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Mental fatigue influence on effort-related cardiovascular response: difficulty effects and extension across cognitive performance domains

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Abstract Two experiments investigated cardiovascular effects of mental fatigue as a function of (1) the difficulty of the cognitive challenge with which participants were confronted, and (2) the relevance of that challenge to the activity that instigated the fatigue. In the first, participants performed an easy (fatigue low) or difficult (fatigue high) counting task and then were presented an arithmetic challenge (task B relevance high) or a scanning challenge (task B relevance low) with instructions that they would avoid a noise if they attained a modest performance standard. Analysis of blood pressure responses assessed during the work periods revealed fatigue main effects, reflecting stronger responses for High Fatigue participants, regardless of the character of the second task. In the second, the procedure was the same except that it included a high performance standard and provided the chance to win a prize. Analysis of the pressure data revealed fatigue x work period interactions, reflecting relatively stronger responses among High Fatigue participants in work period 1, but relatively weaker responses among these participants in work period 2. Results confirm previous findings and support an analysis of fatigue influence on effort and associated cardiovascular responses. They also argue against the idea that mental fatigue influence may be confined to relevant cognitive performance realms.

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Introduction

Ask a person on the street who will try harder and be more motivationally aroused when presented a task, a man who is rested or one who is weary, and you are almost certain to hear "rested" in reply. The likely reply makes sense intuitively because weariness, or fatigue, tends to be associated with reduced energy and a sense of increased task difficulty. Nonetheless, there is reason to believe the reply may be incorrect, at least when motivational arousal is assessed in terms of cardiovascular (CV) activation (Brener 1987; Elliott 1969). More specifically, there is reason to believe that fatigue may reduce, promote, or have no impact on effort and associated CV responses, depending on the conditions under which tasks are confronted.

The interaction perspective above is suggested by an analysis of effort, ability, and CV response that has guided work in our laboratory for many years (Gendolla and Wright 2005; Wright and Kirby 2001). Core propositions are: (1) sympathetic nervous system influence on the heart and vasculature varies with momentary effort, or engagement (Light 1981; Obrist 1981); (2) effort expended to meet a performance challenge corresponds to the difficulty of that challenge so long as success is viewed as possible and worthwhile, and is low irrespective of challenge difficulty when success is viewed as impossible or excessively difficult, given the incentive (Brehm and Self 1989); and (3) people with low perceived ability with respect to a performance challenge will view the challenge as more difficult than will people with high perceived ability with respect to the challenge (e.g., Kukla 1972). An implication is that people low in perceived ability should expend more effort and display greater CV responsiveness in attempting to meet a challenge than people high in perceived ability so long as both groups view success as possible and worthwhile. A further implication is that low ability people should withhold effort at a lower level of challenge difficulty than should high ability people, because low ability people should conclude at a lower difficulty level that success is impossible or too costly. This means that when difficulty is high, people who view themselves as less capable should sometimes try less and be less CV responsive than people who view themselves as more capable. Even high ability people should withhold effort if difficulty is great enough. When they do, CV responses should be low for them as well as for low ability people.

The preceding analysis has been brought to bear with respect to the fatigue issue by way of the assumption that ability perception will be diminished to the degree that energy stores are depleted (Scherer 1984). This suggests that fatigue influence on effort and CV response should be determined by the difficulty of a performance challenge in combination with the importance of meeting it. When fatigue causes success to appear impossible or excessively difficult, it should militate against effort and CV responsiveness. That is, it should lead people to withhold effort and display minimal arousal as a result. By contrast, when fatigue leaves unaltered a perception that success is possible and worthwhile, it should potentiate effort and CV responsiveness. That is, it should lead people to exert compensatory effort and experience heightened arousal as a result. Finally, when fatigue leaves unaltered a perception that success is impossible or excessively difficult, it should have no impact on effort and CV responsiveness. That is, it should leave unchanged people's disposition to exert low effort and experience minimal arousal as a result.

Evidence

Evidence for the interaction view of fatigue influence comes from numerous sources (Clements and Turpin 1995; Gendolla and Krüsken 2001; Wright and Dismukes 1995). However, the most compelling comes from studies that have manipulated fatigue and examined its CV influence under conditions that should, in theory, be conducive to different fatigue outcomes. An example is a study that used a gripping task to examine the hypothesis that CV responses should be proportional to fatigue when success is viewed as possible and worthwhile (Wright and Penacerrada 2002). The study also explored the idea that motor fatigue effects should tend to be challenge specific, i.e., confined to related performance systems. Female participants initially performed left or right handedly a series of easy (low fatigue) or difficult (high fatigue) dynamometer grips. They then made and held with their right hand a modest grip while CV measures were taken. Systolic blood pressure (SBP) responses fit the expected effort pattern. Whereas they were stronger under high fatigue conditions among participants who gripped initially with their right hand, they were unrelated to fatigue among participants who gripped initially with their left hand.

A follow-up study (Wright et al. 2003) partially replicated the gripping study's CV findings using a mental task, and extended the findings by examining fatigue effects at low and moderately high levels of challenge difficulty. In it, female participants performed an easy (fatigue low) or hard (fatigue high) counting task and then were presented arithmetic problems with instructions that they could earn a prize by attaining a low or high performance standard. Analysis of data collected during the arithmetic period indicated fatigue × difficulty interactions for SBP, diastolic blood pressure (DBP), and mean arterial pressure (MAP, average pressure over a heart cycle). As anticipated, responses were stronger for Low Fatigue participants when the standard was high, but stronger for High Fatigue participants when it was low, forming a crossover pattern.

Present research

Broad purposes of the present research were to (1) replicate the mental fatigue effects from the immediately preceding study, and (2) extend those effects by obtaining evidence relevant to the possibility that mental fatigue effects may be performance domain specific in the same way that some physical fatigue effects appear to be. Regarding the latter purpose, it could be that resource depletion in one mental performance system (e.g., that involved in counting) tends to affect the perceived ability to perform tasks highly related to that system (e.g., balancing a checkbook), but not the perceived ability to perform tasks weakly related to the system (e.g., learning lines for a play). If this is true, then one would expect a fatigue manipulation involving the system to generate predictable CV effects in people presented highly relevant cognitive challenges, but not in people presented mildly relevant ones. On the other hand, if it is not true, one would expect the fatigue manipulation to produce comparable effects regardless of the challenge presented.

Our first experiment aimed specifically to replicate CV effects observed previously under low performance standard conditions and determine if the effects extend to one type of non-quantitative task, scanning. It also aimed to document that low standard mental fatigue effects are not confined to appetitive performance contexts. The study required female participants to perform initially an easy (fatigue low) or hard (fatigue high) counting task and then presented them either an arithmetic challenge (task B relevance high) or a scanning challenge (task B relevance low) with instructions that they would avoid a noise if they attained a modest performance standard. Our second experiment aimed to replicate effects observed under high performance standard conditions and provide further data relevant to the extension question. It involved a similar procedure, but set a high (rather than a modest) performance standard. The study also used an attractive incentive and male participants to confirm that the original fatigue findings (obtained in the context of an appetitive protocol) were not specific to women.

CV measures were SBP, DBP, MAP, and heart rate (HR). Evidence that SBP is especially sensitive to sympathetic activation (Brownley et al. 2000) led us to believe it would be especially likely to reflect fatigue influence. However, because numerous effort studies have yielded effects for the other CV parameters (Brinkmann and Gendolla 2007; Brown et al. 1998; Gendolla and Richter 2005, 2006a, b; Hilmert et al. 2002; Smith et al. 1990; Wright and Lockard 2006), we did not preclude the possibility that fatigue effects would be manifested in terms of them.

Experiment 1

Method

Overview and predictions

Participants performed for 5 min an easy (fatigue low) or difficult (fatigue high) counting task. Awhile later, they were presented an arithmetic challenge (task B relevance high) or a scanning challenge (task B relevance low) with instructions that they would avoid a noise if they attained a moderate (50th percentile) performance standard. We had two primary expectations. First, we expected that effort-related CV responses would be stronger among High Fatigue participants during the first work period. Second, we expected that effort-related responses would be stronger for High Fatigue participants during the second work period when the second challenge was relevant to the fatigue manipulation, and possibly when the second challenge was not, depending on the extent to which CV fatigue influence extends across these performance domains. Our second expectation was predicated on the assumption that success at the 50th percentile difficulty level would appear possible and worthwhile to both fatigue groups.

Participants and measurement of cardiovascular responses

Participants were 92 female undergraduate volunteers, predominantly of European and African heritage. No attempt was made to control for menstrual cycle phase; instead, cycle phase was assumed to be randomly distributed across conditions. Participants were assigned randomly to one of four conditions in a 2 (fatigue: low, high) × 2 (task B relevance: low, high) factorial design. CV assessments were made with a Dinamap Vital Signs monitor (PRO 100). This device estimates SBP, DBP, and MAP using the oscillometric method and computes HR by tabulating oscillations in its occluding cuff.

Procedure

Participants were met by a female experimenter who seated them at a table on which was an intercom with a CALL button and an informed consent agreement. After providing a study overview, the experimenter left the room so participants could read and sign the consent form.

Baseline Measures. Once participants signed the form, the experimenter returned, attached the Dinamap cuff to the participants = non-dominant arm, and began the baseline period. During this period, participants leafed through magazines while CV measures were taken at 2-min intervals, with sampling starting at the end of the 1st, 3rd, 5th, and 7th minutes. Baseline for each CV parameter was taken as the mean of the final two readings for the parameter. The experimenter was blind to condition at this and all other stages of the procedure.

Following baseline, the experimenter returned to the work chamber. She placed in a corner of the table three envelopes—marked "Task A," "Task B," and "Questionnaire"—and in front of participants a baseline "feeling" questionnaire. The experimenter asked participants to complete the questionnaire and then press the intercom CALL button. On the questionnaire, participants indicated on 11-point scales how happy, angry, energetic, fearful, anxious, mentally sharp, physically tired, and mentally tired they felt (0 = not at all, 10 = extremely). Once participants had done so, they pressed CALL and were directed to open the Task A envelope and follow the instructions inside.

Work Period 1: Fatigue Induction. Task A instructions for Low Fatigue participants indicated that the first task would be to count forward by ones until there was a directive to stop. These participants were told that on the following page they would find lists of blank spaces. In the upper left-hand corner of the page was the number "375." On receiving a signal to begin, participants were to count forward from that number in increments of one. Instructions emphasized that it was important for everyone to count at the same pace. Therefore, the experimenter would set the counting pace by calling out over speakers the word "count" every 3 s. Each time participants heard "count," they were to count forward by one and write the new, computed, number down. Task A instructions for High

Fatigue participants were identical except they directed participants to count backward in increments of three.

Participants pressed CALL when they were ready. This signal prompted the experimenter to play an audiotape of a woman's voice calling out the word "count" at 3-s intervals for 5 min. The experimenter took two CV samples, one after 2 min and one after 4 min. When the period was over, the experimenter turned off the tape and told participants to open the Task B envelope and follow instructions inside.

Work Period 2: Fatigue Influence. For half of the participants (task B relevance high), Task B was a mental arithmetic task involving single-digit multiplication. On four sheets of paper were 254 problems, each followed by a space in which an answer could be provided. Participants were directed to solve as many problems as possible in 3 min, and informed they would avoid a 1-min noise blast at the end of the session if they exceeded the 50th percentile of scores obtained by students who participated in an earlier study version. Instructions indicated that problems could be solved in any order and performance would be measured in terms of the number of correct responses. For the remaining participants (task B relevance low), Task B was a scanning task that involved circling H's on pages filled with jumbled letters. These participants were provided four pages containing 13 × 30 letter matrices. They were directed to circle as many Hs as they could in 3 min and told they would avoid the noise blast if they exceeded the 50th percentile standard. As in the other relevance condition, instructions indicated that responses could be provided in any order and performance would be measured in terms of correct responses.

Once again, participants pressed CALL when they were ready, at which point the experimenter directed them to open the Questionnaire envelope and complete the questionnaire inside. The questionnaire asked participants to rate (1) the difficulty of the first task (0 = not at all, 10 = extremely), (2) how difficult it should be for them to attain the performance standard assigned for task B (0 = not at all; 10 = extremely), and (3) how much effort should be required to attain this standard (0 = very little; 10 = very much). The questionnaire also asked participants to rate on 11-point scales (0 = not at all, 10 = extremely) their current feelings of happiness, anger, energy, fear, anxiousness, mental sharpness, physical tiredness, and mental tiredness.[1] Participants pressed CALL when they were finished. Upon receiving this signal, the experimenter told participants to begin work. As she did during the initial (counting) work period, the experimenter took two CV samples, this time after 30- and then 90 s. When the period ended, the experimenter returned to the chamber for the debriefing. Participants avoided noise regardless of their performance and were given a research credit prior to being dismissed.

Results

Baseline analyses

Mean baseline CV values are in Table 1. Two (fatigue) × 2 (task B relevance) analyses of variance (ANOVAs) on the baseline data yielded only a marginal task B relevance effect for SBP, $F\ (1,\ 90) = 3.19$, $P = .08$. The marginal effect reflected a tendency for resting SBP values to be greater under high- than low task B relevance conditions.

Work period responses

CV response during the work periods was operationalized as change from baseline (Llabre et al. 1991). Two sets of change scores were computed by subtracting base values from the mean of values obtained in each work period. The regression of change onto baseline was reliable for the blood pressure measures (Ps < .05) and approached reliability for HR ($P = .12$). Consequently, we analyzed the change data in the context of 2 (fatigue) × 2 (task B relevance) × 2 (work period) ANCOVAs, in which work period was a repeated-measures factor and baseline was the covariate.[2]

Recall that we had two primary expectations. One was that effort-related CV responses would be stronger among High Fatigue participants during the first work period. The other was that effort-related responses would be stronger for High Fatigue participants during the second work period when the second challenge was highly relevant, and possibly when the second challenge was not, depending on the extent to which CV fatigue influence extends. Thus, we expected either (1) a three way interaction, reflecting a fatigue effect during work period 1 and a fatigue × task B relevance effect during work period 2, or (2) a fatigue effect, reflecting higher values for High Fatigue participants across the periods and regardless of the challenge presented in work period 2. The three-way interaction would indicate domain specificity; the main effect would indicate extension across the domains.

[1] Two additional questions in this experiment and in Experiment 2 asked participants to indicate the degree to which they felt challenged and threatened by task B (Blascovich and Mendes 2000; Blascovich et al. 2000; Blascovich and Tomaka 1996). Analysis showed no consistent relationships between the challenge and threat ratings, on the one hand, and CV responses, on the other. Therefore, those data will not be discussed in detail here.

[2] As a guard against movement artifact, we omitted in all studies CV change values that deviated by more than two standard deviations from the mean of their experimental group.

Table 1 Experiment 1: baseline blood pressure and heart rate

Fatigue		Low		High	
Task B relevance		Low	High	Low	High
SBP	*M*	106.5	109.8	104.9	109.2
	SE	1.6	2.7	2.1	1.9
DBP	*M*	63.4	64.1	60.4	62.6
	SE	1.7	1.9	1.6	1.3
MAP	*M*	80.5	80.3	77.2	79.3
	SE	1.7	2.3	2.0	1.3
HR	*M*	78.1	81.6	76.4	80.4
	SE	1.9	2.2	2.5	2.5
Cell *N*		23	23	25	23

Note: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure; HR = heart rate; *M* = mean; *SE* = standard error

Table 2 presents covariance-adjusted means obtained for SBP, DBP, and MAP. ANCOVAs produced effects for fatigue and work period. For SBP, *F*s were 4.61 (df = 1, 83; $P = .04$) and 7.15 (df = 1, 84; $P = .009$), respectively. For DBP, they were 5.72 (df = 1, 81; $P = .02$) and 15.97 (df = 1, 82; $P < .001$), respectively. For MAP, they were 7.86 (df = 1, 80; $P = .006$) and 19.16 (df = 1, 81; $P < .001$), respectively. The period effect reflected higher values in the second period. The more important fatigue effect reflected stronger responses for High Fatigue participants, across periods and regardless of the challenge in work period 2. Inspection of SBP values reveals that the fatigue effect for that measure was "carried" by responses in the task B relevance low conditions, especially during the second work period. However, the pertinent (fatigue × task B relevance) interaction only approached significance, $F\ (1,\ 83) = 2.85$, $P = .10$. Follow-up simple comparisons, using pooled error terms, indicated that the fatigue effect was reliable for SBP, $F\ (1,\ 167) = 4.26$, $P = .04$, DBP, $F\ (1, 163) = 4.58$, $P = .03$, and MAP, $F\ (1, 161) = 7.59$, $P = .006$, during work period 1, and reliable for DBP, $F\ (1,\ 163) = 4.01$, $P = .05$, and MAP, $F\ (1, 161) = 4.85$, $P = .03$, during work period 2 (Fig. 1).

ANCOVA on the HR data yielded effects for fatigue, $F\ (1,\ 78) = 4.93$, $P = .03$, and period, $F\ (1,\ 79) = 22.36$,

Table 2 Experiment 1: blood pressure change during work period 1 (fatigue induction phase) and work period 2 (fatigue influence phase)

Fatigue			Low		High	
Task B relevance			Low	High	Low	High
SBP	Period 1	*M*	1.33	2.80	6.77	3.98
		SE	1.9	1.9	1.9	1.8
	Period 2	*M*	3.64	6.35	8.31	6.40
		SE	1.9	1.9	1.9	1.8
	Cell *N*		22	21	23	22
DBP	Period 1	*M*	3.34	3.89	6.33	5.34
		SE	1.3	1.2	1.3	1.2
	Period 2	*M*	5.51	6.18	8.38	7.47
		SE	1.3	1.2	1.3	1.2
	Cell *N*		22	20	23	21
MAP	Period 1	*M*	2.20	3.07	5.05	6.54
		SE	1.6	1.6	1.6	1.5
	Period 2	*M*	5.23	6.14	7.85	9.06
		SE	1.6	1.6	1.6	1.5
	Cell *N*		21	21	23	20

Note: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure; HR = heart rate; *M* = mean; *SE* = standard error

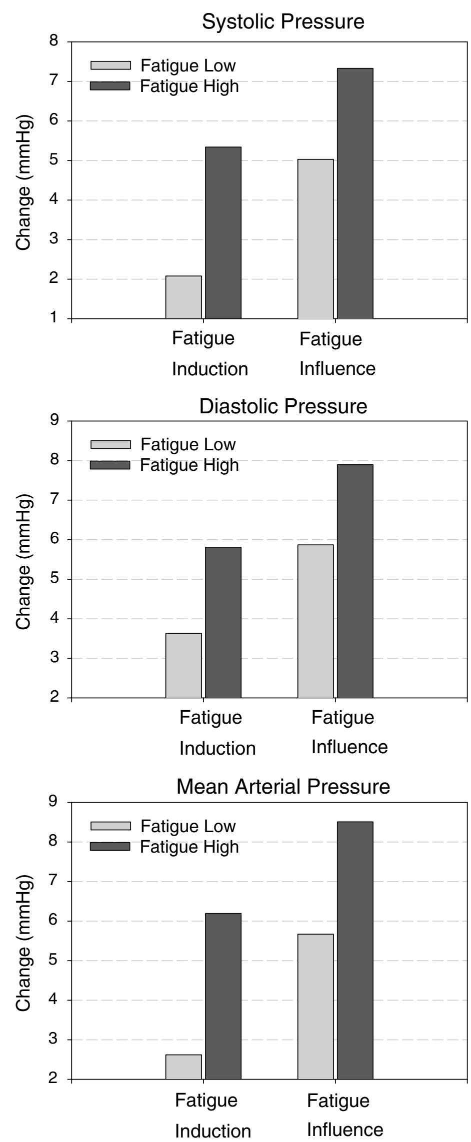

Fig. 1 Experiment 1: Blood pressure responses for Low- and High Fatigue participants during the fatigue induction (first) and fatigue influence (second) work periods

$P < .001$, and a fatigue x period interaction, F (1, 79) = 9.73, $P = .003$. The fatigue and period effects reflected stronger responses overall under high fatigue conditions and during work period 2. Simple effects tests, using a pooled error, revealed two sources for the interaction. One was stronger responses for High Fatigue participants during period 1, F (1, 157) = 13.07, $P < .001$, but not period 2, $F < 1.0$, ns. The other was a rise in responsiveness from the first period to the second among Low Fatigue participants, F (1, 157) = 19.78, $P < .001$, but not High Fatigue participants, $F < 1.0$, ns. Covariance-adjusted HR means for work period 1 were .54 (fatigue-low/task-B-relevance-low), 2.24 (fatigue-low/task-B-relevance-high), 5.33 (fatigue-high/task-B-relevance-low) and 6.74 (fatigue-high/task-B-relevance-high). Those for work period 2 were 5.39 (fatigue-low/task-B-relevance-low), 9.01 (fatigue-low/task-B-relevance-high), 6.61 (fatigue-high/task-B-relevance-low) and 7.84 (fatigue-high/task-B-relevance-high).

Subjective measures

Difficulty and Effort. A 2 (fatigue) × 2 (task B relevance) ANOVA on ratings of the first (counting) task's difficulty produced a fatigue effect, F (1, 90) = 92.91, $P < .001$. As expected, values were higher for High Fatigue participants (task B relevance low $M = 5.48$, task B relevance high $M = 5.20$) than for Low Fatigue participants (task B relevance low $M = 0.52$, task B relevance high $M = 0.83$). Task B difficulty and effort ratings were correlated and patterned similarly across conditions. Therefore, they were averaged to form a task B difficulty index. A two-way ANOVA on the index produced a marginal fatigue effect, F (1, 88) = 2.84, $P = .10$, qualified by a marginal fatigue × task B relevance interaction, F (1, 88) = 2.61, $P = .11$. Consistent with the idea that fatigue increases appraisals of difficulty, values tended to be higher for High Fatigue participants. However, this effect tended to be carried by responses in the low relevance conditions. Pair-wise comparisons indicated that values were higher for High Fatigue participants ($M = 4.76$) than Low Fatigue participants ($M = 3.30$) when task B relevance was low, F (1, 88) = 5.34, $P = .02$, but relatively elevated for both fatigue groups when task B relevance was high (fatigue low $M = 4.25$, fatigue high $M = 4.28$), $F < 1.0$, ns.

Feelings. Two-way ANOVAs on the baseline "feeling" ratings produced only a task B relevance effect for the item "anxious", F (1, 90) = 4.53, $P = .04$. The effect reflected higher ratings when task B relevance was high (fatigue low $M = 5.09$, fatigue high $M = 4.88$) than when it was low (fatigue low $M = 4.00$, fatigue high $M = 3.48$).

Preliminary analyses indicated that work period 2 feeling ratings regressed consistently onto the baseline feeling ratings. Consequently, the period 2 ratings were analyzed with two-way ANCOVAs in which base ratings were covariates. The ANCOVAs yielded effects for the happiness, energy, fear, and mental sharpness. Means are in Table 3. In the case of happiness, there was a fatigue effect, F (1, 89) = 4.92, $P = .03$, reflecting higher values among Low Fatigue participants. In the cases of energy and fear, there were task B relevance effects, Fs (1, 89) ≥ 3.84, $P \le .05$. These were due to higher energy values when relevance was low and higher fear values when relevance was high. In the case of mental sharpness, there was a marginal fatigue effect, F (1, 89) = 3.24, $P = .08$, and a task B relevance effect, F (1, 89) = 11.87, $P < .001$. Values were higher when relevance was low, and tended to be higher when fatigue was low.[3]

Discussion

Findings for blood pressure were relatively straightforward. Analysis indicated stronger responsiveness during work period 2 than during work period 1 and stronger responsiveness for High- than Low Fatigue participants. The fatigue effect for SBP was carried by responses in the low task B relevance conditions; however, the pertinent interaction was not significant. Follow-up tests indicated that the simple fatigue effect was reliable in both work periods for DBP and MAP, and in the first work period for SBP. The effects associated with fatigue comport with those obtained in low standard conditions of the Wright et al. (2003) fatigue study. They also suggest that the CV influence of the counting fatigue manipulation was not domain specific, but rather extended to the low relevance scanning challenge.

Analysis of the HR data revealed effects similar to those for blood pressure, except it showed no fatigue effect during work period 2. The positive fatigue effect during work period 1 provides further evidence that the backwards counting task was more demanding than the forwards counting task. The null fatigue effect in work period 2 does not lend support to our fatigue arguments. However, it

[3] It is difficult to anticipate the impact of fatigue on performance because, in theory, performance outcomes should vary depending on how fatigued performers are and how well they compensate for their fatigue by exerting effort (Fairclough 2001; Fairclough and Graham 1999; Muraven and Slessareva 2003). Further, effort influence can vary depending on the nature of the challenge with which performers are confronted (Harkins 2006). Nonetheless, we examined two performance outcomes, the number of responses provided (i.e., number of Hs circled and problem solutions written) and the number of provided responses that were correct. A two-way ANOVA on the first measure produced only a task B relevance effect, F (1, 90) = 51.09, $P < .001$. Not surprisingly, there were more Hs circled (fatigue low $M = 168.91$, fatigue high $M = 154.09$) than there were solutions written (fatigue low $M = 100.52$, fatigue high $M = 95.68$). A one-way (fatigue) ANOVA on the second measure revealed no effects.

Table 3 Experiment 1: happiness, energy, fear, and mental sharpness ratings

Fatigue	Low		High	
Task B relevance	Low	High	Low	High
Happy	7.67	7.00	6.54	6.88
Energetic	6.48	4.99	5.75	5.52
Fearful	0.87	1.91	1.59	2.34
Mentally sharp	7.16	6.07	6.66	5.34

Note: Means are covariance-adjusted for baseline levels. Cell *N*s are the same as those in Table 1

might be interpreted in terms of the fact the HR is subject not only to sympathetic nervous system control, but also to parasympathetic nervous system control, with sympathetic activity speeding HR and parasympathetic activity slowing it (e.g., Brownley et al. 2000). Conditions conducive to different control patterns are not well understood; however, there are believed to be ones under which parasympathetic activity can limit or block entirely sympathetic influence (Berntson et al. 1993; Obrist 1981). Thus, it is possible that HR responses did not vary with fatigue in work period 2 because the responses of High Fatigue participants were attenuated by a countervailing parasympathetic effect.

Although the period effects for the pressure measures—and for HR in the low fatigue conditions—were not anticipated, they are noteworthy and might be understood in terms of the fatigue analysis on which this research was based. Regarding the latter, it could be that participants were more resource depleted in period 2 than in period 1. If they were, it stands to reason that they would have tried harder and manifested stronger effort-related CV responses during the second period. Naturally, this explanation is post hoc and uncertain. Further, effects like this would not always be expected. Consider, for example, a study in which participants were confronted initially with an especially demanding task and later with an easier one. Nonetheless, the interpretation is worth considering, in part because it could have implications for other research involving CV assessments across time.

Examination of the subjective data confirmed further that the backwards counting task was more difficult than the forwards counting task. Examination also provided some evidence that difficulty appraisals rose, and ability appraisals fell, with fatigue. Concerning ability appraisals, mental sharpness ratings tended to be lower for High Fatigue participants ($P = .08$); concerning difficulty appraisals, task B difficulty index ratings tended to be higher for these participants ($P = .10$). Interestingly, the marginal fatigue effect on the task B difficulty index was carried by responses in the low task B relevance conditions, matching the interaction trend observed for SBP. One possible indication is that the initial fatigue manipulation was weaker when task B relevance was low than when it was high, presumably as a result of chance. Regardless of the interaction trend, the task B index findings comport with the conclusion that fatigue influence extended beyond the highly relevant, quantitative, challenge domain.[4]

Experiment 2

Method

Overview and predictions

Once again, participants performed for 5 min an easy (fatigue low) or difficult (fatigue high) counting task. Later, they were presented an arithmetic (task B relevance high) or scanning (task B relevance low) challenge with instructions that they would earn a modest incentive if they attained a high (90th percentile) performance standard. As in Experiment 1, we expected effort-related CV responses to be stronger among High Fatigue participants during the first work period. However, in this study, we expected fatigue influence in work period 2 to be negative, rather than positive. Thus, we reasoned that effort-related responses should be stronger for Low Fatigue participants during this period when the second challenge was highly relevant to the fatigue manipulation, and possibly when the second challenge was not, depending on the extent to which CV fatigue influence extends.

Participants and measurement of cardiovascular responses

Participants were 99 male undergraduate volunteers, predominantly of European and African heritage. Participants were assigned randomly to conditions in a 2 (fatigue: low, high) × 2 (task B relevance: low, high) factorial design. Data from five were excluded. Four misunderstood or followed incorrectly instructions. One refused to perform task B because he thought there was some "trick" asso-

[4] As in Experiment 1, we examined the number of responses provided and the number of provided responses that were correct. Analysis of the first measure produced a task B relevance effect, $F(1, 92) = 19.92$, $p < .001$, qualified by a fatigue x task B relevance interaction, $F(1, 92) = 4.16$, $p = .04$. Again, more Hs were circled than solutions were written. The interaction reflected tendencies for performance values to decline with fatigue when relevance was low (low fatigue M = 133.92, high fatigue M = 119.00), but improve with fatigue when relevance was high (low fatigue M = 85.65, high fatigue M = 101.00). As a result, the relevance effect was reliable when fatigue was low, $F(1, 92) = 21.53$, $p < .001$, but only approached significance when fatigue was high, $F(1, 92) = 2.89$, $p = .09$. Analysis of the second measure revealed a fatigue effect, $F(1, 45) = 4.07$, $p = .05$, reflecting better performance among High Fatigue participants (M = 99.96) than among Low Fatigue participants (M = 84.09)

ciated with it. CV assessments were made with a Dinamap monitor similar to the one used in Study 1.

Procedure

The procedure was highly similar to that for Experiment 1. Notable differences were threefold. First, in work period 1, participants counted at 5-s intervals instead of 3-s intervals. This provided a weaker instigation to fatigue in the high fatigue conditions, but one that was consistent with the instigation used by Wright et al. (2003), which proved effective with female participants. Second, in work period 2, participants were offered the chance to win a pen instead of the chance to avoid noise. Third, the performance standard in work period 2 was the 90th percentile of previous performances instead of the 50th percentile of previous performances. It also is of note that the experimenter presented in work period 2 only two pages of multiplication problems (122) and two pages of scrambled letters. Following the debriefing, participants were awarded a pen, given a research credit, and dismissed.

Results

Baseline analyses

Baseline CV values are in Table 4. Two (fatigue) × 2 (task B relevance) ANOVAs on the data yielded no effects for SBP or HR. On the other hand, they produced fatigue × task B relevance interactions for DBP, F (1, 92) = 3.82, P = .05, and MAP, F (1, 92) = 3.87, P = .05. In both cases, the interaction reflected lower values for High Fatigue participants when task B relevance was low, Fs (1, 92) ≥ 4.24, Ps < .05, but not when it was high, Fs < 1.0.

Table 4 Experiment 2: baseline blood pressure and heart rate

Fatigue		Low		High	
Task B relevance		Low	High	Low	High
SBP	*M*	114.8	116.9	111.8	115.5
	SE	2.5	2.6	2.6	2.6
DBP	*M*	63.9	61.6	58.5	62.5
	SE	1.6	1.5	1.7	1.6
MAP	*M*	81.8	80.4	77.2	82.0
	SE	1.7	1.4	1.8	1.5
HR	*M*	75.1	75.2	73.9	71.8
	SE	2.3	2.9	2.6	3.1
Cell *N*		26	23	23	24

Note: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure; HR = heart rate; *M* = mean; *SE* = standard error

Work period responses

As before, we computed change scores by subtracting base values from the mean of values obtained in each period. The regression of change onto baseline was reliable for SBP and fell just short of significance for HR (P = .06). Consequently, we analyzed the change data for those measures with 2 (fatigue) × 2 (task B relevance) × 2 (work period) ANCOVAs. The regression of change onto baseline did not approach significance for DBP and MAP. Therefore, we analyzed the change data for those measures with 2 × 2 × 2 ANOVAs.

To review again, we had two primary expectations. One was that effort-related CV responses would be stronger among High Fatigue participants in work period 1. The other was that these responses would be stronger for Low Fatigue participants in work period 2 when the second challenge was relevant, and possibly when it was not, depending on the degree to which fatigue influence extends. Thus, we expected either (1) a three way interaction, reflecting a fatigue effect in period 1 and a fatigue × task B relevance effect in period 2, or (2) a fatigue × period interaction, reflecting higher values for High- than Low Fatigue participants in period 1 and the opposite response pattern in period 2. The triple interaction outcome would indicate domain specificity; the two way interaction outcome would indicate extension.

Table 5 presents the covariance-adjusted means for SBP and the unadjusted means for DBP, and MAP. Analyses

Table 5 Experiment 2: blood pressure change during work period 1 (fatigue induction phase) and work period 2 (fatigue influence phase)

Fatigue			Low		High	
Task B relevance			Low	High	Low	High
SBP	Period 1	*M*	3.33	1.36	2.88	4.07
		SE	2.0	2.0	2.1	2.0
	Period 2	*M*	8.70	6.95	5.35	4.25
		SE	2.0	2.0	2.1	2.0
	Cell *N*		21	22	23	22
DBP	Period 1	*M*	2.52	2.16	3.78	3.83
		SE	1.1	1.4	0.9	0.9
	Period 2	*M*	6.81	7.07	4.83	6.03
		SE	1.2	1.3	1.2	1.6
	Cell *N*		24	22	20	20
MAP	Period 1	*M*	3.96	1.97	5.71	3.50
		SE	0.9	1.1	1.4	1.4
	Period 2	*M*	8.69	8.69	7.02	5.41
		SE	1.0	1.6	1.6	1.6
	Cell *N*		24	19	21	22

Note: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure; HR = heart rate; *M* = mean; *SE* = standard error produced fatigue x period interactions. For SBP, the interaction F was 6.91 (df = 1, 83; $P = .01$); for DBP, it was 7.36 (df = 1, 82; $P = .008$), and for MAP, it was 7.88 (df = 1, 82; $P = .006$). Simple effects tests, using pooled error terms, indicated two sources for the interactions. One was a rise in responsiveness from work period 1 to work period 2 among Low Fatigue participants, $F\text{s} \geq 11.5$, $P\text{s} < .001$, but not among High Fatigue participants, $F\text{s} \leq 1.83$, $P\text{s} \geq .18$. The second was relatively greater responsiveness among High Fatigue participants during period 1, but relatively diminished responsiveness among those participants in period 2. Comparisons of Low- and High Fatigue participants' responses did not approach significance during work period 1; however, they were marginally reliable for SBP, F (1, 165) = 3.45, $P = .07$, and MAP, F (1, 164) = 3.40, $P = .07$, during work period 2 (Fig. 2).

ANCOVA on the HR data yielded only a marginal fatigue effect, F (1, 84) = 3.01, $P = .09$, reflecting a tendency for stronger responses among High Fatigue participants, particularly during work period 1. An *a priori* contrast of HR values for Low- and High Fatigue participants in first work period approached significance, F (1, 169) = 3.32, $P = .07$; the same contrast in the second did not, F (1, 169) = 1.27, ns. Covariance-adjusted HR means for work period 1 were 2.05 (fatigue-low/task-B-relevance-low), .39 (fatigue-low/task-B-relevance-high), 3.66 (fatigue-high/task-B-relevance-low) and 3.35 (fatigue-high/task-B-relevance-high). Those for work period 2 were 5.80 (fatigue-low/task-B-relevance-low), 5.75 (fatigue-low/task- B-relevance-high), 7.89 (fatigue-high/task-B-relevance-low) and 6.49 (fatigue-high/task-B-relevance-high).

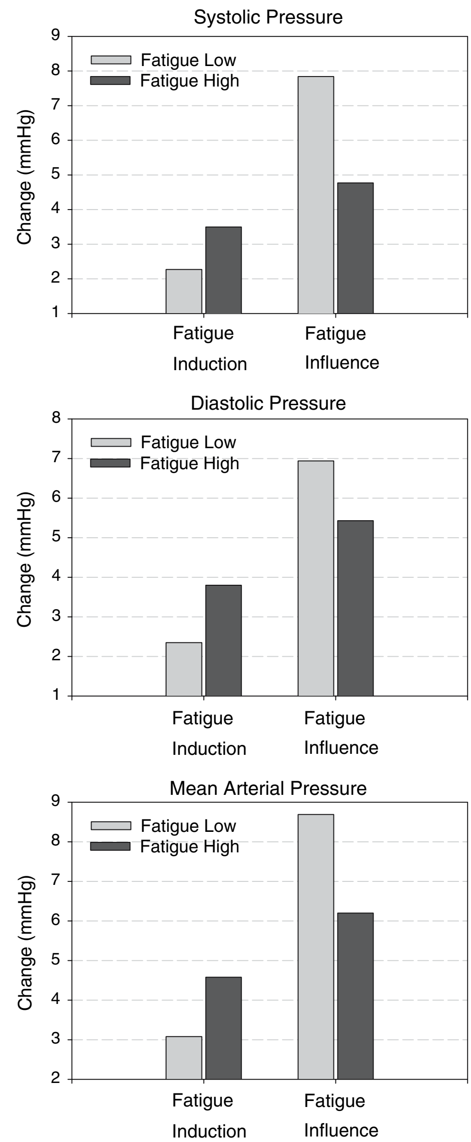

Fig. 2 Experiment 2: Blood pressure responses for Low- and High Fatigue participants during the fatigue induction (first) and fatigue influence (second) work periods

Subjective measures

Difficulty and Effort. A two-way ANOVA on the task A difficulty ratings produced a fatigue effect, F (1, 87) = 28.4, $P < .001$, reflecting higher values for the High Fatigue participants (task B relevance low $M = 3.41$, task B relevance high $M = 2.67$) than for the Low (task B relevance low $M = 0.92$, task B relevance high $M = 0.48$). Task B difficulty ratings and task B effort ratings were correlated and patterned similarly, and thus averaged to form a task B difficulty index. An ANOVA produced no effects.

Feelings. ANOVAs on the baseline "feeling" ratings produced fatigue × task B relevance interactions for anger and fear, Fs (1, 90) = 4.41 and 4.42, Ps = .04. The anger effect was due to marginally higher ratings among Low Fatigue participants when relevance was low (fatigue low $M = 2.72$, fatigue high $M = 1.46$), F (1, 90) = 3.57, $P = .06$, but a reverse pattern when it was high (fatigue low $M = 1.96$, fatigue high $M = 2.67$), F (1, 90) = 1.14, ns. The fear effect was due to lower ratings among High Task B Relevance participants when fatigue was high (task B relevance low $M = 2.24$, task B relevance high $M = 1.17$), F (1, 90) = 4.04, $P = .05$, but not when it was low (task B relevance low $M = 1.59$, task B relevance high $M = 2.13$), $F < 1.0$, ns.

Period 2 feeling ratings regressed consistently onto the base feeling ratings; therefore, they were analyzed with two-way ANCOVAs. The analyses yielded effects on two items. For "happy," there was a task B relevance effect, F (1, 86) = 5.87, $P = .02$. It reflected higher values among Low Task B Relevance participants (Table 6). For "energetic," there was a fatigue × task B relevance interaction, F (1, 86) = 4.84, $P = .03$. Energy ratings were higher

Table 6 Experiment 2: happiness, energy, and anxiousness ratings

Fatigue	Low		High	
Task B relevance	Low	High	Low	High
Happy	7.17	6.44	7.25	6.33
Energetic	6.51	4.81	5.58	5.80
Anxious	5.40	4.03	4.62	4.26

Note: Means are adjusted for baseline levels. Cell Ns are the same as those in Table 4

among Low- than High Task B Relevance participants when fatigue was low F (1, 86) = 8.07, P = .006, but not when it was high, $F < 1.0$, ns. The analyses also revealed a marginal task B relevance effect for the item "anxious," F (1, 86) = 3.68, P = .06, reflecting a tendency for values to be higher when relevance was low.

Discussion

As in Experiment 1, findings for blood pressure were relatively straightforward. Analysis revealed fatigue × period interactions reflecting relatively elevated responses among High Fatigue participants in work period 1 and relatively diminished responses among those participants in work period 2. Simple effects tests indicated a rise in responsiveness from period 1 to period 2 among Low Fatigue participants, but not among High Fatigue participants. Simple fatigue effects did not approach significance during period 1, but were marginally reliable (P = .07) for SBP and MAP during period 2.

The pressure data in period 1 accord in pattern with CV data from the fatigue induction periods of our first study and the Wright et al. (2003) study. However, they suggest a less powerful fatigue manipulation in this case. Critical factors could have been the 5-s counting pace and the use of male participants. The 5-s counting pace provided a weaker instigation to fatigue than the 3-s pace used in Experiment 1. Although the 5-s pace proved effective in the Wright et al. study, that study involved female participants and it is possible that the men in this study felt more math capable than the earlier women did. If the men did have higher math ability appraisals, it stands to reason that they would have exerted less effort in counting and depleted themselves to a lesser degree. The pressure data in period 2 correspond with the second period pressure data in the high standard conditions of the Wright et al. study. They also suggest that the CV influence of the counting fatigue manipulation extended to the low relevance scanning challenge.

Analysis of participants' HR responses indicated that the responses tended to be higher for High Fatigue participants during period 1 (P = .07), but did not differ as a function of fatigue in period 2. The findings for the first period agree with the conclusion that the initial fatigue manipulation was effective, but not especially powerful. Those for the second do not support our fatigue reasoning. However, like some of the HR data from Experiment 1, they may be understood in terms of the role parasympathetic activity plays in determining HR. Specifically, it could be that period 2 HR responses were not stronger among Low Fatigue participants because the sympathetic influence on them was tempered by a countervailing parasympathetic effect.

There were few noteworthy subjective effects in this study, possibly because the fatigue manipulation was limited in strength. As expected, High Fatigue participants had higher task A difficulty ratings. However, they did not have exaggerated task B difficulty values or differ from Low Fatigue participants in terms of reported mental sharpness or tiredness.

General comments

Together, these experiments provide compelling confirmation of the pressure effects that were observed in the Wright et al. (2003) mental fatigue study. Of central importance were effects in the second work period of the studies. Like second period effects in the Wright et al. study, they showed a positive correspondence between fatigue and pressure response under low standard conditions, but an inverse correspondence between fatigue and pressure response under high standard conditions. To be sure, comparisons for some measures were stronger than others. But the pattern was consistent among measures and across studies. It is noteworthy that the findings in Experiment 1 were obtained using an avoidance procedure and findings in Experiment 2 were obtained with males. This suggests that the effects of interest are not limited to one sex or an appetitive performance paradigm.

These experiments also provide evidence that mental fatigue influence may not be limited to related cognitive performance domains. In contrast to what a specificity argument would imply, the studies showed corresponding fatigue effects in the low- and high relevance conditions. Firm conclusions about extension are unwarranted for at least two reasons. One is because these studies had a narrow focus, examining the influence of only one depletion task (counting) and extension to only one performance domain (scanning). The other is because the low- and high relevance tasks may have differed along more than one dimension. For example, they may have differed in terms of difficulty as well as character. This presents the possibility that fatigue would have had no impact on participants' responses in the low relevance conditions if the confound, or set of confounds, had not been present.

Having made the latter point, we might add that we made every effort to match our low- and high relevance tasks in terms of significant dimensions such as difficulty. Further, it may be impossible to identify tasks that differ solely in terms of the cognitive performance systems they involve. The best test of a specificity hypothesis ultimately will be provided by a body of studies that cross validate mental fatigue influence, examining the impact of various fatigue inductions on responses to various post-fatigue challenges. If predictable fatigue effects extend consistently, it will be reasonable to conclude their extension is not artifactual, but rather indicative of a single underlying process, presumably associated with the depletion of a common executive resource (e.g., Baumeister et al. 2005; Gailliot et al. 2007; Muraven et al. 2006; Schmeichel et al. 2003).

Implications

Insofar as data from these and the other fatigue studies we have described support our broader fatigue analysis, they have implications for a range of outcomes in a range of settings. In the laboratory, they imply that fatigue has potential for introducing enormously complex variability into effort-related outcomes through its ability to produce different engagement effects under different task conditions. Outside the lab, they imply that fatigue has potential for producing variable and non-obvious motivational effects and may sometimes have adverse health consequences. The link to health derives from evidence implicating daily CV response patterns in the initiation and progression of negative health outcomes, including hypertension and heart disease (Blascovich and Katkin 1993; Dembroski et al. 1983). Chronically pronounced responses are expected to convey greater health risk than chronically diminished responses. Thus, where fatigue enhances CV responsiveness to daily challenges, it should have potential for having a negative health impact. People who strive occasionally to meet difficult goals in a fatigued state probably experience minimal health risk as a result. However, those who persist regularly in the face of fatigue (e.g., shift workers, people with enduring insomnia) may experience significant risk, particularly if they are members of vulnerable health groups.

Stepping slightly away from the concepts of effort and CV response, data from these and the other studies imply that feelings of fatigue have potential for impacting emotion intensity in variable and non-obvious ways. The link to emotion intensity comes from recent arguments by Brehm that emotion intensity varies non-monotonically with the magnitude of emotion deterrence, first falling sharply, then rising, and then falling precipitously again (Brehm 1999; Brehm and Brummett 1998; Brehm et al. 1999; Brehm and Miron, 2006; Miron et al. 2007). An emotion deterrent is defined as any factor that opposes an emotion or the action being urged by it. Examples would be a sad event occurring to someone experiencing joy (emotion opposed) and military strength in a country against which a leader is urged by anger to aggress (action opposed). Fatigue feelings might or might not have the capacity to oppose an emotion; however, they clearly can oppose action being urged. Consequently, the suggestion is that, in this manner at least, the feelings should be able to exert a subtle and complex influence on affective experience.

Naturally, real world compensatory effects are likely to be trivial in importance if they are of the same small magnitude as the compensatory effects observed here. It is safe to assume, though, that compensation is stronger under conditions where significant fatigue is involved. In the present studies, participants were fatigued for only 5 min with activity that was mildly demanding, at best. In real world settings, more potent fatigue inductions are commonplace.

Theoretical points of note

We might note that although the fatigue studies conducted thus far document important implications of our fatigue analysis, they do not address all implications of the analysis. One implication yet to be examined is that fatigue should have no impact on effort and associated CV responses when it leaves unaltered a perception that success is impossible or excessively difficult. Another is that success importance should moderate fatigue influence so long as success is perceived to be possible. That is, when success is viewed as possible, importance should determine the difficulty level at which fatigued individuals withhold effort and display minimal CV responsiveness.

We also might note that although our fatigue analysis has, to date, construed fatigue in energy resource terms (see earlier discussion), a more expansive construal of fatigue is possible. That is, one could construe fatigue in terms of *any* performance resource that might be brought to bear in coping and temporarily diminished as a result of coping activity. Thus, for example, people whose eyes have been strained from extended visual activity might be conceived as more fatigued with respect to visual tasks than people whose eyes have not been strained. Similarly, people hoarse from speaking might be conceived as more fatigued with respect to vocal tasks than people who are not hoarse. Thinking in these terms extends the range of circumstances to which the fatigue reasoning may be applied, and could represent a productive direction for future fatigue research to take.

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References

Baumeister, R. F., DeWall, C. N., Ciarocco, N. J., & Twenge, J. M. (2005). Social exclusion impairs self-regulation. *Journal of Personality and Social Psychology, 88*, 589–604.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993). Cardiac psychophysiology and autonomic space in humans: Empirical perspectives and conceptual implications. *Psychological Bulletin, 114*, 296–322.

Blascovich, J., & Katkin, E. S. (1993). *Cardiovascular reactivity to psychological stress and disease*. Washington, DC: American Psychological Association.

Blascovich, J., & Mendes, W. B. (2000). Challenge and threat appraisals: The role of affective cues. In J. Forgas (Ed.), *Feeling and thinking: The role of affect in social cognition* (pp. 59–82). Paris: Cambridge University Press.

Blascovich, J., Mendes, W. B., Hunter, S. B., & Lickel, B. (2000). Stigma, threat, and social interactions. In T. F. Heatherton, R. E. Kleck, M. R. Hebl, & J. G. Hull (Eds.), *The social psychology of stigma* (pp. 307–333). New York: Guilford.

Blascovich, J., & Tomaka, J. (1996). The biopsychosocial model of arousal regulation. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (Vol. 29, pp. 1–51). New York: Academic Press.

Brehm, J. W. (1999). The intensity of emotion. *Personality and Social Psychology Review, 3*, 2–22.

Brehm, J. W., & Brummett, B. H. (1998). The emotional control of behavior. In M. Kofta, G. Weary, & G. Sedek (Eds.), *Personal control in action: Cognitive and motivational mechanisms*. New York: Plenum. .

Brehm, J. W., Brummett, B. H., & Harvey, L. (1999). Paradoxical sadness. *Motivation and Emotion, 23*, 31–44.

Brehm, J. W., & Miron, A. M. (2006). Can the simultaneous experience of opposing emotions really occur? *Motivation and Emotion, 30*, 13–30.

Brehm, J. W., & Self, E. (1989). The intensity of motivation. In M. R. Rozenweig & L. W. Porter (Eds.), *Annual review of psychology* (pp. 109–131). Palo Alto: Annual Reviews, Inc.

Brener, J. (1987). Behavioral energetics: Some effects of uncertainty on the mobilization and distribution of energy. *Psychophysiology, 24*, 499–512.

Brinkmann, K., & Gendolla, G. H. E. (2007). Dysphoria and mobilization of mental effort: Effects on cardiovascular reactivity. *Motivation and Emotion* (in press).

Brown, P. C., Smith, T. W., & Benjamin, L. S. (1998). Perceptions of spouse dominance predict blood pressure reactivity during marital interactions. *Annals of Behavioral Medicine, 20*, 286–293.

Brownley, K. A., Hurwitz, B. E., & Schneiderman, N. (2000). Cardiovascular psychophysiology. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 224–264). New York: Cambridge.

Clements, K., & Turpin, G. (1995). Effects of feedback and task difficulty on electrodermal activity and heart rate: An examination of Fowles = three arousal model. *Journal of Psychophysiology, 9*, 231–242.

Dembroski, T. M., Schmidt, T. H., & Blümchen, G. (1983). *Biobehavioral bases of behavior*. Basel; New York: Karger.

Elliott, R. (1969). Tonic heart rate: Experiments on the effects of collative variables lead to a hypothesis about its motivational significance. *Journal of Personality and Social Psychology, 12*, 211–228.

Fairclough, S. H. (2001). Mental effort regulation and the functional impairment of the driver. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload and fatigue* (pp. 479–502). Mahweh, NJ: Erlbaum.

Fairclough, S. H., & Graham, R. (1999). Impairment of driving performance caused by sleep deprivation or alcohol: A comparative study. *Human Factors, 41*, 118–128.

Gailliot, M. T., Baumeister, R. F., DeWall, C. N., Maner, J. K., Plant, E. A., Tice, D.M., Brewer, L. E., & Schmeichel, B. J. (2007). Self-control relies on glucose as a limited energy source: Willpower is more than a metaphor. *Journal of Personality and Social Psychology, 92*, 325–336.

Gendolla, G. H. E., & Krüsken, J. (2001). The joint impact of mood state and task difficulty on cardiovascular and electrodermal reactivity in active coping. *Psychophysiology, 38*, 548–556.

Gendolla, G. H. E., & Richter, M. (2005). Ego involvement and effort: Cardiovascular, electrodermal, and performance effects. *Psychophysiology, 42*, 595–603.

Gendolla, G. H. E., & Richter, M. (2006a). Cardiovascular reactivity during performance under social evaluation: The moderating role of task difficulty. *International Journal of Psychophysiology, 62*, 185–192.

Gendolla, G. H. E., & Richter, M. (2006b). Ego-involvement and the difficulty law of motivation: Effects on performance-related cardiovascular response. *Personality and Social Psychology Bulletin, 32*, 1188–1203.

Gendolla, G. H. E., & Wright, R. A. (2005). Motivation in social settings: Studies of effort-related cardiovascular arousal. In J. P. Forgas, K. Williams, & B. von Hippel (Eds.), *Social motivation: Conscious and nonconscious processes*. Cambridge University Press.

Harkins, S. G. (2006). Mere effort as the mediator of the evaluation-performance relationship. *Journal of Personality and Social Psychology, 91*, 436–455.

Hilmert, C. J., Kulik, J. A., & Christenfeld, N. (2002). The varied impact of social support on cardiovascular reactivity. *Basic and Applied Social Psychology, 24*, 229–240.

Kukla, A. (1972). Foundations of an attributional theory of performance. *Psychological Review, 79*, 454–470.

Light, K. C. (1981). Cardiovascular responses to effortful active coping: Implications for the role of stress in hypertension development. *Psychophysiology, 18*, 216–225.

Llabre, M. M., Spitzer, S. B., Saab, P. G., Ironson, G. H., & Schneiderman, N. (1991). The reliability and specificity of delta versus residualized change as measures of cardiovascular reactivity to behavioral challenges. *Psychophysiology, 28*, 701–711.

Miron, A. M., Parkinson, S. K., & Brehm, J. W. (2007). Does happiness function like a motivational state? *Cognition and Emotion* (in press).

Muraven, M. B., Shmueli, D., & Burkley, E. (2006). Conserving self-control strength. *Journal of Personality and Social Psychology, 91*, 524–537.

Muraven, M. B., & Slessareva, E. (2003). Mechanisms of self-control failure: Motivation and limited resources. *Personality and Social Psychology Bulletin, 29*, 894–906.

Obrist, P. A. (1981). *Cardiovascular psychophysiology: A perspective*. New York: Plenum Press.

Scherer, K. R. (1984). On the nature and function of emotion: A component process approach. In K. R. Scherer & Ekman, P. (Eds.), *Approaches to emotion* (pp. 293–317). Hillsdale, NJ: Erlbaum.

Schmeichel, B. J., Vohs, K. D., & Baumeister, R. F. (2003). Intellectual performance and ego depletion: Role of the self in logical reasoning and other information processing. *Journal of Personality and Social Psychology, 85*, 33–46.

Smith, T. W., Baldwin, M., & Christenson, A. J. (1990). Interpersonal influence as active coping: Effects of task difficulty on cardiovascular reactivity. *Psychophysiology, 27,* 429–437.

Wright, R. A., & Dismukes, A. (1995). Cardiovascular effects of experimentally-induced efficacy (ability) appraisals at low and high levels of avoidant task demand. *Psychophysiology, 32*, 172–176.

Wright, R. A., & Kirby, L. D. (2001). Effort determination of cardiovascular response: An integrative analysis with applications in social psychology. In M. Zanna (Ed.), *Advances in experimental social psychology* (Vol. 33, pp. 255–307). San Diego, CA: Academic Press.

Wright, R. A., & Lockard, S. (2006). Sex, outcome expectancy, and cardiovascular response to a masculine appetitive challenge. *Psychophysiology, 43*, 190–196.

Wright, R. A., Martin, R. E., & Bland, J. L. (2003). Energy resource depletion, task difficulty, and cardiovascular response to a mental arithmetic challenge. *Psychophysiology, 40*, 98–105.

Wright, R. A., & Penacerrada, D. K. (2002). Energy resource depletion, ability perception, and cardiovascular response to a behavioral challenge. *Psychophysiology, 39*, 182–187.