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The relationship between working memory, reinvestment, and heart rate variability

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HIGHLIGHTS

• WM capacity was higher under low pressure compared to high pressure.
• Decision reinvestment is negatively correlated to WM under high pressure.
• HF-HRV level at baseline predicted WM performance under high pressure.

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ABSTRACT

There is growing evidence illustrating the negative aspects of reinvestment on everyday life, however its underlying mechanisms remain unclear. The main aim of this study was to empirically clarify the relationship between reinvestment and working memory (WM). A secondary aim was to investigate the contribution of high-frequency heart rate variability (HF-HRV) to WM. Sixty-two participants took part in a within-subject design in which we measured their WM capacity in a low-pressure and a high-pressure condition while their HF-HRV was measured. In addition, they had to fill out scales assessing their dispositional reinvestment. Results showed that the correlation between reinvestment and WM is negative, exists only in the high-pressure condition, and is specific to the decision component of reinvestment and not the movement component. Moreover, a hierarchical regression analysis revealed that under high pressure resting HF-HRV predicted WM performance above DSRS, whereas DSRS did not predict WM performance above resting HF-HRV.

1. Introduction

Pressure has been defined as “any factor or combination of factors that increases the importance of performing well on a particular occasion” ([1], p. 610). High pressure almost always goes with a decrease of performance, in comparison to low-pressure situations (e.g., [6,15]). It has been suggested that skill failure under pressure is closely related to the cognitive concept of working memory (WM): either by “blocking up” limited capacity WM with ruminations and worries in the cognitive skill domain [3,4] or by “loading WM” with declarative knowledge that prevents the smooth execution of skills that rely on proceduralized knowledge [21,22]. In both cases individuals are believed to “reinvest” cognitive effort in pressure situations in the hope of avoiding performance decrements. Reinvestment can be considered an umbrella term for uniting the various theoretical accounts of how individuals try to deliberately maintain performance stability in high stake situations via increased cognitive effort. Reinvestment was originally assessed using the reinvestment scale [23]. Two context specific scales were developed based on this original scale: the decision-specific reinvestment scale (DSRS; [11]) and the movement-specific reinvestment scale (MSRS; [20]). The DSRS contains two factors: decision reinvestment, reflecting the conscious monitoring of processes involved in making a decision, and decision rumination, referring to the negative evaluation of previous poor decisions [11]. The MSRS contains two factors as well: conscious motor processing, assessing the amount of conscious monitoring while acting out a movement, and movement self-consciousness, assessing the amount of personal concern related to movement [22]. At the level of construct validity, both the MSRS and the DSRS were positively correlated with deliberation, vigilance and hypervigilance [13], which illustrates the fact that reinvestment is related to conscious and effortful thinking. Overall, the reinvestment process has proven to be detrimental to performance in various situations (e.g., [9,10,15]): presumably by taxing limited capacity WM. However, there is currently no direct evidence for this assumed mechanism.

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Complementary to this cognitive account of performance decrements under pressure, physiological reactions to pressure also account for performance decrements. Thayer and colleagues have proposed a direct physiological relation between the parasympathetic activity indexed by heart rate variability (HRV) and cognitive performance due to the network connecting the vagus nerve to the prefrontal cortex [28]. More specifically, the neurovisceral integration model suggests that the activity of the parasympathetic system—via the vagus nerve—may affect the activity of the prefrontal cortex, and ultimately WM performance [8]. The relationship was found in this case with tonic (resting) HRV, however, further research is warranted to also take phasic (or reactivity) HRV (generally calculated as task − baseline) into account. As mentioned by Thayer, Ahs, Fredrikson, Sollers, and Wager [27], both mechanisms play a critical role in the adaptation of the organism to allow effective goal-directed behavior. In addition, this distinction between tonic and phasic components is in line with recommendations from other theoretical backgrounds regarding the relationship between parasympathetic activity and mental load [25], justifying a deeper focus on both mechanisms. This would ensure considering the effects of both cognitive activity and pressure, as we know that the activity of the parasympathetic system is reduced by both cognitive activity [8] and pressure [26]. To date, only limited endeavors have been made investigating the relationship between this physiological model to the cognitive reinvestment account of pressure induced performance decrements (for an exception, see [15]). In this study the authors showed that, in comparison to low decision “reinvesters”, the decision-making performance of high decision “reinvesters” decreased more under pressure. In addition, the parasympathetic activity was found to mediate the influence of decision reinvestment on decision time (i.e., the time needed to generate the first option).

However, to date no studies have investigated the effect of parasympathetic activity on WM under pressure. As pressure induced impairments of WM have been argued to be of potential life-threatening consequence amongst e.g. parachutists [17], it is important to gain a more comprehensive account of the mechanisms associated with performance decrements under pressure. The present research aimed at addressing this shortcoming by investigating the relationship between reinvestment, HRV, and available WM capacity as a function of pressure.

1.1. The present research

In line with Vogel and Awh [32] argument that cognitive theory can substantially benefit from combining an individual-difference approach with an experimental approach we investigate how a person's tendency to reinvest cognitive control influences pressure's effect on available WM capacity. Of particular relevance to the present research, Kinrade, Jackson, and Ashford [10] found that a higher reinvestment score was associated with performance decrements on cognitive tasks, and in particular on tasks placing significant demands on WM, such as a high-complexity modular arithmetic task. It is noteworthy that these results were specific to a high pressure condition, leading to think that pressure is a context-trigger for observing the effects of reinvestment, as it was suggested earlier by Jackson et al. [9]. Presumably, this result emerged as pressure is theorized to trigger rumination and worries that “block up WM” which is no longer available—but needed—for successful task execution (cf. [17]). In addition, we investigate the contribution of the parasympathetic nervous system to WM performance in comparison to reinvestment, an issue that has been unexplored so far, by monitoring the high-frequency component of heart rate variability (HF-HRV), which reflects the activity of the parasympathetic branch of the autonomous nervous system [5].

Therefore the main research question sought to be addressed here is: What is the effect of dispositional reinvestment and HF-HRV on the availability of WM capacity as a function of pressure? More specifically, we address the following questions: Q1) How does dispositional reinvestment affect WM performance in high pressure situations in comparison to low pressure situations? and Q2) What is the contribution of HF-HRV to WM capacity in comparison to reinvestment?

Regarding the first question, we expect WM performance to be disrupted by pressure induced ruminations (based on [3,4,10]) which should be especially pronounced amongst individuals who score high on reinvestment [9,10]. Finally, regarding Q2, due to the influence of HF-HRV on prefrontal activity effectiveness, we investigate in an exploratory fashion its influence on WM capacity in comparison to reinvestment.

In order to answer these questions, we designed the following within-subject experiment, in which we measured participants WM capacity in both a low and a high pressure condition, while monitoring their HF-HRV. In addition, participants had to fill out two established scales measuring specific components of reinvestment, the DSRS and the MSRS.

2. Methods

2.1. Participants

Sixty-two students took part in the study (33 men and 29 women, $M_{age} = 23.58$ years old, age range = 17–35 years old). None of the participants reported having cardiovascular disorders, neurological disorders, diabetes, nor having extraordinary diet habits. The study was approved by the Ethics committee of the local University and followed the principles of the Helsinki Declaration.

2.2. Instruments and tests

2.2.1. Decision specific reinvestment scale

The decision specific component of reinvestment was assessed by the decision-specific reinvestment scale (DSRS; [11]; see [15]). The 13 items of the DSRS are rated on a 5-point Likert scale ranging from 0 (*not characteristic*) to 4 (*very characteristic*). Six items are part of the decision reinvestment factor (e.g., Item 1: I'm always trying to figure out how I make decisions) and seven items belong to the decision rumination factor (e.g., Item 11: I rarely forget the times when I have made a bad decision, even about minor things). For both factors of the DSRS, high Cronbach's alpha values have been shown. Kinrade, Jackson, Ashford, et al. [11] reported an internal consistency of .89 for decision reinvestment and .91 for decision rumination. In this study internal consistencies were .82 for decision reinvestment and .84 for decision rumination. A high score on the decision reinvestment factor reflects a strong propensity for consciously monitoring the decision-making process, while a high score on the decision rumination factor illustrates a strong propensity to reflect upon previous poor decisions [11]. The total score of DSRS was calculated summing up the 13 items.

2.2.2. Movement specific reinvestment scale

The movement-specific component of reinvestment was assessed by the movement-specific reinvestment scale [20]. The German version MSRS consists of nine items (see [12]), with five items belonging to the movement self-consciousness factor (e.g., Item 5: I am self-conscious about the way I look when I am moving), and four items belonging to the conscious motor-processing factor (e.g., Item 4: I am always trying to think about my movements when I carry them out). All items have to be answered using a 6-point Likert scale ranging from strongly disagree to strongly agree. Regarding reliability, Cronbach's alpha values range from .70 to .78 for movement self-consciousness and from .65 to .71 for conscious motor processing [20]. Retest reliability ranges from .67 to .76 [20]. In this study internal consistencies were .69 for movement self-consciousness and .71 for conscious motor processing. A high score on the movement self-consciousness factor reflects a strong concern about making a good impression when moving in public, while a high score on the conscious