length (90 cm) steel-shafted blade style putter (Sedona 2, Ping). The hole was centrally located 0.25 m from the end of a flat 1.5 m x 5 m artificial putting surface (Augin Turftiles) with a Stimpmeter reading of 4.27 m. The finishing position of each putt was marked by a dot sticker and the ball removed; these dots were used to measure distance from the hole at the end of each condition.

Task difficulty was manipulated in three ways: distance from target, hole diameter, and surface contour. In the distance from target conditions, participants putted to a hole located 3 m, 1 m and 0.5 m away. These distances were expected to be harder, easier, and much easier than control, respectively. In the hole diameter conditions, participants putted to a hole with a diameter of 8.1 cm and 5.4 cm; these were 75% and 50% the size of a standard golf hole. These hole diameters were expected to be harder and much harder than control, respectively. In the surface profile conditions, participants putted to a hole with a right-to-left break and left-to-right break. These sloping surfaces were expected to be harder and much harder than control (Carnegie *et al*., 2020). Aside from the manipulated factor, conditions were otherwise the same as control (see above).

Procedure

Participants attended a single testing session. Following preparation and instruction, they completed nine practice putts. They completed eight conditions (described above), with order counterbalanced using a Latin square (Williams, 1949). No technical putting instructions were provided. Participants were instructed to putt at their own pace. They were told that performance was based on the number of holed putts and radial error, and, therefore, they should try to hole the putt and, if they miss the putt, to finish as close to the hole as possible. A £20 reward was offered for the best overall performer. Standard scripted instructions were read out by the experimenter. A ball was placed in position by the experimenter prior to each putt to ensure participants always stood upright. Participants completed self-report measures using a tablet computer after each condition creating a 3 min rest period between conditions.

Statistical analysis

A series of condition multivariate analyses of variance (ANOVAs), followed by Student *t* tests, were employed to examine how performance, psychological, physiological, and kinematic measures changed with task difficulty compared to control. This analytic approach was also used to establish the effects of task difficulty within the three sub-themes: distance from target, hole diameter, and surface profile. Heart rate was subjected to a condition × epoch ANOVA. We report multivariate statistics for these repeated measures ANOVAs to minimize the risk of violating sphericity and compound symmetry assumptions (Vasey & Thayer, 1987). Partial eta-squared (η_p^2) is reported as a measure of effect size, with values of .02, .12 and .26 indicating small, medium, and large effect sizes, respectively (Cohen, 1992). Within-participant correlations were computed between our measures of performance (holed putts, radial error) and each of the heart rate metrics (rate of heart rate deceleration, change in heart rate, heart rate at impact) in each of the eight conditions. These correlation coefficients were transformed using the Fisher Z-transformation (Siegel & Castellan, 1956), and were then averaged, back-transformed, and interpreted. The effect size of the back-transformed coefficients were evaluated using guidelines, with values of .10, .30 and .50 reflecting small, medium, and large effect sizes, respectively (Cohen, 1992).

Results

Effects of distance-based task difficulty

Separate 4 condition (0.5 m, 1 m, 2 m, 3 m) ANOVAs confirmed large-sized effects of distance from the hole on 12 out of 15 measures (Table 1). The increase in distance from the ball to the hole was associated with greater perceived difficulty, decreased putting performance, and higher kinematics while putting. Muscle activity increased during the preparatory phase but this increase did not vary as a function of task difficulty. Although the initial resting heart rate and heart rate at impact were broadly similar across difficulty conditions, the rate of heart rate deceleration and change in heart rate tended to be smaller with increasing distance from the hole (i.e., greater task difficulty).

Heart rate decelerated in the moments before movement onset (Figure 1A). This event-related bradycardia was confirmed by a 4 condition (0.5 m, 1 m, 2 m, 3 m) × 21 epoch (-10, -9.5, -9.0 …. 0 s) polynomial contrast analysis. These contrasts yielded time-varying effects for epoch (linear = $F(1, 39) = 64.02$, $p < .001$, $\eta_p^2 = .63$; quadratic = $F(1, 39) = 118.91$, $p < .001$, $\eta_p^2 = .75$; cubic = $F(1, 39) = 8.51$, $p = .006$, $\eta_p^2 = .18$), condition (linear = $F(1, 39) = 21.18$, $p < .001$, $\eta_p^2 = .35$), and condition by epoch (linear × linear = $F(1, 39) = 18.34$, $p < .001$, $\eta_p^2 = .32$; linear × quadratic = $F(1, 39) = 11.41$, $p = .002$, $\eta_p^2 = .23$; linear × cubic = $F(1, 39) = 18.73$, $p < .001$, $\eta_p^2 = .32$).

Effects of target size-based task difficulty

Separate 3 condition (100%, 75%, 50%) ANOVAs confirmed large-sized effects of target (hole) size on 8 out of 15 measures (Table 2). The decrease in hole size was associated with greater perceived difficulty, poorer putting performance, and lower kinematics while putting. Muscle activity increased during the preparatory phase, but this increase did not vary as a function of task difficulty. The heart rate metrics were mostly unchanged by target size-based task difficulty; the exception was that the rate of heart rate deceleration was larger with decreasing hole size (i.e., greater task difficulty).

Heart rate deceleration in the moments before movement onset (Figure 1B) was confirmed by a 3 condition (100%, 75%, 50%) × 21 epoch (-10, -9.5, -9.0 …. 0 s) polynomial contrast analysis, which yielded time-varying contrast effects for epoch (linear = $F(1, 39) = 75.58$, $p < .001$, $\eta_p^2 = .65$;

quadratic = $F(1, 39) = 64,23$, $p < .001$, $\eta_p^2 = .62$). No condition or condition × epoch contrasts were found.

Effects of contour-based task difficulty

Separate 3 condition (straight, right-to-left break, left-to-right break) ANOVAs confirmed large-sized effects of surface contour on 9 out of 15 measures (Table 3). Compared to straight putts on a flat surface, breaking putts on a sloping surface, especially those with a left-to-right break, were associated with greater perceived difficulty, poorer putting performance, and higher kinematics while putting. Muscle activity increased during the preparatory phase but did not vary as a function of task difficulty. The heart rate metrics were mostly unchanged by contour-based task difficulty; the exception was that initial heart rate was marginally slower before executing breaking putts (i.e., greater task difficulty).

Heart rate deceleration in the moments before movement onset (Figure 1C) was confirmed by a 3 condition (straight, right-to-left break, left-to-right break) × 21 epoch (-10, -9.5, -9.0 …. 0 s) polynomial contrast analysis. These contrasts yielded time-varying effects for epoch (linear = $F(1, 39) = 67.00$, $p < .001$, $\eta_p^2 = .63$; quadratic = $F(1, 39) = 82.35$, $p < .001$, $\eta_p^2 = .68$), and condition (linear = $F(1, 39) = 7.83$, $p = .008$, $\eta_p^2 = .17$). No condition × epoch contrast was observed.

Relationships between cardiac metrics and task performance indices

Within-participant correlations were performed between each cardiac metric (rate of heart rate deceleration, change in heart rate, heart rate at impact) and the separate performance indices (number of holed putts, radial error) across the eight task conditions using the average across the 9 putts for each condition (Table S1, Supplementary Materials). Each participant's Pearson's correlation coefficient (e.g., between change in heart rate and radial error) was transformed using the Fisher Z transformation, the average of these transformed coefficients was computed, the average was back-transformed to a Pearson correlation coefficient, and the size of this coefficient tested for linear independence (i.e., compared with 0 using a *t* test) and interpreted as small, medium or large (Cohen, 1992). These analyses indicated that the rate of heart rate deceleration was strongly related (i.e., large effect size) to the number of holed putts, $r(6) = .-58$, $p = .07$, and radial error, $r(6) = .48$, $p = .11$. The change in heart rate was moderately related (i.e., medium effect size) to holed putts, $r = -.28$, $p = .25$, and radial error, $r(6) = -.23$, $p = .29$. Heart rate at impact was weakly related (i.e., small effect size) to holed putts, $r(6) = -.16$, $p = .35$, and radial error, $r(6) = .11$, $p = .40$. In sum, task performance accuracy was better – more putts were holed and putts finished closer to the hole – when heart rate decelerated faster.

Discussion

The current study sought to evaluate the *intake-rejection hypothesis* (Lacey & Lacey, 1970, 1974, 1980) and *general inhibition hypothesis* (Obrist, 1968; Obrist et al., 1970; 1974; 1969) as explanations for the bradycardia response during preparation for action (Cooke, 2013). We examined the effects of task difficulty on heart rate in the seconds preceding a complex self-paced and goal-directed movement. Heart rate decelerated by about 12 beats per minute over a period of about 8 s until club-ball impact (Figure 1). Subsequently, it then sped up over the next 6 s and returned to and eventually surpassed initial values. This consistent pattern resembled that reported previously in golf putting tasks (Boutcher & Zinsser, 1990; Cooke *et al.,* 2014; Moore et al., 2012; Neumann & Thomas, 2009, 2011). Our findings confirmed that task difficulty influenced the rate but not the magnitude of heart rate deceleration. In particular, the magnitude of heart rate deceleration and heart rate at impact were relatively invariant whereas heart rate began to fall earlier and took longer to reach its minimum with increasing task difficulty (Figure 1). By illustration, when the ball was closest to the hole and putting was easiest, heart rate only began to fall 4 s before the club hit the ball compared to the typical 8 s in the other conditions.

Previous studies have found that the magnitude of the heart rate deceleration response is a feature of expertise, being greater in experts than novices (Cooke *et al.,* 2014; Neumann & Thomas 2009, 2011). The current findings argue that the extent of this bradycardia is not sensitive to task demands. Instead, the onset of the bradycardia was moderated by task difficulty. The *intake* *rejection hypothesis* (Lacey & Lacey, 1970, 1974, 1980) would interpret these data as showing that participants adopted an external focus of attention when preparing to putt a golf ball to a distant target. Variations among task difficulty conditions in the rate of heart rate deceleration might suggest that information in the external environment, such as required ball path and distance from ball to hole, is processed and used to program movement parameters, such as direction and force (Moore *et al*., 2012; Requin *et al*., 1991). Enhanced exteroceptive processing during preparation for action, where novel features of the environment provide information about the task, may therefore aid motor execution. Previous evidence has linked the onset of heart rate changes with performance accuracy (e.g., Moore *et al*., 2012; Neumann & Thomas, 2009; Tremayne & Barry, 2001). For instance, expert pistol shooters' heart rate deceleration began 3.5 s earlier on best shots compared to worst shots (Tremayne & Barry, 2001). Accordingly, the slower rate of heart rate deceleration observed in the current study suggests that attention shifts to process information from the external environment depending on the difficulty of the motor task. More difficult task demands, which required attention to begin earlier and to last longer, were associated with earlier onset and more gradual slowing of heart rate. It should be noted that, in line with the current findings, most previous golf putting studies have failed to find evidence that the absolute change in heart rate was related to variations in putting performance. Instead, they found evidence that the absolute change in heart rate was a characteristic of expertise. We speculate that this consistent finding suggests that the absolute change in heart rate may simply reflect the well-honed and practiced pre-shot routines of experts.

The *general inhibition hypothesis* (Obrist, 1968; Obrist *et al*., 1970; 1974; 1969) explains changes in cardiac activity in terms of accompanying changes in peripheral and/or central somatomotor activity. In accordance with the *cardiac-somatic coupling* principle, decreases in cardiac activity should be accompanied by concomitant decreases in muscle activity. Several issues need to be considered here. First, the hypothesis would expect that the heart rate deceleration response in the seconds before movement onset should be accompanied by reductions in muscle activity.

However, previous golf putting studies (Cooke *et al*., 2014; Moore *et al*., 2012) show that decreases in heart rate in the seconds before the golf swing are accompanied by increases in muscle activity in the upper and lower arms, which are explicitly required to control the putter and execute the task. Similarly, we observed increased electromyographic activity in these arm muscles (see Tables 1, 2 and 3). It should be noted that other muscles, such as postural, oculomotor, or respiratory muscles, may have been deactivated during this preparatory period. This is a possibility given evidence that the eyes are likely to fix on the ball and remain relatively still in the period before movement onset in golf putting tasks (e.g., Moore *et al.,* 2012; Gallicchio *et al*., 2018; Gallicchio & Ring, 2020). Similarly, it is possible that participants varied their rate and depth of breathing before putting (e.g., Neumann & Thomas, 2009). None of these muscles were recorded in the current study and therefore this possibility cannot be discounted. Second, the hypothesis would expect that the onset of the heart rate deceleration response should be preceded by greater muscle activity. However, we found no differences among the eight task conditions in background electromyographic activity in these arm muscles. This evidence would therefore argue against this possibility. It should be conceded that we did not measure the activity of other muscles, which may have been activated prior to the onset of the bradycardia.

Conclusion

The present study found that the rate but not the magnitude of heart rate deceleration in the seconds preceding movement was sensitive to variations in task difficulty. These findings may reflect the effects of the experimental manipulations on attentional (Lacey & Lacey, 1970, 1974, 1980) or motor (Obrist, 1968) processes. The current findings are better explained by the *intake-rejection hypothesis* than the *general inhibition hypothesis*. It should be acknowledged that our interpretation favouring the intake-rejection hypothesis is best supported by our findings from the distance from the hole manipulations (Figure 1A, Table 1). The interpretation receives less support from the size of the hole manipulation (Figure 1B, Table 2). Finally, the interpretation is not clearly supported by the surface contour manipulation (Figure 1C, Table 3). Clearly, additional manipulations, including task difficulty, and markers, such as cortical activity, are needed before we can confidently decide which of the two competing hypotheses best account for cardiac deceleration in preparation for action.

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Figure 1. Mean heart rate change (bpm) in the 10 s prior to and 5 s following putter-ball impact as a function of (A) distance from the hole, (B) size of the hole, and (C) surface contour.

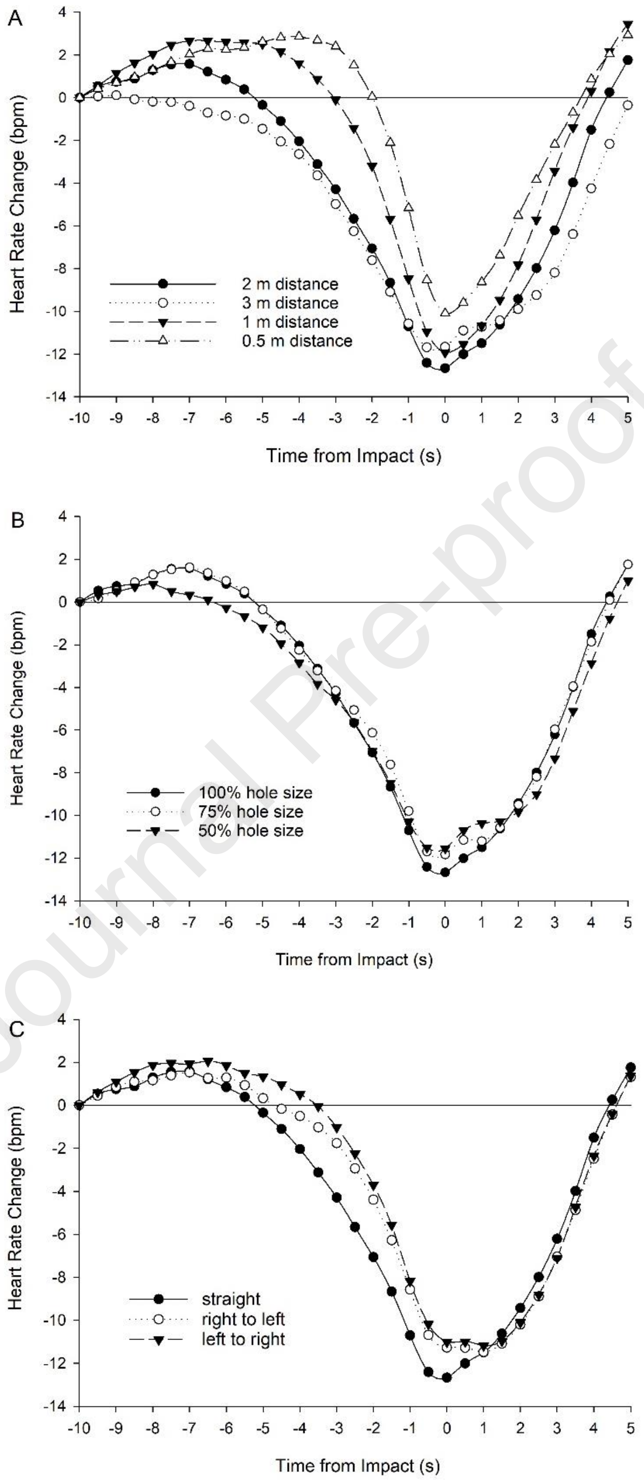

Table 1. Effects of distance from hole on perception, performance, kinematics and physiology.

Measure	Distance								$F(3, 37)$	η_p^2
	0.5 m		1 m		2 m		3 m			
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*		
Difficulty (1-7)	1.61	0.86	2.79 ^{a}	1.36	2.74 ^{a}	1.17	4.68 ^{a,b,c}	1.38	61.63 ***	.83
Number of Holed Putts (0-9)	8.98	0.16	6.90 ^{a}	1.89	6.55 ^{a}	1.88	3.78 ^{a,b,c}	1.98	95.26 ***	.89
Radial Error (cm)	0.04	0.26	7.36 ^{a}	6.54	9.30 ^{a}	7.96	28.14 ^{a,b,c}	18.72	39.22 ***	.76
X-axis Acceleration ($m \cdot s^{-2}$)	0.28	0.07	0.34 ^{a}	0.09	0.50 ^{a,b}	0.14	0.62 ^{a,b,c}	0.18	77.86 ***	.86
Y-axis Acceleration ($m \cdot s^{-2}$)	0.46	0.34	0.48 ^{a}	0.36	0.58 ^{a,b}	0.49	0.67 ^{a,b,c}	0.50	21.67 ***	.64
Z-axis Acceleration ($m \cdot s^{-2}$)	2.34	0.53	2.66 ^{a}	0.61	3.22 ^{a,b}	0.76	3.65 ^{a,b,c}	0.75	84.44 ***	.87
Jerk ($m \cdot s^{-3}$)	2.35	0.54	2.65 ^{a}	0.60	3.18 ^{a,b}	0.71	3.60 ^{a,b,c}	0.73	85.24 ***	.87
Smoothness	61.53	10.54	63.99 ^{a}	10.94	67.74 ^{a,b}	12.56	68.21 ^{a,b,c}	10.30	13.72 ***	.53
Change in Flexor Carpi Radialis EMG (μV)	7.45	8.68	8.49	11.03	8.72	10.10	9.24	11.34	1.38	.26
Change in Biceps Brachii EMG (μV)	1.38	6.04	1.54	7.79	0.59	6.11	0.71	6.62	1.72	.12
Heart Rate (bpm)	84.97	12.39	85.10	12.40	85.95	12.50	85.47	12.74	1.18	.09
Change in Heart Rate (bpm)	-12.96	7.26	-14.60	8.57	-14.25	8.39	-11.77 ^{b,c}	6.85	5.17 **	.30
Rate of Heart Rate Deceleration (bpm)	-194.37	108.97	-134.81 ^{a}	79.10	-122.10 ^{a}	71.88	-78.47 ^{a,b,c}	45.64	35.10 ***	.74
Heart Rate at Impact (bpm)	74.56	11.48	73.69	10.30	75.09	12.65	76.06 ^{a,b}	11.92	4.79 **	.28

Note: Superscripted letters ^{a}, ^{b} and ^{c} indicate significant difference from 0.5 m, 1 m, and 2 m (control) conditions, respectively. * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 2. Effects of size of the hole on perception, performance, kinematics and physiology.

Measure	Size						$F(2, 38)$	η_p^2
	100%		75%		50%			
	M	*SD*	*M*	*SD*	*M*	*SD*		
Difficulty (1-7)	2.74	1.17	4.18 [a]	1.45	5.00 [a,b]	1.20	49.87 ***	.72
Number of Holed Putts (0-9)	6.55	1.88	5.65 [a]	2.20	3.73 [a,b]	2.24	23.10 ***	.55
Radial Error (cm)	9.30	7.96	12.10 [a]	10.06	17.55 [a,b]	12.10	11.33 ***	.37
X-axis Acceleration ($m \cdot s^{-2}$)	0.50	0.14	0.48 [a]	0.14	0.45 [a,b]	0.13	15.04 ***	.42
Y-axis Acceleration ($m \cdot s^{-2}$)	0.58	0.49	0.59	0.53	0.57	0.51	0.47	.02
Z-axis Acceleration ($m \cdot s^{-2}$)	3.22	0.76	3.07 [a]	0.71	3.00 [a]	0.67	8.84 ***	.32
Jerk ($m \cdot s^{-3}$)	3.18	0.71	3.03 [a]	0.67	2.95 [a,b]	0.63	10.06 ***	.35
Smoothness	67.74	12.56	69.03	12.40	67.59	11.82	2.99	.14
Change in Flexor Carpi Radialis EMG (μV)	8.72	10.10	8.27	10.17	8.09	10.92	0.64	.03
Change in Biceps Brachii EMG (μV)	0.59	6.11	1.69	8.99	0.87	7.66	0.53	.03
Heart Rate (bpm)	85.95	12.50	84.84	12.14	84.89	11.98	2.43	.11
Change in Heart Rate (bpm)	-14.25	8.39	-13.45	7.22	-12.38	7.43	2.50	.12
Rate of Heart Rate Deceleration (bpm)	-122.10	71.88	-115.25	61.93	-92.89 [a,b]	55.69	11.19 ***	.37
Heart Rate at Impact (bpm)	75.09	12.65	74.87	11.57	75.18	11.96	0.19	.01

Note: Superscripted letters [a] and [b] indicate significant difference from 100% (control) and 75% conditions, respectively. * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 3. Effects of surface contour on perception, performance, kinematics and physiology.

	Contour						*F*(2, 38)	η_p^2
Measure	Straight		Right-to-Left		Left-to-Right			
	M	*SD*	*M*	*SD*	*M*	*SD*		
Difficulty (1-7)	2.74	1.17	4.32 [a]	1.43	4.50 [a]	1.51	26.53 ***	.58
Number of Holed Putts (0-9)	6.55	1.88	6.28	2.40	5.13 [a,b]	2.13	6.44 **	.25
Radial Error (cm)	9.30	7.96	12.65	12.91	24.62 [a,b]	16.33	16.80 ***	.47
X-axis Acceleration ($m{\cdot}s^{-2}$)	0.50	0.14	0.56 [a]	0.16	0.58 [a,b]	0.17	11.19 ***	.37
Y-axis Acceleration ($m{\cdot}s^{-2}$)	0.58	0.49	0.61	0.54	0.66 [a,b]	0.58	7.02 **	.27
Z-axis Acceleration ($m{\cdot}s^{-2}$)	3.22	0.76	3.51 [a]	0.75	3.50 [a]	0.71	22.27 ***	.54
Jerk ($m{\cdot}s^{-3}$)	3.18	0.71	3.47 [a]	0.72	3.46 [a]	0.69	24.97 ***	.57
Smoothness	67.74	12.56	65.46 [a]	10.95	64.35 [a]	11.15	8.07 ***	.30
Change in Flexor Carpi Radialis EMG (µV)	8.72	10.10	8.33	10.09	9.00	10.84	0.51	.03
Change in Biceps Brachii EMG (µV)	0.59	6.11	0.47	5.77	0.77	6.14	0.41	.02
Heart rate (bpm)	85.95	12.50	83.89 [a]	12.18	84.08 [a]	11.62	7.03 **	.27
Change in Heart Rate (bpm)	-14.25	8.39	-12.80	6.32	-13.07	6.65	1.50	.07
Rate of Heart Rate Deceleration (bpm)	-122.10	71.88	-109.69	54.17	-120.67	61.39	2.30	.11
Heart Rate at Impact (bpm)	75.09	12.65	74.47	11.50	73.60	11.22	2.63	.12

Note: Superscripted letters [a] and [b] indicate significant difference from straight (control) and right-to-left slope conditions, respectively. * $p < .05$, ** $p < .01$, *** $p < .001$.

Highlights

- Heart rate slowing before movement reflects attentional and/or motor processes
- We confirm bradycardia during preparation for action
- Its timing and extent depended on task difficulty
- Data favor *intake-rejection hypothesis* rather than *general inhibition hypothesis*

Declaration of Interest

We declare no conflicts of interest.