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Interactional Influence of Fatigue and Task Difficulty on Cardiovascular Response: Demonstrations Involving an Aerobic Exercise Challenge

Rex A. Wright,

University of North Texas

Jin Joo Shim,

Columbia University

Beverly K. Hogan,

University of Alabama at Birmingham

Jessica Duncan, and

University of Alabama at Birmingham

Casey Thomas

University of Alabama at Birmingham

Abstract

Experiments were executed to provide new evidence relevant to the recent suggestion that fatigue should augment or retard cardiovascular response depending on the difficulty of the challenge at hand. Participants walked on a treadmill while wearing a vest fitted with 5- or 25 pounds of weight. Later, they mounted a recumbent stationary bicycle and were asked to pedal with the chance to earn a modest incentive if they attained a low or high cycling standard (i.e., if they met an easy or difficult cycling challenge). Analysis of CV responses during the cycling period indicated expected interactions for systolic blood pressure and heart rate. Whereas responses were stronger for the heavy vest (i.e., high fatigue) group when the standard was low, they were weaker for this group when the standard was high. Experiments 2 and 3 evaluated a non-fatigue interpretation of the main results and yielded findings that supported the fatigue interpretation.

Keywords

Human motivation; Fatigue; Cardiovascular response; Ability

A recent conceptual analysis addresses the role that fatigue may play in determining cardiovascular (CV) responses in people confronted with performance challenges (Wright, 2009; Wright & Stewart, 2011; for an independent perspective with some common implications, see Kruglanski, Baumeister, Chen, Köpetz, Pierro & Mannetti, 2012). One assumption is that beta-adrenergic influence on the heart and vasculature increases with

effort, that is, the degree to which performers apply themselves in action circumstances (Light, 1981; Obrist, 1981). A second is that effort first rises and then falls precipitously with the difficulty of a performance challenge, with the fall occurring where success appears impossible or excessively difficult given its importance (Brehm & Self, 1989). A third is that difficulty appraisals are positively correspondent to fatigue in relevant performance systems, that is, proportional to renewable resource depletion in those systems (e.g., Fairclough, 2001; Fairclough & Graham, 1999; Hockey, 1997).

The analysis implies that fatigue effects on CV response should not be singular, but rather multifaceted, with fatigue increases augmenting responsiveness under some difficulty and success importance conditions, retarding it under others, and having no impact on it under still others (Figure 1). In theory, fatigue should augment CV responsiveness when it leaves unchanged a perception that success is possible and worthwhile - generating compensatory striving (figure section A). By contrast, it should retard CV responsiveness when it causes success to appear impossible or excessively difficult - leading performers to withhold effort (figure section B). Finally, it should have no impact on CV responsiveness when it reinforces a perception that success is impossible or excessively difficult - confirming performers' intention not to try (figure section C). In short, fatigue influence should be *interactional*, depending on the difficulty of the challenge at hand and the importance of meeting it.

Support

Considerable support has been garnered for this analysis, with the most compelling coming from studies that have shown diverging fatigue effects under different difficulty and success importance conditions (LaGory, Dearen, Teboe, & Wright, 2011; Nolte, Wright, Turner, & Contrada, 2008; Stewart, Wright, Hui, & Simmons, 2009; Wright, Junious et al., 2007; Wright, Martin, & Bland, 2003; see also Marcora, Bosio, & de Morree, 2008, Experiment 1; Schmidt, Richter, Gendolla & Van der Linden, 2010; Wright & Penacerrada, 2002; Wright, Stewart, & Barnett, 2008). An example of the latter is an experiment by Wright et al. (2003) that (1) first required participants to perform a simple (fatigue low) or demanding (fatigue high) counting task, and then (2) presented arithmetic problems with instructions that the participants could earn a prize by attaining a low or high performance standard. As expected, analysis of CV responses measured during the arithmetic period indicated a crossover response pattern for systolic blood pressure (SBP), with similar patterns emerging for diastolic blood pressure (DBP) and mean arterial pressure (MAP). Whereas responses rose with difficulty among low fatigue participants, they fell with difficulty among high fatigue participants. Further, whereas they were or tended to be greater for High Fatigue participants when the standard was low, they were or tended to be greater for Low Fatigue participants when it was high. The crossover pattern was expected for SBP because SBP responses are systematically influenced by heart contractility, which varies directly with beta-adrenergic activation (Berntson, Cacioppo, & Quigley, 1993; Brownley, Hurwitz & Schneiderman, 2000; Fairclough & Mulder, 2011; Kelsey, 2011; Obrist et al., 1978; Richter, Friedrich, & Gendolla, 2008; Richter & Gendolla, 2009).

Although studies showing moderating effects of difficulty and importance are impressive, it is of note that none of them to date has included a manipulation of physical fatigue. Rather,

they have either manipulated mental fatigue or examined fatigue globally as a naturally-occurring - measured – variable.

Present Research

We initiated Experiment 1 below to address the preceding empirical gap, inducing fatigue by having participants perform a preliminary treadmill task wearing a vest loaded with different amounts of weight. In conducting the study, we assumed that beta-adrenergic effects emerge in physical performance contexts as they do in mental performance contexts and function to service metabolic needs of relevant performance structures (e.g., leg muscles). Our central prediction was that vest weight would combine with the difficulty of a post-induction performance challenge to determine effort-related CV responses during the post-induction work period. More specifically, we expected that greater vest weight (higher fatigue) would augment the responses when the post-induction challenge was mild, but retard them when that challenge was strong. This prediction was based on two assumptions. The first was that Heavy Vest (high fatigue) participants would perceive the post-induction challenge as harder than would the Light Vest (i.e., low fatigue) participants. The second was that the Light Vest participants would perceive success as possible and worthwhile in both post-induction challenge conditions, whereas the Heavy Vest participants would perceive success as possible and worthwhile only in the mild post-induction challenge condition.

Our CV measures included SBP, DBP, MAP, and heart rate (HR). Because SBP responses are believed to be especially sensitive to beta-adrenergic influence, we expected them to be especially likely to conform to the predicted interactional pattern. We also expected HR to conform to the predicted pattern because it is largely under beta-adrenergic control at high levels of exercise (Obrist, 1981, p. 22).

Experiment 1

Method

Participants and Measurement of CV Responses—Participants were 75 female undergraduate volunteers of normal or near-normal body weight (body mass index = 17.34–31.93), most of Western European or African heritage. They received class credit for participating and were assigned randomly to one of four groups: Light-Vest/Low-Standard, Light-Vest /High-Standard, Heavy-Vest /Low-Standard, and Heavy-Vest/High-Standard. Data from 7 were excluded due to experimenter error or physiological recording equipment failure. This yielded cell totals of 16 (Light-Vest/Low-Standard), 18 (Light-Vest /High-Standard), 17 (Heavy-Vest /Low-Standard), and 17 (Heavy-Vest/High-Standard). CV measurements were taken with a Dinamap Pro Series pressure monitor, which uses a conventional arm inflation cuff and the oscillometric measurement technique.

Procedure—Participants were met by a female experimenter, escorted to the laboratory chamber and asked to sit at a table that contained a consent statement and a basket of Snickers bars. Once seated, participants signed the consent form and were given a brief mood checklist that included an item asking them to indicate on an 11-point scale (0 = not at all; 10 = extremely) how physically fatigued they felt.

After participants completed the materials, the experimenter escorted them to a hallway and measured their weight and height. As she returned to the laboratory chamber, the experimenter (1) briefly provided an overview of the study, (2) asked participants to be seated on a recumbent stationary bicycle (Fitnex R70 Recumbent Exercise Bike), and (3) attached the Dinamap arm cuff to participants' right arm. Participants were asked to rest for the next 10 minutes while CV measures were taken every 2 minutes. Baseline for each CV parameter was taken as the mean of the final two base samples. The experimenter returned to control room and determined the participants' vest (weight) condition by turning the top card in a stack of index cards that had the words "light" or "heavy" written on them.

After baseline, the experimenter returned, removed the cuff and fitted participants with a light or heavy vest. The light vest contained 5 pounds; the heavy vest contained 25. Once the vest was fitted, the experimenter directed participants to step on a treadmill (Smooth 6.45M Treadmill - Smooth Fitness) and start the 10 minute treadmill (i.e., fatigue induction) period. During this period, participants walked at a modest (2 mile per hour) pace on a flat conveying belt. After the period, the experimenter returned and asked participants to move back to the bicycle. Once participants were seated, the experimenter asked them to complete the mood checklist a second time, indicating their current feelings. After participants completed the checklist, the experimenter attached the Dinamap cuff to their right arm and gave instructions on how to use the bicycle. Special attention was paid to showing participants how to operate the display board, which conveyed information in repetitions per minute (RPMs) about cycling speed.

When the cycling instructions were clear, the experimenter returned to the control room, telling participants that further instructions would be conveyed over a public address (PA) system. Once in the control room, the experimenter (1) determined the standard condition by turning a Standard condition index card, and then (2) read the message below, inserting either "40" (Low) or "60" (High) into the RPM blank. Experimenters were instructed to read this information over the PA system. However, in some cases, they opened the door to the laboratory chamber and presented the information in person, changing the procedure because a second – ongoing – study created distracting noise in the control room.

"Ok. Your pedaling exercise will be to pedal constantly for 10 minutes. Pedaling speed is not critical; however, some consistency in speed among participants is desirable. Therefore, the professor in charge of this study will award a full size Snickers bar sitting in the basket on the table in front of you to everyone who averages a pedaling rate of _____ RPMs."

Participants were asked to raise their left arm if they understood and were ready to begin. Once they did, the experimenter directed them to start pedaling. During the pedaling period, the experimenter recorded CV measures every 2 minutes. After the period, the experimenter returned for debriefing. Following the debriefing, the experimenter awarded all participants a Snicker's bar.¹

¹In this and the other experiments reported here, we replaced sporadic missing CV data with either the mean of immediately adjacent values or – in cases where missing samples were first or last in a period – values that immediately followed or preceded, respectively. Thus, for example, a missing HR value at minute 3 of a post-induction period would be replaced with the mean of HR values obtained at minutes 1 and 5.

Data Analysis

Cardiovascular: Baseline data were examined with 2 (Vest: Light versus Heavy) x 2 (Standard: Low versus High) analyses of variance (ANOVAs). Response during the post-induction (i.e., cycling) period was operationalized as change from baseline (Jamieson, 2004; Llabre, Spitzer, Saab, Ironson, & Schneiderman, 1991). Change scores were computed by subtracting base values from post-induction values and examined with two-way ANOVAs or analyses of covariance (ANCOVAs, baseline as covariate), depending on whether there was a correspondence between baseline and change.

In examining the CV data, we focused on responses obtained at the 1st, 3rd and 5th minutes of the post-induction period, averaging across the samples. We did so because these were periods in which there was complete (minutes 1 and 3) or near complete (minute 5 – 97% of cases) data. After minute 5, considerable data were missing because some participants stopped cycling, with only 76% of cases available by minute 9 – the bulk having been lost in the Heavy-Vest/High-Standard condition. By minute 5, only two participants had stopped cycling, one in the Light-Vest/Low-Standard condition and one in the Heavy-Vest/High-Standard condition. Although our focus was on the 1st, 3rd and 5th minute samples, it is of note that CV responses were, in fact, largely consistent across post-induction sampling periods. To guard against movement artifact, we omitted CV change scores that exceeded their group mean by two or more standard deviations. This resulted in the loss of SBP data from four participants, DBP data from three participants, MAP data from three participants, and HR data from two participants. Where change scores were omitted, corresponding base values were omitted as well. Preliminary analyses were performed on the change data including race (African- versus European heritage) as a factor. These yielded no race effects; consequently, we did not include race in the main CV response analyses.

Body Mass Index and Reported Fatigue: Body mass indexes were computed and examined with a two-way ANOVA. Baseline fatigue data were analyzed with the same ANOVA. Post-treadmill (i.e., post fatigue induction) fatigue change scores were computed by subtracting base values from values collected after the treadmill period. The regression of change onto base was reliable ($p = .03$). Therefore, the change scores were analyzed with an ANCOVA in which baseline served as the covariate.

Results

Cardiovascular Data—Analysis of the base values revealed no effects (Table 1). The regression of SBP change scores onto SBP base values did not approach reliability ($p = .63$). Consequently, we examined the SBP change data with an ANOVA. The ANOVA yielded a Vest x Standard interaction, $F(1, 58) = 25.63, p < .001$, partial $\eta^2 = .31$, reflecting the expected crossover response pattern (Figure 2). Follow-up pair-wise comparisons indicated that responses were stronger under High- than Low Standard conditions for Light Vest participants, $t(58) = 4.74, p < .001$, but stronger under Low- than High Standard conditions for Heavy Vest participants $t(58) = 2.41, p = .02$. Further, whereas Heavy Vest participants evinced stronger responses than the Light Vest participants when the standard was low, $t(58) = 2.60, p = .01$, they evinced weaker responses than the Light Vest participants when the standard was high, $t(58) = 4.60, p < .001$.

The regression of HR change onto baseline HR was marginally reliable ($p = .08$). Accordingly, we examined HR change scores with an ANCOVA. The ANCOVA yielded a Vest x Standard interaction, $F(1, 59) = 10.76$, $p = .002$, partial $\eta^2 = .15$, reflecting a response pattern similar to that obtained for SBP. Responses were stronger under High- than Low Standard conditions for Light Vest participants, $t(59) = 4.22$, $p < .001$, but not for Heavy Vest participants. Whereas Heavy Vest participants evinced stronger responses than Light Vest participants when the standard was low, $t(59) = 2.08$, $p = .04$, they evinced weaker responses than those participants when the standard was high, $t(59) = 2.59$, $p = .01$.

Change score means for DBP and MAP are in Table 2. Regressions of change onto base were reliable ($p < .03$); therefore, we applied ANCOVAs. The ANCOVAs produced a Vest x Standard interaction for MAP, $F(1, 58) = 4.28$, $p = .04$, partial $\eta^2 = .07$, reflecting a response pattern correspondent with the patterns observed for SBP and HR. Pair-wise comparisons indicated that responses were stronger under High- than Low Standard conditions for Light Vest participants, $t(58) = 2.62$, $p < .001$, but not for Heavy Vest participants. Heavy Vest participants evinced marginally weaker responses than the Light Vest participants when the standard was high, $t(58) = 1.88$, $p = .07$, but not when it was low.

Body Mass and Self-Reported Fatigue—The ANOVA on the body mass index data ($M = 23.13$) yielded no effects, as did the ANOVA on the baseline fatigue ($M = 2.40$) data. Analysis of the fatigue change scores revealed an unexpected Standard effect, $F(1, 62) = 4.58$, $p = .04$, partial $\eta^2 = .07$, reflecting higher fatigue reports in the High Standard conditions (adjusted means: Light Vest $M = 1.60$, Heavy Vest $M = 2.06$) than in the Low Standard conditions (adjusted means: Light Vest $M = -.41$, Heavy Vest $M = .92$). It is of note that participants did not yet know their RPM cycling standard at the time they provided their post-treadmill fatigue reports. Thus, the Standard effect on the fatigue measure is almost certainly spurious. It also is of note that although the Vest effect was not reliable in the analysis of the fatigue data, the fatigue means were ordered as one would expect, with higher values for Heavy Vest participants.

Discussion

SBP responses were stronger under High- than Low Standard conditions among Light Vest (low fatigue) participants, but in the reverse pattern among Heavy Vest (high fatigue) participants. Further, they were stronger for Heavy- than Light Vest participants when the standard was low, but in the reverse pattern when the standard was high. Other CV responses were similar, although pair-wise effects for HR and MAP were less consistent and the Vest x Standard interaction did not attain significance for DBP. These findings comport with expectations and provide important new support the suggestion that fatigue should (1) augment CV responsiveness when it leaves unchanged a perception that success is possible and worthwhile, and (2) retard CV responsiveness when it causes success to appear impossible or excessively difficult. The findings conceptually replicate findings from previous studies and extend those findings by documenting interaction effects in a physical – aerobic – performance context.

Analysis of the body mass scores and base fatigue ratings indicated no effects, which is consistent with our assumption that the groups did not differ in body mass or fatigue upon arrival. Analysis of the fatigue change scores provided little support for our assumption that Heavy Vest participants were more fatigued after the treadmill exercise and, indeed, yielded an unexpected Standard effect. The unexpected effect is curious, but of little concern because it is almost certainly spurious and, importantly, presents no obvious alternative account of the main CV results. The absence of a Vest effect in the analysis of fatigue change scores is curious as well, although it could reflect reluctance on the part of some participants to admit to being tired, perhaps due to interpersonal dynamics peculiar to the experimenters involved.

A feature of the study that does present an alternative account of the main results is the fact that participants wore their vest while cycling. This allowed for the possibility that observed CV effects were due not to fatigue, but rather the weight of the vest being worn while cycling. The possibility seemed unlikely because participants were in a recumbent sitting position when they cycled, which should have mitigated the effect of vest weight. Nonetheless, it could not be ruled out and called for further research.

Experiment 2

Experiment 2 addressed the alternative account above. It involved a procedure virtually identical to that in Experiment 1 except that it (1) included no treadmill period, (2) included only Heavy Vest conditions, and (3) required participants to complete only the initial mood checklist. All participants were assigned the heavy vest and cycled wearing it. Logic was twofold. First, if vest weight during cycling was the key determinant of participants' CV responses in Experiment 1, then the CV results should resemble the CV results obtained in the Heavy Vest conditions of that study. Specifically, one should find a reduction in effort-related CV response moving from the Low- to the High Standard condition. Second, if treadmill fatigue was the key determinant of participants' CV responses in Experiment 1, then CV results should be different. Specifically, one should find that without the fatigue generated by the treadmill activity, CV responses increase moving from the Low- to the High Standard condition as they did for Light Vest participants in Experiment 1. We assumed that recumbent positioning during cycling in fact minimized the influence of vest weight. Thus, we predicted that effort-related CV responses would rise from the low- to the high standard condition, focusing especially on SBP and HR.

Method

Participants and Measurement of CV Responses—Participants were 38 female undergraduate volunteers of normal or near-normal body weight (body mass index = 17.77–35.14), most of Western European or African heritage. They received class credit for participation and were assigned randomly to either a Low- or High Standard condition. Data from two were excluded due to equipment failure, yielding cell totals of 20 (Low Standard) and 16 (High Standard). CV samples were obtained using the same equipment that was used in Experiment 1.

Procedure—The procedure was the same as that Experiment 1 with three exceptions. First, all participants were assigned the heavy vest following the point at which their height and weight were measured. Second, the treadmill period was omitted. All participants proceeded to the cycling period (previously the post-induction period) when the baseline phase was completed. Third, the mood checklist was administered only at baseline. It also is of note that all Standard instructions were delivered through the PA system. CV sampling periods (baseline and cycling) were the same as those in Experiment 1.

Results

Baseline CV data were examined with one-way (Standard: Low versus High) ANOVAs, which produced no effects (Table 3). As in Experiment 1, CV change scores were computed by subtracting base values from cycling period values and examined in the context of one-way ANOVAs or ANCOVAs. In examining the data, we focused on responses obtained at the 1st, 3rd and 5th minutes of the cycling period, averaging across the samples. We did so because these were the periods of focus in Experiment 1, making a similar focus necessary for purpose of comparison. Although we focused on these samples, it is of note that CV responses were largely consistent across cycling sampling periods. To guard against movement artifact, we omitted CV change scores that exceeded their group mean by two or more standard deviations, also eliminating corresponding baseline values. This resulted in the loss of SBP data from one participant, DBP data from one participant, MAP data from one participant, and HR data from two participants. Preliminary analyses indicated no effects for race (African- versus European heritage). Therefore, we did not include race in the main CV response analyses.

Regression of change onto base values did not approach reliability for SBP and HR ($p > .14$). Therefore, we examined those data with ANOVAs. Analyses indicated a Standard effect for HR, $F(1, 32) = 14.86$, $p < .001$, partial $\eta^2 = .32$, reflecting stronger responses in the High Standard condition (Figure 3). Careful inspection of the SBP data revealed the presence of a value in the High Standard condition that tended to be extreme, but fell short of the exclusion criteria. With this in mind, we also examined the SBP change scores by (1) determining the proportion of scores in each condition that were at or above the median for both groups (31.67), and (2) performing an ANOVA on the arc sin transformed proportions (Langer & Abelson, 1972; Winer, 1971). This analysis revealed a Standard effect, $F(1, 33) = 4.48$, $p = .04$, reflecting stronger responses for High Standard participants (proportion = .64 as compared to .41 for Low Standard participants). DBP and MAP means are in Table 4. The regression of change onto base was reliable for MAP ($p = .05$), but not DBP ($p = .26$). Thus, we examined the MAP data with an ANCOVA and the DBP data with an ANOVA. Analysis indicated a Standard effect for MAP, $F(1, 32) = 5.88$, $p = .02$, partial $\eta^2 = .12$, reflecting stronger responses in the High Standard condition. ANOVAs on the body mass ($M = 23.17$) and base fatigue data ($M = 2.86$) revealed no effects.

Discussion

Analysis of the SBP, HR, and MAP data indicated stronger responses under High Standard conditions. This response pattern contrasts with that for Heavy Vest participants in Experiment 1 and is consistent with suggestion that the main results from that study were

due to fatigue, rather than vest weight during cycling. The conventional ANOVA result for SBP change was non-reliable; however, the secondary (arc sine) ANOVA suggested that this might have been misleading, affected by a potentially non-representative value. Analysis of the body mass and base fatigue data supported our assumption that groups were equivalent in terms of mass and fatigue when they arrived.

Notably, no participants stopped pedaling during the cycling period. A contributing factor surely was the lack of fatigue generated by treadmill activity. An additional factor might have been greater clarity of cycling instructions. It might be recalled that in Experiment 1, we had difficulty conveying instructions in some cases because of distracting noise (see Method). We had no such difficulty here.

Experiment 3

Experiment 3 addressed further the vest weight interpretation. It involved a procedure virtually identical to that in Experiment 1 except that it required participants to remove their vest prior to mounting the bicycle and beginning the post-induction (cycling) period. Our central prediction was that vest weight during the fatigue induction period would combine with the difficulty of the cycling challenge to determine effort-related CV responses during the post-induction period, with greater weight augmenting the responses when the challenge was mild, but retarding them when the challenge was strong.

Method

Participants and Measurement of CV Responses—Participants were 56 female undergraduate volunteers of normal or near-normal body weight (body mass index = 13.80–30.30), most of Western European or African heritage. They received class credit for participation and were assigned randomly to one of the four conditions. Data from one participant were excluded due to equipment failure, yielding cell totals of 13 (Light-Vest/Low-Standard), 14 (Light-Vest/High-Standard), 14 (Heavy-Vest/Low-Standard), and 14 (Heavy-Vest/High-Standard). CV samples were obtained using the same equipment that was used in Experiments 1 and 2.

Procedure—The procedure was the same as in Experiment 1 except that it required participants to remove their vest prior to beginning the post-induction period. All Standard instructions were delivered through the PA system. CV sampling periods were the same as before.

Results

Cardiovascular Data—Baseline CV data were examined with 2 (Vest: Light versus Heavy) x 2 (Standard: Low versus High) ANOVAs, which produced no effects (Table 5). Change scores were computed by subtracting base values from post-induction period values and examined in the context of two-way ANOVAs or ANCOVAs. In this study, we obtained CV data from all participants at all minutes of the post-induction period.² Preliminary

²One participant (Heavy-Vest/Low-Standard) stopped pedaling as the last – 9 minute – sample was being taken. Following the rule outlined in Footnote 1, we inserted values for the adjacent 7 minute sampling period.

analyses indicated no interactions involving time or race. Therefore, we averaged across all samples and did not include race in the main CV analyses. To guard against movement artifact, we omitted CV change scores that exceeded their group mean by two or more standard deviations, excluding corresponding base values as well. This resulted in the loss of SBP data from four participants, DBP data from two participants, MAP data from three participants, and HR data from two participants.

Regressions of change onto base values did not approach reliability for SBP and HR (p s = .21). Therefore, we examined those data with ANOVAs. Analyses indicated Standard effects [SBP: $F(1, 47) = 12.79, p < .001$, partial $\eta^2 = .21$; HR: $F(1, 49) = 14.96, p < .001$, partial $\eta^2 = .23$], qualified by Vest x Standard interactions [SBP: $F(1, 47) = 4.47, p < .001$, partial $\eta^2 = .09$; HR: $F(1, 49) = 5.51, p = .02$, partial $\eta^2 = .10$]. The Standard effects reflected stronger responses under High Standard conditions; the interactions reflected crossover patterns broadly – though not perfectly - compatible with those obtained in Experiment 1 (Figure 4). Pair-wise comparisons indicated that SBP and HR responses were stronger under High- than Low Standard conditions for Light Vest participants [SBP: $t(47) = 3.98, p < .001$; HR: $t(49) = 4.35, p < .001$], but not for Heavy Vest participants. Whereas SBP responses tended to be stronger for Heavy Vest participants when the standard was low, $t(47) = 1.77, p = .08$, they did not differ by vest when the standard was high. Whereas HR responses were weaker for Heavy Vest participants when the standard was high, $t(49) = 2.13, p = .04$, they did not differ by vest when the standard was low.

The regression of change onto base values was reliable for MAP ($p = .04$), but not DBP ($p = .38$). Consequently, we examined the DBP data with an ANOVA and the MAP data with an ANCOVA. Analysis indicated a Vest effect for DBP, $F(1, 49) = 4.98, p = .03$, partial $\eta^2 = .09$, and a Standard effect for MAP, $F(1, 46) = 13.00, p < .001$, partial $\eta^2 = .22$. Table 6 shows that DBP responses were stronger overall among Light Vest participants and MAP responses were stronger overall in the High Standard conditions. Although the Vest x Standard interactions were not reliable (p s = .11), responses for both measures tended to be stronger for Light Vest participants under High- but not Low Standard conditions.

Body Mass and Self-Reported Fatigue—An ANOVA on the body mass data ($M = 23.12$) yielded no effects, as did an ANOVA on the base fatigue ($M = 3.36$) data. An ANCOVA on the fatigue change scores produced a near-reliable Vest effect, $F(1, 50) = 3.72, p = .059$, partial $\eta^2 = .07$, reflecting higher fatigue reports among Heavy Vest participants (adjusted means: Low Standard $M = 1.79$, High Standard $M = .79$) than among Light Vest participants (adjusted means: Low Standard $M = .15$, High Standard $M = .29$).³

Discussion

ANOVAs revealed Vest x Standard interactions for SBP and HR, with responses in patterns similar to those observed in Experiment 1. DBP and MAP responses were comparable,

³One reviewer requested body mass index means for individual groups in all studies. In Experiment 1, the means were 22.90 (Light-Vest/Low-Standard), 21.78 (Light-Vest /High-Standard), 20.93 (Heavy-Vest /Low-Standard), and 22.23 (Heavy-Vest/High-Standard). In Experiment 2, they were 23.64 (Heavy-Vest /Low-Standard), and 22.61 (Heavy-Vest/High-Standard). In Experiment 3, they were 22.90 (Light-Vest/Low-Standard), 23.54 (Light-Vest /High-Standard), 22.13 (Heavy-Vest /Low-Standard), and 24.32 (Heavy-Vest/High-Standard).

although interactions for those measures fell short of significance. Collectively, the findings comport with the fatigue interpretation of the main Experiment 1 results and argue against the vest weight alternative.

Although the crossover response patterns observed for SBP and HR were similar to those obtained in Experiment 1, they were less robust. In Experiment 1, simple Vest (fatigue) effects were reliable under Low- and High Standard conditions. By contrast, in this experiment, the simple Vest effect was reliable only for SBP when the standard was low and reliable only for HR when the standard was high. Whereas Experiment 1 showed a reliable decline in SBP response moving from the Low- to the High Standard condition among Heavy Vest participants, this experiment did not. The weaker effects could have been due to the smaller number of participants, which reduced statistical power. They also could indicate that cycling vest weight had some influence on the perceived difficulty of the cycling challenge in Experiment 1, just not enough to account for the main CV results. If the heavier vest enhanced difficulty slightly, its presence might have led Heavy-Vest/Low-Standard participants to strive harder and Heavy-Vest/High-Standard participants to be especially prone to withhold effort.

As expected, analysis of the body mass scores and base fatigue reports indicated no effects. Interestingly, analysis of the fatigue change scores revealed a near-reliable ($p = .059$) Vest effect, reflecting greater increases in fatigue among Heavy Vest participants. This comports with our assumption that Heavy Vest participants were more depleted after the fatigue induction (treadmill) period and recommends further caution in interpreting curious fatigue report findings from Experiment 1.

Conclusions and Observations

These studies provide important new support for the interactional fatigue analysis. Experiment 1 showed the implied crossover response pattern using a protocol that allowed participants to wear while cycling the vest that initially fatigued them. Experiment 2 addressed the vest weight alternative explanation of the main findings, suggesting that results for Heavy Vest participants could not be explained in vest weight terms. Experiment 3 addressed the alternative explanation further, documenting interactional effects for SBP and HR under conditions where participants cycled with their vest removed.

To the degree that our vest weight procedure approximates fatigue experience outside of the laboratory, these studies have implications for responses that may occur in daily life. Specifically, they imply that physical fatigue might be associated with a distinctive CV response profile characterized by response augmentation under some performance conditions and response retardation under others. There is evidence that chronically exaggerated CV responses can elevate health risk (Bongard, al' Absi, & Lovallo, 2011; de la Torre, 2002; Glass, 1977; c.f., Carroll, Phillips, & Lovallo, 2011), which presents the possibility that physical fatigue could increase such risk when it is pronounced, persistent and experienced under conditions that require or encourage engagement. To illustrate, consider a long term and unassisted caregiver of an elderly person with Alzheimer's dementia. This person could have the chance to sleep only during limited intervals and be confronted regularly with physical challenges that must be met in a timely fashion, such as

feeding, bathing, changing and moving the care recipient. If the caregiver functions in a consistently depleted state, he or she would be expected to exhibit consistently elevated CV responses that could prove toxic in time. The studies also imply that physical fatigue might be associated with a distinctive *effort* profile that sometimes – but not always – yields performance impairment.⁴

Presumably, diverse groups are vulnerable to physical fatigue influence, including not only people with sleep challenges, but also people with a poor diet, inadequate exercise, and health conditions such as Type II diabetes. A group especially relevant to these studies might be the obese because they carry daily a burden of extra weight that could sometimes increase their fatigue trajectory over time (Browning, Baker, Herron, & Kram, 2006). Naturally, extensions of the present findings to the obese should be made guardedly. Wearing a weighted vest is not the same as being overweight. Nonetheless, the potential link is there and could prove fruitful as a path for future investigation.

A final observation pertains to fatigue influence on mood. It is possible that fatigue sometimes leads to mood deterioration. This is potentially significant because Gendolla and his colleagues (e.g., Gendolla, Brinkmann, & Silvestrini, 2011; Gendolla & Krüskén, 2001, 2002) have generated compelling evidence that negative moods can enhance difficulty appraisals and produce ultimately interactional CV effects comparable to the CV fatigue effects discussed here. The Gendolla findings suggest that where fatigue induces a negative mood, mood influence might combine with fatigue influence to lead fatigued performers to (1) show especially exaggerated CV responses during the augmentation phase of fatigue influence, and (2) attain more quickly (i.e., at lower levels of difficulty and success importance) the retardation phase of fatigue influence. Exploration of these combinatorial effects also could prove fruitful as a path for future investigation.

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⁴Unfortunately, we failed to measure performance in these studies. Future investigations could easily do so (e.g., by recording cycling speed or distance) and should since this could provide valuable evidence relevant to the assumption that predicted CV effects are mediated by effort.

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Figure 1.
Effort as a function of fatigue and difficulty (adapted from Figure 1 in Stewart et al., 2009).

Figure 2.

Systolic blood pressure and heart rate responses (with standard errors) for Light- and Heavy Vest (i.e., Low-and High Fatigue) participants at different standard levels during the post-induction (cycling) period (Experiment 1).

Figure 3. Cardiovascular responses for Heavy Vest participants at different standard levels during the cycling period (Experiment 2).

Figure 4. Systolic blood pressure and heart rate responses (with standard errors) for Light- and Heavy Vest (i.e., Low- and High Fatigue) participants at different standard levels during the post-induction (cycling) period (Experiment 3).

Table 1

Baseline Blood Pressure and Heart Rate: Experiment 1

(Vest)	(Standard)	Light		Heavy	
		Low	High	Low	High
SBP	M	111.80	109.81	113.66	114.55
	SD	12.17	12.09	10.60	6.94
	n	15	17	16	16
DBP	M	64.67	65.34	65.69	68.77
	SD	10.79	8.84	9.17	7.60
	n	16	17	17	15
MAP	M	81.13	81.15	82.35	86.80
	SD	10.65	10.11	9.73	5.85
	n	14	18	17	16
HR	M	80.85	80.72	84.29	83.44
	SD	17.71	11.70	16.31	11.76
	n	15	18	17	16

Note: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure; HR = heart rate; M = mean; SD = standard deviation; n = number per condition.

Table 2

DBP and MAP Change: Experiment 1

(Vest) (Standard)		Light		Heavy	
		Low	High	Low	High
DBP	M	1.43	8.60	5.83	5.94
	SD	8.13	8.08	8.08	8.12
	n	15	17	17	14
MAP	M	6.09	15.92	10.18	9.13
	SD	10.35	10.35	10.31	10.50
	n	13	18	17	15

Note: DBP = diastolic blood pressure; MAP = mean arterial blood pressure; M = mean; SD = standard deviation; n = number per condition. Means are residualized (covariance-adjusted) with respect to baseline.

Table 3

Baseline Blood Pressure and Heart Rate: Experiment 2

(Standard)		Low	High
SBP	M	104.71	103.55
	SD	8.18	11.14
	n	20	15
DBP	M	57.90	56.38
	SD	7.69	5.53
	n	19	16
MAP	M	75.16	73.30
	SD	7.53	7.35
	n	19	16
HR	M	81.30	78.73
	SD	12.03	16.34
	n	19	15

Note: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure; HR = heart rate; M = mean; SD = standard deviation; n = number per condition.

Table 4

DBP and MAP Change: Experiment 2

(Standard)		Low	High
DBP	M	10.86	17.77
	SD	10.59	10.96
	n	19	16
MAP	M	14.12	23.23
	SD	11.03	11.04
	n	19	16

Note: DBP = diastolic blood pressure; MAP = mean arterial blood pressure; M = mean; SD = standard deviation; n = number per condition. MAP means are residualized (covariance-adjusted) with respect to baseline.

Table 5

Baseline Blood Pressure and Heart Rate: Experiment 3

(Vest)	(Standard)	Light		Heavy	
		Low	High	Low	High
SBP	M	103.25	103.14	104.14	105.62
	SD	8.24	5.42	8.35	9.77
	n	12	13	13	13
DBP	M	56.27	57.67	56.79	57.54
	SD	4.91	7.59	5.48	4.02
	n	13	12	14	14
MAP	M	72.77	73.54	73.29	73.75
	SD	5.23	7.47	6.33	5.55
	n	12	12	14	13
HR	M	85.21	80.39	85.04	83.40
	SD	12.62	10.98	10.10	7.77
	n	12	14	14	13

Note: SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure; HR = heart rate; M = mean; SD = standard deviation; n = number per condition.

Table 6

DBP and MAP Change: Experiment 3

(Vest) (Standard)		Light		Heavy	
		Low	High	Low	High
DBP	M	10.90	18.96	9.55	9.98
	SD	9.51	5.61	7.61	9.93
	n	13	12	14	14
MAP	M	12.85	27.14	14.22	19.68
	SD	9.77	9.73	9.77	9.77
	n	12	12	14	13

Note: DBP = diastolic blood pressure; MAP = mean arterial blood pressure; M = mean; SD = standard deviation; n = number per condition. MAP means are residualized (covariance-adjusted) with respect to baseline.