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Starting slow: The effects of response-switching frequency on patterns of cardiovascular reactivity

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Research findings suggest that switching between competing response sets can be resource demanding. The current study focused on concurrent health-relevant physiological effects of task switching by assessing cardiovascular response at varying levels of switch frequency. The participants performed a response-switching task at three different levels of response set switching frequency (low, medium and high) while measurements of blood pressure and heart rate were taken. One group was exposed to response-switching frequency conditions in the order low → medium → high, while the other group was exposed to the same task conditions in the reverse order (i.e. high → medium → low). The results showed that the participants in the low → medium → high switch frequency group recovered faster from initially heightened systolic blood pressure when compared with participants in the high → medium → low group. It is concluded that the results point to a physiological "carry over" effect associated with beginning a task at rapid response switching frequency levels, and suggest the importance of habituation to task demands as a means of offsetting potentially unhealthy levels of reactivity. Implications for modern work environments are discussed.

Keywords: attention switching; cardiovascular reactivity; switching frequency

Introduction

The scientific community has reached no firm consensus on how our bodies respond to different types of acute stressors and what implications these responses have for our long-term health (see Dimsdale, 2008 for a review). One approach to better understand the mechanisms underlying these stress responses is to measure how responses change at different levels of task demand.

One dimension of cognitive task demand, which has been of interest in recent years is the demand incurred where a task requires switching between multiple skills and response sets. Referred to in lay terms as "multi-tasking", tasks requiring response set switching can be more challenging than repetitive task environments where response requirements remain constant. Modern work environments are increasingly demanding and often require rapid switching between multiple skills and responses in context (Mayer & Solga, 2009).

One cost of switching response set is a slowing of response time on switch trials (Allport, Styles, & Hsieh, 1994). Furthermore, the more frequently a person is

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required to switch response set, the slower their reaction time on switch trials and the greater their level of fMRI brain activation in the dorsolateral prefrontal cortex (Garavan, Ross, Li, & Stein, 2000). The role of medial and dorsolateral prefrontal cortices in response set switching has been confirmed by other researchers (DiGiorolamo et al., 2001), and the research in this area generally points to the conclusion that switching between competing response sets can be resource demanding. Nevertheless, although fMRI research has added to our understanding of the neurological demands of response switching, we are not aware of any research that examines the cardiovascular burden of switching, specifically, the impact of switching frequency on measures of cardiovascular response. A focus on the cardiovascular correlates of task-switching frequency is important if we are to better understand what physiological cost arises from task switching and how this maps onto the known costs to performance. Additionally, possible health implications for individuals whose work environments require rapid switching can also be better understood by introducing cardiovascular correlates into the equation.

Cardiovascular responses associated with different work demands are potentially important because of the health implications posited in the Reactivity Hypothesis (Orbist, 1981; see Carroll, in press for an excellent commentary). Cardiovascular reactivity (CVR) refers to changes in blood-flow patterns, from a baseline level, in response to some psychological or physical challenge or stressor (Manuck, Kasprowicz, Monroe, & Larkin, 1989; Tuomisto, 1997). While CVR is generally an adaptive response, which readies the individual to deal with challenges or stressful situations, the Reactivity Hypothesis holds that when elevated blood pressure and heart rate persist over time, even in the absence of the original demand, the risk of heart disease or cardiac events increases (Carroll, in press; Light, Dolan, Davis, & Sherwood, 1992; McEwen, 1998; Orbist, 1981).

Researchers using cardiovascular response outcomes have struggled to understand how participants' responses to laboratory-induced acute stressors relate to the lived experience of daily and chronic stressors (Dimsdale, 2008). For example, Hughes, Howard, James, & Higgins (in press) argue that the process of adaptation to stressors over multiple exposures has been under-explored in the empirical literature. Consequently, while initial responses to acute stressors have been closely observed, analysis of recovery and return to normal or resting blood-flow levels is less often presented. In the current study, cardiovascular responses were assessed while participants performed a response-switching task at three different levels of switch frequency (i.e. low, medium and high). The task was designed to model the occupational challenge of switching between response sets during a single task.

The hypothesis for the study was that with increased switch frequency, both heart rate and blood pressure would increase. Two counter-balanced groups were tested. One group of participants was exposed to task conditions of increasing switch frequency (low → medium → high) while the other group was exposed to task conditions of decreasing switch frequency (high → medium → low). The two counter-balanced groups were also compared to examine whether order of difficulty affected rate of recovery towards baseline blood pressure levels.

Method

Thirty-seven female undergraduate students aged 17–26 years completed a three-block response-switching task. So as to account for possible order effects, participants were alternately assigned to one of two groups. One group of participants was exposed to task conditions of increasing switch frequency (low → medium → high) while the other group was exposed to task conditions of decreasing switch frequency (high → medium → low).

The response switching task used in the current study was based on the one used by Rogers and Monsell (1995). On each trial, participants were presented with an array of numbers on a PC screen, ranging in value from 1–4 to 6–9 and appearing in same-digit arrays of 1–4 or 6–9 digits in length (e.g. 2 2 2 2 2 2; or 7 7 7). Numbers were presented in either green or red font. If participants saw green numbers, they were to count the number of digits and press one key if the number exceeded 5, and another key if the number was less than 5. If participants saw red numbers they were to respond to the numerical digit value by pressing one key if the digit value was greater than 5 and another if it was less than 5. There were 90 trials in each block. A change of font colour signalled that a switch from one task set to the other was required.

Participants were exposed to three blocks of trials, each of which required switching response set at a different frequency level. Full instructions were issued at the outset, and 20 practice trials were provided to minimise the effect of task novelty on performance in the first trial block. In the high frequency (HighF) block switches occurred every 2–4 trials; in the medium frequency (MedF) block, switches occurred every 4–6 trials; in the low frequency (LowF) block, switches occurred every 6–8 trials. Switches were quasi-random, so as to be unpredictable for participants. One group received the blocks in the order HighF → MedF → LowF while the second group received them in the order LowF → MedF → HighF. Each block took approximately four minutes to complete and a recovery period of 90 seconds was provided between the end of one block and the start of the next.

A MS700 Automatic Digital Blood Pressure Monitor (Mars Corporation) was used to measure systolic and diastolic blood pressure and heart rate throughout the experiment. CVR for each block was measured by taking a baseline pre-task reading of systolic blood pressure (SBP), diastolic blood pressure and heart rate (HR), then retaking these measures twice during each block and subtracting the baseline from the average in-block readings.

Results

A 2 × 3 mixed ANOVA was used to analyse for effects of Switch Frequency (HighF/MedF/LowF) and of Sequence Group (HighF first/LowF first). ANOVA revealed a main effect of switch frequency on reaction time (RT) performance ($F[1,34] = 20.99$, $p < 0.001$), with RT in the HighF block (mean = 1058 ms) being slower than RT in the MedF (mean = 882 ms) and LowF (mean = 900 ms) blocks. ANOVA also revealed a significant group × switch frequency effect on SBP reactivity ($F[1,35] = 13.77$, $p = 0.001$). Post-hoc t-tests revealed that participants exposed to the LowF block first had lower SBP reactivity in both subsequent (MedF and HighF) blocks ($p < 0.005$ for both comparisons). Participants exposed to the HighF block showed a more sustained high SBP reactivity on the MedF block, but reduced SBP reactivity on the LowF block. HighF first participants had higher SBP reactivity on the MedF block when compared with LowF first participants ($t[35] = -2.581$, $p = 0.014$). Overall, HighF first participants had elevated reactivity throughout the task and did not return to baseline SBP levels (see Figure 1).

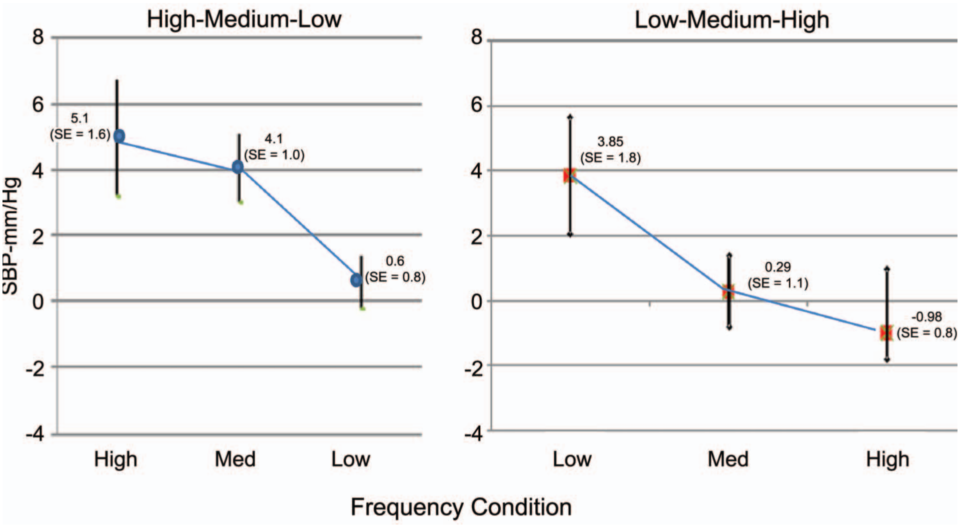

Figure 1. SBP reactivity at three switch frequency levels for the high → low and low → high groups.

To test for any bias in the group comparison arising from pre-existing differences in cardiovascular health, two steps were taken. First, a two-way independent samples ANOVA was used to compare resting blood pressure in both groups. No significant differences were observed between groups on mean resting baseline SBP ($f[35] = 0.24$, $p = 0.62$), DBP ($f[35] = 0.35$, $p = 0.18$) or HR ($f[35] = 0.14$, $p = 0.93$). Also, the 2 (group) $\times$ 3 (switch frequency) ANOVAs reported above were re-run using both resting SBP as covariates to test for any covariance between resting SBP and SBP change as a result of attention switching demands. No significant covariance was found ($f[35] = 2.43$, $p = 0.11$).

Discussion

Contrary to our expectations, the findings of the current study do not suggest that rapid rates of response switching are necessarily accompanied by a larger cardiovascular response than slower rates of switching. (A higher first-phase SBP response was observed for the group who commenced with high frequency, but this difference was not statistically significant at the 5% level.) However, while higher switching frequency did not induce higher cardiovascular response immediately, there was a lasting carry-over effect on CVR of "starting fast". Generally, the effects of practice and habituation to task demands will result in reduced CVR as a task progresses (c.f. McEwen, 1998). However, in the current study, this effect was attenuated by the initial demands of the high frequency switching condition. The group that began with the high frequency demand experienced slower physiological habituation and recovery when compared with the group that began with the low frequency demand.

These findings may be accounted for in part by the need to recruit additional resources at a neural level to cope with high frequency demands (c.f. Garavan et al., 2000), particularly when high frequency switching demands are high during the early stages of learning. At the same time, future studies should investigate whether "starting slow" as opposed to "starting fast" moderates resource use for high frequency response switching at the level of the brain. Also, with poorer average performance recorded in the higher frequency block, further studies might examine whether differences in mood and motivation generated in response to early performance failures in high frequency response-switching tasks impacts subsequent levels of stress reactivity and resource use. By "starting slow" participants in the current study were given an opportunity to perform well and habituate to the response-switching demands. As a consequence, they may have become more confident and comfortable with task demands. Conversely, by "starting fast" the high frequency first group may have experienced a highly aroused, possibly anxious, state that was maintained at slower switching frequency rates to improve performance after initially high demands and perceived performance difficulties.

The current study was limited in a number of ways. No information was collected regarding established predictors of CVR, such as weight, smoking status, etc. However, the study was restricted to females in early adulthood to eliminate known variance arising from gender and age differences and all participants were healthy and active. Also, there was random assignment to groups to experimental conditions and no group differences were found on mean resting blood pressure. Thus, it is argued here that the group assignment procedure was unlikely to have resulted in any significant bias towards higher CVR in either group. Although the sample size of 37 appears small, it is comparable in size to past studies that have reported on cardiovascular responses to psychological challenge (e.g. Falkner, Onesti, Angelakos, Fernandes, & Langman, 1979; Kamarck, Manuck, & Jennings, 1990). Furthermore, the current study used only two attention switching frequency orders and future studies should include further counterbalance conditions and control groups who perform in the contexts sustained demands (e.g. multiple low frequency switching or high frequency switching blocks) so as to ascertain what is a "normal" rate of habituation to switching demands.

The current study can be said to be a laboratory model of acute instance of a stressor or hassle. We can only speculate as to whether CVR patterns would persist with chronic exposure to switching requirements. It is likely that there are complex interactions between attention switching demands, cardiovascular habituation to demands and perception of task demands in real world settings. At the same time, we can point to previous studies, which have found associations between "daily hassles" or "micro-stressors" and coronary health outcomes (Twisk, Snel, Kemper, & van Mechelen, 1999). We can also suggest that future research in this area seek to assess the relationship between task switching demands and cardiovascular responses in real world work settings, while also considering the conditions under which those task switching demands are interpreted as stressful. Tasks requiring frequent switching may or may not be interpreted as a hassle, and further research in this area might explore whether the interpretation of attention switching demands impacts directly on blood pressure responses.

The current study highlights other implications for future studies of task switching and its physiological correlates. First, task-switching frequency may have implications for both performance and cardiovascular response, but researchers using this task switching paradigm should report the frequency at which participants are forced to switch response set and ideally vary switch frequency experimentally to provide useful comparison that can further our understanding of the relationship between cardiovascular responding and performance in the context of variation in attention switching. Second, the results of the current study suggest a significant cardiovascular carry-over effect from fast to medium attention switching demands and further research should seek to confirm this effect and examine more closely the relationship between processes of recovery and carry-over in experiments that examine cardiovascular response to challenges.

Overall, the findings of the current study suggest that it is worth investigating the physiological costs of working within task environments that ultimately require the ability to rapidly switching between multiple response sets. It may be that "starting slow" and gradually increasing switch demands will facilitate lower overall cardiovascular burden. Further research might extend this work by determining its generalisability to other contexts and by combining fMRI and cardiovascular measurement techniques with measures of in-task mood and motivation fluctuations to examine the overall burden of response set switches in the brain–body matrix. Closer examination of personality factors which predict the magnitude of individuals' CVR reactions to changing demand levels and of the effects of age on this CVR–demand relationship is also warranted. Such research could prove instructive to those involved in the design of work environments and schedules.

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