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Heart Rate is Distinctly Influenced by Complexity of Instructions and Direction of Attentional Focus

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A B S T R A C T

Background: Contemporary theories propose that adopting an external focus of attention allows the body's system to self-organize, resulting in more efficient and automated control of motor behavior. In that context, our purpose in this study was to measure heart rate to test whether altering focus of attention would elicit a physiologic response during a static balancing task.

Methods: Twenty-three college aged participants (M = 23.3 ± 5.63years) balanced on an AccuSway Balance Platform while performing a secondary supra-postural task. Center of pressure (COP) and heart rate was measured throughout each trial. Participants completed three baseline trials followed by three trials in each of two experimental conditions presented in a counterbalanced order. In the baseline trials, participants were instructed to "maintain your balance to the best of your ability." Internal focus (IF) instructions were "focus on minimizing movement of your hand, while maintaining your balance to the best of your ability." External focus (EF) instructions were "focus on minimizing movement of the sheet, while maintaining balance to the best of your ability."

Results: Results indicated: (a) a significant change in heart rate during trials in all conditions, $p < .001$, (b) a significantly lower heart rate for trials completed in the baseline condition compared to trials completed under either the IF or EF instructional set, $p < .001$, and (c) a significantly more rapid lowering in heart rate during trials completed under EF instructions compared to IF instructions, $p < .001$. There were no significant differences in the COP between any of the conditions ($p > 0.05$).

Conclusion: The results of this study demonstrate that the complexity and attentional direction of instructions may differentially influence heart rate responses during motor performance. Further explanations and implications for future research are discussed.

1. Introduction

The effects of attentional focus on the performance of motor skills have captured much attention for the past two decades. The majority of research on this topic has compared the effects of internal versus external focus cues on the performance and learning of motor skills (Chua, 2021). Internal focus cues have been defined as those that direct the performer's attention toward some aspect of the movement itself, whereas external focus cues direct the performer's attention toward the outcome of the movement (G. Wulf, and Prinz, W., 2001). A substantial body of literature has shown that using external focus cues tends to improve motor performance compared to prompting an individual's focus their conscious attention internally (for a review see (Chua, 2021).

The most prominent explanation for the observed performance and motor learning benefits of an external focus is the constrained action hypothesis (McNevin, 2002; G. Wulf, McNevin, N. H., & Shea, C. H., 2001). According to this hypothesis, focusing internally constrains the motor system and leads to undesirable conscious control of movements, whereas focusing externally allows the motor system to naturally self-organize. Initial support for the constrained action hypothesis came from studies showing higher response frequencies on balancing tasks when participants focused externally versus internally (McNevin, 2002). Additional support for this hypothesis has demonstrated that, during force production, an internal focus of attention leads to greater co-contraction between the agonist and the antagonist muscles causing inefficient motor control (Lohse, 2011). On the contrary, an external focus of attention has been shown to promote enhanced performance with lower muscular activity (Lohse, 2011; Vance, 2004) and more efficient neural activity (Kuhn, 2013).

One class of attentional focus research has examined the effects of focus instructions on attentional demands using dual-task paradigms. Most of these studies have supported the prediction of the constrained action hypothesis that attentional demands are lower under external focus compared to internal focus conditions. For example, (G. Wulf, and Prinz, W., 2001) demonstrated that during a balancing task individuals had shorter probe reaction times when focusing on the balance platform (i.e., external) compared to when focusing on the feet (i.e., internal). Likewise, (Ille, 2013) found that sprinters had decreased reaction times when focusing on the finish line compared to their legs. More recently, (Sherwood, 2020) showed that an external focus of attention led to more accurate performance in a dual task paradigm, particularly when the motor and cognitive demands were high.

Although research has produced extensive support for the benefits of external focus on motor performance outcomes and attentional

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demand, the effects of internal and external focus on physiological responses are not well understood. A few studies have examined heart rate in relation to mental focus, but these studies have focused on comparing attention directed to a task-relevant or task-irrelevant cue (D. L. Neumann, & Heng, S. , 2011; Schucker, 2016). Specifically, (D. L. Neumann, & Heng, S. , 2011) as well as (Schucker, 2016) used attention allocation strategies categorized as associative (i.e., focus of bodily sensations) or dissociative (i.e., focus on a mental distraction) to investigate attentional focus effects on heart rate. Only two experiments (Mullen, 2012; D. Neumann, & Brown, J. , 2013) have examined heart rate in the context of the internal vs. external attentional focus paradigm. These studies have supported the idea that an external focus is associated with lower heart rate responses. However, a major limitation in both studies was the lack of symmetry between internal and external focus instructions. For example, (D. Neumann, & Brown, J. , 2013) provided three instructional cues during the internal condition, whereas the external condition only provided two cues, differing in complexity. Ideally, internal and external instructions should only differ by one or two words (Wulf, 2013). Thus, the differing complexity of instructional sets in these studies represents a limitation that may have confounded the results.

In light of the aforementioned limitations and the relative scarcity of research in this area, it is important for future research to pursue a clearer understanding of the impact of attentional focus on heart rate. Heart rate has been demonstrated as a reliable indicator of motor performance (H. Mansikka, Simola, P., Virtanen, K., Harris, D., & Oksama, L. , 2016a) and demands on attention (Jorna, 1992; H. Mansikka, Simola, P., Virtanen, K., Harris, D., & Oksama, L. , 2016a; Perusse-Lachance, 2012). For example, heart rate is frequently used as a measure of a pilot's mental workload in aviation research (H. Mansikka, Simola, P., Virtanen, K., Harris, D., & Oksama, L. , 2016a; H. Mansikka, Virtanen, R., Harris, D., & Simola, P., 2016b). More specifically, heart rate is used to assess the attentional demands placed on the pilot that provides valuable insight about the available mental capacity during tasks with high cognitive load (H. Mansikka, Simola, P., Virtanen, K., Harris, D., & Oksama, L. , 2016a; H. Mansikka, Virtanen, R., Harris, D., & Simola, P., 2016b). Understanding the connection between focus of attention and heart rate will provide additional insight into the broader effects of attentional changes under internal and external focus conditions and help to inform coaching and instructional decisions in the context of cognitively demanding motor tasks.

We sought to address this need in the current study using a static balancing dual task similar to the one used in (McNevin, 2002) experiment. Specifically, in the present study we measured balance performance and heart rate throughout the course of each trial so that intra-trial fluctuations could be detected. The use of a dual task presumably increased attentional demand compared to standard balancing. Given the relationship between attentional demand and heart rate seen in previous research, we believe this task provided a relatively sensitive platform for examining heart rate across attentional focus conditions. Based on (McNevin, 2002) findings we predicted there would be no differences in balance performance, measured through changes in center of pressure displacement (COP), between the experimental conditions. Based on the prediction of constrained action hypothesis that focusing externally should reduce attentional demand, along with the observed connection between heart rate and attentional demand in previous studies (e.g., (H. Mansikka, Simola, P., Virtanen, K., Harris, D., & Oksama, L. , 2016a; H. Mansikka, Virtanen, R., Harris, D., & Simola, P., 2016b; Perusse-Lachance, 2012), we also predicted that adopting an external focus of attention would lead to lower heart rate values compared to either baseline measures or trials following internal focusing instructions.

2. Materials and Methods

2.1. Subjects

There were 23 university students (15 males, 8 females; M age = 23.3, SD = 5.63 years) who volunteered to participate in the present experiment. All methods were reviewed and approved by a university ethics committee. Prior to data collection, all participants provided written informed consent. All participants were naïve to the purpose of the study. All procedures were approved by the university's Institutional Review Board prior to the start of the study.

2.2. Apparatus and task

An AccuSwayPLUS Balance Platform from Advanced Mechanical Technology Incorporated (AMTI) was used to acquire COP data, with a sampling rate of 200Hz for each 30-second trial (version 2.01.00, June 2006). The platform was linked to a Windows computer loaded with the accompanying software through AMTI's PJB-101 interface which converted applied force into volts.

We also used a Polar RS800CX heart rate monitor, with a capture rate of 30 heart rates per trial (i.e., one every second) which allowed heart rate to be measured concurrently throughout the duration of each 30-second trial.

A lightweight white piece of fabric was loosely draped over a coat rack so that it did not touch the floor and ensured the weight of the fabric could not be used as a base of support affecting the participant's balance (Riley, 1999).

2.3. Procedures

Forty-eight hours prior to arriving at the laboratory, all participants were contacted via email reminding them not to consume caffeine for 24 hours or eat a large meal in the three hours prior to their testing appointment. Upon arrival to the laboratory, the participants were given a brief overview of the various apparatuses and the task. We used this procedure to increase and standardize the participant's comfort level with the experimental protocol as stress can cause variations in heart rate. The participant was then instructed to sit down for five minutes prior to beginning data collection to allow their heart rate to return to resting levels.

Prior to data collection, participants put on a heart rate monitor, and the researcher verified that the monitor was working properly. The participants then stood on the force platform in a static anatomical position with their feet spaced evenly apart (anteroposteriorly and mediolaterally). Then they were instructed to flex their dominant-side elbow to 90 degrees and pronate their forearm to a neutral position. The hanging fabric was moved toward the participant so the sheet was touching the tips of their fingers while at the same time not blocking their view of a streamer hanging from the ceiling. Participants were then instructed to focus their vision on the streamer hanging three meters away. This was done so that all participants visually focused on the same point throughout all testing sessions.

Participants were tasked with balancing on the platform while maintaining contact with the hanging fabric. All participants completed a total of nine 30-second balancing trials during their testing session with a 30-second rest period between each trial. They began with three trials in a baseline condition. Following the three baseline trials, participants completed three trials in each of the remaining focus conditions (i.e., internal or external) in a counterbalanced order. Immediately preceding each of the nine trials, instructions were provided to appropriately direct participants' attention. Instructions for the baseline condition were "balance to the best of your ability." Instructions for the internal focus (IF) and external focus (EF) conditions were (a) "focus on minimizing movement of your hand, while maintaining balance to the best of your ability" and (b) "focus on minimizing the movement of the sheet, while maintaining balance to the best of your ability," respectively.

2.4. Data analysis

We measured postural sway via changes in COP throughout each trial. The standard deviations of each 1-second window were averaged to obtain a mean moving window standard deviation of the COP (McNevin, 2002). These values were then analyzed using a univariate repeated measures analysis of variance (ANOVA) to assess differences in the measured postural sway. Heart rate was measured concurrently throughout each 30-second trial at a frequency of 1 hz. This resulted in thirty heart rate values (i.e., one for each second of the trial) per trial for each participant within each condition. Data were analyzed using a 3 (condition) by 30 (heart rate measures) ANOVA with repeated measures on both factors. The alpha level was set to 0.05 for all analyses. Upon finding significant differences, post-hoc procedures were completed using the Bonferroni test.

3. Results

3.1. Center of Pressure

The mean COP was similar between Baseline, IF, and EF conditions. The results of the ANOVA detected no significant differences between the three conditions, $F (2, 44) = .689$, $p = .823$, $\eta p2 = .006$.

Table 1. Descriptive summary of center of pressure (COP) measures during 30-second trials.

	Baseline	Internal	External
Time Block*	M ± SD	M ± SD	M ± SD
1	0.0267 ± 0.138	0.0247 ± 0.0138	0.0271 ± 0.0173
2	0.0259 ± 0.0158	0.0244 ± 0.0148	0.026 ± 0.0179
3	0.0256 ± 0.0153	0.0244 ± 0.014	0.0271 ± 0.0173
Total	0.026 ± 0.015	0.0245 ± 0.0142	0.0267 ± 0.0175

Note: Time block represents the average of ten 1-second windows

3.2. Heart Rate

Mean heart rate was lower throughout the entire 30-second trial in the Baseline condition compared to the IF and EF conditions. At the beginning of the trial, heart rate values were higher in the EF compared to the IF condition, but this order was reversed at the end of the trial. This observation was supported by a significant Condition * Second interaction, $F (2, 58) = 2.613$, $p < .001$, $\eta p2 = .106$. Bonferroni post-hoc testing revealed that this interaction was the result of a more rapid drop in heart rate during the EF condition compared to the IF condition. Specifically, following peak values, occurring at the 3-second time point in all conditions, heart rate showed a significant decrease earlier in the EF condition (7-second time point, $p = .004$) compared to the Baseline condition (11-second time point, $p = .05$). No significant reduction in heart rate occurred during the IF condition.

The main effects for Condition, $F (2, 44) = 23.734$, $p < .001$, $\eta p2 = .519$, and Second, $F (2, 29) = 34.149$, $p < .001$, $\eta p2 = .608$ were also significant. Post-hoc comparisons following the main effect for Condition revealed that average heart rate was lower in the Baseline condition compared to the IF and EF conditions. Post-hoc comparisons following the main effect for Second revealed that heart rate significantly changed throughout the course of the trial in all three conditions. Mean concurrent heart rate values for each condition are displayed in Figure 1.

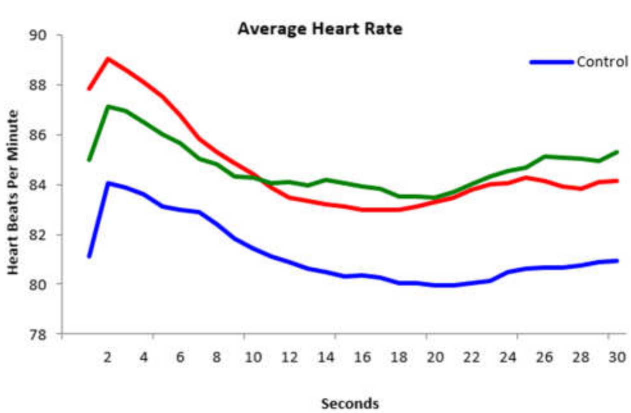

Figure 1. Heart rate data for the Baseline, External, and Internal conditions, revealing the changes in heart rate over time.

4. Discussion and Conclusion

The purpose of the current study was to investigate the effects of focus of attention on heart rate during a static balancing task. Based on previous research demonstrating the connection between cognitive demand and heart rate (H. Mansikka, Simola, P., Virtanen, K., Harris, D., & Oksama, L. , 2016a; H. Mansikka, Virtanen, R., Harris, D., & Simola, P., 2016b; Perusse-Lachance, 2012) and the predictions of constrained action hypothesis (McNevin, 2002; G. Wulf, McNevin, N. H., & Shea, C. H., 2001) that an external focus should reduce cognitive demands, we hypothesized that heart rate would be lower in the external focus condition compared to internal focus and baseline conditions. We also hypothesized, based on (McNevin, 2002) findings, that the COP for static balance would be similar between conditions. As predicted, the analysis of COP data indicated that there were no significant differences in postural sway between the experimental conditions. The similarity of these results to (McNevin, 2002) findings suggests that the prescribed task was properly replicated in the current study.

The results of the analysis of the heart rate data were not consistent with our predictions, given that average heart rate values were not significantly different between the two attentional focus conditions. A noteworthy observation, however, was a significant interaction in the change in heart rate between the internal and external conditions. Our analysis revealed that participants' heart rates dropped at a more rapid rate during trials completed in the external condition compared to trials completed in the internal condition. This interaction may be explained by the constrained action hypothesis (McNevin, 2002; G. Wulf, McNevin, N. H., & Shea, C. H., 2001). According to this hypothesis, the external instructions would have promoted enhanced efficiency and organization of the motor system during the balancing task. Such enhanced efficiency may have led to a reduced mental workload and reduced stress response, which consequently elicited a greater change in the cardiovascular system (i.e., a more rapid reduction in heart rate) during trials in the external condition relative to trials in the internal condition.

An additional valuable finding in the current study was the brief spike in heart rate that occurred within the first few seconds of each trial in all conditions. According to (Allen, 1983), the body's immediate response to stress involves an activation of the sympathetic nervous system and a release of epinephrine and norepinephrine. This initial hormonal release often causes an increase in heart rate, lasting between two and three seconds. This reported cardiac response to stress is consistent with observations in the current study. The quick increase in heart rate was followed by a gradual lowering of heart rate, possibly indicating that participants were "coping" with the initial stress of performing the balance task. Given that heart declined more rapidly in the external condition compared to internal and baseline conditions, it is possible that focusing externally had a positive impact on this coping process. Future research should explore the potential connection between focus of attention and coping with stress during motor tasks.

Although focus of attention was associated with distinct patterns of heart rate change throughout the 30-second trials, we found no significant main effect of attentional focus on heart rate. This result was contrary to our predictions and to previous research on focus of attention and heart rate (Mullen, 2012). As mentioned previously, this prior research contained methodological shortcomings (i.e., structural differences between internal and external focus instructions) that could have confounded results. The well-matched internal and external instructions employed in the current study may constitute one explanation for our distinct findings. Another possible explanation could be that the dual task used in the current study did not tax the attentional capacity enough to present the hypothesized attentional focus effects. A recent study by (Sherwood, 2020) examining attentional focus and dual tasks also failed to show significant differences between attentional focus instructions in one of their experiments. However, after increasing the complexity of the secondary task in Experiments 3 and 4, they were able to detect differences between internal and external focus conditions. Future research should investigate how attentional focus instructions may impact heart rate when performing complex motor skills.

In the present study, we observed that heart rate values were significantly lower during baseline trials compared to trials completed in the internal and external conditions. One potential explanation for this finding is that baseline trials were always performed at the beginning of the study directly following a rest period. However, this reason for lower baseline heart rates is not likely because the experimental task was not physically demanding, as evidenced by relatively low heart rates during task execution and the gradual decline in heart rate during trials in all conditions. Additionally, participants were provided 30 seconds of rest between each trial, so any heart rate increases that were caused by the practiced task should have been negated prior to the subsequent trial.

A more plausible explanation for the lower heart rates during baseline is that participants were given less information in the instructions for the baseline condition. Specifically, baseline instructions prompted participants to focus on only one thing (i.e., maintaining balance), whereas the internal and external instructions prompted participants to focus on two things at once (i.e., minimizing hand movement or sheet movement, in addition to maintaining balance). Thus, the internal and external instructions likely presented a greater attentional demand than the baseline instructions. Memory research by (Peterson, 1959) suggests that working memory has a capacity of 7 ± 2 items. Perhaps, the constraints of the working memory system and the attentional demand imposed by the relatively complex internal and external focus instructions elicited a heightened stress response. Physiological responses to stress are numerous and diverse, but the specific response of most interest in the present study was that of increased heart rate. Acute stress causes activation of the sympathetic nervous system, triggering an increase in heart rate (Rozanski, 1999). Therefore, we propose that the relatively elevated heart rates observed in the internal focus and external focus conditions, compared to baseline, were likely caused by an acute stress response that was presumably prompted by the delivery of more complex instructions in those two conditions. Such a connection between heart rate and cognitive stress has been documented in previous literature (Moray, 1979; Roscoe, 1992), but future research is needed to validate the potential role of instruction complexity on cognitive stress and heart rate changes.

The results of the current study showed that the provision of attentional focus instructions led to significantly increased heart rates during a static balancing task compared to baseline trials, regardless of the direction of the focus instruction. However, in line with the constrained action hypothesis, participants' heart rates decreased at a faster rate during trials in the external focus condition compared to trials in the internal focus condition. Overall, this study demonstrates that instructions of differing complexity and attentional direction can elicit distinct heart rate responses during the performance of a motor task. Based on the results of the current study, it would be advisable for practitioners to limit the complexity of instructions to avoid eliciting negative physiological responses. Future research is warranted to further examine the specific connections between instruction complexity, attentional direction, cognitive stress, and heart rate responses.

Conflicts of Interests

The authors declare no conflict of interest, financial or otherwise, associated with this research.

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