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Stress, Uncertainty and Decision Confidence

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Abstract We successfully manipulated decision confidence in a probabilistic prediction task by means of stress as induced by excessive cognitive demands. In particular, our results indicate that decisions (based on high and low, but not intermediate levels of uncertainty) made under stress (confirmed by skin conductance measures) are associated with increased confidence when outcome probabilities are incompletely known (20% residual uncertainty). A different pattern was found when outcome probabilities were completely known (0% residual uncertainty). Here, stress led to decreased decision confidence when decisions were associated with intermediate levels of uncertainty but had no effect in case of high and low levels of uncertainty. In addition we provide evidence for ambiguity—(understood as implicit-risk) assessment being impaired under stress conditions.

Keywords Decision confidence · Stress · Skin conductance · Uncertainty · Ambiguity · Risk

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Introduction

Everyday we have to make quick decisions under stressful conditions. One can rarely focus exclusively on one task but is rather frequently interrupted by competing demands that are too complex to be solved straightaway. Once, these cognitive demands and unsolved problems reach a certain threshold they might lead to a considerable degree of stress. Emotional states associated with stress influence people's reasoning processes, because most intense emotional states are accompanied by high levels of autonomic arousal (see Pham 2007). Increased arousal states reduce the processing capacity available for performing cognitive tasks (Sanbonmatsu and Kardes 1988) and are associated with more affect-based reasoning (Pham 2007). High arousal states are also known to impair working memory capacity (Darke 1988; Humphreys and Revelle 1984) and cognitive functions mediated by the prefrontal cortex (Arnsten 2009) as well as they tend to reduce decision accuracy (e.g. Cumming and Harris 2001; Keinan 1987; Klein 1996). However, effects of intense arousal on cognitive performance are not always negative (Humphreys and Revelle 1984). Aroused individuals show increased efficiency in information processing by narrowing down their cue-utilization to more diagnostic cues at the expense of less diagnostic cues (Bacon 1974; Hockey 1973; Pham 1996).

Most importantly for the present investigation, decision makers' emotional states can affect their cognitive evaluations of a risk (e.g. Johnson and Tversky 1983). A series of studies indicate that negative emotion states with strong arousal increase risk-seeking (e.g. Fessler et al. 2004; Leith and Baumeister 1996; Mano 1994). Furthermore, incidental (unrelated to the object of judgment) emotional arousal is often misinterpreted as an integral (related to the object of

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judgment) affective response to a target resulting in more polarized evaluations of this target (Reviewed in Pham 2007). According to Gorn et al. (2001) incidental arousal is misconstrued as an integral response to the target resulting in polarization because people "feel strongly about" the target. Now, decision confidence has long been a popular field of research (e.g. Williamson 1915; Johnson 1939; Adams and Adams 1961; Fischhoff et al. 1977; Vickers and Packer 1982; Griffin and Tversky 1992; Baranski and Petrusic 1998, 1999; Harkin and Mayes 2008; Kepecs et al. 2008). The most prominent finding is the hard-easy effect or over- and under confidence effect. It denominates the frequent observation that subjects tend to overestimate the accuracy of their responses to difficult decisions and underestimate it for easy decisions. However, results are conflicting (reviewed in Moore and Healy 2008).

When it comes to stress, Baranski and Petrusic (1998) speak of the historically ubiquitous finding of equal mean confidence under speed and accuracy stress (e.g., Festinger 1943; Garrett 1922; Johnson 1939). However, apart from Schaeffer's (1989) work the influence of stress on decision confidence as compared to a straight control condition seems to lack investigation. Schaeffer (1989) reports that stress induced by annoying context sound leads to increased confidence in the decisions that are made. In short, excessive cognitive demands tend to elicit a stress response which includes heightened arousal (Schaeffer 1989) and high arousal can increase risk-seeking (Fessler et al. 2004; Leith and Baumeister 1996; Mano 1994).

The aim of the present study is to replicate the result of a stress-related increase in decision confidence for stress induced by excessive cognitive demands and further to differentiate between decisions associated with varying degrees of uncertainty. To provide degrees of uncertainty we applied a decision-task developed by Huettel et al. (2005) while stress was controlled by a non solvable performance test (META, Gatternig and Kubinger 1994). Because the results of this experiment immediately raised further questions we conducted a second, slightly modified one straightaway, so we report two experiments in the following. Strikingly, for the second experiment we provided a condition with 0% residual uncertainty.

Materials and Methods

Experiment 1

Participants

Subjects were 17 (11 females) healthy volunteers (mean age = 23.8 years, SD = 2.18) recruited from and tested at the University of Vienna. Participants gave informed consent and none had any neuropathological history or were on medication. All subjects were right-handed and had normal or corrected to normal vision.

Procedure

Participants were invited to sit on a comfortable chair in our experiment room. Stimuli were presented on a computer screen placed in front of them (distance about 50 cm) using the software *Presentation* (Neurobehavioral systems). The experiment consisted of two sessions. For both sessions, one single trial was composed of three phases: context, response and feedback (Fig. 1). During the initial context phase, a series of eight simple shapes (circle or triangle) were visually presented one after each other (400 ms presentation duration; 350 ms inter stimulus interval) in the center of the screen. The number of shapes per type (circle or triangle) for each trial was randomly drawn from a total of five different probability distributions: 34% chance of eight shapes of one type, 30% of seven, 17% of six, 13% of five, and 6% of four shapes of each type. The order of shapes within the series was randomized and trials were equally likely to have more circles or more triangles. After the offset of the last shape a single response cue ("?") appeared at the center. Now, study participants had to decide whether the next shape will be a circle or a triangle based on the instruction that the more shapes of one kind were prior presented, the more likely it's following appearance would be. Subjects indicated their decision by pressing one of four buttons with their right hand, arranged from left to right as follows: high confidence in a triangle, low confidence in a triangle, low confidence in a circle, and high confidence in a circle. After that, a single feedback stimulus (either a circle or triangle) was presented for 1,000 ms.

The probability of each feedback stimulus depended on how many stimuli of that type had been presented: if eight, 80%; seven, 72.5%; six, 65%; five, 57.5%; and four, 50%. Thus, the outcome uncertainty associated with each trial

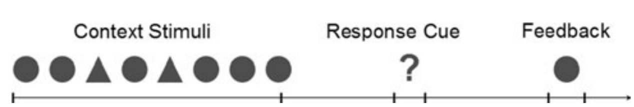

Fig. 1 Schematic view of the experimental design. In each trial, participants were shown a series of eight simple shapes (*circle or triangle*) whose composition provided information for the decision in that trial. Stimuli were rapidly presented (duration, 400 ms; interval, 350 ms) in the *center* of the screen. After the offset of the last shape a single response cue was presented and subjects indicated their decision by pressing one of four highlighted buttons on a keyboard: high-confidence triangle, low-confidence triangle, low-confidence circle and high-confidence circle. In succession a feedback stimulus was presented that was consistent with the decision or not. (reproduced and modified from Huettel et al. (2005))

type is given by the complement of these probabilities, and ranged from 20 to 50%. As it appeared a more naturalistic setting, we kept the residual uncertainty of 20% of the original Huettel-task (Fig. 2). Subjects were never explicitly told these feedback probabilities. Again, they were instructed that if more stimuli of a given shape were presented this shape was more likely to appear next.

After the offset of the feedback stimulus there was a 500 ms interval before the onset of the next trial. In total, 100 trials were provided. Subjects had no preparatory training before the session. This first session lasted about 20 min.

For the second session (about 25 min), blocks of ten trials were preceded by a very difficult nonverbal performance test (Fig. 3). During the instruction prior to the experiment a solvable example-item was presented and explained while all real tasks used in the experiment weren't solvable anymore. In the original version of the test subjects have 5 min to find the correct answer while in the present study they were given only 30 s. They got no feedback and there was no timeline informing subjects about how much time of the 30 s was left. The task is to apply certain transformation-rules on an initial symbol-chain and to check which of the 6 additionally presented symbol-chains on the right side is not producible by means of these rules. The rules mean the following: A can be substituted by BA but not BA by A, B can be substituted by ABB but not the other way round, etc. Subjects can apply as many rules as they want to and these as often as they want.

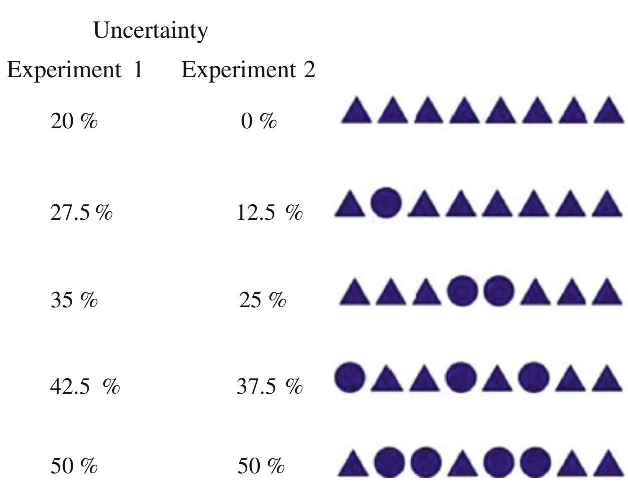

Fig. 2 Uncertainty varied with the number of shapes of each type. If all stimuli were of one type, there was 20% uncertainty in experiment 1 and 0% uncertainty in experiment 2. That is, the probability for the feedback stimulus was 80% (exp.1)/100% (exp.2) to be of the presented type. As the composition of shapes grew more balanced, the uncertainty associated with selecting the more probable shape increased. (adapted from Huettel et al. (2005))

Initial symbol-chain	
CBB	
Transformation-rules:	Which chain is NOT producible by means of the given rules?
A → BA	DCECABB
B → ABB	ECABBDBD
C → DB	CADBDBABB
D → EC	CCEAFEAEDB
E → EAE	CBCDAABBB
BB→ CD	EBAEDCECBB

Fig. 3 The task is to apply the given transformation-rules on the initial symbol-chain and to check which of the 6 symbol-chains on the *right side* is not producible by means of these rules. The rules mean the following: A can be substituted by BA but not BA by A, B can be substituted by ABB but not the other way round, etc. Subjects can apply as many rules and these as often as they want. In this instruction item there is an F inserted in the 4th line, clearly indicating the correct answer. Note that in the experimental runs all symbol-chains were producible

The test in its original form assesses if people abandon the given rules and look for an alternative way to solve the items. In this case (the example-task) there is an F inserted in the 4th row which clearly indicates that this chain is not producible. However, the later presented items lack this "trick" and are all producible, so that there is no correct answer. Subjects were told that they could either deal with the task step by step applying the rules or by looking for meta-rules, i.e. "tricks". When debriefed they all reported having tried both ways in turn. Thus, the difference of session two compared to session one was that cognitive stress was induced. The order of sessions was counterbalanced between participants.

To provide physiological data related to different degrees of stress between both sessions we measured skin conductance during the entire experiment. For those measurements we used the Bio-feedback System Nexus-10 (Mind Media BV) and the Software Biotrace+. Skin conductance was measured at 32 Hz by using a SC Sensor (NX-GSR1A, Ag–AgCl finger electrodes) at participants' left middle and ring fingers. Subjects were instructed to keep the left hand in a relaxed position on the table.

Skin conductance data were averaged within both sessions to compare their levels of arousal. It was expected that cognitive stress leads to higher levels of arousal which in turn should be evident in measures of skin conductance.

Results

We calculated Wilcoxons signed-ranks tests for all five uncertainty conditions. In trials associated with 20% uncertainty subjects showed on average a significantly higher decision confidence in the stress condition (M = .92; SD = .12) than in the control condition (M = .86; SD = .17), $z = -2.158$, $p = .031$ *(2-tailed)*, $r = -0.37$. In trials associated with 42.5% uncertainty subjects showed on average as well a significantly higher decision confidence in the stress condition (M = .26; SD = .29) than in the control condition (M = .15; SD = .19), $z = -2.158$, $p = .028$ *(2-tailed)*, $r = -0.37$. The same was found for trials associated with 50% uncertainty (M control = .06 (SD = .11), M stress = .19 (SD = .25), $z = -2.383$, $p = .016$ *(2-tailed)*, $r = -0.42$) (See Fig. 4). Reaction times measured as the interval between onset of response cue and button press were shorter (trend) in the stress condition (M = 1,062.95 ms; SD = 379 ms) than in the control condition (M = 1,302.71 ms; SD = 477 ms), $z = -1.81$, $p = .074$ *(2-tailed))*.

Experiment 2

Participants

Subjects were 19 (9 females) healthy volunteers (mean age = 25 years (SD = 2.47) recruited from and tested at the University of Vienna. Participants gave informed consent and none had any neuropathological history or were on medication. All subjects were right-handed and had normal or corrected to normal vision.

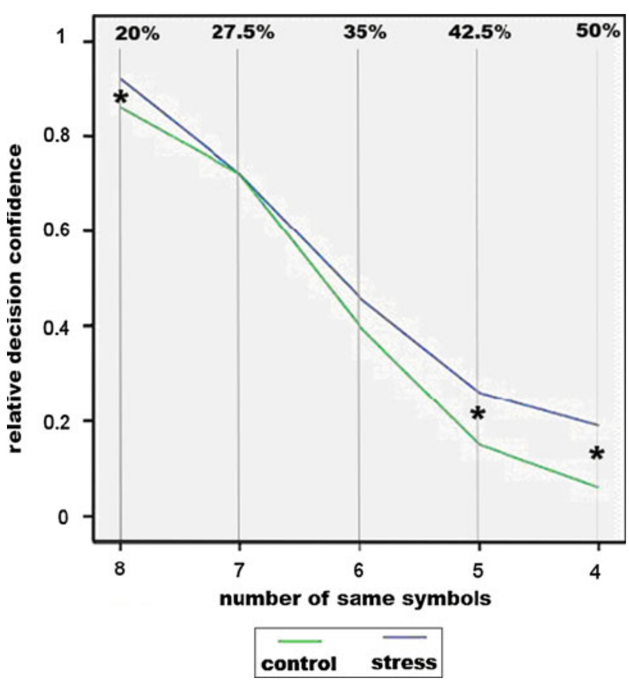

Fig. 4 Experiment 1 (20% rest-uncertainty): Decision confidence and uncertainty resulting from the different shape distributions (within single trials each consisting of 8 consecutive shape presentations) and for both the stress condition and the control condition. *Asterisks* mark significant differences between conditions

Procedure

Since we wondered if the observed effects in Experiment 1, especially for low uncertainty trials, could in part be due to subjects not taking into account the residual uncertainty when stressed, we conducted a second experiment where we used a residual uncertainty of 0% instead of 20%. The probability of each feedback stimulus depended on how many stimuli of that type had been presented: if eight, 100%, seven, 87.5%, six; 75%, five, 62.5% and four, 50%. Here the uncertainty ranged from 0 to 50% (Fig. 2). Apart from this change this experiment is identical to the first.

Results

Analysis using Wilcoxons signed-ranks test revealed significantly higher decision confidence in the control (M = .5; SD = .31) than in the stress condition (M = .37; SD = .29), $z = -2.017$, $p = .044$ *(2-tailed)*, $r = -0.33$ for trials associated with 25% uncertainty. For trials associated with higher or lower uncertainty we found no significant effects. We found no significant differences in reaction time between conditions although in contrast to the first experiment reaction times here were on average longer in the stress than in the control condition (M*control* = 1,000.63 ms (SD = 403.9 ms), M*stress* = 1,066.08 ms (SD = 492.3 ms)) (Fig. 5).

Experiment 1 Versus Experiment 2

Analyses were conducted using a 2 (stress) × 2 (residual uncertainty) × 5 (8, 7, 6, 5, or 4 symbols of the same shape presented) design Analysis of Variance (ANOVA) on confidence with residual uncertainty being a between-subject and stress being a within-subject factor**.** It revealed a significant interaction effect of residual uncertainty × stress on decision confidence, F (1, 33) = 4.6, $p = .039$, $r = .35$ (Greenhouse- Geisser corrected). Comparing the only cases for which an absolutely certain decision was possible which were 8 equal symbols in the second experiment (0% uncertainty) to cases of 8 equal symbols in the first experiment (20% residual uncertainty) we found a significant difference in decision confidence for the control conditions but not for the stress conditions. With respect to control conditions, subjects showed a significantly higher decision confidence in exp. 2 (M = .95; SD = .09) than in exp. 1 (M = .86; SD = .17), U = 93, $z = -2.253$, $p = .024$*(2-tailed)*, $r = -0.38$. Instead, with respect to stress conditions, mean decision confidence in

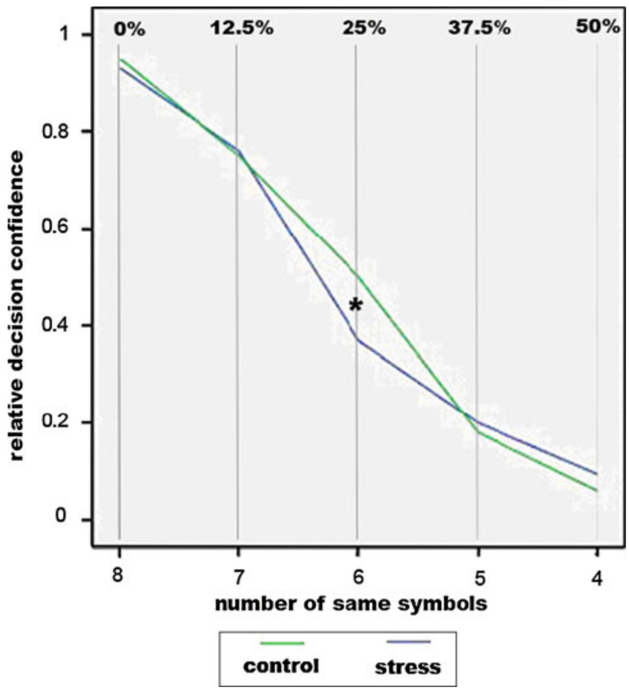

Fig. 5 Experiment 2 (0% rest uncertainty): Average Decision confidence for all shape distributions (within single trials each consisting of 8 consecutive shape presentations) and for both the stress condition and the control condition. *Asterisks* mark significant differences between conditions

experiment 1 was .92 (SD = .12) and in experiment 2 it was .93 (SD = .08) (non significant difference). This indicates on the one hand the presence of ambiguity *or* implicit-risk assessment under normal conditions which is not the case when subjects are stressed by cognitive excessive demands and on the other hand differential effects of stress on decision confidence depending on the reliability of information. Reaction times were longer in the control condition of experiment 1 (M = 1,302.71 ms; SD = 477 ms) than in the control condition of experiment 2 (M = 1,000.63 ms; SD = 404 ms), although this difference didn't reach significance ($z = -1.85$, p = *.064 (2-tailed))*. However, such a difference was not observed when comparing the stress conditions (M*stress1* = 1,044.74 ms (SD = 379 ms), M*stress2* = 1,066.08 ms (SD = 492 ms), $z = -0.079$, p = *.95 (2-tailed))*.

Skin Conductance

Analyses were conducted using a 2 (Stress/control) × 2 (residual uncertainty) mixed-design Analysis of Variance (ANOVA) on skin conductance data with residual uncertainty being a between-subject and stress/control being within-subject factors. It revealed a significant main effect of stress on skin conductance which was higher in the stress conditions (exp. 1: mean = 1.358 (SD = 1.39), exp. 2: mean = .809 (SD = .839) than in the control conditions (exp.1: mean = .924 (SD = 1.122), exp2: mean = .374 (SD = .412), F (1, 30) = 6.25, $p = .018$, $r = .42$ (Greenhouse- Geisser corrected). Residual uncertainty was only almost significant (F (1, 30) = 3.54, $p = .07$) while the interaction effect of stress and residual uncertainty was found highly insignificant (F (1, 30) = .006, $p = .94$).

Discussion

We found two effects of interest here. The first is the observation of differential effects of stress on decision confidence, depending on stimulus probability and residual uncertainty, i.e. reliability of information. In particular, experiment 1 revealed differences in decision confidence between stress and no stress for conditions with high and low residual uncertainty whereas experiment 2 revealed such a difference only for a medium residual uncertainty level, but not for high and low levels. This finding seems difficult to interpret given that the only difference between experiment 1 and experiment 2 was that experiment 2 contained one condition of 100% outcome certainty. Unfortunately, at this stage it remains unclear what this different patterns of stress-related effects on decision confidence tell us. However, we do note that our results demonstrate that differences in residual uncertainty lead to varying degrees of stress effects on decision confidence which is the only thing that we want to conclude from our results so far. Future studies will provide deeper insight into the specific pattern of our results.

The second effect we found is that implicit risk assessment might be impaired when subjects are stressed. In our case risk assessment refers to the awareness of manipulated error probability due to varying numbers of appearing shapes of one kind before a decision had to be made and due to implemented residual uncertainty. It is difficult to imagine that these slight differences were consciously perceived. Thus, under control conditions (no stress) participants seemed to have some sort of unconscious awareness of this manipulation. In contrast, under stress conditions participants did not even provide expected responses in case of a 100% clear decision situation which is why we interpret this finding as a lack of implicit risk assessment under conditions of stress. Implicit is understood as information being processed in the absence of awareness but still influencing behaviour (see Walla et al. 1999 and Rugg et al. 1998).

Although the differences in reaction time between conditions in the present study didn't reach significance, the observed trends are consistent with the frequent observation of a negative relation between decision confidence and reaction time (e.g. Johnson 1939). The observation of impaired implicit risk assessment is consistent with Schaeffer (1989) reporting that stress-related effects on decision making include an increase in the use of heuristics and also with Keinan (1987) who reports screening of alternatives to happen in a more hazardous fashion when subjects are stressed. The observed confidence-related stress effects match previous results reported in the literature only in part.

Like Schaeffer (1989) we observed an increase in decision confidence in stressed subjects, but only in trials associated with either high or low stimulus uncertainty and just when the task included residual uncertainty (20%, Exp.1). In addition, when outcome probabilities were known stress even led to decreased confidence (Exp.2). The stress-induced increase in confidence in the first Experiment is consistent with Pham's (2007) notion of polarization of evaluations due to misinterpreted incidental arousal but again, only in part. Lerner and Keltner (2001) report that fear tends to elicit risk-aversion whereas anger tends to trigger risk-seeking even though both are high-arousal negative emotions. The crucial point here is that although we observed a stress-related increase in arousal in both experiments, the same stress-manipulation in interaction with the respective degrees of residual uncertainty might have led to different emotional responses in participants and therefore different confidence patterns. However, our results fit the idea of ecological rationality. On the one hand, when stressed one might tend to be more cautious. On the other hand, in order to adapt to situations associated with reduced processing capacity subjects might experience an increased need for certainty, as doubt and uncertainty lead to further consideration and occupy resources. In the present study which of the possible responses is elicited seems to depend on an interaction of stress and residual uncertainty.

Conclusion

We provided evidence for discontinued ambiguity-assessment under stress. We showed that stress-exposure can lead to very different effects on decision confidence if only the underlying probabilities are altered, i.e. the degree and reliability of information is modified. Overall, our results aren't supportive for the Hypothesis predicting stress exposure to lead to increased decision confidence. The effects seem more complex than previously thought. It appears that we are the first to report a stress-related decrease in decision confidence. Decreased confidence can be understood as a tendency towards indecisiveness, which might not only be problematic in everyday decision making but is as well a common symptom in both depressive and obsessive–compulsive patients (Sachdev 2005). Thus, our take home message is that the effect of stress on decision confidence is not linear and varies as a function of factors such as level of uncertainty. Future research should therefore further specify both conditions under which stress increases confidence but as well conditions where stress leads to decreases in confidence.

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