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ABSTRACT

Adaptive mechanisms to protect cognitive performance under stressors through compensation in energy investment have previously received much research attention. However, stressors have also often been found to substantially reduce both performance and investment. The mechanisms underlying this dual negative effect are still unclear. This study tested the hypothesis that stressors can immediately hamper performance, which in turn reduces energy investment in later phases. In an experiment (N = 103), we compared control and stressor conditions (noise or time pressure), investigating the effects of stressors on performance and information-sampling investment (as behavioural measure of energy investment) in two phases of a judgment task. The results showed an instant negative effect of stressors on performance and a delayed negative effect on information-sampling investment. Furthermore, impaired initial performance predicted the decline in investment over time. Finally, the effects of stressors on investment decline were partially mediated through initial performance level. The present findings contribute to theories aiming to explain the relationship between hampered performance and motivational losses.

INTRODUCTION

For decades, researchers have been interested in how stressors such as noise and time pressure affect human cognitive functioning in general, and judgment in particular. Research on stressors in cognitive performance has traditionally considered stressor effects in terms of reduced cognitive capacity. This ‘cognitive capacity’ tradition is based on the limited-capacity resource models of Kahneman (1973) and Norman and Bobrow (1975). The latter authors stated that “the processing resources for any system are limited, and when several processes compete for the same resources, eventually there will be a deterioration of performance” (p. 44). Broadbent (1957) already suggested that the negative impact of environmental stressors on performance is due to their imposition of demands on attentional or cognitive capacity. The notion that stressors like time pressure and noise reduce cognitive capacity has been widely adopted in the literature (e.g. Ariely & Zakay, 2001; Hockey & Hamilton, 1983, Payne, Bettman, & Johnson, 1993).

However, despite the detrimental effect of stressors on cognitive capacity, performance levels are often maintained under stressors. Several models have therefore advanced the idea that reduced cognitive capacity under stressors can be compensated by increases in energy mobilization (e.g., Hockey & Hamilton, 1983; Hockey 1986) or motivational arousal (Brehm & Self, 1989). In the present study, we use the general term *energy investment* to denote these similar concepts of energy mobilization and motivational arousal.

In his compensatory control model, Hockey (1997) argued that despite stressors hampering cognitive capacity, task performance often remains stable because people can compensate for reduced cognitive capacity by (deliberately) directing more energy to the task at hand. However, because increased energy investment is often difficult or aversive, compensation strategies imply serious processing costs. Therefore, compensation aiming to protect task performance requires a high motivation to overcome the more general goals of preserving energy and maintaining desired affective states (see e.g., Hockey 1997; Kahneman, 1973). The motivational intensity theory of Brehm and Self (1989) similarly advances that motivation poses an upper limit to the increase in energy investment allowed when attempting to compensate for hampered cognitive capacity. Hence, it can be concluded that 'compensation theories' generally state that to maintain performance under stress, high motivation is a necessary requirement because it determines whether or not energy investment may be increased to compensate for the negative effects of stressors on cognitive capacity.

Evidently, people are not always highly motivated in a task (or they can simply be unable to compensate for the effects of stressors). Not surprisingly then, stressors have often been found to substantially impair performance (e.g., Roets, Van Hiel, Cornelis, & Soetens, 2008; Rothstein, 1986; for an overview, see Staal, 2004). Moreover, various studies have demonstrated that stressors can also lead to a decline in energy investment. In particular, studies in the 'motivated cognition' approach on judgment and decision making (e.g., Kruglanski & Webster, 1996; Richter & Kruglanski, 1998) have explicitly focused on the potential for stressors like noise and time pressure to decrease the individual's willingness to invest in information sampling and processing before reaching a judgment (see, e.g., De Dreu, 2003; Richter & Kruglanski, 1998).

The negative effects of stressors on performance and investment have predominantly been studied separately, but the combination of the accumulated findings suggests that there may be an alternative pattern for the compensation perspective. In particular, instead of leaving performance unaffected while increasing energy investment, stressors may also impair both performance and investment. Indeed, Roets et al. (2008) have recently demonstrated that noise and time pressure stressors can hamper both performance *and* information-sampling investment in judgment tasks. However, the mechanisms underlying the decline of both performance and investment are yet unclear. In particular, this twofold decline may either indicate that stressors have ‘parallel’ negative effects on performance and energy investment, or alternatively, there may be a causal relationship between the two effects, (i.e., the effect on investment may be the result of the effect on performance or vise versa).

Three possible mechanisms underlying the negative effects of stressors on performance and energy investment

The first possibility regarding the negative effects of stressors on performance and energy investment is that these effects occur independently and should be considered parallel effects. Indeed, whereas stressors can have a dual negative effect on performance and investment, this does not necessarily mean that these effects are causally related. Setting fire to a piece of paper produces both light and heat but this does not mean that the heat is caused by the light or that the light is caused by the heat. For the purpose of this study we label this possibility the “parallel effects account”.

The second possibility refers to a causal relationship that can be labeled ‘performance-through-investment’. This account is based on the premise that the amount of energy a person invests determines his or her task performance. For example, the energy students invest in their school work is believed to have a significant impact on how well they do on exams. Hence, it is possible that stressors initially hamper investment and that this reduced investment leads to impaired performance.

The third possibility refers to the inversed causal relationship, based on Kruglanski and Webster's (1996) assumption that reduction of available cognitive resources may subsequently reduce the willingness to invest (further) energy. In particular, this assumption implies that cognitive capacity reduction due to stressors may immediately hamper performance, while motivational decrements in investment under stressors occur as the result of impaired performance. As such, the "investment-through-performance mechanism" assumes that impaired performance may be the source rather than the result of investment decline.

Remarkably, to date, the literature on stressors effects in judgment and decision making has neglected to investigate these three explanations in a single research design.

The present research

The aim of the present study is to test the merit of these three accounts to explain the dual negative effect of stressors on performance and energy investment in judgment tasks. For the purpose of the present study, energy investment is operationalized as a behavioral measure of information-sampling investment; i.e., the amount of information that is sampled before reaching judgment. To test the three possibilities outlined above, we study the stressor effects in a judgment task that previously has shown to be sensitive to the detrimental effects of stressors on both performance and behavioral information-sampling investment (see, Roets et al., 2008). Moreover, to test the potential causality between performance and investment under stress, the pattern of performance and investment is examined over time in two consecutive phases of the task. In particular, we test whether the presence of a stressor affects one variable immediately whereas stressor-induced changes in the other variable occur only at a later stage. Subsequently, we test whether the immediate stressor effect on one variable predicts these changes over time in the other variable (i.e., deviations from the initial performance or investment levels).

METHOD

Participants

One-hundred-and-three undergraduate students (69 % female, mean age = 20.0 years, SD = 1.75) with normal hearing and normal or corrected vision participated in the study in partial fulfillment of course requirements.

Stimuli and Materials

Participants completed a judgment task adapted from Mayseless and Kruglanski (1987) by Roets, Van Hiel, and Cornelis (2006; see also Roets & Van Hiel, 2008), in which they had to identify a single digit (ranging between 1 and 6) that was presented very briefly (50 ms) on a computer monitor. The digit was masked with an array of '&' signs before and after exposure. Participants could request additional exposures by pressing a button (i.e., the key '7') and were allowed to operate this button repeatedly until they felt able to reach a judgment regarding the digit's identity. After they confirmed their judgment by pressing an 'identification' button (1 to 6), a new digit was displayed.

Procedure and Design

Participants were told that they would take part in an experiment "that aimed to explore the ease with which particular digits are identified". They first completed two exercise trials after which they were randomly assigned to a control condition or a stressor condition (i.e., time pressure or noise). In the *control condition*, participants were only provided with the general instructions. In the *time pressure condition*, participants were explicitly instructed to reach judgment on the digit's identity as fast as possible. They were also informed that if their judgment response latencies exceeded five seconds, the phrase 'please respond faster' would appear on the monitor after reaching judgment on the trial (see, Van Hiel & Mervielde, 2002). In the *noise condition*, participants heard a loud, continuous beep tone (1000 Hz, 80 dB) during the experimental series[1] (see, Van Hiel & Mervielde, 2007). All participants were presented trials for 210 seconds, with a maximum of 60 trials[2]. No feedback was provided and participants were unaware of whether they needed to complete a fixed amount of trials, or whether the task had a fixed duration.

Measurements

To obtain measures of information gathering investment and performance early and later on in the judgment task, we split the experimental block in two halves (referred to as phases) based on the total number of trials participants completed[3]. Mean proportion of correct identifications (i.e., performance), and mean number of requested digit exposures (i.e., information-sampling investment) were computed for both phases.

RESULTS

Two participants in each stressor condition and one in the control condition were identified as outliers performing more than 2 SD below the average of their group during the experiment and were therefore omitted from the analyses.

Effects of noise and time pressure on performance and information sampling investment

Preliminary ANOVA's confirmed the functional similarity of the two stressors, showing no differences between the effects of noise and the effects of time pressure on performance, $F(1, 60) = .25$, $MSE = .00$, $p = .62$, $\eta^2 < .01$, and $F(1, 60) = 1.22$, $MSE = .02$, $p = .27$, $\eta^2 = 02$, for phase 1 and phase 2 respectively, and no differences in information sampling, $F(1, 60) = .17$, $MSE = .00$, $p = .68$, $\eta^2 < .01$ and $F(1, 60) = .20$, $MSE = .00$, $p = .85$, $\eta^2 < .01$ for phase 1 and phase 2 respectively, all *ns*. Moreover, ANOVA's with repeated measures of performance and investment showed no interaction effects between type of stressor and phase, $F (1, 60) = .93$, $MSE = .01$, $p = .34$, $\eta^2 = .02$, $F (1, 60) = .21$, $MSE = .00$, $p = .65$, $\eta^2 < .01$, respectively, demonstrating that there was no difference between the two stressor condition in performance and investment pattern over time either. To increase statistical power, these conditions were merged into one 'stressor' condition (as opposed to the control condition) in further analyses.

A first ANOVA with repeated measures of performance in phase 1 versus phase 2 showed that the presence of a stressor had an overall detrimental effect on performance, $F (1, 96) = 13.23$, $MSE = .02$, $p < .001$, $\eta^2 = .12$. An additional main effect of phase showed lower performance in the second phase compared to the first phase, $F (1, 96) = 13.50$, $MSE = .01$, $p < .01$, $\eta^2 = .12$. No interaction effect between stressor and phase was found, $F (1, 96) = .28$, $MSE = .01$, $p = .60$, $\eta^2 < .01$ (see Figure 1). Of particular interest here is the significant negative impact of stressors on performance in phase 1, $F (1, 96) = 13.14$, $MSE = .01$, $p < .001$, $\eta^2 = .12$, showing that stressors hamper performance immediately. On average, participants in the control condition correctly responded on 96.6% of the trials in phase 1 ($SD = 4.5$) whereas mean proportion correct answers in the stressor condition was only 89.2% ($SD = 11.7$).

A second ANOVA with repeated measures of investment in phase 1 versus phase 2 revealed that the presence of a stressor had no significant overall effect on information gathering investment, $F(1, 96) = .23$, $MSE = .34$, $p = .63$, $\eta^2 < .01$. A significant effect was found for phase, with less information sampling investment in the second compared to the first phase $F(1, 96) = 5.96$, $MSE = .05$, $p < .05$, $\eta^2 = .06$. Most importantly, a significant interaction effect between stressor and phase was obtained, showing a substantial decline in investment over phases, only when a stressor was present, $F(1, 96) = 10.35$, $MSE = .05$, $p < .01$, $\eta^2 = .10$. Stressors did not reduce information-sampling investment immediately, but instead a clear decline in information gathering was noted when comparing the first to the second phase (mean difference = -.18, *SD* = .34, see Figure 2). Conversely, in the control condition, there was a minimal increase in information sampling investment from phase 1 to phase 2 (mean difference = .03, *SD* = .27). As can be seen in Figure 2, the significant decline in investment when a stressor was present was primarily due to the substantially reduced investment in the second phase of the task, $F(1, 96) = 3.20$, $MSE = .16$, $p = .077$, $\eta^2 = .03$, rather than to the very minimal heightening in the initial phase $F(1, 96) = .41$, $MSE = .24$, $p = .52$, $\eta^2 < .01$.

In conclusion, the ANOVA's show an immediate negative effect of stressors on performance, and a negative effect on information sampling investment over phases. Because in the first phase performance but not investment is already hampered, reduced investment cannot be the source of hampered performance here, hence excluding the 'performance-through-investment' mechanism as an explanation for the effects in this task. However, a causal relationship in the other direction (i.e., investment-through-performance) is possible. We therefore tested whether initial performance is a predictor of investment decline, and whether the effects of stressors on investment are mediated by performance.

Initial performance as predictor of the decline in information-sampling investment

Regression analysis revealed a significant effect of performance in phase 1 on the difference in information gathering investment between phases (information gathering at T1 minus information gathering at T2), $F(1, 96) = 8.69$, $p < .01$. The standardized regression coefficient ($\beta = .29$) showed that lower performance levels in phase 1 predicted a greater decline in information gathering between phases.

Mediated effect of stressors on information gathering investment through performance

Next, mediation analysis was conducted using bootstrapping to estimate the indirect effects of stressors on investment (see Preacher and Hayes, 2004). Bootstrapping is a nonparametric approach to effect-size estimation and hypothesis testing, "accomplished by taking a large number of samples of size *n* (where *n* is the original sample size) from the data, *sampling with replacement*, and computing the indirect effect, in each sample" (Preacher & Hayes, 2004; p. 722). This procedure has recently been advanced as a superior alternative to test mediation effects compared to the regression methods and Sobel tests. Bootstrapping analyses have high statistical power, require no assumptions about the shape of sampling distributions and yield confidence intervals which allow testing hypotheses about the population value of indirect effects.

The mediation analysis showed a significant indirect effect of stressors on information gathering changes through initial performance (Indirect effect estimate = .03, $SE = .01$, $p < .05$, 95% CI [.0026 - .0581]). In addition to the indirect effect, a direct effect of stressors on the decline in information gathering remained (Direct effect estimate = .08, *SE* = .04, $p < .05$).

DISCUSSION

The present study evaluated the detrimental effects of noise and time pressure on performance and information-sampling investment in judgment. Three possible mechanisms that may underlie these effects were evaluated: i.e., parallel effects, performance-through-investment, and investment-through-performance. The results demonstrated that stressors impaired initial performance and caused a decline in information-sampling investment over time. Moreover, the lower the performance in the beginning of the judgment task, the larger the decline in motivation to gather information in the next phase of the task. Through this causal relationship, the effect of stressors on changes in information sampling investment was partially mediated by its effect on initial performance. It can be concluded that the indirect effect on investment demonstrates the role of an investment-through-performance mechanism in the detrimental effects of stressors on energy investment. The remaining direct effect indicates that there is also an additional parallel effect of stressors on investment that occurs independently from the effect on performance.

Investment compensation or decline under stressors: the role of performance importance and investment utility

Because the explicit aim of the present study was to investigate the link between performance and investment in cases when stressors impair both investment and performance, a task was used that has previously shown this negative dual effect (see Roets et al., 2008). On a more general level however, an interesting question pertains to why some tasks typically yield a dual negative effect of stressors while for other tasks the alternative compensation pattern was found (see Hockey, 1997).

Most relevant to this issue, Brehm and Self (1989) stated that only with high task motivation, people are willing to increase energy investment if necessary to maintain performance. In their motivational intensity theory, these authors described motivation as “a multiplicative function of need, value of the potential outcome, and the perceived probability that a properly executed behavior will produce the desired effect” (p. 110). Hence, two aspects underlie the motivation to invest energy: (1) the perceived importance (i.e., need and value) of high performance, and (2) the perceived utility of energy investment to improve or maintain performance levels. The degree to which these factors are present may explain the different pattern of stressor effects in different tasks.

In tasks where the perceived importance of high performance is relatively low, investment motivation may be especially fragile and easily disturbed by stressors. This is likely to be the case in the present experiment where performance on the task had little consequences and was not rewarded or sanctioned in any way. A deflated tire will probably not prevent a cyclist from investing additional energy when he’s one mile away of winning a major championship, but it may certainly reduce his willingness to invest energy in a training session when nothing is at stake.

The second important aspect refers to the perceived probability that a properly executed behavior will produce the desired effect, or alternatively stated, the belief that increased investment will substantially improve performance. In the present task, the potential effectiveness of increased investment for bolstering performance seems limited indeed and it can be assumed not to outweigh the disadvantages of expected prolonged exposure to the aversive stressor (see e.g., Brehm & Self, 1989; Hockey, 1997).

CONCLUSION

Although performance under stressors can be bolstered by boosting energy investment, this mechanism seems limited to conditions where motivation is already high. Otherwise, stressors impair both performance and investment. Moreover, for these cases, inferior performance under stressors is not necessarily a consequence of low investment, but instead, it can be the source of impaired investment and motivation. In particular, the present results attest to a general mechanism in which energy investment declines over time as a function of initial performance under stressors. Future research and interventions that aim to minimize the detrimental impact of stressors on cognitive functioning should benefit from taking this particularly ‘destructive’ mechanism into consideration.

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Note:

[1] All participants in the time pressure condition confirmed before the experimental trials started that they had understood the demand to identify the digit as quick as possible. In the noise condition the continuous presence of the 1000 Hz beep tone for each participant was verified by the experimenter.

[2] Number of trials for the control, noise and time pressure conditions were M = 55.92 (SD = 5.68), M = 57.17 (SD = 6.09), and M = 54.34 (SD = 7.75). No significant differences between conditions were found with regard to the total number of trials completed, $F(2, 95) = 1.52$, $p = .22$, $\eta^2 = .03$.

[3] For example, for a participant who completed all 60 trials, phase 1 consists of the first 30 trials and phase 2 consists of the last 30 trials. For a participant who completed only 52 trials before time ran out, phase 1 and phase 2 consisted of the first and the last 26 trials respectively. An alternative division in two phases based on the total time yielded a virtually identical split and did not affect the findings.