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a r t i c l e   i n f o

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a b s t r a c t

Subjective stress states elicited in the context of performance are composed of three broad syndromes as measured by the Short Stress State Questionnaire (SSSQ): Task-engagement, Worry and Distress (Helton, 2004). They are supposed to emerge from the interplay between environmental demands and metacognitive beliefs, but this assumption remains untested. Our research addressed this issue and tested the hypothesis that subjective stress states syndromes may be explained by environmental demands, metacognitive beliefs and their interplay. We recruited 210 participants who completed a working memory, vigilance or magazine-reading task. Our main results revealed that each syndrome of stress is explained by a specific set of predictors: Distress is explained by the dynamic between metacognition and environmental demands, Worry was only predicted by metacognition and Task engagement is explained by both environmental demands and metacognition. Our results were discussed in reference to the S-REF model (Wells & Matthews, 1994) and they brought some insight in when environmental and metacognitive factors predict stress state components in performance settings.

1. Introduction

Lazarus and Folkman (1984) argued that perceived stress increases when the environment is appraised as taxing or exceeding one's resources and as endangering well-being. Matthews, Hillyard, and Campbell (1999) described three fundamental stress-state syndromes corresponding to clusters of stress-related outcomes. Task Engagement relates to strong energetic arousal, task motivation, and concentration (Matthews et al., 2010); Distress relates to low hedonic tone, tension, confidence, and perceived control; and Worry relates to self-focus, negative ideation, and cognitive interference.

Subjective stress states are thought to emerge from the activity of three levels of cognition within the S-REF architecture (Wells & Matthews, 1994). The first (lowest) level is a network of elementary processing units where stimuli (e.g., external stimulus information, cognitive state information) undergo automatic low-level processing. These elementary processing units may generate intruding beliefs (e.g., the processing of monotonous tasks reduces motivation and favors cognitions of lack of confidence and control) (Matthews et al., 2002). Accordingly, subjective stress states have been shown to be sensitive to environmental demands (Wells & Matthews, 1994). Working memory tasks that exceed an individual's processing capacities, impose a high workload, lead to emotional strain, and force them to maintain a high level of effort in order to compensate for processing inefficiency. Such tasks are expected to engender high levels of Task Engagement. Conversely, monotonous vigilance tasks designed to elicit loss of motivation and energy are expected to engender a decrease in Task Engagement. Because WM and vigilance tasks are resource demanding, they should both increase distress. Matthews et al. (2002)'s findings are in line with these expectations and they revealed a decrease in worry for all tasks. The authors argue that laboratory settings promote a decline in Worry because they only require participants to follow a protocol and meet the experimenter's expectations, and do not, therefore, threaten their self image.

The executive part of the S-REF (second level) may be engaged by lower intruding beliefs linked to social, psychological, or physical threats. The appraisal and regulation of intrusive thoughts from lower-level units in order to reduce perceived threats involves two main metacognitive functions: monitoring (allocation of vigilance to the information flowing from lower-level units) and control (coping processes enable the control or strategic modification of information resulting from the monitoring activity). However, the metacognitive activities associated with the S-REF are guided by self-knowledge stored in the long-term memory (third level). This third-level consists of a number of interrelated metacognitive beliefs which can be measured using Cartwright-Hatton and Wells (1997) Metacognitions Questionnaire (MCQ). The MCQ consists of five sub-scales focusing on positive beliefs about worry (i.e., worrying is useful), general negative beliefs

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(i.e., worrying is uncontrollable and dangerous), cognitive confidence (i.e., lack of confidence in one's attention and memory), beliefs about the need to control thoughts (i.e., one's tendency to try and suppress disturbing thoughts), and cognitive self-consciousness (i.e., one's tendency to focus attention inwards to monitor thoughts). Several studies evidenced significant relationships between subjective stress states and metacognition. Positive beliefs, general negative beliefs about thoughts and cognitive self-consciousness were mainly and positively related to Worry. Cognitive confidence and negative beliefs about the uncontrollability of thoughts and corresponding danger were positively related to Distress, and negative beliefs about thoughts in general were related to one Task Engagement subscale (Matthews et al., 1999; Spada, Nikcevic, Moneta, & Wells, 2008; Roussis & Wells, 2008; Cook et al., 2015).

Finally, subjective stress states can emerge from the interplay between the three levels of the S-REF model (Wells & Matthews, 1994, 1996). For example, obsessional patients have particularly negative metacognitive beliefs about worrying, which make lower-processing units more sensitive to bad thoughts. As a result, cognitive interferences related to the Worry syndrome are more frequent and more intense. Although the interrelations between the three cognitive levels of the S-REF are a core aspect of Wells and Matthews' theory (1994, 1996), previous research has examined the separate effects of metacognitive beliefs (Matthews et al., 1999) and environmental demands (Matthews et al., 2002) on subjective stress states.

In summary, the S-REF model has given rise to hypotheses suggesting that subjective stress states are linked to both metacognitive beliefs and environmental demands. Although the results of previous studies partially support these hypotheses, it remains unclear whether third-level metacognitive beliefs moderate the effect of environmental demands on subjective stress. Our research addressed this issue by examining the effects of interactions between environmental demands and metacognitive beliefs on subjective stress states.

For this purpose, we evaluated the fit of multivariate models of subjective stress states in order to measure the effects of cognitive task manipulation on the three subjective stress-state syndromes. We expected levels of Distress and Task Engagement to increase when participants are asked to carry out tasks that solicit their cognitive resources (Matthews et al., 2002). We hypothesized that experimentally induced increases in Distress and Task Engagement would be greater for participants who carried out the WM and Vigilance tasks than for participants who carried out the less demanding control task. Finally, we expected Worry scores to decrease for all our participants (Matthews et al., 2002).

We added measures of metacognitive beliefs to our models in order to determine the effect of these variables on subjective stress states. We expected three dimensions of the MCQ (positive beliefs about worrying, cognitive confidence, and negative beliefs about thoughts in general) to have a positive effect on Worry. In addition, we expected the impact of environmental demands on Worry scores to increase as scores for the above three metacognitive beliefs increased. We expected the cognitive confidence dimension of the MCQ to have a positive effect on Distress scores, hypothesizing that higher levels of cognitive confidence would be associated with increased effects of the WM and Vigilance tasks on Distress. We expected negative beliefs about thoughts in general to have a negative effect on Task Engagement scores. We expected negative beliefs about the uncontrollability of thoughts and corresponding danger to have a positive effect on Distress (Cook et al., 2015).

We added the *Task factor ∗ Metacognition* interaction terms to our models in order to test the hypothesis that metacognitive beliefs moderate the effects of the processing of cognitive task demands on subjective stress-state syndromes (Wells & Matthews, 1994, 1996). We expected the WM and Vigilance tasks to have a greater impact on Task Engagement as the level of negative beliefs about thoughts in general increased (Matthews et al., 1999; Matthews et al., 2002; Wells & Matthews, 1994).

We also added the *Task factor ∗ Time ∗ Metacognition* interaction terms to our models in order to test the hypothesis that metacognitive beliefs moderate the effect of time on subjective stress-state syndromes.

2. Method

2.1. Participants

We recruited 210 university students (149 women, 61 men) with a mean age of 21.05 years (SD = 2.9). We divided the participants into three subgroups. Group 1 (n = 70, 49 women, mean age = 22.04, SD = 3.11) performed an undemanding task ("Magazine" or control condition); group 2 (n = 70, 40 women, mean age = 21.84, SD = 2.38) performed a complex working memory task; and group 3 (n = 70, 60 women, mean age = 19.22, SD = 2.23) performed a vigilance task.

2.2. Assessments

2.2.1. Measures of subjective stress states

We used a French version of the *Short Stress States Questionnaire* - SSSQ. The original English version of the SSSQ (Helton, 2004) consists of 24 items covering three subjective stress states: Task Engagement (8 items), Worry (8 items), and Distress (8 items). All the items on the scale are rated using five-point response scales. Pre-task and post-task measures of subjective stress for the three subjective stress states are obtained by asking participants to complete the SSSQ before (pre-task version) and immediately after (post-task version) they carry out a task.

We previously estimated the psychometric properties of the French SSSQ on 210 French students (unpublished study). According to the classic true-score theory (see Allen & Yen, 1979), it is necessary to estimate the extent to which a translation affects the proportion of the variance in each score that is explained by measurement error (cross-cultural effect). Therefore, we began by estimating and maximizing the reliability coefficient of each subgroup of items with respect to Helton's (2004) three-factor measurement model. For this purpose, we estimated for each scale the reliability value if each item was deleted.

Internal consistency of the Distress related was satisfactory for both the pre-task ($\alpha = 0.78$) and post-task ($\alpha = 0.80$) versions. However, we reported a low item whole correlation for the sixth item for both the pre- ($r = 0.10$) and post-task forms ($r = 0.36$). The internal consistency was further improved (to $\alpha = 0.83$ for the pre-task version and $\alpha = 0.81$ for the post-task version) by removing the sixth item from the group. Internal consistency for the eight items measuring Task Engagement was only just acceptable (pre-task version $\alpha = 0.68$, post-task version $\alpha = 0.72$).

We reported a low item whole correlations for the 2nd (pre-task $r = 0.01$, post-task $r = 0.21$) and the 22nd items (pre-task $r = 0.33$, post-task $r = 0.32$). Removing the 2nd and 22nd items from each version greatly improved the internal consistency (pre-task version $\alpha = 0.72$, post-task version $\alpha = 0.78$). Subsequent analyses were based on the six remaining items. The eight items in the third group measure Worry. Internal consistency for the eight items measuring Worry was only just acceptable (pre-task version $\alpha = 0.66$, post-task version $\alpha = 0.75$). We reported a low item whole correlation for the 14th (pre-task $r = 0.31$, post-task $r = 0.21$), 15th (pre-task $r = 0.33$, post-task $r = 0.33$), 16th (pre-task $r = 0.29$, post-task $r = 0.28$), and 18th items (pre-task $r = 0.43$, post-task $r = 0.37$).

Removing these items greatly improved the internal consistency (pre-task version $\alpha = 0.70$, post-task version $\alpha = 0.80$).

We further performed a Principal Component Analysis using the 17 remaining items with the package *Psych* (Revelle, 2015) of the *R* software (R Core Team, 2013). Results of the Bartlett's test of sphericity confirmed that there are correlations between the remaining 17 items that we considered appropriate for factor analysis matrix correlation (chi-square = 16,239.1; $p < 0.0001$). The parallel analysis revealed three eigenvalues, ranging from 2.27 to 3.59. The screeplot revealed that only these three eigenvalues were above randomly generated eigenvalues. These three eigenvalues met Kaiser's criterion, so we retained a three-factor solution for both the pre-task and post-task versions. These solutions explain 49% of the pre-task variance and 54% of the post-task variance (Table 1). The three factors corresponded to the seven items of the Distress sub-scale (factor loadings ranged from 0.46 to 0.89), the six items of the Task-Engagement sub-scale (factor loadings ranged from 0.41 to 0.87), and the four items of the Worry sub-scale (factor loadings ranged from 0.47 to 0.87).

2.2.2. Metacognitive beliefs

We used the French version of the MCQ (Larøi, Van der Linden, & d'Acremont, 2009), which assesses five metacognitive beliefs via 65 items noted on 4-point Likert scales (from 1 "do not agree" to 4 "agree very much"). The beliefs assessed are positive beliefs about worry - MCQ1 - (19 items), negative beliefs about the uncontrollability of thoughts and corresponding danger - MCQ2 - (16 items), cognitive confidence - MCQ3 - (10 items), negative beliefs about thoughts in general - MCQ4 - (13 items), and cognitive self-consciousness - MCQ5 - (7 items). Criterion-related validity results show that the French MCQ-65 provides reliable (Cronbach's α values of between 0.65 and 0.87) and valid measures of metacognitive beliefs (Larøi et al., 2009).

2.3. Experimental tasks

2.3.1. Magazine task

Participants were told they had been recruited for a market research exercise. They were asked to select one of several popular current affairs and sports magazines and to read it for 15 min. When they had finished reading, they gave their opinion about the magazine via a short questionnaire.

2.3.2. Complex operation-word span task (WM task)

We used a complex WM task because they elicit both physiological (Gianaros, van der Veen, & Jennings, 2004) and psychological stress states (Matthews et al., 2002). Participants were asked to look at series of five items displayed on a screen. Each item consisted of a simple arithmetic equation, such as "(6/2) + 5 = 8?", and a recall word. Participants had to check a box printed on a sheet of paper if the equation was correct and to leave the box blank if the equation was incorrect. A recall word was shown above each calculation. At the end of every series of five items, participants were asked to write, in order of appearance, the words presented with each calculation. We allocated 15 s to this part of the task. The task consisted of sixteen blocks of five arithmetic equations and five neutral, concrete words (Syssau & Font, 2005). Participants had to recall the five words for each block. We paired our sixteen blocks of five words according to their mean number of letters (M = 6.35, SD = 0.36) and their mean frequency of use in everyday language (M = 18.53, SD = 3.25). Time pressure was imposed by reducing the amount of time available for studying each equation from six seconds for each problem in the first block to three seconds for each equation in the final block.

2.3.3. Vigilance task

We used the "moving bar" test from version 2.3 of the Test of Attentional Performance (Zimmerman & Fimm, 2002). In this test, a light-colored strip moves up and down the center of the screen. The deflection of the vertical movements from the center varies. Participants were told to detect and press the response button when the upward deflection was much larger (target). The task involved 2800 trials with 36 targets and lasted 30 min.

2.4. Procedure

Participants were tested individually in a quiet room in our laboratory. They were asked to complete the pre-task versions of the SSSQ and 65-item MCQ, and then to do their allotted task, after which they completed the post-task versions of the SSSQ.

2.5. Statistical analyses

Before testing our main hypotheses, we first estimated the reliability of the French SSSQ measures using Cronbach's α and we reported satisfactory reliability (Table 2). Second, we used the *lm* function in R (R Core Team, 2013) to estimate differences between experimental groups at

Table 1
Factor structure of the pre and post task forms of the French SSSQ. Items were associated with Distress, Task engagement, and Worry in the first row according to results reported by Helton (2004).

	Factor 1		Factor 2		Factor 3	
	Pre-task	Post-Task	Pre-task	Post-task	Pre-task	Post-task
Distress						
Item 1	0.68	0.46	− 0.01	0.15	0.03	0.14
Item 3	0.75	0.57	− 0.05	− 0.10	0.03	0.32
Item 4	0.75	0.43	− 0.02	− 0.06	0.03	0.41
Item 7	0.55	0.38	− 0.16	− 0.27	−0.06	0.30
Item 8	0.75	0.84	0.14	0.06	− 0.11	− 0.01
Item 9	0.77	0.89	0.07	0.03	− 0.01	− 0.09
Item 10	0.63	0.83	− 0.02	− 0.05	0.05	− 0.03
Task engagement						
Item 5	−0.31	0.03	0.47	0.58	−0.06	−0.06
Item 11	0.09	0.07	0.72	0.87	0.05	0.02
Item 12	0.11	0.01	0.78	0.85	0.16	0.04
Item 13	−0.14	−0.12	0.73	0.81	0.03	−0.03
Item 17	−0.15	−0.21	0.43	0.41	−0.24	−0.02
Item 21	0.05	0.20	0.69	0.58	−0.19	0.08
Worry						
Item 19	−0.03	−0.07	0.02	0.02	0.86	0.87
Item 20	−0.01	−0.01	0.07	0.01	0.84	0.87
Item 23	−0.08	−0.17	−0.10	−0.04	0.47	0.65
Item 24	0.07	0.20	−0.07	0.10	0.67	0.69
Eigenvalue	3.59	3.28	2.61	3.09	2.27	2.93
Variance explained %	21	19	15	18	13	17
Cronbach α	0.83	0.81	0.72	0.78	0.70	0.80

Table 2
Means (M), Standard Deviations (SD), and internal consistency measures for the French Short Stress States Questionnaire measures.

	Distress				Task engagement				Worry			
	Pre-task		Post-task		Pre-task		Post-task		Pre-task		Post-task	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Magazine reading task	9.95	3.47	9.68	2.92	20.83	3.60	19.07	4.46	8.82	3.78	6.5	3.16
Vigilance task	10.46	3.95	15.57	5.93	20.57	3.75	19.02	5.08	8.89	3.29	7.03	3.15
Working memory task	10.33	4.64	14.08	5.78	18.84	4.7	20.19	4.9	9.07	3.56	7.10	3.22
Cronbach's α value	0.83		0.81		0.71		0.77		0.70		0.72	

baseline with respect to their subjective stress state measures (see Table 2). For this purpose, we modeled the "Task" factor as two dummies−with Magazine task as the reference level (Magazine task = 0; Vigilance task = 1; WM task = 2). We did not find any significant effects of the "Task" factor on either Distress ($F(2.207) = 0.30$; $p = 0.74$) or Worry ($F(2.207) = 0.09$; $p = 0.91$). However, the "Task" factor affected Task Engagement ($F(2.207) = 4.99$; $p = 0.007$), as there was a significant difference between the Task Engagement scores for the Magazine task and the WM task ($B = -1.98$; $p = 0.004$). The difference between the Task Engagement scores for the Magazine task and the Vigilance task was not significant ($B = -0.25$; $p = 0.71$).

We used the *lmer* function in the *lme4* package in *R* (Bates, Maechler, Bolker, & Walker, 2013) and the Maximum Likelihood method to assess how well the data fit the mixed-effects model M_{ij}. Mixed-effects models are well suited to analyzing longitudinal data. Our preliminary analyses revealed that the intercepts (i.e., means) for Task Engagement differed between subjects. Furthermore, the measures for each participant are interdependent (i.e., repeated measures). Consequently, we adjusted estimates of model parameters for "subjects" (van Montfort, Johan, & Ghidey, 2014) by estimating between-subjects variance in the mean of the dependent variable. We computed the amount of variance between the levels of the factor included in the random part of the model by adding random effect to the intercept. The intercept, the subsequent covariates, and their interactions were modeled using fixed effects parameters: "Time" was modeled as a dummy, with SSSQ pre-task measures as the reference level (pre-task measures = 0; post-task measures = 1); "Task" was modeled as two dummies – with the "magazine task" as the reference level.

We tested a series of models including Distress (M_{iD}), Worry (M_{iW}), or Task Engagement (M_{iTE}) scores as the dependent variable. The first series of mixed-effects models (M_{1j}) incorporated the intercept, the dummy modeling the "Time" factor, the dummy modeling the "Task" factor, the "Time" ∗ "Task" interaction term, and the random effect for "Subject". Our objective was to assess the contribution of the "Time" ∗ "Task" interaction to the overall regression, over and above the individual first-order effects of "Time" and "Task" (Cohen, Cohen, West, & Aiken, 2003). We compared this first series of models with a second series (M_{2j}) that incorporated metacognitive beliefs as covariates. Because of the intercorrelations between MCQ subscales (Larøi et al., 2009) and the risk of colinearity when all these subscales are included as explanatory variables in the same model, we used the *leaps* package in *R* (Lumley & Miller, 2015) to select which of the five metacognitive beliefs had to be added to our regression models as explanatory variables. In order to determine the specific subsets of metacognitive beliefs to include in M_{2D}, M_{2W}, and M_{2TE}, we used a stepwise forward selection to search models that best adjusted the data and lying in the range between M_{1j} and models including all five metacognitive measures. The quality of our models fit was estimated using the Akaike's information criterion (AIC). AIC takes into account the number of regression coefficients being tested and penalizes the less parsimonious model. The significance of the improvement in the quality of our models fit was estimated using the distributed chi-squared likelihood-ratio test (L.Ratio). The significance was set at $p \leq 0.05$. The fit of the M_{1D} model (AIC = 2458.9) was improved by including MCQ2 (AIC = 2439.3; L-Ratio = 21.61; $p < 0.001$) in M_{2D}. The fit of the M_{1TE} model (AIC = 2420.1) was improved by including MCQ4 (AIC = 2414.4; L-Ratio = 7.65; $p = 0.006$) and MCQ3 (AIC = 2409.3; L-Ratio = 7.10; $p = 0.007$) in M_{2TE}. Finally, the fit of the M_{1W} model (AIC = 2152.4) was improved by including MCQ1- (AIC = 2123.7; L-Ratio = 30.77; $p < 0.001$) and MCQ2 (AIC = 2116; L-Ratio = 9.64; $p = 0.002$) in M_{2W}. These metacognitive beliefs were included in our second series of models which were compared with a third series (M_{3D}, M_{3W}, and M_{3TE}) in which we added the "*Metacognitive Beliefs*" ∗ *dummies modeling the* "*Task*" factor interaction terms. Finally, we compared this third series of models with a fourth series (M_{4j}) in which we added the "*Metacognitive Beliefs*" ∗ *dummies modeling the* "*Task*" ∗ *dummy modeling the* "*time*" factor interaction terms We compared p value obtained in models the best-adjusted with adjusted p values (Holm-Bonferroni stepwise method). This method enables us to counteract the problem of multiple testing and to control the *Family Wise Error Rate* (FWER). Unadjusted p values must be less than their related adjusted p values to be significant.

3. Results

3.1. Models including distress as the dependent variable (M_{iD})

Results from M_{1D} showed that the dummy coding for the covariate Time was not significant ($B = -0.26$; $p = 0.68$). Distress scores for the Vigilance ($B = 0.51$; $p = 0.50$) and WM ($B = 0.38$; $p = 0.62$) tasks did not differ significantly from the Distress scores for the Magazine task. The Time ∗ Task interaction showed that Distress scores increased with time as participants completed the Vigilance ($B = 5.37$; $p < 0.001$) and WM ($B = 4.74$; $p < 0.001$) tasks. Comparing M_{1D} (AIC = 2458.9) and $M2_D$ (AIC = 2439.3) revealed a significant effect of MCQ2 ($B = 0.13$; $p < 0.001$) on Distress, and comparing M_{2D} and M_{3D} (AIC = 2431.9) showed that M_{3D} best fit the data. The effect of the WM task on Distress increased as MCQ2 scores increased ($B = 0.21$; $p = 0.001$). However, in $M3_D$ the main effect of MCQ2 on distress was no longer significant. Our results revealed that the fit between our model (M_{4D}) and the data was altered by including the three-way interaction *metacognition* ∗ *time* ∗ *task* term (AIC = 2436.8). Therefore, we discarded M_{4D}.

3.2. Models including task engagement as the dependent variable (M_{iTE})

Results from M_{1TE} showed that the dummy coding for the covariate Time was significant ($B = -1.76$; $p = 0.003$). Task Engagement scores for the Vigilance and Magazine tasks did not differ significantly ($B = -0.25$; $p = 0.73$), but the difference between the Task Engagement scores for the Magazine task and the WM task was significant ($B = -1.98$; $p = 0.01$). The Time ∗ Task interaction showed that Task Engagement scores increased with time as participants carried out the WM task ($B = 3.10$; $p < 0.001$), but the interaction term was not significant for the Vigilance task ($B = 0.21$; $p = 0.80$). Comparing M_{1TE} (AIC = 2420.1) and M_{2TE} (AIC = 2409.3) revealed significant effects of MCQ3 ($B = -0.11$; $p < 0.008$) and MCQ4 ($B = 0.12$; p b 0.006) on Task Engagement, and comparing M_{2TE} and M_{3TE} (AIC = 2415.1) showed that the fit between the model and the data was altered by including the MCQ3 ∗ Vigilance task ($B = -0.10$; $p = 0.32$), MCQ3 ∗ WM task ($B = -0.15$; $p = 0.19$), MCQ4 ∗ Vigilance task ($B = 0.10$; $p = 0.41$), and MCQ4 ∗ WM task ($B = 0.07$; $p = 0.49$) interaction terms. Our results revealed that the fit between our model (M_{4TE}) and the data was altered by including the three-way interaction *metacognition ∗ time ∗ task* term (AIC = 2416.8). Therefore, we discarded M_{3TE} and M_{4TE}.

3.3. Models including worry as the dependent variable (Mi_W)

Results from M_{1W} revealed that the dummy coding for the covariate "Time" was significant ($B = -2.32$; $p < 0.001$). Worry scores for the Vigilance ($B = 0.06$; $p = 0.91$) and WM ($B = 0.25$; $p = 0.66$) tasks did not differ significantly from those for the Magazine task. The Time ∗ Task interaction was not significant for either the Vigilance task ($B = 0.46$; $p = 0.40$) or the WM task ($B = 0.34$; $p = 0.52$). Comparing M_{1W} (AIC = 2152.4) and M_{2W} (AIC = 2116.0) revealed significant effects of MCQ1 ($B = 0.10$; $p < 0.001$) and MCQ2 ($B = 0.07$; $p = 0.02$) on Worry, and comparing M_{2W} and M_{3W} (AIC = 2120.4) showed that the fit between the model and the data was altered by including the MCQ1 ∗ Vigilance task ($B = -0.05$; $p = 0.34$), MCQ1 ∗ WM task ($B = -0.04$; $p = 0.49$), MCQ2 ∗ Vigilance task ($B = 0.06$; $p = 0.31$), and MCQ2 ∗ WM task ($B = -0.03$; $p = 0.62$) interaction terms. Our results revealed that the fit between our model (M_{4W}) and the data was altered by including the three-way interaction *metacognition ∗ time ∗ task* term (AIC = 2122.0). Therefore, we discarded M_{3W} and M_{4W}.

Statistical estimates of the models that produced the best fits are shown in Table 3. We reported significant effects of Vigilance task ∗ Time, WM task ∗ Time and MCQ2 ∗ WM task interactions on Distress. Task engagement was significantly predicted by the time factor, the WM task, the WM task ∗ time interaction, MCQ3 and MCQ4. We reported significant effects the time factor, MCQ1 and MCQ2 on Worry. Finally, the comparison of adjusted (Holm-Bonferroni method) and unadjusted p values confirmed that all unadjusted p values b 0.05 were significant.

4. Discussion

Since Matthews et al. (1999) defined and proposed a model of subjective stress states, a number of studies have shown that subjective stress states are sensitive to environmental demands (Helton, 2004; Matthews et al., 1999; Matthews et al., 2002; Matthews et al., 2010; Matthews, Szalma, Panganiban, Neubauer, & Warm, 2013) and related to metacognitive beliefs (e.g., Matthews et al., 1999). Although stress states were hypothesized to result from the interplay between low-level (environmental demands) and high-level (metacognition) units of the S-REF cognitive architecture (Wells & Matthews, 1994, 1996), prior to our study there were no experimental results supporting this hypothesis. Our research addressed this issue and we provided insight into when environmental demands, metacognitive beliefs, and the interplay between these two factors contribute to changes in subjective stress states.

Worry increased for participants who tended to believe that worrying is uncontrollable, dangerous (MCQ2), and helps one to solve problems (MCQ1), more Worry declined for all our participants (Model M_{2w}), as predicted by the hypothesis that experimental tasks are not appraised as threatening the self (Matthews et al., 2002). Our results support the premise that Worry is mostly explained by a specific metacognitive profile comprising positive metacognitive beliefs about using worry as an efficient style of coping and negative metacognitive beliefs concerning the uncontrollability and danger of worrying (Matthews et al., 1999; Wells, 2007; Wells & Matthews, 2015). Finally, the effect of the Environmental Demands ∗ Metacognition interaction term on stress states was not significant, which is in line with the idea that cognitive intrusions related to Worry are "(…) an epiphenomenon of parallel processing at the lower level, and (…) a result of facilitation of lower-level activation by top-down influences" (Wells & Matthews, 1994).

We reported a main negative effect of the WM task and the Time factor on Task Engagement, but the WM task factor positively moderated this effect. In other words, monotonous tasks (e.g., vigilance tasks) produce task disengagement but tasks that challenge processing

Table 3

Parameters values from the mixed-effects models that best adjusted the data for Distress (M_{3D}), Task Engagement (M_{2TE}) and Worry (M_{2W}). Adjusted p values were obtained using Holm-Bonferroni method.

	Fixed effects					Random effect (intercept)	
	B	SE	CR	p value	Adjusted p value	Variance	SD
Distress - M_{3D}	-	-	-	-		3.89	1.97
Time	− 0.26	0.63	− 0.41	0.68	0.05	-	-
Vigilance task	0.51	0.72	0.72	0.47	0.01	-	-
WM task	0.38	0.72	0.53	0.60	0.016	-	-
Vigilance task ∗ Time	5.37	0.90	5.97	b 0.001	0.006	-	-
WM task ∗ Time	4.74	0.90	5.28	b0.001	0.007	-	-
MCQ2	0.03	0.04	0.60	0.55	0.012	-	-
MCQ2 ∗ Vigilance task	0.03	0.06	0.51	0.61	0.025	-	-
MCQ2 ∗ WM task	0.19	0.06	3.02	0.001	0.008	-	-
Task Engagement - M_{2TE}	-	-	-	-		6.79	2.61
Time	− 1.75	0.58	− 3.03	0.003	0.01	-	-
Vigilance task	− 0.25	− 0.25	− 0.35	0.73	0.025	-	-
WM task	− 1.98	0.73	− 2.72	0.007	0.012	-	-
Vigilance task ∗ Time	0.21	0.82	0.25	0.80	0.05	-	-
WM task ∗ Time	3.10	0.82	3.78	b0.001	0.007	-	-
MCQ3	− 0.11	0.04	− 2.69	0.008	0.02	-	-
MCQ4	0.15	0.04	3.35	b0.001	0.008	-	-
Worry - M_{2W}	-	-	-	-		4.41	2.10
Time	− 2.32	0.39	− 5.98	b0.001	0.007	-	-
Vigilance task	0.06	0.53	0.12	0.90	0.05	-	-
WM task	0.25	0.53	0.48	0.63	0.025	-	-
Vigilance task ∗ Time	0.46	0.54	0.84	0.40	0.012	-	-
WM task ∗ Time	0.34	0.54	0.64	0.52	0.016	-	-
MCQ1	0.10	0.02	4.66	b0.001	0.008	-	-
MCQ2	0.07	0.02	3.14	0.002	0.01	-	-

Note: B = unstandardized regression coefficient, SE = standard errors, CR = critical ratios, SD = Standard Deviation, WM = working memory, MCQ1 = positive beliefs about worry, MCQ2 = negative beliefs about the uncontrollability of thoughts and corresponding danger, MCQ3 = cognitive confidence, MCQ4 = negative beliefs about thoughts in general -SPR.

capabilities and require sustained effort (WM tasks) favor increased Task Engagement (Matthews et al., 2002). Although metacognitive beliefs are posited as key determinants of subjective stress states (see Wells & Matthews, 1994, 1996), previous studies have not used multivariate modeling methods to analyze the effect of metacognitive beliefs on Task Engagement. Our study (model M_{2TE}) furthers research by showing that lack of confidence in one's memory and concentration capacities (i.e., cognitive confidence) and negative beliefs about the need to control thoughts and the harmful consequences of not controlling them (i.e., SPR) are negatively and positively related to Task Engagement, respectively. Previous research has demonstrated the positive correlation between SPR and measures of proneness to anxiety, but not the significant correlation between SPR and the tendency to focus on one's thoughts and feelings (Cartwright-Hatton & Wells, 1997). Most of the items in our French version of the Task Engagement scale relate to confidence in one's abilities, wish to succeed, and expectations of performing proficiently on the task at hand. Consequently, in laboratory settings, SPR is likely to promote a style of thinking that enables subjects to cope with environmental demands by remaining focused on their objective. Conversely, a lack of confidence in one's cognitive abilities is likely to result in an individual evaluating the task as exceeding his or her resources and thereby promote task disengagement.

As expected (Matthews et al., 2002), both the WM and Vigilance tasks induced a significant increase in Distress compared with the Magazine task. Hence, the most demanding tasks, which overloaded the participants' cognitive capacities, elicited affective changes in the form of Distress (Matthews et al., 2002). The MCQ2 metacognitive factor (proneness to have negative beliefs about the uncontrollability of thoughts) did not significantly predict Distress, but the effect of the "Task" factor ∗ MCQ2 interaction term on distress was significant. Our study furthers research by showing that previously published correlations between metacognitive beliefs and Distress (Matthews et al., 1999) may not be robust: Distress may not be directly related to MCQ2-related metacognitive beliefs, but such beliefs may amplify the effect of environmental demands on Distress. Spada, Mohiyeddini and Wells (2008) reported that individuals who believe that worrying is uncontrollable (MCQ2) tend to engage in threat monitoring, a maladaptive coping strategy. They postulated that such strategies promote the monitoring of threat concepts and lead individuals to overestimate environmental challenges. The originality of our research was to provide empirical support for this hypothesis by showing that Distress is impacted by environmental demands and by the interplay between these demands and specific metacognitive beliefs.

In conclusion, our research showed that the contribution of between-individual differences in metacognitive beliefs to increases in subjective stress states varies according to the type of task being undertaken and the form of the stress state. The Worry syndrome is unaffected by environmental demands, as it is mainly the result of personal factors such as the tendency to believe that worrying is both dangerous and helps to solve problems. The Task Engagement syndrome is explained by both environmental demands and metacognitive beliefs. SPR and cognitive confidence have opposite effects on motivation and willingness to succeed, but levels of Task Engagement increase when a task exceeds processing capabilities and requires sustained effort. Distress was the only stress-state syndrome to be affected by the dynamic interaction between environmental and personal factors. Although cognitively demanding tasks increased the level of Distress for all our participants, the deleterious effect of demanding tasks on Distress increased as participants' negative beliefs about the uncontrollability of thoughts increased.

These results shed new light on some previous results. In a study by Helton, Shaw, Warm, Matthews, and Hancock (2008), switching the workload parameter of a vigil task to either higher or lower did not alter the levels of Distress reported by participants. Several studies have reported similar results, leading to the hypothesis that Distress reflects appraisal of a task as inducing low controllability and threat, rather than reflecting the absolute workload imposed by the task (Matthews et al., 2013). Our results suggest an additional hypothesis, as the effect on Distress caused by varying the workload parameter, as in the study by Helton et al. (2008), may be moderated by participants' metacognitive beliefs.

The present research has a number of limitations. First, the psychometric properties of the French SSSQ were tested in an exploratory research (unpublished study), and results revealed a need to rewrite some items that were removed from the actual version of the questionnaire. Further studies are needed to address this issue and to perform a Confirmatory Factor Analysis. Our investigation of the effect of environmental demands and metacognitive beliefs on stress states was carried out in a laboratory setting. In order to determine the external validity of our results, further studies are needed in order to assess how well the model fits data obtained in more natural contexts, such as work settings. In addition, the effect of the interaction *metacognition ∗ task* was only significant for MCQ2 predicting distress. This lack of significance for most of our *metacognition ∗ task* interaction effects may be explained by the nature of the tasks employed in this research. Matthews et al. (2002) have previously outlined that experimental tasks are not appraised as threatening the self. Therefore we can assume that metacognition would as much moderate the effect of environmental demands on subjective stress as participants are asked to complete tasks that trigger threats. Future studies should address this issue using experimental settings that trigger perceptions of threat (e.g., *Trier Social Stress Test* developed by Kirschbaum, Pirke, & Hellhammer, 1993). The multiple regression analyses carried out by Fairclough and Venables (2006) showed that psychophysiological measures of stress explain a substantial portion of the variance for both Task Engagement and Distress. These findings and our results would indicate that subjective stress states are complex phenomena involving the interplay between metacognitive beliefs, environmental demands, and physiological outcomes (Wells & Matthews, 1994, 1996). To the best of our knowledge, this set of variables and their interaction terms have never been included in mixed effects models of subjective stress states. Such analyses could be used to test the hypothesis that each subjective stress state is the result of a specific subset of environmental, physiological, and metacognitive factors.

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