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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 motor processing factor reflects a strong propensity to consciously control and monitor the process of movement [22]. The total score of MSRS was calculated summing up the 9 items.

2.2.3. Working memory capacity

We used the well-established automated operation span score as an index of WM capacity [31]. As in the original operation span task [30]—which has proven to be sensitive to pressure induced changes within individuals [17]—participants have to solve math problems while trying to remember an unrelated set of letters. The task included a total of 15 trials (3 trials each with 3, 4, 5, 6, and 7 letters to remember). An example of a three-item trial might be: is $(8 / 2) - 1 = 1$? (correct/incorrect?) → F; is $(6 * 1) + 2 = 8$? (correct/incorrect?) → P; is $(10 * 2) - 5 = 15$? (correct/incorrect?) → Q. After verifying the three equations in this example, participants were asked to select the presented letters with a mouse click from an array of 12 potential letters in the order that they were presented (in this case F P Q). The primary measure of WM capacity was the Ospan score [31], calculated as the total number of letters recalled across all error-free trials. See Unsworth et al. [31] for full task details. The task lasted the same amount of time in the low-pressure and high-pressure conditions, approximately 15 min.

2.2.4. Visual analogue scale

A visual analogue scale (VAS), consisting of a 100 mm vertical line, was used to assess perceived stress intensity. The line was anchored by the words “no stress at all” at the bottom of the line, and “maximum stress” at the top of the line. Participants were required to cross a point somewhere on the line to indicate their level of stress. The measure of perceived stress intensity was taken as the distance (in mm) from the bottom of the line. Such VAS scales have been used to assess stress intensity in previous research [18].

2.2.5. Heart rate variability

HRV was measured using the eMotion HRV device (Mega Electronics, Kuopio, Finland), with a sampling rate of 1000 Hz. Heart rate was recorded using two chest electrodes. We used disposable ECG pregelled electrodes (Ambu L-00-S/25, Ambu GmbH, Bad Nauheim, Germany). The negative electrode was placed in the right infraclavicular fossa (just below the rigid clavicle) while the positive electrode was placed on the left side of the chest, below the pectoral muscle in the left anterior axillary line. From heart rate recordings we extracted HRV using interbeat interval data that was exported to Kubios software (University of Eastern Finland, Kuopio, Finland). Artifacts were removed using the automatic low filter provided by the Kubios software. We calculated the time and frequency domain parameters. The following frequency bands were used to define HF with Fast Fourier Transform: 0.15 Hz to 0.40 Hz [5]. To assess the activity of the parasympathetic system we were interested in the HF band normalized unit.[1]

While the main research investigating the relationship between HRV and cognition has mainly considered tonic resting HRV [28], it has been acknowledged that both tonic and phasic HRV play important functional roles [27]. Hence, it is necessary to consider both resting and task HRV. Baseline HF-HRV was taken for 5 min, and task HF-HRV was realized during the last 5 min of the task. Even if the OSPAN lasts longer (approximately 15 min), there is a need to have equal HRV measurement time in order to be able to compare the data [5]. We chose to take the last 5 min of the task and not the first 5 min to be able to include the effects of pressure in our HRV calculation, a method that has already been adopted in related research dealing with pressure [15] or emotional manipulation [14].

Finally, researchers strongly recommend controlling for respiration when analyzing HF-HRV, due to the influence of respiratory rate on HF-HRV [5]. Therefore, we computed an estimate of respiratory rate based on the central frequency of HF calculated with an autoregressive spectral analysis as suggested in previous research [7,15,24]. This method was found to be highly correlated with strain gauge measures of respiration [29].

2.3. Procedure

Participants were invited to the lab on two separate days, for both the low pressure and the high pressure condition. On the day before the experiment, they were asked to follow their usual sleep routine, not to engage in hard physical training, while they were further asked neither to eat, drink coffee/tea, nor smoke 2 h before the experiment. They were welcomed to the lab by the experimenter and signed the informed consent form. At the beginning of the first session, the participant had to fill out the two reinvestment scales (i.e., DSRS and MSRS). Afterwards sensors were attached to measure HRV, and they were invited to sit and relax. Baseline was taken during 5 min. Subsequently, the experimenter read out the instructions, and asked the participant to follow the onscreen instructions of the computerized WM task.

Regarding the pressure manipulation, we followed Baumeister and Showers [2] recommendations mentioning that pressure is typically manipulated by one or a combination of factors such as audience presence, competition, performance contingent rewards and punishments, and ego-relevance of the task. In order to strengthen motivation, in both conditions participants were told that they were involved in a competition where the three best could win a voucher for a hydrojet massage. In the high pressure condition, participants were told in addition that the test they were going to perform was supposed to reflect one's general intelligence, and that their results will be publicly displayed on campus, in lectures, and seminars. Moreover, during the experiment in the high pressure condition, each time the percentage of math success was shown on the screen, the experimenter indicated to the participant that his/her current score was below the mean generally achieved by a similar population. Finally, in the high pressure condition there was a second experimenter sitting next to the participant, who was introduced to the participant as having the task to “note any peculiarities in the participant's behavior”. Concretely, the second experimenter was writing from time to time with a pencil on a sheet of paper, in order to remind the participant that he/she was being observed. Before starting the task, the participant was asked to fill out the VAS, as well as right after the task. After filling out the VAS sensors were detached. The low pressure and high pressure conditions were separated by one week and were counterbalanced, meaning that half of the subjects started with the high-pressure condition, while the other half started with the low-pressure condition. Participants were debriefed about the goals of the experiment after the second session and were thanked for their participation. A comprehensive graphical overview of the experimental procedure is displayed in Fig. 1.

2.4. Data analysis

Data were checked for normality and outliers. Kolmogorov–Smirnov tests on our dependent variables were non-significant meaning that our data were normally distributed, and no univariate outliers were detected (± 3.29 *SD*). HF-HRV values were computed for the 5-min baseline and for the 5-min at the end of the task. A preliminary check was done with respiratory rate, to investigate whether it changed across measurement times, with a repeated-measures ANOVA with time (pre- vs. post-) and condition (low pressure vs. high pressure) as within-subject variables. Respiratory rate values were estimated for the different measurement times: low-pressure condition baseline ($M = 14.61$, $SD = 1.67$); low-pressure condition task ($M = 14.82$, $SD = 1.78$); high-pressure condition baseline ($M = 14.62$, $SD =$

[1] We also ran the analyses with other markers of the parasympathetic system, HF power and the root mean square of the successive differences (RMSSD), and the pattern of results was overall similar.

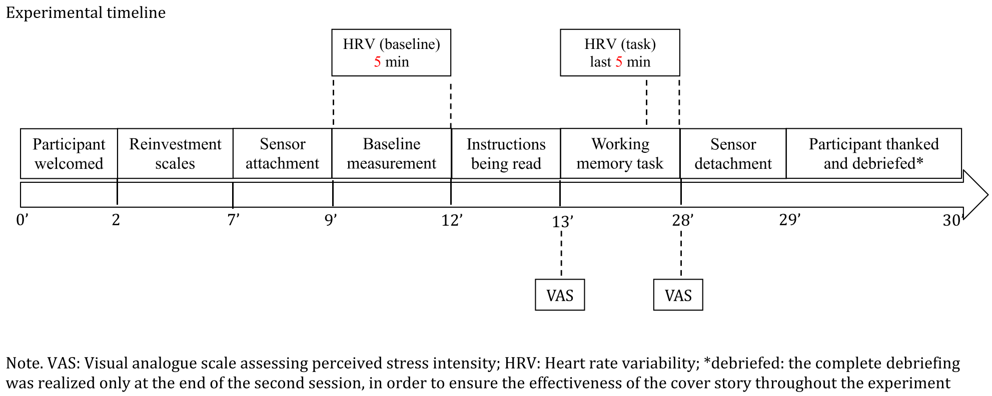

Fig. 1. Experimental timeline. Note. VAS: Visual analogue scale assessing perceived stress intensity; HRV: Heart rate variability; *debriefed: the complete debriefing was realized only at the end of the second session, in order to ensure the effectiveness of the cover story throughout the experiment.

1.89); and high-pressure condition task ($M = 14.97$, $SD = 1.97$). A repeated-measures ANOVA with Greenhouse–Geisser correction showed neither a main effect nor an interaction: for condition $F(1.000, 61.000) = 0.08$, $p = .778$, partial $\eta^2 < .01$; for time $F(1.000, 61.000) = 2.224$, $p = .141$, partial $\eta^2 = .01$; and for condition × time $F(1.000, 61.000) = 0.159$, $p = .692$, partial $\eta^2 < .01$. Therefore, respiratory rate did not differ across measurement times; however we will still control for it in all upcoming analyses involving HF-HRV.

Regarding the main analyses performed, first a pressure manipulation check was realized with a repeated-measures MANOVA with time (pre- vs. post-) and condition (low pressure vs. high pressure) as within-subject variables. Dependent variables were VAS and HF-HRV. Second, the change in WM performance between the low-pressure and high-pressure condition was investigated with a repeated-measures ANOVA. Third, the relationship between reinvestment (i.e., MSRS and DSRS) and WM performance was investigated with Pearson correlations. Fourth, in order to clarify the contribution of HF-HRV (baseline, task, reactivity) to WM performance in comparison to reinvestment, two successive hierarchical regression analyses were run.

3. Results

The descriptive statistics and the correlation matrix of all study variables are presented in Table 1.

3.1. Pressure manipulation check

A repeated-measures MANOVA indicated a main effect of time, Wilks's lambda = 0.240, $F(2, 60) = 95.183$, $p < .001$, partial $\eta^2 = .76$; a main effect of condition, Wilks's lambda = 0.767, $F(2, 60) = 9.115$, $p < .001$, partial $\eta^2 = .23$; and an interaction effect between time and condition, Wilks's lambda = 0.734, $F(2, 60) = 10.876$, $p < .001$, partial $\eta^2 = .27$. Follow-up repeated-measures ANOVAs with Greenhouse–Geisser corrections were run independently for VAS and HF-HRV. For VAS (Fig. 2), a main effect of time was found, $F(1.000, 61.000) = 109.729$, $p < .001$, partial $\eta^2 = .64$, as well as a main effect of condition, $F(1.000, 61.000) = 18.534$, $p < .001$, partial $\eta^2 = 23$, and an interaction effect between time and condition, $F(1.000, 61.000) = 8.662$, $p = .005$, partial $\eta^2 = .12$. For HF-HRV (Fig. 3), a main effect of time was found, $F(1.000, 61.000) = 73.869$, $p < .001$, partial $\eta^2 = .55$, and an interaction effect between time and condition, $F(1.000, 61.000) = 12.881$, $p < .001$, partial $\eta^2 = .17$. No effect of condition was found, $F(1.000, 61.000) = 1.585$, $p = .213$, partial $\eta^2 = .03$. Controlling for respiratory rates did not change the results.

In summary, an increase of pressure between pre- and post-task was found both at the subjective and physiological level, illustrated by an increase on the VAS and a drop in HF-HRV. In addition, this increase of pressure from pre- to post-task was higher in the high-pressure condition in comparison to the low-pressure condition.

Table 1
Descriptive statistics and correlation matrix of full study variables.

	Mean	*SD*	1	2	3	4	5	6	7	8	9	10	11	12
1_DSRS total	49.00	32.60	–											
2_MSRS total	44.00	24.53	.39**	–										
3_WM score LP	39.89	13.32	−.16	−.09	–									
4_WM score HP	35.00	16.70	−.27*	−.21	.57**	–								
5_Pre VAS LP	26.58	17.25	.08	.01	−.09	−.18	–							
6_Post VAS LP	43.06	20.53	.16	.01	−.31*	−.16	.40**	–						
7_Pre VAS HP	29.87	19.63	.14	−.04	−.21	−.18	.53**	.42**	–					
8_Post VAS HP	55.89	20.14	.16	.18	−.06	−.33**	.33**	.47**	.49**	–				
9_HF-HRV baseline LP	40.60	17.29	−.02	−.06	.38**	.41**	−.23	−.23	.06	−.06	–			
10_HF-HRV end task LP	28.28	13.19	−.14	−.07	.45**	.39**	−.24	−.21	.15	.05	.75**	–		
11_HF-HRV baseline HP	40.95	15.88	−.18	.06	.22	.40**	−.24	−.09	−.07	−.13	.32**	.38**	–	
12_HF-HRV end task HP	22.55	11.33	−.32*	.10	.26	.41**	−.19	−.03	−.05	−.08	.34**	.44**	.67**	–

Note: DSRS: Decision-specific reinvestment scale; MSRS: Movement-specific reinvestment scale; WM: Working memory; LP: Low pressure condition; HP: High pressure condition; VAS: Visual analogue scale; HF-HRV: High-frequency heart rate variability (the normalized units obtained through Fast Fourier Transform were used here).
* $p < .05$.
** $p < .01$.

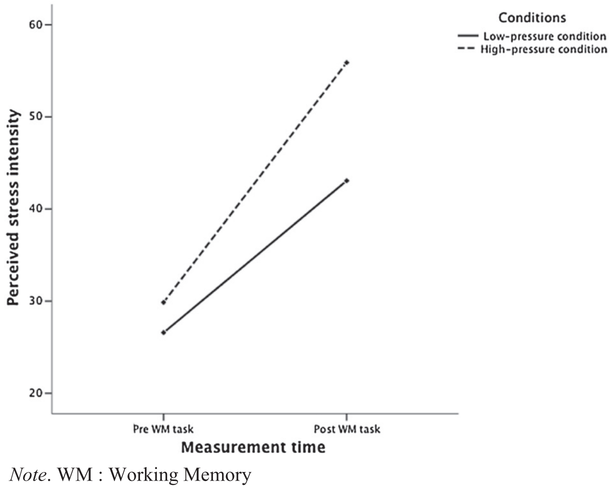

Fig. 2. Perceived stress intensity change across conditions and measurement times. *Note*. WM: Working memory.

3.2. Working memory performance

In order to examine the change in WM performance between the low- and high-pressure conditions, a repeated-measures ANOVA with Greenhouse–Geisser correction was run with condition (low-pressure vs. high-pressure) as a within-subject variable and WM score as a dependent variable (Fig. 4). A main effect of condition was found, $F(1, 61) = 7.250$, $p = .009$, partial $\eta^2 = .11$, showing that the WM score was higher in the low-pressure condition in comparison to the high-pressure condition.

3.3. Correlations between reinvestment and WM performance

In order to clarify the relationship between reinvestment and WM performance, we ran a correlation analysis, between the MSRS, DSRS, and WM scores, for both the low- and high-pressure conditions. For the low-pressure condition, neither the MSRS ($p > .05$) nor the DSRS ($p > .05$) was found to correlate with WM score. However, for the high-pressure condition, we found a significant negative correlation between the DSRS and the WM score ($r = -.27$, $p = .037$, 95% confidence intervals: $-.48$; $-.02$), while no correlations were found between the MSRS and the WM score ($p > .05$). In summary, we found that the relationship between reinvestment and WM score is negative, specific to DSRS, and exists only when the participant is under pressure.

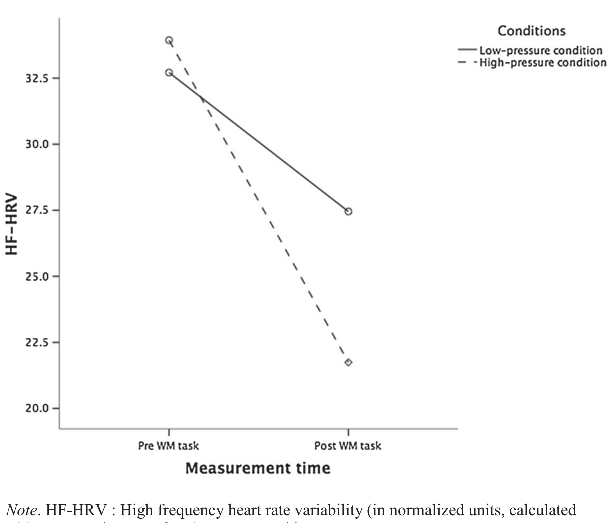

Fig. 3. HF-HRV change across conditions and measurement times. *Note*. HF-HRV: High frequency heart rate variability (in normalized units, calculated with Fast Fourier Transform); WM: Working memory.

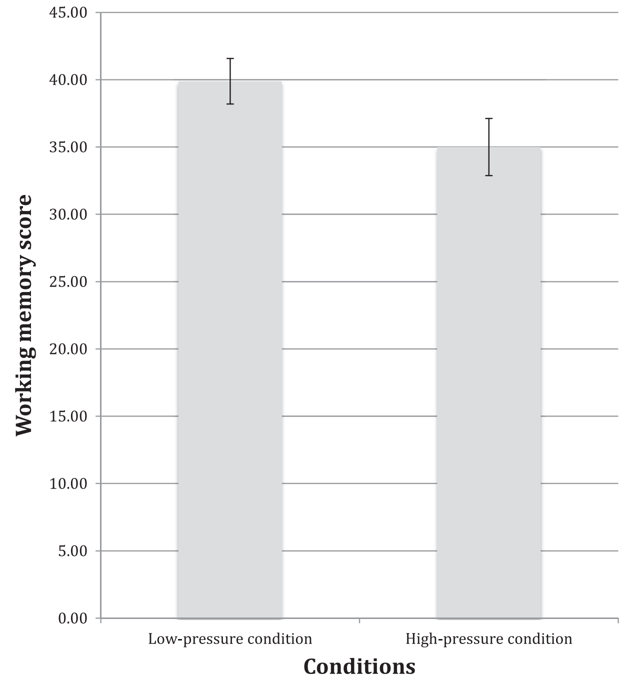

Fig. 4. Working memory score in low-pressure and high-pressure conditions. Error bars represent standard errors.

3.4. Contribution of HF-HRV to WM score

To clarify the contribution of HF-HRV to WM score in comparison to reinvestment, two successive hierarchical regression analyses were performed, with WM score in the high-pressure condition as a dependent variable. The change in respiratory rate (i.e., task − baseline) in the high-pressure condition was controlled for at Step 1. It did not account significantly for WM score variance ($p = .106$). DSRS was entered at Step 2, predicting significantly ($\beta = -.24$, $p = .048$) a change of 7% in WM score variance in the high-pressure condition. The three related HF-HRV variables (i.e., baseline, task, reactivity) were entered in a stepwise fashion at Step 3, in order to clarify which significantly affected WM capacity. HF-HRV baseline was the only parameter to be retained, and was found to explain significantly ($\beta = .34$, $p = .006$) 10% of WM score variance in the high-pressure condition, reaching a total of 17% WM score explained variance in the high-pressure condition. For the second hierarchical analysis, similarly to the first one respiratory rate was controlled for at Step 1. The three related HF-HRV variables (i.e., baseline, task, reactivity) were entered at Step 2. Again only HF-HRV baseline was retained, and was found to explain significantly ($\beta = .38$, $p = .008$) 13% of WM score variance in the high-pressure condition. However this time entering DSRS at Step 3 did not produce a significant improvement in the model. Therefore, DSRS did not explain any further WM score variance beyond the variance explained by HF-HRV (baseline) in this regression model.

4. Discussion

The main aim of this paper was to empirically clarify the relationship between reinvestment and WM. A secondary aim was to understand the role of HR-HRV (tonic and phasic) on WM performance in comparison to reinvestment. A manipulation check with the VAS and HF-HRV showed that pressure was higher in the high-pressure condition in comparison to the low-pressure condition, indicating that our pressure manipulation was successful. In addition, the WM performance was found to decrease from the low pressure condition to the high pressure condition, evidencing the effects of pressure on WM performance [17].

Regarding Q1 (How does dispositional reinvestment affect WM performance in high pressure situations in comparison to low pressure situations?), we found a negative correlation between decision-specific reinvestment and WM performance in the high pressure condition which is the first direct evidence for the proposed theoretical assumption that individuals who tend to reinvest have less available WM capacity, probably due to the fact that their WM is “blocked up” with ruminations and worries. Hence, this finding suggests that “reinvesters” are more likely to fail in high-stake tasks that rely on WM such as math exams [19], or more importantly in life-threatening situations such as engaging a safety device when parachuting [17]. Of further relevance to Q1, the fact that we only found a relationship in the high pressure condition is in line with previous work showing that the tendency to reinvest only had an influence in high pressure situations [9,10,15], reinforcing the idea that pressure triggers the reinvestment process. In addition, the relationship between reinvestment and WM was specific to the DSRS and not to the MSRS arguing in favor for a specificity of reinvestment components: a decision-specific and a movement-specific component [10]. In line with these results, high decision reinvestment was also found to be related to lower perceived coping effectiveness, and to lower subjective performance satisfaction, during regular season games in which players were experiencing pressure [13].

Regarding Q2 (What is the contribution of HF-HRV to WM capacity in comparison to reinvestment?), the correlation of HF-HRV on WM that we found in our study (cf. Table 1) supports the theoretical perspective of the neurovisceral integration model [28] and is in line with previous findings linking a higher resting vagal tone to a higher WM performance [8]. The fact that resting HF-HRV (and not task HF-HRV or reactivity HF-HRV) was the only significant HF-HRV parameter in the hierarchical regression analysis predicting WM performance highlights the importance of tonic resting HRV on cognitive performance [27]. This initial finding might have important implications in terms of theory development and intervention design. Although caution is warranted due to the correlational nature of the present findings, it seems feasible that for example, people aiming at improving WM performance, especially in high pressure situations, might want to think about influencing resting HF-HRV levels. Moreover, the fact that resting HF-HRV predicted WM score performance in the high pressure condition above DSRS whereas DSRS did not explain additional WM score variance above resting HF-HRV in the hierarchical regression models, is in line with studies evidencing the greater influence of neurophysiological variables in comparison to trait self-reported variables when predicting performance under pressure (e.g., [16]).

A limitation of our study is that we did not differentiate between different kinds of pressure induced: e.g. between “monitoring pressure” and “performance-contingent outcome-related pressure” [6]. These respective types of pressure might affect performance in a different manner: In this respect, “performance-contingent outcome-related pressure” is assumed to trigger distraction from task-relevant information; whereas, “monitoring pressure” has been suggested to prompt individuals to closely attend to skill execution/cognitive processes, which ultimately disrupts skill execution. In Introduction, we argued that both of these effects of pressure are related to “loading WM” with information that disrupts task performance. However, in the present research we only showed how pressure limited the availability of WM capacity and not how this further relates to further task performance in the cognitive or motor skill domain. Therefore, future research might want to distinguish the specific effects of different types of pressure in relation to reinvestment and HRV in cognitive and motor tasks.

5. Conclusion

This paper was aimed to investigate empirically for the first time the relationship between reinvestment and WM performance. The findings showed a negative correlation existing exclusively under pressure, and concerning specifically the decision component of reinvestment. Moreover, the role of HF-HRV on WM in comparison to reinvestment was clarified, evidencing its importance to underlie WM processes. At the applied level, our findings suggest that the tendency of individuals to reinvest and the negative consequences associated to it could be compensated by a HRV training aimed to enhance the resting activity of the parasympathetic system, such as heart rate variability biofeedback achieved through paced breathing [33].

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