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Influence of control and physical effort on cardiovascular reactivity to a video game task

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Abstract

This study investigated the influences of both perceived control and physical effort on cardiovascular reactivity. Undergraduates (N = 32) played a video game task interrupted by aversive noise. Perceived control of the noise was manipulated by instructions indicating the presence or absence of a contingency between performance and noise presentations. Physical effort was manipulated by controlling the physical force required to perform the task. There was a significant main effect of control on systolic blood pressure (SBP) and total peripheral resistance (TPR), with both increasing more during low than high control conditions. The results suggest that high perceived control over aversive noise in an effortful task reduces SBP and TPR reactivity relative to low perceived control. The results are consistent with the idea that control buffers the reactivity associated with task performance under aversive conditions.

Descriptors: Autonomic, Preejection period, Blood pressure, Total peripheral resistance

Perceiving that one has control over important goal-relevant life circumstances such as job-related decisions or the timing of a stressful life event has been proposed to reduce the risk of illness and mortality (Karesek, Baker, Marxer, Ahlbom, & Theorell, 1981; Marmot, Bosma, Hemingway, Brunner, & Stansfeld, 1997; Rodin, 1986; Steptoe, 1983; Syme, 1990; Taylor, Kemeny, Reed, Bower, & Gruenewald, 2000; Theorell & Karasek, 1996). In particular, investigators have proposed that having control of goal-relevant life events can reduce an individual's cardiovascular disease risk (Bosma et al., 1997; Glass, 1977; Marmot, Bosma, Hemingway, Brunner, & Stansfeld, 1997; Schnall, Landsbergis, & Baker, 1994; Theorell & Karesek, 1996). Excessive cardiovascular reactivity has been invoked as a possible mediating link between low control and subsequent disease risk. Specifically, repeatedly eliciting exaggerated cardiac and vascular responses is hypothesized to damage arterial walls, contribute to plaque formation, and accentuate the progression of the atherosclerotic process (Manuck, 1994). However, it is not clear when situations of low or no control over aversive events produce enhanced cardiac or vascular reactivity. Moreover, the specific pattern of cardiovascular reactivity to situations of low or high control may be key to whether there are atherogenic effects. For instance, sympathetic cardiac activation accompanied by increased vascular resistance may be more damaging than the same sympathetic cardiac activation not accompanied by increased resistance. Before we can assess the potential relevance of the cardiovascular reactivity hypothesis as it relates to controllability, we must determine the nature of the overall hemodynamic response to conditions of low and high control.

The cardiovascular effects of control over short-term, laboratory-based stressors typically have been investigated by varying an individual's control or perception of control over some goal-relevant outcome such as aversive noise or shocks (Bongard, 1995; Houston, 1972; Lovallo et al., 1985; Manuck, Harvey, Lechleiter, & Neal, 1978; Obrist et al., 1978). In many of these studies, the control conditions are operationalized as active coping (high control with a behavioral demand) versus passive coping (low control with or without a behavioral demand). The majority of these studies have shown an increase in cardiovascular reactivity in participants who have control, typically over aversive events, compared to those who do not have control (Bongard, 1995; Houston, 1972; Lovallo et al., 1985; Manuck et al., 1978; Obrist et al., 1978; Sherwood, Dolan & Light, 1990). For example, in a study by Sherwood, Dolan, and Light, pairs of participants performed a reaction time task for which their combined performance would determine a monetary reward. Participants in the active coping condition exerted control by performing the reaction time task,

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whereas participants in the passive coping condition observed their teammate, but made no overt behavioral responses. As in this study, active coping tasks in laboratory settings often differ from passive coping tasks not only by the degree of control, but also by requiring greater physical effort. The confounding of control and effort poses a problem when interpreting studies of cardiovascular reactivity because heart rate and other cardiovascular functions may be increased simply due to increased metabolic demands, a phenomenon known as cardiac-somatic coupling (Obrist, Lawler, & Gaebelein, 1974; Obrist, Webb, Sutterer, & Howard, 1970).

Several investigators have acknowledged the potentially confounding effects of physical effort in controllable laboratory tasks (Lovallo et al., 1985; Manuck et al., 1978; Obrist et al., 1970; Elliott, 1969), and some have attempted to reduce or eliminate this confound (DeGood, 1975; Gerin, Litt, Deich, & Pickering, 1995; Gerin, Pieper, Marchese, & Pickering, 1992; Hokanson, DeGood, Forrest, & Brittain, 1971).[1] In studies by Hokanson et al. and DeGood, investigators attempted to remove the confounding effects of physical effort by yoking a participant who has control (defined as choice over time of rest periods) with one who does not. Here, when effort was held constant across control conditions, and control was defined as having choice, then having control was associated with reduced SBP reactivity compared to not having control. Manuck et al. suggested that these results differ from the typical active/passive coping studies showing increased reactivity with control because exerting control over the timing of rest periods required little or no mental or physical effort. In a study by Gerin et al. in which physical effort was held low and constant across control conditions, having control resulted in reduced cardiovascular reactivity. However, in this study, participants' performance provided control of a reward, namely, leaving the study early, rather than control over a stressor. This contrasts with many active/passive coping studies where the stimulus being controlled is aversive. Thus, both physical effort and the nature of what is being controlled may be important determinants of cardiovascular reactivity in studies varying control.

Few studies have attempted to vary physical effort in order to distinguish the effects of control of aversive stimulation across levels of physical effort. If physical effort is required to exert control over a stressor, and if this effort is an important factor in producing enhanced cardiovascular reactivity (Steptoe, 1983), then we need to assess the effect of control on reactivity while independently varying, and preferably quantifying, physical demand.

Physical effort is not the only factor that is sometimes confounded with control in motivated performance studies. Having control over a goal-relevant stimulus may also be associated with greater motivation, a higher level of involvement, and sometimes, better performance than not having control. For example, in the Sherwood, Dolan, and Light (1990) study, participants in the active coping task were significantly more involved, believed the outcome of the task to be more important, and had higher perceived control than they did in a passive coping task. Confounding motivational state with a control manipulation makes it difficult to infer the source of the difference between task conditions. Likewise, if task performance varies as a function of the experimental manipulation, task differences in reactivity may be due to performance level. Thus, we used a video game task to assess the cardiovascular effects of control of aversive noise blasts, and kept performance at 50% accuracy (on average) for each experimental condition to hold performance constant, and to maintain a relatively high level of difficulty for each participant. In addition, we held motivation relatively constant and high by offering participants $1.00 for each task if they performed as well as they had during a practice session (and participants did not know that performance level was fixed). Finally, we assessed task involvement to see if participants were differentially involved in the task across control conditions.

The primary goal of the present study was to assess the effects of control and physical effort on cardiovascular reactivity by experimentally manipulating both. Cardiovascular reactivity measures in the present study include those assessed in previous studies of control and reactivity, namely, blood pressure, heart period, cardiac output, and total peripheral resistance. Control was manipulated in the present study by influencing perceived control. Thus, participants did not have veridical control over the presentation of aversive stimuli. Others have shown that the perception of control is sufficient in order to observe effects of control (Corah & Boffa, 1970; Geer, Davison, & Gatchel, 1970; Glass & Singer, 1972; Manuck, et al., 1978). Based on the results of Gerin et al. (1992, 1995), Bohlin et al. (1985), Hokanson et al. (1971), and DeGood (1975) where physical effort was held constant or low, we predicted that the independent effect of high control would be reduced reactivity compared to low control. Specifically, we expected that systolic blood pressure would increase more and heart period would shorten more in the low control compared to the high control condition. The independent effect of control on CO and TPR was more difficult to predict because studies that have assessed these variables have not held effort constant across conditions (Lovallo et al., 1985; Sherwood, Dolan, & Light, 1990). Thus, we made no predictions regarding these variables.

Method

Participants

Participants were 32 students (21 women) recruited from undergraduate psychology classes at Pennsylvania State University and compensated with course extra credit and $5.00 for their participation. The ethnicity of participants was 70% White, 23% Asian, and 7% Latin. Participants were excluded if they reported a family history of high blood pressure (either parent), asthma, or other cardiovascular or respiratory illnesses. Participants had at least 5 hr of sleep prior to the testing day and were asked to abstain from alcohol for at least 12 hr prior to the session. Participants were not asked to refrain from caffeine or nicotine. Most of the subjects used caffeine on a daily basis (94%), although most of the daily users had abstained from caffeine for at least 2 hr prior to the start of the experiment (71%). Twenty-four participants were nonsmokers, 6 occasional smokers, and 2 daily smokers.

Physiological Measures

ECG and impedance signals were recorded using a Minnesota Impedance Cardiograph (Model 304B, Instrumentation for Medicine, Greenwich, CT). Aluminum-mylar electrode bands were placed in a tetrapolar configuration using the method outlined by Sherwood, Allen, Fahrenberg, Kelsey, Lovallo, and van Doornen (1990). Respiration was recorded using a respiration belt (EPM Systems, Midlothian, VA) around the waist and below the lowest impedance

[1]Some investigators (Bongard, 1995; Manuck, Harvey, Lechleiter, & Neal, 1978; Soloman, Holmes, & McCaul, 1980) have also assessed the role of mental effort in the cardiovascular reactivity associated with active coping tasks. Although we have focused here on the role of physical effort, future studies will need to further assess the role of mental effort in these active coping.

band electrode. Physiological signals were digitized (12 bit A/D) and stored for off-line processing. ECG and dZ/dt were sampled at 500 Hz, and respiration and Z_0 at 250 Hz using customized data acquisition software (ANS Suites, Ohio State University). After computer-aided visual inspection of the raw physiological signals, 1-min values for heart period (HP), cardiac output (CO), and preejection period (PEP) were obtained from the ensemble-averaged ECG and ZCG signals using customized analysis software (Kelsey & Guethlein, 1990). Blood pressure measurements (SBP, DBP, and mean arterial pressure; MAP) were recorded once per minute during each of the 4-min baselines and 4-min tasks using a Dinamap automated blood pressure monitor (Model 1846SX; Criticon, Tampa, FL). Total peripheral resistance (TPR) was calculated for each minute using the formula (MAP/CO) $\times$ 80. Respiratory sinus arrhythmia (RSA; heart period variance at the respiratory frequency) was estimated from the heart period for each minute using the method of Porges and Bohrer (1990; MXedit, ver. 2.01, Delta-Biometrics, Bethesda, MD).

Video Game Task

We used a custom-designed computer video game task. Small blue squares "dropped" from the top of the computer screen and the goal of the task was to "catch" the falling squares with an on-screen paddle located at the bottom of the screen. The participant could move the horizontally oriented paddle left and right using two force keys as response buttons (PCB Piezotronics, Depew, NY). Each force key was attached to a wooden dowel (3 cm diameter; 19.5 cm long; force keys attached 2.5 cm from the dowel end) that the participant held in each hand. The force keys were operated using the thumbs. The performance level was held at an average of 50% accuracy using a staircase tracking method. Thus, when the participant made several successful catches in a row, the difficulty level of the task increased, which decremented performance, and when the participant made several unsuccessful catches in a row, the difficulty level of the task decreased to enhance performance. At controlled intervals (15–45-s ISIs) during each 4-min task, a blast of white noise at 88–92 dB SPL(A) was presented through headphones. The duration of each noise blast was 50 ms with a zero rise time. A total of seven blasts were heard during each task, with blasts timed to occur only after unsuccessful catches.[2] No blasts occurred in either the first or last 15 s of the task. During the task, the participant sat upright in a comfortable recliner with eyes approximately 83 cm from the screen. The horizontal and vertical visual angles of the screen were 16.0° and 12.6°, respectively.

Self-Report Measures

Perceived control measure. Perceived control was assessed both pre- and posttask by asking participants to endorse the statement "I have (or had) control over the noise blasts" using a 7-point Likert-type scale ranging from 1 (strongly disagree) to 7 (strongly agree) with another descriptive anchor at the midpoint of the scale (moderately agree).

Involvement and stressfulness measures. Task involvement was measured using the following question after each task: "Please rate how involved you were in the task on a scale of 1 to 5 where 1 is not at all involved and 5 is very involved." Stressfulness also was obtained after each task using the following question: "Please rate how stressful you think the previous task was on a scale from 1 to 5 where 1 is not at all stressful and 5 is very stressful." The participant verbally reported his or her ratings.

Design

The design of the study was a 2 (high control/low control) $\times$ 2 (high effort/low effort) within-subjects design with the order of conditions counterbalanced. We randomly chose 8 orders from the possible 24 orders. Each of the 8 orders was represented by 4 participants. Control was manipulated by the instruction set provided just prior to each task. In the high control conditions, participants were told that noise blasts could be prevented by their performance on the task. In the low control conditions, participants were told that the noise blasts were random. In fact, noise blasts were pseudorandomly presented for all conditions (see Video Game Task section). Physical effort was manipulated by changing the amount of force required to move the paddle on the screen. In the high effort condition, participants were required to press on the force keys at 70% of their maximum voluntary force. In the low effort condition, participants were required to press on the force keys at 30% of their maximum voluntary force.

Procedure

The experimenter described the procedure to the participant, who then gave informed consent and completed a health questionnaire. The participant was seated in a recliner in a testing room adjacent to the control room with the computer collecting the physiological data. The band electrodes and respiration belt were placed, and the blood pressure cuff was secured around the participant's nondominant arm. Next, the experimenter left the room while the participant completed several dispositional self-report measures that are not reported here (e.g., locus of control) during a 10-min electrode stabilization. Following this, the participant sat quietly for a 4-min resting baseline.

After the baseline period, the experimenter entered the testing room and collected measurements of the participant's maximum voluntary force on the force keys. The experimenter instructed the participant to use his or her thumbs to press as hard as possible on each force key at the sound of a tone. This procedure was completed three times and the maximum voluntary force was calculated by averaging the six values.

Following the maximum voluntary force determination, the participants performed a practice task to give a benchmark for their performance level for subsequent tasks. Via an intercom from the control room an experimenter explained the task, then asked appraisal questions.[3] The appraisals for the practice task will be reported elsewhere. Participants were told to work as hard as possible on the task and that they would receive $1.00 for the first task as long as they reached a preset criterion of performance. The practice task was performed without noise blasts or instructions about control and required 50% of maximum force. After the instructions were given, an experimenter entered the testing room, started the practice task, and then left the room. After the practice task was completed, an experimenter entered the testing room and reset the program for the next task.

[2] A pilot study of 32 psychology students was used to assess whether noise blasts presented either randomly or only after unsuccessful catches produced the most believable manipulation of control. From this pilot study, we determined that when noise blasts were presented after unsuccessful catches, both the low and high control conditions were believable and distinct from one another.

[3] Appraisal items included ratings of stressfulness on a scale of 1 (not at all stressful) to 5 (very stressful) and ratings of coping ability on a scale of 1 (cannot cope at all) to 5 (can cope very well).

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After the practice task, participants performed two short (approximately 75 s each) familiarization tasks to give them some experience with both the high and low control conditions.[4] The experimenter explained to the participant that she or he would be performing two short tasks and then gave instructions for the high control condition. The high control familiarization task was programmed with three noise blasts, all of which occurred after unsuccessful catches. The experimenter then gave instructions for the low control condition, which was programmed with three noise blasts, two following unsuccessful catches and one following a successful catch. No physiological recordings were made during these familiarization sessions.

Following the familiarization task, the participant performed the four, 4-min tasks, which differed by control and effort. A 4-min baseline period preceded each task. The experimenter gave the control and effort instructions for the task via an intercom. In addition, the experimenter explained that the participant could earn $1.00 for the task as long as she or he performed as well as in the initial practice task. The pretask manipulation check of the control condition was completed immediately after instructions for the task were given. After each task, the participant was asked to verbally rate task involvement and task stressfulness. This procedure was repeated for each of the remaining tasks. After the final task, the participant was debriefed, thanked, and compensated with $5.00 and course credit.

Data Analysis

Physiological measures. We calculated Pearson's correlation coefficients between baseline and task scores for the physiological dependent variables separately for each participant. These correlations were higher than .60 for at least one-third of participants, indicating that the task level of some dependent variables was related to the basal levels. Therefore, in order to assess the task-related effects on the cardiovascular variables, we conducted separate regressions for each subject using baseline scores to predict task scores. The resulting residualized change scores were used for all analyses. To maximize the reliability of blood pressure, cardiac output, and total peripheral resistance, we aggregated over multiple measures by calculating the mean over the four task minutes and the mean over the four baseline minutes for SBP, DBP, MAP, TPR, and CO. Residualized change scores were calculated using these means. Some data loss occurred for BP measurements due to movement of the participants' upper arm while pressing the force keys. Participants were included in the blood pressure, CO, and TPR analyses only if they contributed at least two blood pressure measurements for each task and baseline measure. In 95% of the cases, the means for each 4-min task or baseline were comprised of three or more readings. There were 24 participants who met this criterion (18 women, 6 men; 69% White, 26% Asian, and 5% Latin; represented six of the eight task orders three times each, one order four times, and one order two times). In contrast to blood pressure changes, cardiac and autonomic responses tended to peak at the beginning of the task, which is common in laboratory tasks such as the game used in the present study (Quigley, Feldman Barrett & Weinstein, 2002; Tomaka & Blascovich, 1994; Tomaka, Blascovich, Kelsey, & Leitten, 1993). To be sure to capture any potential changes as a function of the task, residualized change scores for HP, PEP, and RSA were calculated by predicting the first minute of the task with the final minute of the baseline.

[4]We determined in the pilot testing that a short practice task was necessary to give participants enough information about the task so that they could immediately perceive the differences in control between the high and low control condition.

Results

Manipulation Checks

The effect of effort on average force. To confirm the manipulation of physical effort, a 2 (control) × 2 (effort) ANOVA was performed on average force. Consistent with the requirements of the task, there was a main effect of effort on average force, $F(1,31) = 119.59$, $p < .001$, such that participants exerted more force under high effort conditions (mean [M] ± SEM = 1215.5 ± 50.9 centiNewtons [cN]) than under low effort conditions (M = 763.7 ± 33.3 cN). There was no main effect of control and no interaction between control and effort on average force, $F(1,31) = 0.55$, $p = .46$; $F(1,31) = 0.65$, $p = .63$, respectively). These results confirm that the effort manipulation was successful and was not influenced by the control conditions.

The effect of the control manipulation on perceived control. We assessed the effectiveness of the control instructions to ensure that participants reported higher perceived control prior to high control conditions than low control conditions. Consistent with the intended effect of the manipulation, there was a main effect of control instructions on pretask perceived control, $F(1,31) = 29.35$, $p < .001$, such that perceived control of noise blasts was greater under high control conditions (M = 4.6 ± 0.2) than under low control conditions (M = 2.5 ± 0.3). There was also a main effect of pretask effort instructions on perceived control, $F(1,31) = 6.49$, $p < .05$, such that perceived control of noise blasts was higher before completing the low effort tasks (M = 3.8 ± 0.3) than before the high effort tasks (M = 3.2 ± 0.3). There was no interaction between control and effort on perceived control, $F(1,31) = 1.63$, $p = .16$. These results suggest that the control manipulation was successful in giving participants the perception that they would have greater control over the noise blasts under the high control than the low control conditions. In addition, the instructions regarding effort also influenced perceived control, although examination of the mean control ratings shows that the effect of effort instructions was considerably smaller than the effect of the control instructions.

Because it was possible that participants' perceptions of control might have changed as a result of experience with the task, we also assessed the effect of the control and effort instructions on posttask perceived control. One participant had missing data for this analysis. Again, consistent with the intended effect of the manipulation, there was a main effect of control instructions on posttask perceived control, $F(1,30) = 10.22$, $p < .05$, such that perceived control of noise blasts was greater under high control conditions (M = 4.4 ± 0.2) than under low control conditions (M = 3.0 ± 0.3). There was no main effect of the effort manipulation on posttask perceived control, $F(1,30) = 0.34$, $p = .56$, and no interaction between control and effort, $F(1,30) = 0.11$, $p = .74$). These results suggest that the control manipulation continued to be successful in giving participants the intended perception regarding control over the noise blasts even after completing the tasks.

The effect of control and effort on task involvement. We asked participants to self-report their involvement in each task to address the possibility that involvement varied across task conditions. Posttask ratings of task involvement were assessed in a 2 (control) × 2 (effort) repeated measures ANOVA with one participant's

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data missing. There were no effects of control, effort, or their interaction on task involvement, all Fs$(1,30) < 1.0$, all ps $> .40$. Therefore, any differences found between tasks on other measures are not a result of differences in task involvement.

Posttask ratings of task stressfulness. An ANOVA on posttask ratings of stressfulness revealed no significant main effects or interactions across tasks, all Fs$(1,31) < 2.5$, all ps $> .13$. The task means (on a scale from 1 to 5) and SEMs were: low control/low effort = 2.3 ± 0.2; low control/high effort = 2.4 ± 0.2; high control/low effort = 2.3 ± 0.2; high control/high effort = 2.6 ± 0.2. Thus, all tasks were seen as moderately stressful, and there were no differences as a function of task conditions.

The Effects of Control and Effort on Cardiovascular Reactivity

Having established that both control and physical effort manipulations were effective and that task involvement and perceived task stressfulness did not confound control and effort conditions, we then assessed the influence of control and effort on cardiovascular reactivity. Two (control) × 2 (effort) repeated measures ANOVAs were performed on the residualized change scores for all dependent variables: SBP, DBP, MAP, TPR, CO, HP, PEP, and RSA. Mean raw baseline and task values for each dependent measure are shown in Table 1.

Blood pressure, TPR, and CO. There was a significant main effect of control on SBP residualized change scores, $F(1,23) = 4.97$, $p = .04$, but no significant main effect of effort, $F(1,23) = 1.49$, $p = .23$. There was a marginally significant interaction between control and effort on SBP residualized change scores, $F(1,23) = 2.90$, $p = .10$. SBP increased more under low control than under high control conditions (see left panel of Figure 1). ANOVAs conducted on DBP residualized change scores revealed no main effects of control or effort, nor any interaction, all Fs $<$ 1.2, all ps $> .30$.

There was a main effect of control on TPR residualized change scores, $F(1,23) = 4.06$, $p = .056$, but no main effect of effort nor any interaction, $F(1,23) = 0.78$, $p = .39$; $F(1,23) = 0.44$, $p = .51$; respectively. TPR increased more under low control than under high control conditions (see right panel of Figure 1). To assess whether or not the component variables making up TPR also were altered by control, we examined residualized change scores for CO and MAP for the four conditions. There were no main effects of control, effort, or their interaction on residualized CO change scores, all Fs$(1,22) < 2.0$, all ps $> .17$, or residualized MAP change scores, all Fs$(1,23) < 1.35$, all ps $> .25$. Examination of the means showed that small decreases in CO in most conditions and increases in MAP across all conditions produced the TPR effects (see Table 1).

Cardiac variables. There was a marginal main effect of control on HP residualized change scores, $F(1,31) = 3.10$, $p = .09$. Low control tended to be associated with a greater shortening of HP ($M = -18.7 \pm 8.2$; raw mean) than high control ($M = -2.5 \pm 8.4$). Heart rate thus increased slightly with low control ($M = 1.1 \pm 0.6$) and did not change with high control ($M = -0.2 \pm 0.6$). In addition, as would be expected due to cardiac-somatic coupling, there was a main effect of effort on HP change scores, $F(1,31) = 17.40$, $p < .01$. HP shortened more under high effort conditions ($M = -24.9 \pm 7.9$) and lengthened slightly under low effort conditions ($M = 3.7 \pm 8.4$). Heart rate increased under high effort conditions ($M = 1.6 \pm 0.6$) and decreased slightly under low effort conditions ($M = -0.7 \pm 0.6$). There was no interaction between control and effort on HP change scores, $F(1,31) = 0.67$, $p > .42$.

There were no main effects of control or effort or their interaction on PEP change scores, all Fs$(1,31) < 1.0$, all ps $> .80$. To obtain an estimate of parasympathetic activity that is controlled for respiration rate (Grossman, Stemmler, Karemaker, & Wieling, 1988), regression analyses were performed for each participant to predict first task minute RSA scores from RSA scores for the final minute of the baseline plus residualized respiration rate scores (calculated by regressing respiration rate during the first minute of the task on respiration rate during the final minute of the baseline). The resulting residuals were used as respiration-corrected RSA scores in the repeated measures ANOVA. There were no significant effects of control, effort, or their interaction on respiration-corrected RSA scores, all Fs < 1.0, all ps $> .62$.

Discussion

The results of the present study demonstrated that perceived control has an influence on SBP and TPR reactivity in a motivated performance task. When physical effort was high, both SBP and TPR increased more under low control than under high control

Table 1. *Mean (SEM) Raw Physiological Values for Baseline and Task by Condition*

	Low control				High control			
	Low effort		High effort		Low effort		High effort	
	Baseline	Task	Baseline	Task	Baseline	Task	Baseline	Task
SBP	107.6 (2.2)	107.9 (2.5)	106.1 (2.2)	110.5 (2.6)	107.1 (2.2)	107.5 (2.2)	107.6 (2.3)	106.7 (2.0)
DBP	67.7 (1.2)	70.9 (1.7)	66.7 (1.4)	70.2 (1.5)	66.9 (1.5)	69.3 (1.4)	67.4 (1.1)	69.5 (0.92)
MAP	82.2 (1.6)	86.0 (2.1)	81.3 (1.6)	87.7 (2.3)	81.6 (1.6)	84.7 (1.7)	83.1 (1.4)	85.2 (1.2)
TPR	1255 (71)	1343 (92)	1249 (76)	1390 (88)	1258 (76)	1316 (79)	1285 (76)	1323 (80)
CO	5.57 (0.28)	5.54 (0.31)	5.59 (0.28)	5.45 (0.30)	5.56 (0.29)	5.49 (0.29)	5.54 (0.29)	5.58 (0.31)
HP	881 (23.5)	870 (17.8)	887 (21.2)	860 (18.4)	870 (19.8)	887 (18.3)	882 (22.4)	859 (16.5)
PEP	100.3 (1.5)	101.3 (1.7)	99.8 (1.6)	100.8 (1.8)	100.9 (1.5)	102.1 (1.5)	100.2 (1.6)	101.7 (1.6)
RSA	7.13 (0.22)	6.61 (0.21)	7.24 (0.21)	6.71 (0.20)	7.15 (0.21)	6.67 (0.21)	7.18 (0.24)	6.55 (0.19)

Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, MAP = mean arterial pressure, TPR = total peripheral resistance, CO = cardiac output, HP = heart period, PEP = preejection period, and RSA = respiratory sinus arrhythmia. Sample size for HP, PEP, and RSA = 32. Sample size for SBP, DBP, MAP, TPR, and CO = 24.

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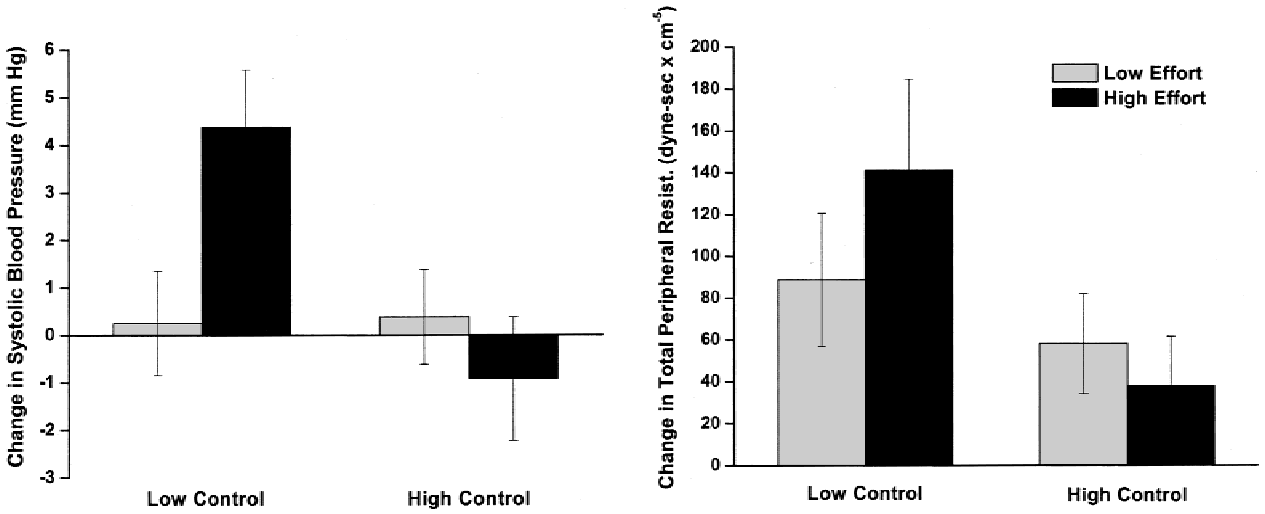

Figure 1. The effects of control and physical effort on systolic blood pressure and total peripheral resistance raw change scores. Error bars represent the standard error of the mean. Note: Statistical analyses were performed on the residualized change scores.

conditions. Our findings are conceptually similar to results of Geer et al. (1970) and Geer and Maisel (1972), who found lower autonomic reactivity (in the form of skin conductance responses) under control conditions relative to no control conditions in reaction time experiments requiring a button press. These previous studies, however, did not equate physical effort across control conditions. Because the present study manipulated effort independently of control, held motivation constant, and showed that task involvement did not differ by condition, it provides perhaps the most straightforward evidence to date for the proposition that control over an aversive stimulus during a motivated performance task reduces SBP and TPR reactivity, particularly when considerable physical effort is required to exert control. Interestingly, however, SBP reactivity was very modest under low control, low physical effort conditions suggesting that perhaps the more detrimental condition with regard to cardiovascular risk is low control accompanied by substantial physical effort.

Physical effort or overt responding per se has been postulated by several investigators to play a role in the effects of control over stressors. For example, following the results of Hokanson et al. (1971) and DeGood (1975), and based on their own findings with cognitive tasks requiring substantial mental effort but little physical effort, both Manuck et al. (1978) and Soloman, Holmes, and McCaul (1980) suggested that one would only observe reductions in vascular reactivity under high control conditions when the task demands were not effortful. However, the results of the current study suggest that this proposition is not tenable, because the task used in the current study was both mentally and physically effortful.

Physical effort exerted in the service of control was key to Jay Weiss's theorizing about control over aversive stimulation in animals. He proposed that the magnitude of stress responses evoked in such experiments was a joint function of (a) the number of responses required to exert control, and (b) the relevance of the feedback received after making a response (Weiss, 1972, 1977). Relevant feedback occurred when the response was followed by stimuli signaling less environmental aversiveness (typically the cessation of the aversive stimulus). Stress responses were theorized to be larger both when the number of responses required to cope with the stressor increased and when the feedback was not relevant. This conceptualization is consistent with the marginal interaction between control and effort observed with SBP such that during low control conditions, reactivity is minimal when physical effort is low, but increased when physical effort is high. In addition, when physical effort is high and equal across the control conditions, the SBP reactivity evoked by relevant feedback (i.e., high control conditions) is lower than when the feedback is not relevant. Although there was no significant interaction of control and physical effort for TPR, the pattern of results is similar to that seen with SBP (see Figure 1). Weiss's conception was based on the effects of control on stress responses such as weight loss and ulcer formation in animals, and is not specific with regard to which stress responses will be affected. In addition, his results were based on comparisons across groups of experimental and yoked animals whose responses were not equated. It will be important for future research with humans and animals to consider not only the cognitive, but the physical demands involved in exerting control over an aversive stimulus.

Control had only a small or insubstantial effect on the cardiac and autonomic variables. It is not uncommon to find that changes in HP (or as often measured, heart rate) do not reliably track differences between control and no control (e.g., Geer et al., 1970; Soloman et al., 1980). This may be due to the fact that HP is multiply determined by autonomic and nonautonomic variables (Berntson, Cacioppo, & Quigley, 1991). To explore the possible autonomic differences between these conditions, we examined an estimate of parasympathetic change, RSA, and an estimate of sympathetic change, PEP. Although RSA was reduced under all task conditions in the current study (uncorrected raw change scores: −.46 to −.59), it was not differentially affected by either control or effort. The changes in PEP, the putative sympathetic estimate, in the present study were very small (0.94–1.50 ms) under all conditions and are nearly within the measurement error of this variable. Given the proposed importance of sympathetic activation in the damaging effects of repeated, exaggerated cardiovascular reactivity, it is important to consider what the PEP results suggest (Kaplan, Manuck, Adams, Weigand, & Clarkson, 1987; Kaplan, Manuck, Williams, & Strawn, 1993; Kaplan, Pettersson, Manuck, & Olsson, 1991; Strawn et al., 1991). Unfortu-

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nately, there were relatively large increases in TPR (a proxy for afterload) in the current study for many participants and across conditions, suggesting that we must be cautious in making the inference that PEP is an unbiased estimate of sympathetic activity in the current context (Berntson et al., 1994; Newlin & Levenson, 1979). Because of the difficulty of interpreting PEP under these conditions, we are reluctant to infer anything about potential sympathetic changes from these results.

There is an interesting difference between our results and some previous results with humans in which physical effort was minimal across control conditions. In some previous studies where control was exerted under minimal physical effort (Averill, 1973, Bohlin et al., 1985; Gerin et al., 1992), SBP and heart rate reactivity were observed to be greater under low control than high control conditions, consistent with the current findings. However, other studies in which perceived control was manipulated with minimal physical effort produced different results (e.g., Manuck et al., 1978; Solomon et al., 1980). In these latter two studies, high control was associated with greater SBP and HR reactivity. The former and latter studies differ in the affective value or salience of the stimuli over which participants had perceived control. In previous studies showing reactivity to be reduced by the perception of control, the event being controlled was positive or benign. For example, in the Gerin et al. study, participants controlled the length of the experiment and Averill's participants controlled the pace of the presentation of mental arithmetic problems. Conversely, in studies showing high control to be associated with greater cardiovascular reactivity, the stimuli being controlled were typically highly aversive. For example, in the Manuck et al. study, the participants were told that they would hear "tone shocks" (115 dB) that were described as "painful, but not dangerous" and participants rated themselves as more anxious (regardless of condition) during the tasks relative to the baseline periods. Similarly, Solomon et al. used electric shocks that were described as "painful." Thus, in studies in which the stimuli being controlled are affectively very unpleasant, control does not appear to attenuate the cardiovascular reactivity associated with a laboratory task. However, in studies in which the stimuli being controlled are affectively pleasant, or only mildly unpleasant, control does appear to attenuate the cardiovascular responses to the task. This proposition is also consistent with the results of the current study. Here, the aversive stimuli were referred to as "noise blasts" (88–92 dB) and were never described as painful. Ratings of stressfulness reported after each task suggested that, on average, the participants considered the tasks only moderately stressful. Moreover, in a follow-up study using a nearly identical methodology, we asked participants to report their perceptions of the noise blasts after all tasks were completed. In this follow-up study, 35 participants reported the overall aversiveness of the noise blasts to be 2.34 on a scale from 1 to 5 (1 = not at all aversive; 5 = very aversive). Thus, although we can only speculate at this point, the rather modest negative affective quality of the aversive stimuli in the current study may have played a role in the cardiovascular buffering effects of high control. The relatively moderate aversiveness of the task may also explain the small task-related cardiovascular changes. More studies are needed in which the affective quality of the stimulus or situation being controlled is examined while physical effort is measured or held constant across conditions. These studies will help to determine which of these factors plays a larger role in buffering or enhancing reactivity. The current findings are significant because they demonstrate that when physical effort is held constant across control conditions, having control over a mildly aversive stimulus has beneficial effects on blood pressure and TPR reactivity. It should be kept in mind, however, that these data cannot be generalized to the studies of beneficial health effects of longer term control.

The relatively small cardiovascular effects observed here do not permit any inferences about how control and physical effort exerted during a brief laboratory task will impact cardiovascular risk. Rather, the current results indicate that laboratory assessments attempting to make such statements about risk should be more attentive to factors such as the physical effort required to exert control, and the affective quality of the stimulus being controlled and the nature of the experimental situation. These factors, which have received little attention in the context of laboratory studies, may be very important in assessing the validity of the cardiovascular reactivity hypothesis (Manuck, 1994).

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