THE EFFECT OF ACUTE RESISTANCE EXERCISE ON FEELINGS OF ENERGY AND FATIGUE

by

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(Under the Direction of Patrick J. O’Connor)

ABSTRACT

Purpose: The effect of acute moderate-to-high intensity resistance exercise on energy and fatigue feelings was examined as was resting physiologic tremor as a potential biological correlate of fatigue feelings. Methods: Fourteen physically inactive females reporting persistent fatigue feelings completed 3 conditions in random order 1 day-week$^{-1}$ for 3 consecutive weeks. Resting tremor amplitude was assessed before the conditions. Mood was assessed before conditions, every 11 min and 40 s during, and 20 and 30 min following conditions. Results: Vigor was significantly higher for 70% 1-RM compared to control ($t=3.12$, $p=.01$). Fatigue was significantly lower for 15% 1-RM/placebo compared to control ($t=-2.59$, $p=.04$). Hand tremor amplitude was positively correlated with baseline fatigue feelings ($r=.36$). Conclusions: Acute moderate-to-high intensity resistance exercise increased energy feelings during and following exercise compared to control. Tremor may be a biological correlate of fatigue feelings.

INDEX WORDS: Energy, Fatigue, Mood, Tremor, Weight lifting, Vitality
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“For God hath not given us the spirit of fear; but of power, and of love, and of a sound mind.”

- 2 Timothy 1:7

I would first like to thank God for the abilities which He blessed me with that allow me this pursuit. As yet another chapter appears to be unfolding in this day to day rollercoaster that we all take for granted, I am humbled by the abilities that the Lord has allowed me to carry through this life. The real probability is that few eyes will graze across these words from this point forward, but if you are reading this, thank you for the role that you play in someone’s life and please remember to thank Him for the role He plays in yours.

Through the opportunity for growth that this thesis has been I have realized a number of things. Primarily, life is neither about those who win the race or those who pace others by their footsteps, nor is it about learning to follow the lead of another. I have learned that my life is about those who run step for step with me continuously by my side. For this blessing, I cannot express the debt of gratitude I owe to the love of my life Lisa, and my ironically perfect family. To each of you, Lisa, Jimmy, Rita, Josh and Anna, I owe a part, if not all of my life, and every ounce of my love, for you all, not this or anything else, make me who I want to be.

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CHAPTER 1
INTRODUCTION

Feelings of low energy and fatigue have become a common societal problem. Approximately 24% of the U.S. population report persistent fatigue (37). There is also a strong association between feelings of fatigue and health-related quality of life. Both contribute to a myriad of issues of daily living, such as health problems, cognitive and physical performance, and overall productivity (51). Therefore, reliable methods for improving feelings of fatigue and low energy could have dramatic beneficial effects on enhancing quality of life.

Individuals commonly attempt to transiently improve feelings of low energy and fatigue through various methods including the consumption of caffeine and/or snack foods containing high levels of simple sugars. Although potentially effective, caffeine may have adverse side effects including increased anxiety and sleep disturbance (29). Frequent consumption of snack foods may also result in negative health consequences such as increased body weight and fat mass (27).

Although an extensive amount of research has examined the effect of healthful alternatives such as exercise on mood, relatively little scientific research has focused on whether an acute bout of exercise improves feelings of low energy and fatigue. The majority of exercise research has focused on ameliorating negative mood states such as depression (e.g. 16, 49) and anxiety (e.g. 50, 52). Although much less attention has been placed on examining the influence of exercise on feelings of energy and fatigue specifically, a small number of studies have reported reductions in feelings of fatigue or improvements in feelings of energy following acute
low-to-moderate intensity exercise (e.g. 24, 74). These results illustrate the potential for acute exercise to improve feelings of energy and fatigue.

The time course and dose-response effects of exercise on post-exercise feelings of energy and fatigue are poorly understood. Potential moderating factors have rarely been examined. Potential moderators include age, sex, sleep habits, the level of pre-exercise feelings of energy and fatigue, the degree to which feelings of energy and fatigue change during the course of the exercise session, and the exercise stimulus, including rest intervals and mode. The weight of the available evidence indicates that moderate intensity, lower-body, dynamic exercise such as walking and cycling is often associated with improvements in feelings of energy and fatigue following acute exercise (56, 74).

Resistance exercise has become an increasingly popular mode of exercise because of associated health benefits including increased muscular strength, bone mineral density, and physical function (31). The effects of acute bouts of resistance exercise on feelings of energy and fatigue are poorly understood. A literature search yielded only five published investigations that examined the effects of acute resistance exercise on feelings of energy and fatigue (4, 19, 43, 62, 73). From this small body of research, it is difficult to formulate scientifically defensible conclusions. This problem is due, in part, to a number of key methodological limitations.

The psychological consequences of acute resistance exercise could not be examined conclusively in three of the five studies due to the lack of a control comparison condition (43, 62, 73). Although the remaining two studies (4, 19) utilized a control condition, neither used both a no-treatment condition to control for the potential confound of the passage of time and a placebo condition to control potential attention effects. One of these studies also failed to assess and report the rest interval between exercise sets (4), yet rest interval is likely to be a moderating
factor for post-workout feelings of fatigue (73). In the other study the results were confounded because social and environmental interactions were not controlled because the participants were allowed to leave the testing area during the post-exercise assessment period (19). Social interaction effects during the resistance exercise sessions were not controlled in any of these investigations. A final potential limitation was that both upper- and lower-body exercise was performed. Perceptual responses to upper-body exercise are higher compared to lower-body exercise (54).

The primary purpose of the investigation summarized here was to evaluate changes in feelings of energy and fatigue during and for 30 min following an acute bout of moderate-to-high intensity, lower-body resistance exercise. Novel aspects of the investigation are: (a) the focus on sedentary participants characterized by persistent feelings of low energy and fatigue; (b) the focus on lower-body weight lifting exercises; (c) the use of both a no-treatment control condition and a placebo condition which will strengthen the research design; and, (d) the more frequent assessment of mood during exercise compared to prior research; this approach will better assess the time course of changes in mood during exercise.

A secondary purpose of the present investigation was an exploratory examination of the relationship between the intensity fatigue feelings and physiologic tremor. The central nervous system (CNS) is thought to play a role in both physiologic tremor and feelings of fatigue. Specifically, there is an emerging body of evidence that links the cerebellum, basal ganglia, and related thalamic structures involved in the control of movement to fatigue mood states (13). Drugs known to act on the central nervous system and to affect feelings of energy and fatigue also have been reported to affect tremor (7, 45, 47, 67, 71). Other drugs which rapidly increase CNS dopamine levels attenuate tremor (7) and also enhance feelings of energy (32).
In summary, there is evidence suggesting overlap in the CNS neurology that underlies both physiologic tremor and feelings of fatigue. Given that nearly one quarter of the population report persistent fatigue (37), the identification of neurological correlates of fatigue feelings is of interest. However, no investigation has empirically examined the association between the intensity of fatigue feelings and physiologic tremor. Thus, the present investigation examined physiologic tremor as a potential biological correlate of fatigue feelings.
CHAPTER 2
REVIEW OF LITERATURE

This literature review has two main sections. The first section reviews relevant literature on the influence of an acute bout of exercise on energy and fatigue mood states. The second section concerns physiologic tremor as a possible biological correlate of fatigue feelings.

Acute Exercise and Energy/Fatigue

Feelings of energy and fatigue have been conceptualized in different ways. For instance, fatigue has been reported as both a side-effect of the treatment of cancer, as well as a prominent symptom of the disease (65). This review focuses on energy and fatigue conceptualized as moods. Specifically, the mood state of energy may be defined as positive, subjective feelings about one’s capacity to perform cognitive or physical activities, while the mood state of fatigue can be defined as negative, subjective feelings about having reduced capacity to complete such activities (51).

The effects of exercise on mood have been extensively researched (60). Interest has been placed on the ability of exercise to ameliorate the negative consequences associated with negative mood states (62). A number of studies have also reported exercise both as a mood-regulating strategy and as a method to enhance mood (e.g. 3, 5, 36, 74). The focus of the available research has varied considerably. One type of investigation has examined the relationship between chronic exercise, or exercise training, and feelings of energy and fatigue (53). Although others (e.g. 57, 78) have reviewed the available evidence on the relationship between acute exercise and mood states, very little research has focused on the effects of acute
exercise on feelings of energy and fatigue. There is evidence that a single bout of moderate intensity aerobic exercise can improve feelings of energy and fatigue (24, 57). However, a very limited amount of research has been focused upon gaining a greater understanding of the effects of resistance exercise on feelings of energy and fatigue.

Resistance exercise has been used as a stimulus to examine various psychological effects including depression (e.g. 49, 68-70), anxiety (e.g. 2, 33, 50, 52, 61), and cancer fatigue (66). Only a small number of studies have examined the effects of acute resistance exercise on mood states (33, 52, 61).

**Literature Search**

Literature was identified by searching *Google Scholar, PubMed, PsycInfo, PsycArticles,* and *Web of Science* databases, using search terms and phrases such as resistance exercise, resistance training, weight lifting, weight training, strength training, and anaerobic exercise. These phrases were combined with search terms such as “POMS,” “Profile of Mood States,” “EFI,” “SEES,” “PANAS,” “SF-36,” fatigue, energy, vigor, vitality, or mood. Search terms such as tremor, physiologic tremor, and physiological tremor also were used to identify relevant physiologic tremor literature. Papers which utilized acute resistance exercise as an exercise intervention and also reported mood score data on energy and fatigue were identified; the reference lists of those studies were then examined for additional sources. The search yielded 5 experimental studies that reported the effects of acute resistance exercise on feelings of energy and fatigue. Studies were excluded in which resistance exercise was not indicated as the specific exercise intervention and in which mood scores for energy and fatigue were not reported.
Evidence

Five studies were identified from the literature search: 2 randomized controlled trials (4, 19) and 3 quasi-experimental designed studies (43, 62, 74).

Quasi-Experimental Evidence

Three quasi-experimental design studies that assessed the relationship between acute resistance exercise and feelings of energy and fatigue were identified. The studies were delineated as quasi-experimental as a result of either the lack of a control comparison condition (62, 74) or the lack of random assignment to the control comparison condition (43).

Rehor et al. Study

In a study of the alterations of mood states following an acute bout of exercise, 44 volunteer university students in either weight training, racquetball, or circuit training classes were examined (62). The participants in the resistance exercise condition (n=14) responded to the Profile of Mood States questionnaire (44) before and after one class session. During the exercise session, participants performed three sets of three basic lifts at approximately 70% of their one-repetition maximum (1-RM). The results of the study indicated a significant increase in vigor across the 45 minutes of the exercise session (Cohen’s d ES = ~0.70); the authors reported no significant changes in fatigue (62).

Although a significant increase in feelings of energy was reported following an acute bout of resistance exercise, key methodological issues should be discussed. No precise description was given of the exact lifts performed, the number of repetitions completed in each set, or the rest interval between sets. The design was also confounded by the absence of a control comparison condition. Moreover, the acute results may also be confounded by previous exposure to chronic resistance training, and potential habituation to the effects of such training.
McGowan et al. Study

The effects of acute resistance exercise were examined in a sample of 39 volunteer college students. Participants in the resistance exercise condition (n = 28) completed the Profile of Mood States (44) questionnaire prior to and following a weight training class session. Control condition participants (n = 11) were involved in a traditional classroom lecture session (43). Participants in the resistance exercise condition were instructed to complete 4 sets of 4 repetitions at 80% 1-RM on the exercises of front squat and bench press. Results indicated that resistance exercise participants experienced a decrease in feelings of vigor (ES: 0.75) compared to the control group; participants also reported a slight increase in feelings of fatigue (ES: 0.02). These results were inconsistent with Rehor and colleagues (62) in that a large decrease in vigor was reported following an acute bout of resistance exercise.

The inconsistent nature of the results may be explained by specific research design issues. The number of participants in the exercise and control conditions was unequal and participants were not randomly assigned to conditions. Also, because a sport psychology lecture is not comparable to exercise, the control condition may not have been effective.

Moreover, participants in the resistance exercise condition were allowed to supplement the exercise protocol with additional lifts (i.e. arm curls, triceps extensions, leg curls, or leg extensions). Data on those lifts were not reported or analyzed. Allowing additional lifts diminished control over the independent variable because different muscle groups were targeted and different numbers of exercises, total repetitions, and total work were completed. This may have adversely influenced the accurate report of mood data following the actual resistance exercise protocol.
Additionally, the timing of mood measurements potentially confounded the results. Although fatigue would be expected to be higher immediately following resistance exercise at a high intensity than 20 – 60 min later, the investigation only measured mood immediately following the exercise session (43).

The design also allowed for potential history and habituation biases. For example, no fitness measures were incorporated into the design to assess participants’ experience level with resistance exercise or perception of the intensity of the resistance exercise. Fitness measures could have controlled for any initial differences in experience and fitness level.

Tharion et al. Study

The most practical results from the quasi-experimental studies were reported in an examination of the mood states of 9 men and 9 women (19-35 years of age) prior to and following six different resistance exercise protocols (2 workout protocols with 2 variations of each protocol) (74). The workout protocols differed on total work completed, total number of repetitions completed on 8 exercises (bench press, dual leg extension, military press, weighted sit-ups, pull-downs, seated rows, preacher arm curls, and leg press), and the length of the rest interval between exercise sets. Results indicated a large increase in Profile of Mood States (44) fatigue scores 2-min post-exercise; scores returned to baseline within 48 h. Feelings of energy (vigor) were found to decrease immediately following resistance exercise, but increased above baseline scores 2-h later (74). Similar to Rehor and colleagues (62), an increase in feelings of energy was reported following an acute bout of resistance exercise. Moreover, results were consistent with previous literature that reported an initial decrease in vigor and an initial increase in fatigue immediately following resistance exercise (43, 62).
The results also have important implications for future research. A significant main effect (ES: 0.92) of rest interval on fatigue was found (74). A shorter rest interval of 1 min between sets, as opposed to 3 min between sets, was associated with more fatigue, and the fatigue persisted for up to 120 min post-workout. This result showed that increasing the rest interval from 1 to 3 min is an effective strategy to attenuate post-workout fatigue.

The results also indicated an interaction effect (ES: 1.19) of work level, rest interval, and repetitions on fatigue (74). The effect was decomposed and indicated that more fatigue was experienced with shorter rest in combination with either more total work, or the same total work with more repetitions (74). Therefore, future studies should be designed to control for the combination of work, rest interval, and number of repetitions.

Although the study provides sound evidence of the relationship between acute resistance exercise and feelings of energy and fatigue, along with beneficial methodological considerations regarding rest interval and total repetitions, specific design issues limit the interpretation of the results. The study incorporated a within-subjects design with repeated measures, but did not include a control comparison condition. Although the study randomized the workout order across subjects to control for order effects, matched the total work between routines, and had equal numbers of men and women, the lack of a control comparison condition makes a precise interpretation of the effect of the intervention difficult.

The number and order of the exact exercises that were performed also may have negatively influenced mood scores. For example, bench press, military press, pull-downs, seated rows, and preacher arm curls are upper-body exercises, but differ in the primary and secondary muscles that are targeted. Perhaps limiting the amount of exercises to one particular large
muscle group would have allowed greater control. Also, although a variety of muscle groups were targeted, the order in which the exercises were performed was problematic.

The initial Profile of Mood State (44) scores of the study sample also should be considered in comparison with college-age norms. The sample appears to have a similar profile to the iceberg profile reported in elite wrestlers (48). Scores appeared to be significantly lower on all mood states except vigor, where the sample reported significantly more energy than college-age norms (74). The initial differences suggest a ceiling effect for vigor. Finally, the 24- and 48-h post-exercise mood measurements were also confounded. Because participants did not remain in the lab, a number of outside events could have confounded the report of mood data on the final two follow-up examinations.

Based on the available quasi-experimental evidence, the relationship between acute resistance exercise and feelings of energy and fatigue appears to be inconsistent. Such inconsistency could be attributable to differences in, or flawed, methodological design. Experimental evidence could provide more compelling information.

**Experimental Evidence**

The literature search identified 2 randomized controlled trials that allowed examination of the relationship between acute resistance exercise and feelings of energy and fatigue. Both experimental investigations (4, 19) utilized random assignment and a control comparison condition.

*Bartholomew et al. Study*

In a study of changes in psychological state following resistance exercise of different workloads, 54 volunteer undergraduate students were randomly assigned to one of three experimental conditions: 50% of 1-RM, 80% of 1-RM, or a no-exercise control condition in
which weight, height, and body composition measurements were taken (4). The resistance exercise session consisted of 3 sets of 5 repetitions on the upper-body exercises of bench press, overhead press, and dumbbell row, using either 50% or 80% 1-RM. Scores on the Exercise-Induced Feeling States Inventory (EFI; 21) were obtained pre-, 10 min post-, 25 min post-, and 40 min post-exercise to examine psychological state (4). Scores on the revitalization and physical exhaustion sub-scales indicated feelings of energy and fatigue, respectively (21).

Results indicated an increase in revitalization (feelings of energy) for both intensity groups (4). The low intensity group (50% 1-RM) reported the largest increase in feelings of energy (ES: 0.66), compared to the control condition, at 25 min following the resistance exercise protocol. The high intensity group (80% 1-RM) reported increased feelings of energy (ES: 0.21), compared to the control condition, within 10 min following the exercise protocol. Given the range of effect sizes across groups (ES: 0.15 – 0.66), feelings of energy appear to increase following acute resistance exercise of differing intensities (4).

Results did not indicate as large an effect for fatigue. Physical exhaustion scores did decrease over time for both exercise conditions. Participants in the 50% 1-RM condition reported a small to moderate increase (ES: 0.36), compared to controls, in feelings of fatigue 10 min following the workout; both conditions reported a decrease in fatigue across time, particularly at 40 min follow-up (50% 1-RM vs. control = ES: 0.10; 80% 1-RM vs. control = ES: 0.28) (4). However, the smaller effect of resistance exercise on reduction of feelings of fatigue may be due to the potential inaccuracy of the EFI as a measure of fatigue (4). The physical exhaustion sub-scale may not be as sensitive to changes in fatigue as were seen with the revitalization scale and energy.
Although the findings did indeed support the contention that acute resistance exercise results in decrease in feelings of fatigue and increases in feelings of energy, there are a number of methodological issues to consider when interpreting the results. The individuals in the exercise conditions were taken from weight lifting classes that the individuals had self-selected to attend. This allows history effects that may bias expectations about mood state responses. Moreover, each individual in the exercise conditions had 6 weeks of resistance exercise training prior to the experiment (4). Such prolonged prior exposure to lifting elicits training effects. Those effects potentially confound data attributable to the acute resistance stimulus.

A more significant design issue is the structure of conditions. The control condition did not appear to be a comparable condition to the exercise stimulus. During the control session, body composition data were collected over approximately the same duration as the exercise conditions (4). Although the body composition data were not released to the individuals until the end of the sessions, participants’ affective state could have been negatively or positively affected by the process. For instance, in utilizing the three-site skinfold test, participants’ mood could have been negatively influenced by focusing attention on his/her subcutaneous body fat. Similarly, greater control could have been attained by standardizing the exercise sessions. Results may have been confounded by social interaction effects resulting from participants lifting with each other.

Finally, reporting the rest interval between sets would have strengthened the results of the energy and fatigue data. The small effect on fatigue, yet large increase in energy may have been influenced by the amount of rest participants had during the exercise session. The relationship between exercise intensity and the mood measure could also have significantly moderated the results. For example, negligible differences in fatigue scores were reported across the groups.
The authors suggested that these data could be attributed to the potential lack of sensitivity in the physical exhaustion sub-scale of the EFI (4).

**Focht and Koltyn Study**

The psychobiological responses to moderate (50% 1-RM) and high (80% 1-RM) intensity acute resistance exercise were also assessed in 84 experienced and inexperienced weightlifters (19). Participants were randomly assigned to one of three conditions: 50% 1-RM, 80% 1-RM, and a no-exercise control condition. Individuals in the 50% 1-RM condition performed 3 sets of 12-20 repetitions with a 45-75 s rest interval between sets on bench press, leg press, torso-arm pulldown, and overhead press. Those in the 80% 1-RM condition completed 3 sets of 4-8 repetitions with a 120-150 s rest interval between sets on the same lifts. The control condition participants viewed a videotape of resistance exercise techniques that was of comparable duration to the exercise sessions (19). Prior to the experimental and control conditions and immediately, 20-, 60-, 120-, and 180-min after, participants completed the Profile of Mood States (44) questionnaire to assess mood state (19). Participants were also instructed to refrain from ingesting any mood altering substances such as coffee, tea, alcohol, and drugs for 6 h before the testing session. After the 60-min follow-up, participants were allowed to leave the testing area, but were instructed to return at 120-min and 180-min for the final two follow-up examinations (19).

The study indicated similar results for energy and fatigue. Participants in both exercise conditions reported an increase in fatigue immediately following the workout; however, scores were reduced below baseline, indicating a persistent decrease in fatigue, within 60 min of completion of the workout. Compared to controls, acute resistance exercise appeared to have a small-to-moderate effect on feelings of fatigue up to 60 min post-exercise (80% 1-RM vs.
control = ES: 0.16) (19). Participants reported decreased vigor immediately following resistance exercise; however, feelings of energy increased over time (19). There was a small-to-moderate effect for feelings of energy 60 min following acute resistance exercise (50% 1-RM vs. control = ES: 0.05; 80% 1-RM vs. control = ES: 0.48) for both intensities (19).

Key strengths and weaknesses evident in the Focht & Koltyn (19) study should be taken into consideration when interpreting the results. The researchers strengthened the design when potential history effects were controlled for by evaluating any significant differences between experience levels of participants. The evaluation found no significant differences between the inexperienced lifters and the experienced lifters (19).

However, there are a number of key design weaknesses. The control condition of viewing a resistance exercise technique video does not appear to be a comparable comparison to the exercise treatment. The video may also have had a positive or negative effect on mood responses. Another key limitation is the exercise session protocol. Although the protocol is succinct in that 4 exercises are used that target large muscle groups, the differences in the number of repetitions and rest interval between the groups potentially confounds the results. Although having the participants perform a fewer number of repetitions (4-8 vs. 12-20) with a heavier weight load (80% vs. 50% 1-RM) and longer rest between sets (120-150 s vs. 45-75 s) appears logical, the authors failed to match the groups on total work completed. Exercising at different total workloads confounds the potential effects of intensity and total work. Employing a design on which total workload was matched between groups would eliminate one plausible explanation for the results (74).

Another limitation of the study was that, upon completion of the 60-min follow-up, participants were allowed to exit the testing room, and they were asked to return for a 120-min
follow-up and a 180-min follow-up (19). Participants were only instructed to continue to refrain from ingesting mood-altering substances and not to perform any additional physical exercise. However, there are events that could take place, even in a short time that could influence mood. By allowing participants to leave the testing room, researchers lost a great degree of experimental control.

**Conclusions**

The available evidence of the effects of acute resistance exercise on feelings of energy and fatigue was reviewed. Results suggested that acute resistance exercise of 50% - 80% 1-RM done for 3-5 sets of 8-12 repetitions is associated with an immediate increase in feelings of low energy and fatigue. However, feelings of low energy and fatigue also have been shown to improve compared to pre-exercise baseline scores when mood has been measured 25 – 60 min following exercise (4, 19). Thus, the beneficial effects of acute resistance exercise on feelings of energy and fatigue appear to have a delayed onset. Although the limited amount of evidence to date suggests that resistance exercise facilitates improvements in feelings of low energy and fatigue, the exact nature of the relationship is still unknown.

**Future Research**

Based upon the key design and methodological weaknesses described in this review, future research should focus on designing studies with improved experimental control in order to isolate the specific effects of acute bouts of resistance exercise on feelings of energy and fatigue. Studies should utilize a pretest-posttest design in which mood data are obtained at multiple time points during and following the resistance exercise protocol. Studies should also minimize potential confounds associated with the exercise protocol by focusing and standardizing the manipulation. For example, future studies could attempt to focus on either the upper- or lower-
body and focus on specific, large muscle groups such as the chest, back, or quadriceps. Total number of sets, total number of repetitions, and rest interval between sets should also be specified.

Intensity of resistance exercise is also a key factor to focus on when designing future research. Results of previous investigations suggested that larger, more persistent increases in feelings of energy were reported after low intensity (50% 1-RM) compared to high intensity (80% 1-RM) resistance exercise (4, 19). However, methodological issues with design and exercise protocol potentially confounded the interpretation of those results. Future studies that seek to compare different intensities of resistance exercise should match the total work of different conditions.

Finally, future research should attempt to utilize both a no-treatment control condition and an attention/placebo condition that are more comparable to the exercise stimulus. For example, attention/placebo control condition participants could go through the exact same protocol as exercise condition participants with little or no weight. Participants would actually perform the movements associated with the lifts being used without the presumed active treatment ingredient (high absolute or relative exercise intensity).

**Physiologic Tremor**

Physiologic tremor is a normal, involuntary rhythmic oscillation with variable amplitude and a mean frequency range of 8 – 12 Hz (22). Classified as a postural tremor on the basis that it occurs when a limb is positioned against gravity (7), physiologic tremor is often most noticeable when the outstretched hand is held constant (23). Although numerous central and peripheral factors are thought to contribute to tremor, the causes of physiologic tremor are incompletely understood. It has been suggested that the causes of tremor can be reduced to a limited number
of factors, including peripheral mechanical factors, peripheral and central reflex loop feedback, and activity (i.e. central oscillations) in regions of the CNS (14, 17, 23).

**Peripheral Factor Involvement in Tremor**

Peripheral mechanical factors are thought to be dominant influences on the generation and alterations of tremor (23). The resonant frequency of an extremity is a key peripheral factor which is primarily determined by the inertia of the limb and joint stiffness (17, 23). This is to say that the joint system of the extremity, comprised of the joint and its associated muscles, has mechanical properties analogous to a spring-mass system (23). The frequency at which this system oscillates is a function of the inertia of the limb, or mass in the system, and the stiffness of the muscle, or spring (14, 23). For example, during exercise, muscle contraction would increase tremor through increases in the frequency of oscillations resulting from increased stiffness about the joint. Other key peripheral mechanisms for alterations in tremor include “changes in muscle contraction dynamics, proprioceptive reflexes, and muscle receptor properties” (21, p.1769). Changes in muscle contraction dynamics and muscle receptor properties (e.g. contributions of muscle spindles to the stretch reflex) play a critical role in exercise-induced alterations of tremor. During exercise, once firing rates of motor units become unduly low compared to the constant speed of muscle contraction, the stabilizing effect of the stretch reflex declines and tremor develops (21, 41).

Reflex loop feedback also contributes to tremor as muscle activity is relayed to the CNS via reflex loops. The simplest peripheral reflex loop involves feedback of a movement through activation of the muscle spindle, transmission of the signal through the Ia afferent monosynaptically onto the motoneuron, and through the motor axon to stimulate the extrafusal muscle fibers (23). Central reflex loop feedback, the most basic central factor, relays muscle
activity from the periphery to the CNS (23). The most salient example of a central reflex loop to the present review and proposed investigations is one that regulates targeted movements. As a function of the cerebellum, the progress of a movement is relayed via feedback to a module which compares the motor command with the actual position of the extremity (23). The signal from the comparator drives the motor apparatus and contributes to changes in tremor (23).

Central Nervous System Involvement in Tremor

Although peripheral mechanical factors are thought to be the dominant influences on tremor (23), CNS involvement in tremor has been well-established. Evidence at the level of the CNS suggests that tremor may be a neurological correlate of fatigue feelings. Results from animal and human, brain imaging, and pharmacological investigations link central regions (e.g. cerebellum, basal ganglia, and related thalamic structures) involved in the control of movement and tremor to fatigue mood states (13).

Central oscillations occur when brain neurons produce rhythmic activity. When this activity is related to motor commands and the frequency is 8 – 12 Hz (23), the oscillations may be a mechanism for the generation of and/or alterations in tremor (14). Such central oscillators, which are independent of peripheral input (23), plausibly arise from rhythmic activity of a group of neurons within a nucleus (14). A number of animal experiments have indicated such activity to be present within cells in the inferior olive and the thalamus (38-39). Central oscillations at the level of the inferior olive are of particular importance to the relationship between tremor and fatigue feelings as the inferior olive has direct projections to the cerebellum (illustrated in Figure 1 (46) on page 33), a brain region shown to be associated with feelings of fatigue (10).

CNS involvement in tremor also stems from variations in efferent activity from the motor cortex (34). In an investigation of the central mechanisms in human enhanced physiologic
tremor, individuals with persistent mirror movement syndrome and controls were compared using transcranial magnetic stimulation, long-latency reflexes, and cross-spectral analysis of electromyography time series recorded from the wrist extensors (34). The authors concluded that the 8 to 12 Hz component of enhanced physiologic tremor is transmitted transcortically, originating from two separate generators from both sides of the motor cortex (34).

CNS involvement in tremor also stems from variations in central afferent feedback to the motor cortex (17). Specifically, physiologic tremor is affected both by oscillations in sensorimotor loops and by oscillations of central neuronal networks (17). Variations in motor-related cortico-cortical interactions also play a role in tremor (59). Raethjen and colleagues (59) used epicortical recordings from the M1 and supplementary motor areas of the brain along with surface electromyographic recordings to examine synchronized activity as an indicator of the involvement of physiologic tremor in cortico-cortical interactions. The authors concluded that the cortical correlates of physiologic tremor may be involved in linking different cortical motor centers (59).

The CNS circuits that produce and modulate tremor appear to overlap with circuits that contribute to feelings of fatigue. A preliminary model is presented in Figure 2 on page 34 (46). During the measurement of physiologic hand tremor, feedback from the basal ganglia and cerebellum modify efferent motor signals on a moment-by-moment basis to maintain the hand in an outstretched position opposing gravity (34). Interactions between excitatory (cerebellar) and inhibitory (basal ganglia) projections to the motor cortex optimize motor control and regulate tremor. Feedback from the cerebellum to the motor cortex, via the ventral intermediate nucleus in the thalamus, is excitatory, while feedback from the basal ganglia to the motor cortex, via the ventral oral posterior nucleus in the thalamus, is inhibitory (14). This mechanism is supported
by physiological evidence from a study that reported synchronized bursting from a central oscillator, or an increase in amplitude, resulting from excitatory drive from the subthalamic nucleus and inhibitory action from the globus pallidus externus (55). Evidence from positron emission tomography (PET) imaging studies has also suggested the ventral intermediate nucleus in the thalamus as an overlapping area associated with regulation of mood and tremor (11). Effective stimulation of the ventral intermediate nucleus of the thalamus leads to suppression of abnormal cerebellar activation in Parkinson’s disease patients (11).

**Brain Imaging Evidence for Tremor – Fatigue Link**

Positron emission tomography (PET) imaging studies have reported cerebellar overactivity associated with essential tremor (9, 28) and increased cerebellar blood flow in Writer’s tremor (76) and orthostatic tremor (77). There is an emerging body of evidence that links the cerebellum, basal ganglia, and related thalamic structures involved in the control of movement to fatigue mood states (13). Brain-imaging studies have indicated the importance of the cerebellum and cerebellar activity in both fatigue mood states and tremor. In a study of the neural correlates of chronic fatigue syndrome (CFS), behavioral performance and neural activity was measured using rapid event-related functional MRI in 16 CFS patients and 16 matched healthy controls while the participants were engaged in a motor imagery task and a control visual imagery task (12). Results indicated that CFS patients had greater cerebellar activation (12). In a similar study of brain regions involved in fatigue sensation, 8 CFS patients were found to have decreased uptake of acetylcarnitine in the cerebellum (35). In a combined sample of CFS patients and normal controls, significant positive associations have been reported between the intensity of fatigue feelings and cerebellar blood oxygen level dependent responses to a demanding, fatigue-inducing cognitive task (10).
Human and animal investigations also suggest that fatigue feelings may occur due to failure of limbic-motor integration within the basal ganglia, altering striatal and thalamic circuits proposed to be involved in fatigue states (6, 8, 64). For example, animal studies have examined the role of dopamine in the nucleus accumbens in behavioral activation and effort-related decision making to provide evidence of plausible neural circuitry involved in fatigue and depression (64). Concurrent choice tasks show that rats with dopamine depletions in the nucleus accumbens reallocate instrumental behavior, such as food-seeking behaviors, toward selection of less-effortful types (64). Similarly, a recent PET study assessing basal ganglia hypermetabolism and symptoms of fatigue during interferon-alpha therapy found that self-reported fatigue was associated with increased glucose metabolism in the left nucleus accumbens and putamen (6).

**Human Pharmacological Evidence Linking Tremor and Fatigue Feelings**

Given that patients with tremor disorders such as Parkinson’s disease and essential tremor are characterized by a high prevalence of fatigue (30, 72), pharmacological interventions treating such disorders provide supportive evidence for an association between physiologic tremor and feelings of energy and fatigue. Levadopa, a dopamine precursor which is a pharmacological intervention commonly used in combination with carbidopa in dopamine replacement therapy to stimulate rapid increase in CNS dopamine levels, attenuates tremor in the treatment of Parkinson’s disease (7). Literature reviews also suggest that pharmacologic agents used in the treatment of depression that rapidly improve dopamine functioning, such as bupropion, enhance low energy feelings (71). There is evidence that, through direct and indirect actions on dopamine release and reuptake, some selective serotonin reuptake inhibitors such as sertraline and fluoxetine increase feelings of low energy in some patients (71). Conversely, dopamine-
depleting agents used in treatment of hyperkinetic mood disorders and hypertension, can cause tremor, depression, and parkinsonism (63).

The pharmacological evidence supporting the hypothesized link between fatigue feelings and tremor provided by stimulant drugs is not as conclusive. There is evidence that pharmacological agents known to produce stimulant effects, such as caffeine and β-adrenergic agonists, increase both energy feelings and physiologic tremor (47). For example, a recent investigation of hand tremor in relation to smoking habits and the consumption of caffeine measured tremor in 49 smokers/snuffers and in 49 non-smokers/non-snuffers (18). Results indicated increased hand tremor in response to caffeine and nicotine (18). Also, results from a study of the effect of typical consumptive levels of caffeine (~ 3 mg caffeine/kg bodyweight) on physiologic tremor suggested that oral ingestion of a single dose of caffeine at typical consumptive levels results in significant increases in physiologic tremor (45). Such doses of caffeine often reduce feelings of fatigue. However, there is a small body of conflicting pharmacological evidence regarding the effect of stimulant drugs known to increase feelings of energy on physiologic tremor. A meta-analytic review of the available evidence on methylxanthine use for exacerbations of chronic obstructive pulmonary disease showed that methylxanthine use resulted in non-significant increases in tremor (1). Also, a non-significant increase in hand tremor in response to 200 mg of caffeine was found among surgeons (26).

In summary, evidence suggesting overlap in the CNS neurology that underlies both physiologic tremor and feelings of fatigue implicates physiologic tremor as a plausible neurobiological correlate of fatigue feelings. Presently, no published investigation has empirically examined the potential correlation between fatigue feelings and physiologic tremor.
References


Figures

Figure 1. Projections from inferior olive and other neural structures (46).
Figure 2. A preliminary model for an overlapping neural basis for physiologic tremor and feelings of fatigue (46).
CHAPTER 3

THE EFFECT OF ACUTE RESISTANCE EXERCISE ON FEELINGS OF ENERGY AND FATIGUE

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Abstract

Purpose: This investigation examined the effect of acute (~35 min) moderate-to-high intensity (70% 1-RM) resistance exercise on feelings of energy and fatigue in physically inactive college women reporting persistent above-average frequency of fatigue feelings.

Methods: Fourteen physically inactive, female volunteers (age, 20 ± 1 yr) who reported persistent above-average frequency feelings of fatigue (≥ 30 days) completed 3 conditions (70% 1-RM, 15% 1-RM/placebo, and no-exercise control) in random order. Participants were tested 1 day per week for 3 consecutive weeks. In the exercise conditions, participants performed 4 sets of 10 repetitions of 3 lower-body resistance exercises: dual leg press, dual leg extension, and dual leg curl. Vigor and fatigue mood state scores were obtained immediately before the conditions, every 11 min and 40 s during the condition, and 20 and 30 min following the conditions.

Results: A 3 CONDITION X 6 TIME repeated-measures ANCOVA showed a significant main effect for vigor (P = .01, η²_p = .21). Vigor scores were significantly higher for 70% 1-RM compared to no-exercise control (P = .01). No significant difference was found between 70% 1-RM and 15% 1-RM/placebo. There was a significant main effect for fatigue (P = .04, η²_p = .15). Fatigue scores were significantly lower for 15% 1-RM/placebo compared to control (P = .04).

Conclusion: An acute bout of moderate-to-high intensity lower-body resistance exercise increased feelings of energy during and following exercise compared to no-exercise. It is unclear whether this effect is a placebo effect because it did not differ from the placebo condition, but we cannot rule out that resistance exercise at a wide range of intensities produces increased feelings of energy.

Key Words: MOOD, POMS, VIGOR, WEIGHT LIFTING
**Introduction**

Feelings of fatigue and low energy are associated with reduced health and quality of life (5, 13, 30). Nearly one quarter of the population reports persistent feelings of low energy and fatigue (17). Stimulant drugs and snack food consumption transiently improve feelings of fatigue and low energy (15, 28) but these products also can have unhealthy long term effects including drug dependence and weight gain. Safe and healthy methods for improving energy and fatigue mood states, such as exercise, can have substantial beneficial effects on health, quality of life, and work productivity.

Sedentary people who adopt a program of regular exercise report improved feelings of energy and fatigue (26), but the effect of acute exercise on these symptoms has received less attention. Acute bouts of low-to-moderate intensity dynamic, continuous exercise (e.g. walking, jogging, and cycling) have been associated with transient improvements in feelings of energy and fatigue (12, 25, 28). The effect of acute resistance exercise (weight lifting) on feelings of energy and fatigue is less clear in part because no experiment has focused on this question. Also, results from prior investigations that involved the mood consequences of acute weight lifting are difficult to interpret because of design and methodological limitations. These limitations included the failure to use both a no-treatment and a placebo control condition and the failure to control plausible confounding factors such as social interactions during or after exercise (2, 10).

The primary purpose of the present investigation was to determine the influence of an acute (~35 min) bout of moderate-to-high intensity (70% 1-RM) resistance exercise on feelings of energy and fatigue. The exercise duration was chosen to be consistent with physical activity recommendations. The intensity was selected to be comparable to intensities previously used in investigations of the effect of exercise on feelings of energy and fatigue. Physically inactive
participants reporting higher than average frequency of persistent (≥ 30 days) feelings of low energy and fatigue were targeted as a group likely to benefit psychologically from an acute bout of resistance exercise. It was hypothesized that the intensity of feelings of fatigue would increase immediately following the acute bout of moderate-to-high intensity lower-body resistance exercise and decrease below baseline levels 20 and 30 min following the cessation of exercise. Reciprocal responses were predicted for feelings of energy.

**Methods**

**Participants**

Fourteen physically inactive women were recruited from classes and approved electronic listservs at The University of Georgia. Exclusion criteria included: (i) the absence of persistent, frequent feelings of fatigue and low energy during the past month defined as a raw score greater than 17 on the vitality scale of the SF-36 Health Survey (29), (ii) any history of resistance exercise training defined as weight lifting performed at a frequency of twice or more per week for more than 3 consecutive weeks, (iii) any prior injury or medical condition for which maximal exercise testing is contraindicated as described by the ACSM’s Guidelines for Exercise Testing and Prescription (1), (iv) the use of any mood-altering medication within the past month, (v) regular physical activity defined both as reporting an average of more than 2 exercise bouts per week during the prior month and expending more than 260 kilocalories per kilograms body weight during the week prior to participating as measured by a 7-Day Physical Activity Recall questionnaire (3), (vi) scores suggesting any of the following DSM-IV psychiatric disorders as measured by the Psychiatric Diagnostic Screening Questionnaire (31): generalized anxiety disorder, panic disorder, social anxiety disorder, major depressive disorder, and substance abuse disorder; and, (vii) moderate intensity pain or higher (greater than 3 on a 0 to 10 Numerical
Graphical Rating Scale) at any body location (23). Sample size was determined using a statistical power calculation (8). The calculation assumed a two-tailed alpha of .05 and a correlation between repeated measurement trials of 0.70. A sample of 14 participants was adequately powerful (1-β = .86) to detect a moderate-sized (0.50) condition by time interaction effect.

Measures

Mood

The intensity of feelings of energy and fatigue were quantified using 5-item scales from the short form of the Profile of Mood States (POMS-SF) questionnaire (19). The participants were asked to respond as to how they felt “right now.” Evidence indicates POMS-SF vigor and fatigue scores measure the intensity of energy and fatigue mood states (22). Mood states were measured six times: immediately before the conditions, every 11 min 40 s during the conditions, and 20 and 30 min following the conditions.

Exercise Intensity and Muscle Pain

To determine exercise and muscle pain intensity, heart rate and ratings of both perceived exertion and pain intensity in the legs were obtained following each exercise set. Heart rate was assessed within the first 5 s after each set using a Polar S120™ heart rate monitor. Perceived exertion and pain intensity ratings were obtained within 15 s after each set using well validated exertion (6-20) and pain intensity (0-10) scales (4, 7). Methods for rating pain and exertion were consistent with prior protocols for pain (7) and exertion (11) with the exception that the terms “discomfort” and “fatigue” were not used in the RPE instructions.
Physical Activity

Physical activity was measured prior to each testing session using the 7-Day Physical Activity Recall questionnaire (7-d PAR) (3). Participants indicated the time spent sleeping and engaged in moderate, hard, and very hard physical activities. Energy expenditure was calculated using established methods (3).

Testing and Conditions

Testing Day 1

Upon arrival at the testing facility, participants were informed of the procedures, risks, and benefits of participation. They then provided written consent using a form approved by the Institutional Review Board. Each participant completed medical and physical activity history questionnaires, a 7-d PAR, and the POMS-SF questionnaire.

Each participant then walked (~30 m) to a Fitness Center to determine predicted one-repetition maximum (1-RM) on the lower-body resistance exercises of leg press, leg extension, and leg curl. Predicted 1-RM was used to minimize injury risk among these inexperienced participants and followed the protocol of Brzycki (6). Instructions included demonstrations of correct lifting techniques for each exercise. For each exercise, the participant was instructed to select a “light weight” she could lift 10 repetitions. The speed of each repetition was controlled with a metronome set at a cadence of 30 beats per min; thus, each repetition was performed for a total of 4 s (2 s flexion and 2 s extension). Perceived exertion and muscle pain intensity ratings were obtained during the 2 min rest interval that followed each set. The participant then completed a second set that consisted of a self-selected “moderate” weight that she estimated could be completed 8 repetitions. A weight estimated to be lifted no more than 5 repetitions was used in the next set. During this set, the weight was lifted as many times as possible until the
pace could not be maintained. Predicted 1-RMs were then calculated based on a prediction equation that takes into consideration the weight lifted and the number of repetitions performed (6). This prediction equation has been used with numerous samples and has error comparable to other equations used to predict 1-RM (18).

*Testing Days 2-4*

Testing sessions on days 2 – 4 involved moderate-to-high intensity resistance exercise (70% 1-RM) on one day, low intensity resistance exercise (placebo/15% 1-RM control) on a second day, and no exercise (no-treatment control) on a third day. Participants were randomly assigned to one of the six possible testing orders. Testing sessions were performed at approximately the same time of day with an approximately one-week interval between each session. Measurements of physiologic hand and foot tremor were made before and after the three conditions and these data are presented in a separate, companion paper (14).

*Conditions*

*70% 1-RM Treatment Condition*

Following arrival, tremor assessment was completed first. After tremor measurement and walking (~ 5 m) to an adjacent testing room, participants sat and completed the 7-d PAR, the POMS-SF and a numerical graphical rating scale assessing pain intensity for the whole body (23). Participants then walked (~30 m) to the Fitness Center and, following oral instructions and a demonstration of proper lifting technique, performed 4 sets each of 3 exercises in the following order: seated dual-leg press, seated dual-leg extension, and seated dual-leg curl. The first set (a warm-up) consisted of 10 repetitions at approximately 35% 1-RM. The remaining 3 sets consisted of 10 repetitions at 70% 1-RM.
All repetitions were paced by a metronome and performed for a total of ~4 s (2 s flexion and 2 s extension) (21). Each set was completed in 40 s and followed by a 2-min rest interval. During the rest period heart rate was measured and participants gave ratings of perceived exertion and muscle pain intensity. A 3-min rest interval was used between each exercise and participants completed the POMS-SF during this time. At the completion of the 3rd exercise, participants returned to the lab (~30 m) for the measurement of physiologic tremor. After tremor assessment that occurred from 1 to 15 min post exercise, the participant walked (~5 m) to an adjacent testing room where she sat and completed the POMS-SF at 20 and 30 min post-exercise. Conversation was minimized between the researcher and the participant during testing sessions.

**Placebo Condition**

The protocol for the placebo condition was identical to the 70% 1-RM condition but consisted of low intensity resistance exercise. Each participant performed four sets of 10 repetitions each on dual-leg press, dual leg-extension, and dual-leg curl at an intensity of ~15% 1-RM.

**No-Treatment Control**

The protocol for the no-treatment control condition was identical to the 70% 1-RM and placebo conditions except that no weight lifting exercises were performed. The participant sat on the exercise machines for the length of time required during the two exercise conditions. Each participant moved to the different exercise machines and completed ratings of perceived exertion and muscle pain intensity and mood measurements following the exact time progression as in the 70% 1-RM and placebo conditions.
Statistical Analyses

Data analyses were conducted using SPSS 14.0. Preliminary graphical and descriptive analyses were performed to test for outliers and assumptions. Data in the tables are expressed as mean and standard deviations while standard errors are used in the figures.

The primary mood analyses used a 3 CONDITION X 6 TIME ANCOVA with repeated measures on the time variable and baseline scores as a covariate to test for interaction and main effects on vigor and fatigue. The ANCOVA model was used to reduce error variance resulting from differences in baseline mood scores between conditions. Effect sizes for F-statistics were expressed as partial eta-squared ($\eta^2_p$). When the sphericity assumption was violated based on Mauchly’s test, the Huynh-Feldt adjustment was used. Pairwise comparisons with Bonferroni correction were used to assess specific differences between conditions and times. Standardized mean difference scores were calculated to assess the magnitude of effects for 70% 1-RM and the placebo conditions at each time point compared to the no-treatment control condition. At each time point, the mean of the control condition was subtracted from the mean of the exercise condition and the difference was divided by the baseline pooled standard deviation to yield the standardized mean difference scores.

Results

Characteristics of the participants included: age (20.1 ± 0.9 yrs), weight (62.2 ± 11.3 kg), resting pain intensity (0.8 ± 1.1), SF-36 vitality scale raw score (13.1 ± 3.4), 1-RM leg press (80.7 ± 13.3 kg), 1-RM leg curl (45.4 ± 8.6 kg) and 1-RM leg extension (24.1 ± 6.8 kg). Characteristics associated with the experimental conditions are presented in Table 1.
Means and standard deviations for energy and fatigue measures are presented in Table 2 and Figures 1 and 2. The magnitude of the standardized effects for the 70% 1-RM condition and placebo condition at each time point is depicted in Figure 3.

For vigor, the assumption of sphericity was violated ($W = .126, X^2 = 75.53, p = .000, \epsilon = .542$). The condition-by-time interaction ($F_{(8, 152)} = .46, p = .78, \eta^2_p = .02, \epsilon = .542$) and the main effect for time ($F_{(4, 152)} = 1.96, p = .14, \eta^2_p = .05, \epsilon = .542$) were not statistically significant. The main effect for condition was statistically significant ($F_{(2, 38)} = 5.08, p = .01, \eta^2_p = .21$). Pairwise comparisons indicated that vigor scores were significantly higher in the 70% 1-RM condition compared to the control ($t = 3.12, p = .01$), but there was no difference between the placebo condition and control ($t = 2.14, p = .12$) or between the 70% 1-RM condition and the placebo condition ($t = .97, p = 1.00$).

For fatigue, the assumption of sphericity was violated ($W = .549, X^2_{(9)} = 21.85, p = .009, \epsilon = .932$). The condition-by-time interaction ($F_{(8, 152)} = .85, p = .56, \eta^2_p = .04, \epsilon = .932$) and the main effect for time ($F_{(4, 152)} = 1.89, p = .12, \eta^2_p = .05, \epsilon = .932$) were not statistically significant. The main effect for condition was statistically significant ($F_{(2, 38)} = 3.40, p = .04, \eta^2_p = .15$). Pairwise comparisons indicated that fatigue scores were significantly lower in the placebo condition compared to the no-treatment control condition ($t = -2.59, p = .04$).

**Discussion**

Results of a small number of prior studies suggest that an acute bout of resistance exercise can improve feelings of energy and fatigue (2, 10, 27). This evidence is inconclusive due to limitations of the research designs that have been used. The present experiment improved and/or extended prior related research (i) by recruiting sedentary women who lacked frequent feelings of energy, (ii) by measuring mood during the exercise phase of the experiment, (iii) by
exerting better control over the exercise stimulus, (iv) by exerting better control over social interactions, and (v) by using both a placebo and a non-exercise control condition.

**Feelings of Energy**

The most salient finding of this investigation was that, among young, sedentary women reporting below average feelings of energy immediately prior to the exercise bout, feelings of energy were higher during and following an acute bout of moderate-to-high intensity resistance exercise compared to a non-exercise control condition. The effect size was somewhat larger here (ES range of 0.37 to 0.73) than in previous studies (ES range of 0.30 to 0.36) involving an acute bout of resistance exercise (2, 10). The timing of the mood measures in the different investigations likely contributed to these differences in the magnitude of the effect. The present investigation found the largest effect sizes during the exercise intervention rather than 20 to 30 min after exercise cessation. Previous investigations did not examine changes in the intensity of feelings of energy during the exercise intervention (2, 10, 27).

Feelings of energy increased quickly during the exercise phase. The largest increase occurred following the first exercise (leg press) in the 70% 1-RM condition. This mood response opposed our prediction that the intensity of feelings of energy would be reduced during the exercise phase. Our prediction was based on the knowledge that moderate-to-high intensity exercise results in muscle fatigue and increased perceptions of effort (16). Our results most likely can be explained by the relatively short duration of continuous exercise (40 s) and the substantial rest interval between sets. The three exercises were performed in a 10 min and 40 s period during which the participant spent 75% of the time resting. Related research in which the rest interval was manipulated between sets of weight lifting exercise found that longer rest periods, 3 min versus 1 min, were associated with less fatigue (27).
One strength of the present investigation was the inclusion of a placebo condition. The possibility that mood responses to exercise could result from a placebo effect is widely recognized (20), yet no other published investigation has included a placebo condition in the examination of the effect of an acute bout of resistance exercise on feelings of energy. Thus, a placebo condition was included in the present investigation that consisted of very low intensity resistance exercise. The intensity was selected to be the lowest intensity allowed by the equipment that also would be credible as a non-trivial exercise stimulus to a novice weight lifter. This condition was designed to be as identical as possible to the moderate-to-high intensity exercise condition yet lack the theoretical “active ingredient” (the true active ingredient is currently unknown) required to bring about a true change in mood. The placebo condition produced increased feelings of energy that were statistically no different than what occurred with the moderate-to-high resistance exercise condition. Accordingly, it is plausible that the effect of moderate-to-high intensity resistance exercise on feelings of energy is a placebo effect (9). There is presently no generally accepted gold standard placebo condition for acute exercise and it has been argued that no adequate “exercise placebo” can be devised (24). An equally plausible conclusion, however, is that very low intensity resistance exercise has an effect on feelings of energy that is similar to that produced by moderate-to-high intensity exercise. This conclusion is supported by the similar pattern and magnitude of improvements in feelings of energy in the placebo condition and the moderate-to-high intensity resistance exercise condition.

Regardless of which interpretation is made, regression to the mean is an unlikely explanation for the exercise-associated increases in feelings of energy because vigor scores were reduced during the post-exercise period.
Feelings of Fatigue

An acute bout of moderate-to-high intensity resistance exercise had no effect on feelings of fatigue compared to the no-exercise control condition. We predicted that feelings of fatigue would be increased immediately following each of the three exercises because of the moderate-to-high exercise intensity. The substantial rest interval between sets, however, likely contributed to the observation that fatigue scores did not change in the 70% 1-RM condition.

Fatigue scores were lower during and following the placebo condition compared to the no-treatment control condition. One plausible interpretation is that a very low intensity bout of resistance exercise has a placebo effect on feelings of fatigue (9). However, it also is plausible that very low intensity resistance exercise acts as a minimal intervention that improves feelings of fatigue to a greater extent than moderate-to-high intensity resistance exercise. This explanation is strengthened given that the magnitude of improvements in the intensity of fatigue feelings was consistently larger for the placebo condition than the moderate-to-high intensity condition compared to no-treatment. Regardless, these findings cannot be explained by regression to the mean because fatigue scores were reduced even though baseline fatigue scores were lower than college sample norms (19). The lower than normal baseline POMS-SF fatigue scores were somewhat surprising because participants reporting SF-36 vitality scale scores one-half standard deviation below U.S. population norms were recruited (29). Thus, higher than average POMS-SF fatigue scores were expected but the opposite was found. It is possible to have low vitality scores and low baseline POMS-SF fatigue scores. This is because the vitality scale inquires about the frequency of feelings of energy and fatigue while the POMS-SF fatigue scale evaluates the intensity of fatigue feelings. We speculate the sample tested here experienced frequent periods of low intensity fatigue in the month prior to participant recruitment.
Conclusions

The primary finding of this investigation was that an acute bout of moderate-to-high intensity lower-body resistance exercise increased the intensity of feelings of energy during and after exercise compared to a no-exercise control condition. The effect appears to be a placebo effect as the effect did not differ from the placebo condition. However, because the placebo condition consisted of an acute bout of low intensity resistance exercise we cannot rule out that resistance exercise of a wide range of intensities produces increased feelings of energy. The findings highlight the need to establish a consensus placebo for acute exercise if the psychological responses to acute exercise are to be elucidated in a compelling fashion.
References


### Table 1. Mean ± SD condition-related characteristics (N = 14).

<table>
<thead>
<tr>
<th></th>
<th>70%1-RM</th>
<th>15%1-RM</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Expenditure</td>
<td>251 ± 21</td>
<td>239 ± 17</td>
<td>243 ± 19</td>
</tr>
<tr>
<td>(kcal·kg·wk(^{-1}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting Pain</td>
<td>0.3 ± 0.8</td>
<td>0.2 ± 0.4</td>
<td>0.4 ± 0.7</td>
</tr>
<tr>
<td>Intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%1-RM Leg Press</td>
<td>69.5 ± 3.6</td>
<td>23.3 ± 5.2</td>
<td>0</td>
</tr>
<tr>
<td>%1-RM Leg Ext.</td>
<td>69.7 ± 5.9</td>
<td>14.8 ± 2.3</td>
<td>0</td>
</tr>
<tr>
<td>%1-RM Leg Curl</td>
<td>71.0 ± 1.6</td>
<td>11.2 ± 1.4</td>
<td>0</td>
</tr>
<tr>
<td>%1-RM All</td>
<td>70.1</td>
<td>16.4</td>
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<tr>
<td>Exercises</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Leg Press RPE</td>
<td>13.5 ± 2.5</td>
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<td>6</td>
</tr>
<tr>
<td>Leg Ext. RPE</td>
<td>16.0 ± 1.8</td>
<td>9.2 ± 2.2</td>
<td>6</td>
</tr>
<tr>
<td>Leg Curl RPE</td>
<td>14.7 ± 2.3</td>
<td>6.6 ± 0.9</td>
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</tr>
<tr>
<td>RPE All Exercises</td>
<td>14.7 ± 2.2</td>
<td>7.4 ± 1.3</td>
<td>6</td>
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<tr>
<td>Leg Press HR (bpm)</td>
<td>110 ± 10</td>
<td>84 ± 8</td>
<td>77 ± 11</td>
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<tr>
<td>Leg Ext. HR</td>
<td>122 ± 18</td>
<td>98 ± 10</td>
<td>76 ± 9</td>
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<tr>
<td>Leg Curl HR</td>
<td>115 ± 17</td>
<td>81 ± 8</td>
<td>78 ± 11</td>
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<td>HR All Exercises</td>
<td>116 ± 15</td>
<td>88 ± 9</td>
<td>77 ± 10</td>
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<td>Leg Press Pain</td>
<td>1.8 ± 0.8</td>
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<td>0</td>
</tr>
<tr>
<td>Leg Ext. Pain</td>
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<td>0.4 ± 0.4</td>
<td>0</td>
</tr>
<tr>
<td>Leg Curl Pain</td>
<td>1.2 ± 1.3</td>
<td>0.04 ± 0.1</td>
<td>0</td>
</tr>
<tr>
<td>Pain All Exercises</td>
<td>1.6 ± 1.3</td>
<td>0.1 ± 0.2</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 2. Mean ± standard deviations for vigor and fatigue scores by condition (N = 14)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Phase</th>
<th>Timing</th>
<th>Baseline</th>
<th>Exercise or control phase</th>
<th>Recovery</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre Ex</td>
<td>Post Ex 1</td>
<td>Post Ex 2</td>
<td>Post Ex 3</td>
</tr>
<tr>
<td>70%1-RM</td>
<td>Fatigue</td>
<td>4.4 ± 4.3</td>
<td>2.9 ± 3.4</td>
<td>3.8 ± 3.1</td>
<td>3.8 ± 3.4</td>
<td>3.6 ± 3.5</td>
</tr>
<tr>
<td>70%1-RM</td>
<td>Vigor</td>
<td>4.1 ± 3.6</td>
<td>5.6 ± 4.3</td>
<td>5.9 ± 4.6</td>
<td>5.5 ± 4.7</td>
<td>4.7 ± 4.7</td>
</tr>
<tr>
<td>15%1-RM</td>
<td>Fatigue</td>
<td>3.9 ± 4.0</td>
<td>2.1 ± 2.9</td>
<td>2.2 ± 2.1</td>
<td>2.0 ± 2.1</td>
<td>2.1 ± 2.3</td>
</tr>
<tr>
<td>15%1-RM</td>
<td>Vigor</td>
<td>4.4 ± 3.8</td>
<td>5.2 ± 4.1</td>
<td>4.9 ± 3.8</td>
<td>5.2 ± 3.6</td>
<td>4.6 ± 3.5</td>
</tr>
<tr>
<td>Control</td>
<td>Fatigue</td>
<td>4.9 ± 3.9</td>
<td>4.4 ± 3.3</td>
<td>4.2 ± 3.5</td>
<td>4.4 ± 3.6</td>
<td>4.6 ± 3.8</td>
</tr>
<tr>
<td>Control</td>
<td>Vigor</td>
<td>3.9 ± 4.8</td>
<td>3.6 ± 5.1</td>
<td>2.8 ± 5.0</td>
<td>3.2 ± 4.9</td>
<td>2.8 ± 5.4</td>
</tr>
</tbody>
</table>

Note: Ex 1 = leg press, Ex 2 = leg extension, Ex 3 = leg curl
Figures

Figure 1. Mean (±SE) vigor scores in the three conditions across six measurement times.
Figure 2. Mean (±SE) fatigue scores in the three conditions across six measurement times.
Figure 3. Magnitude of standardized effect for 70% 1-RM and placebo/15% 1-RM conditions across time. For every variable at each time point, the mean in the control condition was subtracted from the mean in the exercise condition and the difference was divided by the baseline pooled standard deviation.
CHAPTER 4

THE INTENSITY OF FEELINGS OF FATIGUE ARE ASSOCIATED WITH
AND PHYSIOLOGIC TREMOR\textsuperscript{1}

\textsuperscript{1}Herring, M. P. & P. J. O'Connor. To be submitted to \textit{International Journal of Neuroscience}.
Abstract

Purpose: This investigation examined the correlation between physiologic tremor and fatigue feelings. Methods: Fourteen physically inactive, female volunteers (age, 20 ± 1 yr) who reported persistent above-average frequency of fatigue feelings (≥30 days) completed 3 testing sessions, 1 per week for 3 consecutive weeks. Vigor and fatigue mood state scores and physiologic tremor data were obtained at each session. Results: Hand tremor amplitude was positively correlated with fatigue scores (r = .358, 95% CI: (0.06, 0.60), N = 42). Hand tremor amplitude was weakly correlated with vigor scores. Conclusions: Feelings of fatigue are positively related to hand tremor amplitude. Given the scope of the problem of fatigue, this relationship warrants further investigation.

Key Words: AMPLITUDE, ENERGY, MOOD, POMS, VIGOR
Introduction

Feelings of fatigue have been described as a window to the brain (7), but the neural basis for these feelings is poorly understood. Given that nearly one quarter of the population report persistent fatigue (22), the identification of neurological correlates of fatigue feelings is of interest. This brief report summarizes an initial investigation examining the association between feelings of fatigue and physiologic tremor.

Physiologic tremor is a normal, involuntary rhythmic oscillation with a mean frequency range of 8 – 12 Hz in a body part held in a stationary position, often most noticeable in the outstretched hand (14). The causes of physiologic tremor are incompletely understood. Peripheral factors including the resonant frequency of the extremity (9), primarily determined by the inertia of the limb and joint stiffness (11, 14), and muscle receptor properties (e.g. muscle spindle contributions to the stretch reflex) are key determinants of tremor (13, 23).

Although peripheral mechanical factors are thought to be the dominant influences on tremor (14), central nervous system (CNS) involvement in tremor has been well-established (9, 13, 24). Variations in efferent activity from the motor cortex (20), central afferent feedback to the motor cortex (11) and motor-related cortico-cortical interactions (31) all play a role in tremor. For example, during the measurement of physiologic hand tremor, feedback from the basal ganglia and cerebellum modify efferent motor signals on a moment-by-moment basis and help to maintain a stable, outstretched hand (20). Feedback from the cerebellum to the motor cortex, via the ventral intermediate nucleus in the thalamus, is excitatory and feedback from the basal ganglia to the motor cortex, via the ventral oral posterior nucleus in the thalamus, is inhibitory (9). A balance between this excitatory and inhibitory feedback optimizes motor control and minimizes tremor.
There is an emerging body of evidence that links the cerebellum, basal ganglia, and related thalamic structures involved in the control of movement to fatigue mood states (8). Brain imaging studies report that patients with Chronic Fatigue Syndrome (CFS) have greater cerebellar activation (6) and a reduced uptake of acetylcarnitine in the cerebellum (21). In a combined sample of CFS patients and normal controls, significant, positive associations have been reported between the intensity of fatigue feelings and cerebellar blood oxygen level dependent responses to a demanding cognitive task that induced feelings of fatigue (5). Based on results from both human and animal studies, other authors have suggested that feelings of fatigue may occur, in part, due to a failure of limbic-motor integration within the basal ganglia, altering striatal and thalamic circuits proposed to be involved in fatigue states (2, 4, 32).

Patients with tremor disorders, such as Parkinson’s Disease, are characterized by a high prevalence of fatigue (18, 34). Drugs that rapidly increase CNS dopamine levels, such as levadopa, attenuate tremor in the treatment of Parkinson’s Disease (3). Other drugs which rapidly increase CNS dopamine levels, such as buproprion, also enhance feelings of energy (33). Not all the available pharmacological evidence consistently supports a hypothesized link between tremor and fatigue. Some stimulant drugs, such as caffeine and nicotine, which improve feelings of low energy and fatigue in some (27-28) but not all (1, 19) reports, were found to increase physiologic tremor (27-28).

In summary, there is evidence suggesting overlap in the CNS neurology that underlies both physiologic tremor and feelings of fatigue. No published investigation has empirically examined the association between the intensity of feelings of fatigue and physiologic tremor. The primary purpose of the present investigation was to explore the association between the intensity of feelings of fatigue and physiologic tremor. Based on the available evidence, a
moderate sized positive correlation between hand tremor amplitude and feelings of fatigue was hypothesized. A negative association was hypothesized between hand tremor amplitude and feelings of energy.

Methods

Participants

Fourteen physically inactive women who reported above average frequency of persistent feelings of fatigue were recruited from classes and approved electronic listservs at The University of Georgia (15). Participants read and signed an informed consent document approved by the Institutional Review Board.

Measures

Mood

The intensity of feelings of energy and fatigue were quantified using 5-item scales from the short form of the Profile of Mood States (POMS-SF) questionnaire (26). The participants were asked to respond as to how they felt “right now.” Evidence indicates POMS-SF vigor and fatigue scores measure the intensity of energy and fatigue mood states (30).

Physiologic Tremor

Physiologic tremor was measured in the right hand using a single plane accelerometer (Grass Model SPA1). The accelerometer was attached to an amplifier (Grass P511). Output of the amplified signal was stored on a computer (Dell) running Spike2 (version 5.16) software (Cambridge Electronic Design micro1401 mk II) that was used to acquire and analyze the data. All tremor data were obtained while participants were seated in an E-Z Leg-Up rehabilitation chair (model #4500; Rehab Seating Systems, Inc., Brookline, MA) house in a copper-lined Faraday cage.
The accelerometer was secured on the back of the right hand between the 2\textsuperscript{nd} and 3\textsuperscript{rd} metacarpals with athletic pre-wrap. The arm, from the elbow to the wrist, was supported by an armrest. While the tremor data were acquired, participants were instructed to remain relaxed and motionless, looking straight ahead with eyes closed. The hand was extended parallel to the floor and maintained in that position for one minute. The procedure was completed 3 times interspersed with 1-min rest periods.

Raw tremor amplitude data in the frequency range 0 – 12 Hz were analyzed using fast fourier transformation (FFT) of the signal with a Hanning window. Reliability was assessed using intraclass correlations (ICC 3, 3) (25). The ICC model used was a two-way (14 participants and 3 trials) mixed effects model (participants were considered random effects and trials fixed effects). The ICC model used absolute agreement and the average measures option. The mean of the three trials was used as the criterion measure for analysis because the ICC was .88.

Statistical Analyses

Data analyses were conducted using SPSS 14.0 (SPSS Inc., Chicago, IL). Preliminary graphical and descriptive analyses were performed to test for outliers and assumptions. Data in the tables are expressed as mean and standard deviation. The primary tremor analysis used Pearson correlations to examine the direction and magnitude of the association between hand tremor amplitude and mood scores using data from the 14 participants acquired on three separate test days (total N = 42).

Results

The participants were 20.1 ± 0.9 yrs and weighed 62.2 ± 11.3 kg. Means and standard deviations for mood and tremor are presented in Table 1. Pearson correlations between tremor
amplitude and mood scores are illustrated in Figure 1. Hand tremor amplitude was positively correlated to fatigue scores ($r = 0.358$, 95% CI: $(0.06, 0.60)$, $N = 42$). A scatterplot of hand tremor amplitude and fatigue scores is presented in Figure 2. Hand tremor amplitude was weakly correlated with vigor scores ($r = 0.076$, 95% CI: $(-0.230, 0.380)$, $N = 42$).

**Discussion**

This investigation revealed a moderate positive relationship between the intensity of feelings of fatigue and physiologic hand tremor amplitude. This finding suggests that physiologic tremor is a biological correlate of feelings of fatigue.

The magnitude of the correlation between the intensity of feelings of fatigue and physiologic hand tremor could have been affected by small sample bias given that the present investigation reported results from 14 subjects combined across 3 different testing sessions ($N = 42$). Although examination of the fatigue – tremor correlation for each testing day ($N = 14$) indicated values within the observed 95% confidence interval ($N = 42$) the magnitude of the relationship may have been driven by a few influential data points. For example, Figure 2 illustrates one potential outlier (fatigue: 14, amplitude 13.79). While the tremor amplitude for this data point was ~ 3 standard deviation units above the sample mean, the corresponding fatigue score was only ~ 2 standard deviation units above the sample mean. Moreover, this fatigue score was only 1.4 standard deviations above the college sample mean reported in the POMS manual for fatigue ($7.3 \pm 4.8$) (25). When this point was removed, the magnitude of the correlation decreased ($r = 0.212$, 95% CI: $(-0.095, 0.490)$, $N = 41$).

The results indicating a weak correlation between feelings of energy and physiologic tremor may be attributable to the difference between energy and fatigue constructs. Factor analytic studies of mood questionnaires have yielded distinct energy and fatigue factors which
provide evidence feelings of energy and fatigue represent separate constructs (26, 29). We speculate that energy and fatigue symptoms are regulated by somewhat different biological mechanisms and therefore are differentially correlated to physiologic tremor.

The present investigation was an exploratory examination of the relationship between the intensity of feelings of fatigue and physiologic tremor. Although experts have concluded that tremor amplitude is largely influenced by peripheral factors (14), the cerebellum, basal ganglia, and motor cortex also are involved in physiologic tremor (9, 13, 20, 31). Given the influence of peripheral mechanical factors, it is important to note that this investigation conceptualized fatigue as a mood state, defined as negative, subjective feelings about the reduced capacity to perform cognitive or physical activities (30). While muscular fatigue, conceptualized as a failure to sustain force or power output or a failure to maintain the motor unit recruitment during a task (10), likely influences symptoms of fatigue (12), it was not a focus of this report. Based upon both the plausibility of overlapping CNS neurology underlying feelings of fatigue and physiologic tremor and the findings of this investigation, the relationship between the feelings of fatigue and physiologic tremor warrants further investigation. Future research should focus upon examining the relationship with larger samples of participants exhibiting the full range of fatigue symptom intensity.
References


### Tables

**Table 1. Mean and standard deviation for mood scores and tremor amplitude (N = 42)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vigor</td>
<td>4.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Fatigue</td>
<td>4.4</td>
<td>4.0</td>
</tr>
<tr>
<td>Tremor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand</td>
<td>5.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

*Note: Tremor is expressed as amplitude mean and standard deviation in units of milli-g.*
Figures

Figure 1. Magnitude of the correlation between hand tremor amplitude and feelings of fatigue and energy. Error bars correspond to the upper and lower bounds of a 95% confidence interval for each correlation.
Figure 2. Scatterplot of hand tremor amplitude and fatigue scores (N = 42)
CHAPTER 5

CONCLUSIONS

Results of a small number of previous studies suggest that an acute bout of resistance exercise can improve feelings of energy and fatigue (2, 7, 17). Nonetheless, the evidence is far from conclusive due to limitations of the research designs that have been used. The present investigation improved and/or extended prior related research (i) by recruiting physically inactive women who lacked frequent feelings of energy, (ii) by measuring mood both during and following the exercise phase of the experiment, (iii) by exerting better control over the exercise stimulus, (iv) by exerting better control over social interactions, and (v) by using both a placebo and a no-exercise control condition.

The primary finding of this investigation was that an acute bout of moderate-to-high intensity lower-body resistance exercise (70% 1-RM) increased the intensity of feelings of energy during and following exercise compared to a no-exercise control condition. It is unclear whether the effect is a placebo effect as the effect did not significantly differ from the placebo condition. However, because the placebo condition consisted of an acute bout of low intensity resistance exercise (15% 1-RM), we cannot completely rule out that resistance exercise performed at a wide range of intensities (15% to 70% 1-RM) produces increased feelings of energy.

The lack of a significant effect on fatigue feelings for moderate-to-high intensity resistance exercise is most likely attributable to the substantial rest interval between sets. The finding that fatigue scores were significantly lower during and following the placebo condition
compared to the no-treatment control condition has multiple interpretations. One plausible interpretation is that a very low intensity bout of resistance exercise has a placebo effect on feelings of fatigue (6). It also is plausible that very low intensity resistance exercise acts as a minimal intervention that improves feelings of fatigue to a greater extent than moderate-to-high intensity resistance exercise. These findings highlight the need to establish a consensus placebo for acute exercise if the psychological responses to acute exercise are to be elucidated in a compelling fashion.

When interpreting the findings of this investigation an important consideration is the selection of the participant sample. Based upon the small to moderate effect sizes (.30 - .36) reported in previous investigations (2, 7) using samples characterized by average or above-average feelings of energy, the exclusion criteria in this investigation were used to select a sample characterized by above-average feelings of low energy and fatigue that would be expected to benefit to a greater extent psychologically from acute resistance exercise. By recruiting physically inactive individuals characterized by frequent feelings of low energy and fatigue, a larger magnitude of effect was expected from the exercise stimulus. An important consideration is that the lower than normal baseline POMS-SF fatigue scores reported by the present sample also likely influenced the findings. The low baseline scores were somewhat surprising because participants reporting SF-36 vitality scale scores approximately one-half standard deviation below the U.S. population mean were recruited (19). Thus, higher than average POMS-SF fatigue scores were expected but the opposite was found. The below-average POMS-SF fatigue scores might have resulted, in part, from other exclusion criteria. For example, exclusion criteria were used to obtain a sample free of any medical or psychiatric condition. Regardless, it is possible to have low vitality scores and low baseline POMS-SF
fatigue scores. This is because the vitality scale inquires about the frequency of feelings of energy and fatigue while the POMS-SF fatigue scale evaluates the intensity of fatigue feelings. Thus, we speculate that the sample tested here experienced frequent periods of low intensity fatigue in the month prior to participant recruitment.

The present investigation also explored the relationship between the intensity of fatigue feelings and physiologic tremor based upon evidence suggesting overlapping CNS neurology at the level of cerebellum, basal ganglia, and motor cortex underlying both fatigue feelings and physiologic tremor (3-5, 9-10, 15-16). The findings suggest physiologic tremor may be a biological correlate of fatigue feelings. Given the plausibility of overlapping CNS neurology and the findings of this investigation, the relationship between feelings of fatigue and physiologic tremor warrants further investigation with larger samples.

The findings of both the primary and secondary purposes of this investigation indicate differential effects on feelings of energy and fatigue. The differential effects on energy and fatigue reported in the present investigations suggest that these constructs are distinct. Some previous literature has conceptualized energy and fatigue as polar opposites on a single bipolar mood continuum, which is perhaps simpler than conceptualizing each mood state as a separate unipolar construct (13). A unipolar conceptualization, which allows for simultaneous feelings of both energy and fatigue, has been supported by factor analytic studies of mood questionnaires (i.e. POMS) that have yielded distinct energy and fatigue factors, providing evidence that feelings of energy and fatigue represent separate constructs (11-12). More compelling evidence has been provided by investigations of exercise effects on energy and fatigue feelings. The present findings indicated a simultaneous increase in feelings of energy and decrease in feelings of fatigue at the onset of exercise. Similar findings have been reported in previous investigations.
of exercise effects on energy and fatigue feelings (2, 7). Moreover, we can speculate that the
different magnitude of association between physiologic tremor and the intensity of feelings of
energy and fatigue found here suggests that energy and fatigue feelings are regulated by
somewhat different biological mechanisms. These findings indicate the continued need to
investigate central nervous system mechanisms underlying exercise-induced changes in feelings
of energy and fatigue.

The present findings also can be considered in comparison to the effects of acute aerobic
exercise. A relatively large body of previous research has indicated that acute aerobic exercise,
typically characterized by lower-body, dynamic exercise such as walking and cycling, can
improve feelings of energy and fatigue (14, 18). The magnitude of the effect of moderate-to-
high intensity resistance exercise on increases in energy feelings was somewhat larger (ES range:
~0.37 to 0.73) in the present investigation than comparable (in intensity) bouts of aerobic
exercise (ES range: ~0.2 to 0.6) in previous investigations of the effect of acute aerobic exercise
on feelings of energy and fatigue (1, 8). These differences are likely the result of rest intervals
inherent in resistance exercise, although no investigation has evaluated this contention.
Compared to aerobic exercise, the interval nature of resistance exercise leads to a significantly
shorter duration of continuous exercise with rest periods interspersed. The largest effect sizes in
the present investigation were reported during the exercise bout when participants spent
approximately 25% of the bout engaged in continuous lifting exercise and approximately 75% of
the bout resting. This difference in structure between the two exercise modes likely contributes
to the differential effects on feelings of energy and fatigue.
Future Research

The findings of these experiments indicate the need for future investigations aimed at the clarification of the behavioral consequences of acute resistance exercise on feelings of energy and fatigue. Findings also point to future research aimed at understanding the neurophysiological mechanisms that regulate exercise-induced changes in energy and fatigue feelings and the relationship between those mood states and physiologic tremor. There also is a continued need to establish an appropriate placebo condition for acute exercise if the psychological consequences to acute exercise are to be elucidated in a more compelling fashion. Future investigations should examine the effects of acute low and moderate-to-high intensity resistance exercise utilizing an additional placebo condition such as imagery to gain a better understanding of the potential “active ingredient” underlying exercise-induced changes and the potential dose-dependent relationship for intensity.

The findings of both the examination of mood responses to resistance exercise and the association between fatigue feelings and tremor highlight the need for large randomized controlled experiments conducted with physically inactive participants characterized by above-average frequency of fatigue feelings (indicated by SF-36 vitality scores less than or equal to 13) and above-average intensity fatigue feelings (indicated by baseline POMS-SF fatigue scores greater than 7) and with fatigued participants with medical conditions that commonly report exacerbated fatigue (i.e. depression) to learn more about the generalizability of the observed effects.

The initial finding of a positive relationship between fatigue feelings and physiologic tremor amplitude highlights the need for future studies to clarify the relationship both before and in response to resistance exercise. A potential future experiment could induce fatigue using a
dopaminergic antagonist and assess mood and tremor responses pre- and post-exercise to gain a better understanding of dopamine as a potential neurophysiologic mechanism underlying both changes in energy and fatigue feelings and changes in physiologic tremor.

Finally, based upon the similar, but somewhat larger magnitude of effect for the present resistance exercise findings compared to previous findings for acute aerobic exercise, future examinations also should compare the effects of acute resistance exercise to the effects of acute aerobic exercise using a protocol to equate the duration of continuous exercise across conditions to gain a better understanding of what characteristics within the specific exercise stimuli may be influencing mood responses. For instance, an experiment could be designed to compare a lower-body dynamic exercise such as cycling to lower-body resistance exercise using 1 min continuous exercise bouts with 60 – 90 s rest intervals interspersed to examine the magnitude of the effect of the interval nature of resistance exercise that likely contributed to the results of the present investigation. Regardless, it is imperative that future research on both the effect of acute resistance exercise on energy and fatigue feelings and the relationship between feelings of fatigue and physiologic tremor should focus upon examining these relationships with larger samples that include participants who report both above-average frequency and above-average intensity of fatigue feelings.
References


