Arousal, Anxiety, and Performance: A Reexamination of the Inverted-U Hypothesis

Shawn M. Arent and Daniel M. Landers

Until recently, the traditional Inverted-U hypothesis had been the primary model used by sport psychologists to describe the arousal-performance relationship. However, many sport psychology researchers have challenged this relationship, and the current trend is a shift toward a more "multidimensional" view of arousal-anxiety and its effects on performance. In the current study, 104 college-age participants performed a simple response time task while riding a bicycle ergometer. Participants were randomly assigned to one of eight arousal groups (between 20 and 90% of heart rate reserve) and were told they were competing for a cash prize. Prior to the task, the Competitive State Anxiety Inventory-2 and Sport Anxiety Scale (SAS) were administered to assess the influence of cognitive and somatic anxiety. As hypothesized, regression analysis revealed a significant quadratic trend for arousal and reaction time. This accounted for 13.2% of the variance, \( F(1, 101) = 15.10, p < .001 \), in performance beyond that accounted for by the nonsignificant linear trend. As predicted by the Inverted-U hypothesis, optimal performance on the simple task was seen at 60 and 70% of maximum arousal. Furthermore, for the simple task used in this study, only somatic anxiety as measured by the SAS accounted for significant variance in performance beyond that accounted for by arousal alone. These findings support predictions of the Inverted-U hypothesis and raise doubts about the utility theories that rely on differentiation of cognitive and somatic anxiety to predict performance on simple tasks that are not cognitively loaded.

Key words: activation, exercise intensity, reaction time

Until recently, the traditional Inverted-U hypothesis had been the primary model used by sport psychologists to describe the arousal-performance relationship. This hypothesis is based on work by Yerkes and Dodson (1908), which focused on the decision-making abilities of mice when presented with varying intensities of a stressor. According to the basic tenets derived from this research, optimum performance should be seen at levels of moderate arousal. As arousal approaches extremes (a comatose state on one end and panic attack on the other), performance will decline accordingly. The end result is a curvilinear relationship between arousal and performance that resembles an inverted-U. Modification of this hypothesis for application to sport has also suggested that this relationship is dynamic (Landers & Arent, 2001; Mahoney, 1979). That is, the curvilinear function can shift to the left or right depending on individual characteristics (i.e., high skilled or low skilled, extroverted or introverted) and the type of task (i.e., simple or complex). This inverted-U relationship has been demonstrated across numerous studies in the psychological and motor performance literature (e.g., Anderson, 1990; Babin, 1966; Levitt & Gutin, 1971; Martens & Landers, 1970; Wood & Hokanson, 1965). Other investigators, however, have questioned the lack of clear support for the inverted-U relationship (Hockey, Coles, & Guillard, 1986; Jones, 1996; Neiss, 1988). Despite a number of criticisms, even the most ardent critics have, at times, used the inverted-U hypothesis to support their findings (Hockey et al., 1986) or have stated, "...as a correlational rather than causal hypothesis, it can be said to be supported by the totality of evidence..." (Neiss, 1988, p. 355).

The criticisms of the inverted-U hypothesis have been conceptual and methodological. Investigators (Anderson,
Another criticism of the inverted-U hypothesis is that it is incapable of explaining any relationships between arousal levels and subcomponents of performance (Hockey & Hamilton, 1983). This, though, appears to be due to the global nature of the operational definitions of performance (i.e., winning, losing, or placing in a given event) used in many of the available studies rather than a flaw in the proposed inverted-U relationship itself. The inverted-U function needs to be examined with performance tasks that lend themselves to a ratio scale of measurement and contain task elements known to be important for sport performance.

By not recognizing the conceptual and methodological limitations of the available research, investigators (Hardy & Fazey, 1987; Jones, 1995; Krane, 1992) may have prematurely dismissed the inverted-U as outmoded and replaced it with theory and research derived from multidimensional anxiety models. Multidimensional competitive anxiety theory is primarily based on work in educational and clinical psychology, which advances the notion that anxiety can be separated into subcomponents of cognitive and somatic anxiety (Davidson & Schwartz, 1976; Liebert & Morris, 1967; Morris, Davis, & Hutchings, 1981; Wine, 1971). According to the early multidimensional anxiety researchers (Borkovec, Weerts, & Bernstein, 1977; Davidson & Schwartz, 1976), cognitive worry and somatic anxiety change differentially prior to and during performance evaluation. Furthermore, somatic anxiety increases prior to evaluation, but cognitive worry changes only when performance actually changes. Also, according to Morris and Liebert (1970), cognitive worry is consistently inversely related to performance, but somatic anxiety is related to performance only when cognitive worry is low.

Martens, Burton, Vealey, Bump, and Smith (1983) attempted to adopt these proposals to sport settings by developing the sport-specific Competitive State Anxiety Inventory-2 (CSAI-2). In addition to cognitive worry and somatic anxiety, they included self-confidence in their “multidimensional” instrument. According to Martens, Vealey, and Burton (1990), cognitive anxiety encompasses negative concerns about performance, an inability to concentrate, and disrupted attention before and during performance evaluation. Somatic anxiety is a perception of bodily symptoms of autonomic reactivity, often characterized by feelings of butterflies in the stomach, racing heart, and shakiness. In other words, “somatic anxiety refers to the physiological and affective elements of the anxiety experience that develop directly from autonomic arousal” (Martens et al., 1990, p. 6). Recently, questions concerning the validity of the factor structure of the CSAI-2 have arisen. Confirmatory factor analyses (Cox, 2000; Lane, Sewell, Terry, Bartman, & Nesli, 1999) have not supported the factor structure originally obtained by Martens et al. (1983) in their “exploratory” factor analysis.
Smith, Smoll, and Schutz (1990) developed another multidimensional measure of competitive anxiety, the Sport Anxiety Scale (SAS). The SAS contains subscales of cognitive (expressed as worry and concentration disruption) and somatic anxiety. These subscales were initially identified by Smith et al. (1990) by means of confirmatory factor analysis and were recently verified by Dunn, Dunn, Wilson, and Syrotuik (2000). Tests of multidimensional anxiety theory have not manipulated arousal and examined the moderating effects of cognitive and somatic anxiety on performance. Instead, they have examined cognitive and somatic anxiety scores as a function of manipulating competition and evaluation apprehension, which can increase arousal. For instance, neither of the two most commonly cited CSAI-2 studies that support the separation of cognitive and somatic anxiety (Burton, 1988; Gould, Petlichkoff, Simons, & Veerena, 1987) manipulated arousal levels. These studies merely examined the relationship between anxiety and sport performance by considering “evaluation potential,” “time to competition,” or “time of season.” Further, the findings of these studies are neither entirely consistent with each other nor with the hypotheses derived from multidimensional anxiety theory. Gould et al. (1987) showed nonsignificant trends in cognitive anxiety and a negative linear trend for self-confidence. Burton (1988), on the other hand, showed a significant negative linear trend for cognitive anxiety and a positive linear trend for self-confidence. The only similarity in the findings of the Gould et al. (1987) and Burton (1988) studies is the significant curvilinear trend between somatic anxiety and performance. Surprisingly, this lack of consistent findings has not been mentioned in more recent reviews of multidimensional anxiety theory (Jones, 1995; Wisberg, 1994). Whether these inconsistencies are due to conceptual and methodological factors or to inadequacies in multidimensional theory and instruments used to operationalize cognitive and somatic anxiety remains an open question. Regardless, it remains to be determined whether the current multidimensional competitive anxiety measures can predict significant amounts of performance variance.

In light of the challenges to the adequacy of the Inverted-U hypothesis as an explanation of the arousal-performance relationship, one purpose of this study was to test the validity of these contentions by treating arousal as an independent variable, while holding incentive constant (i.e., competition for a cash prize). The dependent measures were speed of participants’ performance on reaction time (RT), movement time (MT), and simple response time (SRT) tasks. Based on the dynamic nature of the Inverted-U relationship and the type of “simple” performance measures used, it was hypothesized that optimal performance would occur at 60–70% of a performer’s maximal arousal and that the decline in performance at 80 and 90% of maximum arousal would be gradual rather than steep. Another purpose of this study was to examine performance changes as a function of cognitive and somatic anxiety. Based on the multidimensional anxiety findings to date (Burton, 1988; Gould et al., 1987), it was hypothesized that somatic, but not cognitive, anxiety would account for performance variance beyond that explained by arousal alone.

Method

Participants

Participants consisted of 104 college-age students enrolled in exercise science courses at a major southwestern university. Of these, 41 were men, and 63 were women. To minimize fatigue and carryover effects associated with within-participants designs, a between-participants design was used in the present study. Participants were stratified by sex and then randomly assigned to one of the following eight arousal groups: 20, 30, 40, 50, 60, 70, 80, or 90% of relative heart rate reserve (HRR), which was calculated using the Karvonen Method (Karvonen & Vuorimaa, 1988). The use of HRR, which is highly correlated to maximal oxygen uptake (V̇O₂max; Pollock & Wilmore, 1990), allowed for standardization of arousal relative to each participant. Although there is potential for error when using an estimated maximum heart rate, this measure was deemed appropriate given the homogeneity of the healthy college sample. To further reduce variability, potential participants were excluded if they were using medication known to affect heart rate response (e.g., beta-blockers).

Apparatus

Performance Measures. SRT, RT, and MT were used as measures of participants’ performance. The task was performed while participants rode a bicycle ergometer at their assigned percentage of HRR. A two-key telegraph assembly was affixed to a countertop surface approximately waist high on the side participants indicated corresponded to their preferred responding hand. Participants were required to depress a “home” key until presented with the stimulus, which was a red signal light (RT measure). At this time, participants were to move their hand forward rapidly in a sagittal plane a distance of 9 cm to depress a red telegraph key directly in front of the home key (MT measure) and then return to the home key until presented with the next stimulus. The summation of the RT and MT constituted the measure of response time. A white warning light served as a
"ready" signal prior to each stimulus onset. The time between warming light and stimulus light was random between 0.5, 1.0, and 1.5 s to prevent participants from anticipating the impending stimulus.

All participants were familiarized with the procedure before completing a sample trial consisting of four stimulus presentations. Once the participants were familiarized with the task, they completed a performance trial consisting of responses to 12 stimulus presentations while riding the bicycle ergometer at their assigned HRR percentage. Pilot testing with 12 participants indicated that this was the maximum number of responses an individual could reasonably complete while riding at 90% of HRR. The SuperLab 1.0 software package (Cedrus Company, Phoenix, AZ) was used to record RT, MT, and SRT.

Anxiety Measures. To assess the impact of preperformance anxiety on performance, the CSI-2 (Martens et al., 1990) and the SAS (Smith et al., 1990) were administered prior to testing. The CSI-2 is a 27-item instrument with three subscales: cognitive anxiety, somatic anxiety, and self-confidence. Each subscale is composed of nine items that are summed to obtain an estimate of the respective construct. Because one purpose of this study was to determine the contribution of anxiety to the prediction of performance and, more specifically, examine the conceptual separation of cognitive and somatic anxiety, the CSI-2 was administered in its entirety, but only the cognitive and somatic anxiety subscales were used in subsequent analyses.

The SAS is a 21-item instrument containing a somatic anxiety subscale (nine items), and two cognitive anxiety subscales—worry (seven items) and concentration disruption (five items). As with the CSI-2, the items for each SAS subscale are summed to obtain a score for that construct. For both the CSI-2 and the SAS, participants were asked to respond to each item on a 4-point Likert scale ranging from "not at all" to "very much so" based on how they felt at that moment. Both the CSI-2 and SAS were chosen to evaluate whether inconsistencies in the results of research on multidimensional anxiety theory were due to the instrument used or problems associated with the conceptual separation of cognitive and somatic anxiety.

Procedure

Participants were asked to refrain from exercise or consuming caffeine or other stimulants for 3 hr prior to their arrival. On arriving at the laboratory, participants were given a general explanation of the task and signed an informed consent form approved by the Human Subjects Institutional Review Board. Participants were fitted with a Polar Vantage XL heart rate monitor (model #145900; Polar Electro Inc., Port Washington, NY). At this time, they were led to a dimly lighted room and asked to sit in a reclined chair for 20 min. Participants were told to relax and to remain seated until after the experimenter returned so that their resting heart rate (RHR) could be recorded. Measurement of RHR was necessary to calculate relative HRR according with procedures described by Karvonen and Vuorimaa (1988).

Following the rest period, participants were seated at a table and told they would be performing a simple response time task. To hold incentive constant rather than use it to manipulate arousal levels, participants were told that the three fastest responders would receive a $150 award. This was done to instill a sense of competition and increase the cognitive load for this simple task. Participants were then asked to complete the CSI-2 and SAS. While they were doing this, their HRR was calculated and a HR range established based on the percentage of HRR group to which they had been assigned. For example, if a participant had been assigned to the 50% HRR group, the participant’s HR range was from 48–52% of HRR. This typically allowed a 4–5 beat range.

After HRR percentages were determined, the familiarization session for the response time task commenced. During this time, participants sat on but did not pedal the bicycle ergometer. Once participants were comfortable with the performance task, they were instructed to begin pedaling the ergometer. The experimenter then manipulated the tension of the ergometer and the cadence of the participants to get them into their “target” heart rate zone. To ensure a steady state of arousal had been achieved, participants had to stay within the required HRR range for 60 s before beginning a performance trial. Once this steady state was achieved, participants responded to the 12 stimulus presentations. Heart rate was monitored throughout this trial, and, if it deviated from the assigned range, the participant performed the task again until the range was maintained. However, only 3 participants had to repeat this protocol.

Design and Analysis

The 12 performance trials for each participant were combined to get a performance trial average for response time, reaction time, and movement time. Outlier trials (3 standard deviations from mean) were eliminated, and the remaining trials were averaged. For each of the three performance measures, hierarchical regression analyses were then performed using the respective performance measure as the criterion variable. The use of a hierarchical regression analysis was deemed necessary to examine incremental changes in the partitioning of variance explained by each predictor as well as to test the potential curvilinear nature of the proposed model adequately. The linear function of group arousal level was entered as a predictor at Step 1,
followed by the quadratic function of group arousal level at Step 2, the CSAI-2 scores for somatic anxiety at Step 3, the quadratic function of somatic anxiety at Step 4, the CSAI-2 scores for cognitive anxiety at Step 5, and the quadratic function of cognitive anxiety at step 6. In addition, the Pearson product-moment correlations were examined. Separate hierarchical regression analyses were also performed for the SAS scores using each of the three performance measures as the criterion variable. The linear function of group arousal level was entered as a predictor at Step 1, again followed by the quadratic function of group arousal level at Step 2. The SAS scores for somatic anxiety were entered at Step 3, followed by the quadratic function for somatic anxiety at Step 4, worry at Step 5, the quadratic function of worry at Step 6, concentration disruption at Step 7, and the quadratic function of concentration disruption at Step 8.

Results

As hypothesized, regression analysis revealed a significant quadratic trend for arousal and reaction time, $F_{\text{change}} (1, 101) = 15.098, p < .001$. This also accounted for 13.2% of the variance in performance. The performance curve is illustrated in Figure 1 and indicates that, as predicted for a simple task, optimal performance was seen at 60–70% of maximum arousal. The quadratic function for SAS somatic anxiety also predicted a significant amount of variance in RT beyond that predicted by arousal alone, $F_{\text{change}} (1, 99) = 4.094, p < .05$. Together, the quadratic function of arousal and the quadratic function of somatic anxiety (as defined by the SAS) accounted for 18.5% of the variance in RT. None of the other SAS or CSAI-2 predictors were significant, all $p > .10$ and $p > .05$, respectively. Pearson product-moment correlations also revealed that CSAI-2 somatic and cognitive anxiety scores were significantly related, $r = .53, p < .001$ as were SAS somatic anxiety and worry scores ($r = .66, p < .001$) and SAS somatic anxiety and concentration disruption scores ($r = .36, p < .001$). Correlations between the SAS and CSAI-2 subscales are presented in Table 1.

Contrary to the hypothesis, regression analysis revealed a significant linear trend for arousal and movement time, $F_{\text{change}} (1, 102) = 10.973, p < .01$. This accounted for 9.7% of the variance in performance. The performance curve is illustrated in Figure 2, with faster movement times being associated with higher levels of physiological arousal. None of the other CSAI-2 or SAS predictors were significant, all $p > .28$ and $p > .10$, respectively.

As hypothesized, regression analysis also revealed a significant quadratic trend for arousal and response time, $F_{\text{change}} (1, 101) = 12.976, p < .001$, with arousal

<table>
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<th>Subscale</th>
<th>CSAI-2 cog</th>
<th>CSAI-2 som</th>
<th>SAS worry</th>
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Note. CSAI-2 = Competitive State Anxiety Inventory-2; SAS = Sport Anxiety Scale; cog = cognitive; som = somatic; conc = concentration.

**Significantly different from zero, $p < .005$.}

![Figure 1](image1.png)

**Figure 1.** Simple reaction time (RT) performance as a function of percentage of heart rate reserve (%HRR). The Y-axis has been inverted to express the improved performance associated with faster reaction times.

![Figure 2](image2.png)

**Figure 2.** Simple movement time (MT) performance as a function of percentage of heart rate reserve (%HRR). The Y-axis has been inverted to express the improved performance associated with faster movement times.
accounting for 14.8% of the variance in response time performance. The performance curve is illustrated in Figure 3. As with RT, the quadratic function for SAS somatic anxiety also predicted a significant amount of variance in response time beyond that predicted by arousal alone. F change (1, 99) = 6.556, p < .05. Together, the quadratic functions of arousal and somatic anxiety (as defined by the SAS) accounted for 20.4% of the variance in response time. None of the other SAS or CSAS-2 predictors were significant, ps > .10 and ps > .50, respectively.

**Discussion**

The strengths of the present study include the conceptual distinction between arousal and anxiety, controlling for incentive and directly manipulating arousal, the use of more levels of arousal (n = 8) than have previously been investigated, and normalizing these levels of arousal relative to each participant's maximum. These conceptual and methodological issues have not been consistently employed in previous research. Given sufficient attention to these issues, this study found that arousal, more than any other variable examined in this study, explained a majority portion of the variance in RT and SRT (13.2 and 14.8%, respectively) and supported the prediction of an inverted-U relationship between arousal and performance. As expected for simple RT and SRT tasks, the peak of this curvilinear relationship between arousal and performance was skewed slightly to the right (i.e., 50–70% of maximum). In contrast to the predictions of catastrophe theory (Hardy & Parfitt, 1991), there was no sharp decline in performance when participants were cycling between 70–90% of their maximum HR. The support in this study for an inverted-U relationship between arousal and performance suggests that this hypothesis is not outdated, flawed, or useless as some have argued (Hockey et al., 1986; Jones, 1995; Neiss, 1988). Instead, the hypothesis appears viable as long as investigators strive to use rigorous methodology to investigate it.

A nonmonotonic relationship was not found for arousal and MT. Instead, the significant relationship between these two variables was linear and accounted for 9.7% of the variance. This relationship showed that MT performance improved with higher levels of arousal. The ballistic movements in MT are devoid of some cognitive elements present in the RT measure. Because the decision to move constituted part of the RT measure, the MT measure was devoid of decisions, contained few, if any, competing stimuli, and involved a few large muscles where precision, steadiness, and fine motor skills were not required. Under circumstances in which the task complexity is extremely low, the relationship between arousal and performance is linear and more in accord with predictions of drive theory (Spence & Spence, 1966). The habit strength associated with a ballistic arm movement to a target (e.g., reaching for food or a drink) is strong and typically develops early in life. It may be that for simple speed of movement tasks like these (Oxendine, 1984), arousal acts to enhance the probability of performing this task (i.e., greater speed in responding).

Another finding of this study was that somatic anxiety as measured by the SAS contributed to the amount of RT (5.3%) and SRT (5.6%) variance that was explained. This contribution, although significant, was less than half the amount of variance explained by arousal. As predicted, somatic anxiety demonstrates a curvilinear relationship to performance. Furthermore, somatic anxiety increases the amount of variance accounted for in performance above and beyond that accounted for by arousal alone. However, regardless of the order of entry of variables in the regression analysis, neither cognitive (as measured by either the CSAS-2 or SAS) nor somatic anxiety (as measured by the CSAS-2) accounted for a significant amount of performance variance. These results, particularly those for the CSAS-2 somatic measure failed to support the CSAS-2 findings of Burton (1988) and Gould et al. (1987). Without comparable CSAS-2 somatic findings, the results of this study only partially support the second hypothesis of this study.

The failure of the CSAS-2 somatic measure to predict performance may be due partly to the psychometric characteristics of this instrument or the conceptual issues in trying to separate cognitive from somatic anxiety operationally. The CSAS-2 has been criticized for not having adequate psychometric support for partitioning anxiety into distinct cognitive and somatic subcomponents.

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**Figure 3.** Simple response time (SRT) performance as a function of percentage of heart rate reserve (%HRR). The Y-axis has been inverted to express the improved performance associated with faster response times.
criticism is based on recent confirmatory factor analyses (Cox, 2000; Lane et al., 1999) showing that the questions in the CSAI-2 did not support the initial factor loadings derived by Martens et al. (1983). The SAS has better psychometric characteristics that have been supported by confirmatory factor analyses (Dunn et al., 2000; Smith et al., 1990). Inspection of the somatic questions from the CSAI-2 and SAS shows that six of the nine items are identical, but three differ markedly from each other. The CSAI-2 contains one reverse-scored item (“My body feels relaxed”) that is opposite of another item on the CSAI-somatic scale (“My body feels tense”). The SAS-somatic scale contains no reverse-scored items and has unique items dealing with “trembling sensations,” “stomach upset,” and “heart pounding.” It may be that study participants can relate more with the arousal symptoms expressed in the SAS questions than they can with symptoms in the CSAI-2 questions.

Martens et al. (1990) maintained that the “value in measuring cognitive and somatic A-state separately is based on the conceptual arguments and empirical evidence that these two anxiety components are elicited by different antecedents and that they influence behavior differently” (p. 196). Results from this and other recent studies do not support the concept that the cognitive and somatic anxiety components consistently predict performance differently. When differences in predictive utility were found, it was due primarily to the lack of prediction by the cognitive anxiety component. For example, this study found no significant relationships between simple RT, MT, and SRT performance and cognitive anxiety, as measured by either the CSAI-2 or SAS. It may be that, for tasks of the type in which the cognitive load is relatively low (e.g., competitive incentive held constant and one choice of when to respond), somatic anxiety, and particularly cognitive anxiety, do not predict performance well. The findings of a recent meta-analysis of 29 CSAI-2 studies (Graft, Magyar, Becker, & Feltz, 2003) support this idea. For closed skills such as the simple tasks used in this study, the relationship of CSAI-2 somatic and cognitive anxiety to performance was only .01 and .01, respectively. For tasks categorized as being open skills (i.e., greater cognitive load), the correlations between CSAI-2 somatic and cognitive anxiety with performance was .15 and .23, respectively. These latter correlations were statistically significant. These findings suggest that better support for the multidimensional anxiety theory or for the usefulness of the CSAI-2 might be obtained with more complex tasks that contain more of a cognitive load.

Future research in the arousal-performance realm must begin to explore the dynamic nature of the inverted-U hypothesis by using tasks of varying complexity while providing the same level of control and arousal manipulation as the present study. Researchers should also begin to make attempts to apply this approach to more sport-specific situations. However, in doing so, they must exercise caution in providing necessary methodology: directly manipulating arousal, standardizing arousal levels, using a large number of arousal levels, and using performance measures that are both meaningful and lend themselves to objective scoring.

Attempts should also be made to begin to explore the underlying mechanisms that influence the shape of the arousal-performance curve. The inverted-U hypothesis is simply a descriptive relationship; it is not a theoretical explanation. By investigating the potential underlying mechanisms, as suggested by Easterbrook’s Cue Utilization Theory (1959) or by Signal Detection Theory (Swets, 1964), a better understanding of how and why arousal influences performance could be generated and could, thus, potentially improve the predictive ability of the arousal-performance model. In light of the current study, it is increasingly clear that abandoning the inverted-U hypothesis is unwarranted. Instead, the findings of the present study simply suggest the need for better studies in the arousal-performance area.

References


Notes

1. Because it is not conclusively known which, if any, of these CSAI-2 or SAS measures can best predict changes in performance, both measures were used in the present study.

2. Only 9 of the 1,248 trials (0.7%) met the criteria for being outliers. These trials were distributed across the arousal conditions and only constituted one trial for each of 9 different participants.

3. Although the described order of entry for the hierarchical regressions was considered theoretically appropriate, all other possible orders of entry were also tested. In all cases, the only significant predictor of performance was the quadratic function of group arousal level. None of the other predictors was significant, ps > .10.
Authors’ Note

Please address all correspondence concerning this article to Daniel M. Landers, Department of Kinesiology, Box 870404, Arizona State University, Tempe, AZ 85287-0404.

E-mail: Landers@asu.edu