Group 12 Section 602
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Abstract

In response to external stimuli, the body needs compensatory mechanisms that restore homeostatic conditions. In the event that the environment causes the body to fluctuate beyond the pre-set conditions, it must alter its response to balance these changes. A feed forward response is the body's attempt to anticipate upcoming changes to the internal environment and facilitate the proper response to that change. To test this feed forward response, we designed an experiment to measure physiological responses in both males and females in anticipation to exercise to analyze how the body copes with the expected deviations from homeostatic conditions. Our results indicated that there were no significant differences in respiration and blood pressure between genders or experimental groups. Interestingly, the change in heart rate was statistically inconclusive between groups, but significant changes in heart rate were found when combining all participants. Additional studies will need to be done to further explore the compensatory mechanisms involved in feed forward responses.

Introduction

Physiological Systems with Feed Forward Processes

Feed forward processes are found within many physiological systems in the body. Various muscular systems can be regulated by feed forward processes. For example, rapid arm movements activate trunk-stabilizing muscles in anticipation of a postural perturbation.[3] Li and Aruin (2009) found that posture can be changed in anticipation of changes body mass distribution by having subjects catch an object with and without a backpack. Also, manipulation of objects using the hands employs a feed forward mechanism for anticipating the level of force required.[4]

A study by Dampney, *et al.* (2002) also examined the physiological responses to threatening stimuli. When faced with an intimidating situation, the body increases its arterial pressure, heart rate, and vascular flow to the skeletal muscles.[2] This reaction occurs in order to allow the body to anticipate a response so it is well prepared to react immediately in case of a need to fight or flee from the threatening situation at hand.[2]

The cardiovascular system is able to increase heart rate and blood pressure in anticipation of exercise. The body must be able to sustain high metabolic rates during physical exercise, which requires a constant supply of oxygen. The body must adapt to this greater need for oxygen, and many studies are finding that the body actually anticipates this increase in need, and adjusts the oxygen intake appropriately before the physical exertion and increased demand even takes place.[6] This suggests that mechanisms do exist for the body to anticipate metabolic demands in a feed-forward fashion so the body is prepared to exercise.[6] Experiments by Tobin, *et al.* (1986) have tested this phenomenon by instructing participants that they were going to perform on an exercise bicycle. Countdown initiation to experiment commencement allowed measurements between baseline breathing patterns and anticipatory breathing patterns. Breathing patterns increased significantly in response to anticipation of exercise, detectable within one minute of anticipation of exercise.[12]

The physical exertion does not have to be intense, as a study conducted by Kitaoka, *et al*. in 2011 found that simply standing up could produce a feed forward response of the blood flow velocity in the carotid artery and cerebral blood flow in healthy men. Mainly, it was found that blood flow volume decreased significantly just before active standing.[7] This anticipation the body demonstrates before active standing may be caused by a change in the central command and could play a part in the preservation of cerebral perfusion while standing.[7] Another study, performed by Dampney, *et al.* (2002) found that there is an immediate increase in heart rate and ventilation at the beginning of exercise which, again, is a result of the "central command" initiated by the cerebral cortex.

Some studies suggest that the anticipation of exercise is a result of optimizing performance. Ulmer (1996) introduced the complex model of "teleoanticipation" which combines feed-forward planning and feedback control in response to the external environment. A study referenced by Lambert *et al*. (2005) tested the model by conducting experiments to determine the running velocities of experienced runners at 400 m and 1500 m. At the two distances, running velocities remained constant and submaximal among all subjects. In another study, by Lambert, *et al*. (2005), runners were deliberately deceived by mismatching actual and expected running distances. These runners ran at the same velocities as the control group, despite being told the incorrect distance. This suggests that velocity is influenced by the body's prior experience of running various distances – that is to say, the body anticipates and adjusts the amount of physical exertion independent of conscious expectations of distance. In addition, a partial blockade of acetylcholine receptors at the neuromuscular junction with curare, coupled with "intent" to exercise still induced muscle sympathetic nerve activity.[8] Even in the absence of afferent muscle feedback, central commands induce sympathetic activation which also supports the idea that feed forward mechanisms may be influenced by previous exertion experiences. The body may have preset measures of the necessary integration of physical requirements, biochemical levels, metabolic constraints, and muscle reserves to complete exertion tasks.

Another variable that could influence the body's response to exercise is the presence of competition. Confrontational competition among males is a phenomenon that is not unique to humans. These behavioral inclinations are present throughout the animal kingdom and it is predominantly a male affair.[14] The increased level of competition among males stems from selective pressures of male fitness. That is, successful males can enhance their fitness by monopolizing their reproductive performance, which is having access to several females. From a biological standpoint, females do not receive the same profit as males from multiple mates. Females are also competitive; however, males compete more intensely. This sociobiological phenomenon is an idea that has been proposed by many authors, such as Bateman (1948), Williams (1966), and Trivers (1972), to provide an explanation of increased male competitiveness in comparison to female counterparts.

Our proposed experiments aims to measure physiological responses in both males and females via breathing, heart rate and heart pressure changes, in anticipation to exercise to analyze how the body copes with the expected deviations from homeostatic conditions.

We hypothesize that individuals who intend to exercise under competitive or high-pressure conditions will display larger feed forward responses measured by higher heart rates, blood pressure, and respiration rates in comparison to participants who intend to exercise under more relaxed conditions. Furthermore, we hypothesize that male individuals will show larger responses in each of the categories than female individuals. Through our experimental results we rejected this hypothesis because we determined that there were no statistically significant changes between genders or among the three stress situations with respect to expected deviations between resting vitals and vitals taken before anticipation to exercise.

Materials and Methods

Ethical Approval

Participants in this study were recruited from the Physiology 435 lab 602 at the University of Wisconsin Madison. Each participant signed a consent form that listed implications of their participation and risks before they volunteered. No monetary incentive was provided for their participation. The study conformed to ethics standards of the University of Wisconsin Madison.

Methods

In our experiment, we tested three aspects of the body that rely on homeostasis in order to study their relation to a feed forward response, and if different amounts of “anxiety” affect the amount of anticipatory response. Upon arrival, participants stood in an empty room for a period of 2 minutes while measurement devices were set up. We then recorded participants’ average resting heart rate over 30 seconds (beats per minute) with a pulse oximeter, blood pressure (mmHg) with a manual blood pressure cuff, and respiration rates over 30 seconds (breaths per minute) with a respiratory transducer band connected to a polygraph in the Biopac student lab program while participants remained standing. All participants were randomly split into three groups. We then instructed each individual to complete a short running task (See Figure 1 for detailed instructions). The first group of participants was instructed to complete an individual running course while we recorded their times for speed, then return for a recording of new vitals. The second group was instructed to complete a running course while being timed and told that their times were to be compared with individuals in our study of the same gender, then return for a new recording of vitals. The third group was instructed to complete a running course against another individual of the same sex who was waiting at the site of the running course, and return for a new recording of vitals. There was also control group who were simply told their vitals would be taken twice without any anxiety producing instructions to get a better idea of the effect of moving from the first testing station to the second testing station.

After explaining to the participants what they would be doing, we recorded his or her vitals prior to their performance. Participants never had to complete the running courses because we did not actually take a third set of vitals. We then computed the differences between each individual's resting state and pre-run state. Our goal was to see if their bodies adjust in anticipation of physical exercise. We created three different stress levels to see if the amount of anxiety before the exercise was related to the amount of feed forward response (deviation from their resting state levels). We also tailored the sets of instructions given to participants according to their genders to determine if there was a difference in responses between males and females.

In order to determine whether our results were statistically significant, we used a two-factor ANOVA in Microsoft Office Excel 2010 to analyze the variance between our stress levels as well as gender. We found the change in each physiological process by subtracting the initial, baseline measurement from the second (pre-activity) for each participant. We then used the built-in ANOVA function in Excel to generate F and F-critical values, using $\alpha = .05$. If the F value was less than the F-critical, we were unable to reject our null hypothesis. We created graphical representations of the data by finding the average change in each physiological process for each group, and plotting the results on a bar graph.

Group 1: Timed Individual Run
(Recruited participants into a small room where our first recording station was located)

"Hello, thank you for participating in our study. Before we begin, we are going to take some baseline vitals including your heart rate, blood pressure, and respiration rate."

(Recorded vitals)

"Now you will be completing a short running course for us out in the hall. "

(Lead participant out into the hall where there were two chairs, one at each end of the hall to indicate the running course to be completed)

"We will be timing your run from that end of the hall to this end of the hall, do you have any questions about the course or what you are instructed to do? (wait for response) Okay, before you complete the course we are going to take one more set of vitals."

(Recorded one more set of vitals at a second station in the hallway.)

"Thank you. You actually will not be doing any physical exercise. We have gathered all of the information we needed. Thank you for your participation!"

Group 2: Timed Run Comparing Performance to Same-sex Participants in the Study
(Recruited participants into a small room where our first recording station was located)

"Hello, thank you for participating in our study. Before we begin, we are going to take some baseline vitals including your heart rate, blood pressure, and respiration rate."

(Recorded vitals)

"Now you will be completing a short running course for us out in the hall."

(Lead participant out into the hall where there were two chairs, one at each end of the hall to indicate the running course to be completed)

"You will be running from that end of the hall to this end of the hall, and your time will be compared to the other females/males in the study. Do you have any questions about the course or what you are instructed to do? (wait for response) Okay, before you complete the course we are going to take one more set of vitals."

(Recorded one more set of vitals at a second station in the hallway.)

"Thank you. You actually will not be doing any physical exercise. We have gathered all of the information we needed. Thank you for your participation!"

Group 3: Timed Race Against Same Sex Individual
(Recruited participants into a small room where our first recording station was located)

"Hello, thank you for participating in our study. Before we begin, we are going to take some baseline vitals including your heart rate, blood pressure, and respiration rate."

(Recorded vitals)

"Now you will be completing a short running course for us out in the hall."

(Lead participant out into the hall where there were two chairs, one at each end of the hall to indicate the running course to be completed)

"You will be racing from that end of the hall to this end of the hall against [mock participant of same sex who was present and standing waiting at the course]. Do you have any questions about the course or what you are instructed to do? (wait for response) Okay, before you complete the course we are going to take one more set of vitals."

(Recorded one more set of vitals at a second station in the hallway.)

"Thank you. You actually will not be doing any physical exercise. We have gathered all of the information we needed. Thank you for your participation!"

Figure 1- Scripts read to participants according to which group they were randomly assigned

Results

All data collected was analyzed using a two-factor ANOVA test. The change in heart rate between groups was found to change by an average of 9 bpm in the first group (5 females, 4 males), 2 bpm in the second group (5 females, 4 males), and 14 bpm in the third group (5 females, 4 males). This data is statistically inconclusive with an F value of 3.61 and a p value of 0.05. When all experimental groups were combined, a statistically significant change in average heart rate was found to be 8.3 bpm ($F=5.82$, $p=0.019$). No statistically significant changes were found between the three groups with respiration rate ($F=1.47$, $p=0.24$), systolic pressure ($F=0.39$, $p=0.64$), and diastolic pressure ($F=1.76$, $p=0.38$). No statistically significant changes were found between genders overall (15 females, 12 males) with heart rate ($F=1.47$, $p=0.24$), respiration rate ($F=1.2$, $p=0.35$), systolic pressure ($F=0.76$, $p=0.64$) or diastolic pressure ($F=1.16$, $p=0.38$). No statistically significant changes were found within the control group (4 female, 4 males) with heart rate ($F=1.03$, $p=0.33$), respiration rate ($F=0.48$, $p=0.50$), systolic pressure ($F=0.02$, $p=0.88$), and diastolic pressure ($F=0.11$, $p=0.74$).

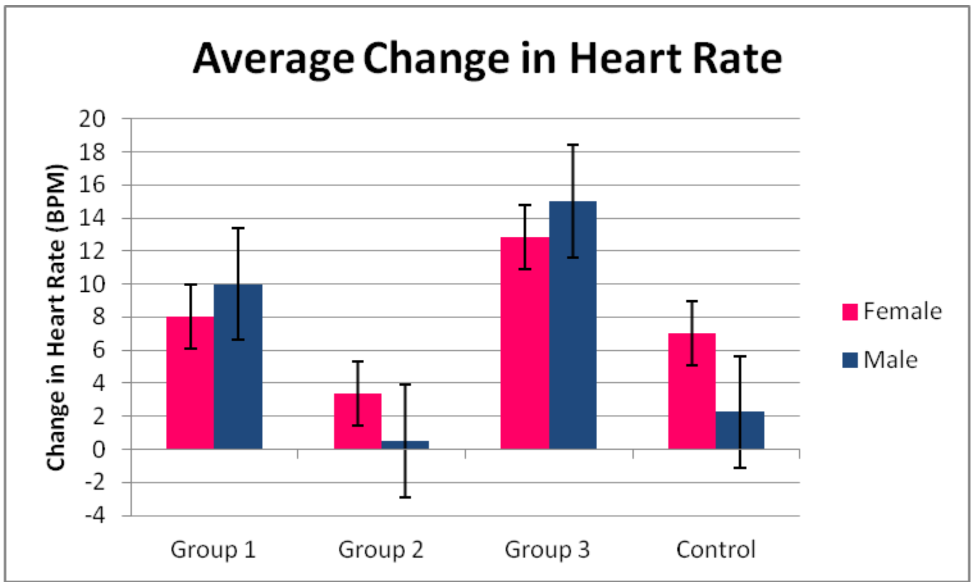

Figure 2 - A graph displaying the average change in heart rate for each group.

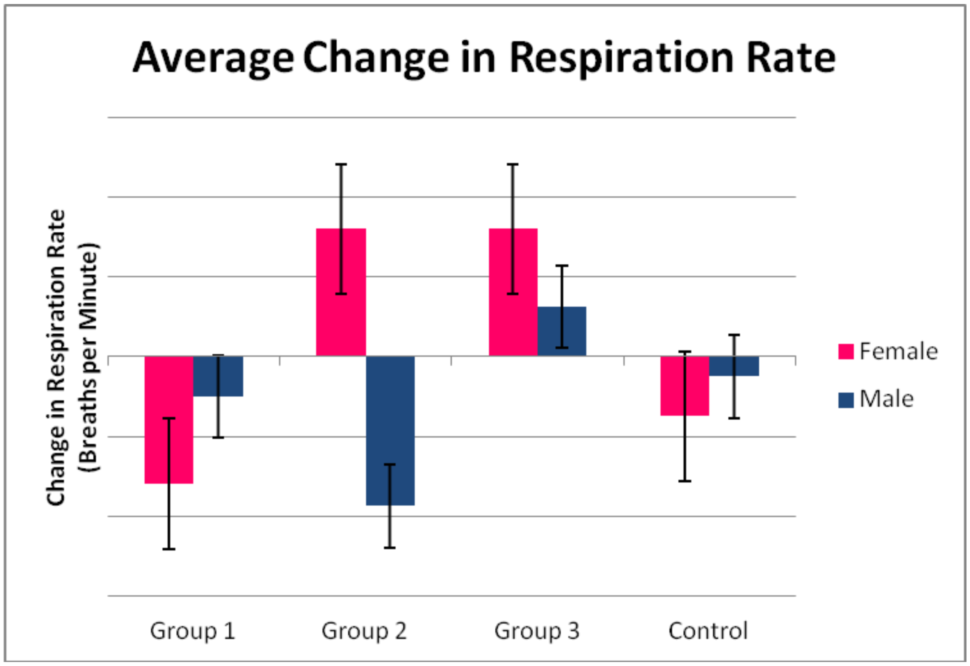

Figure 3 - A graph displaying the average change in respiration rate for each group.

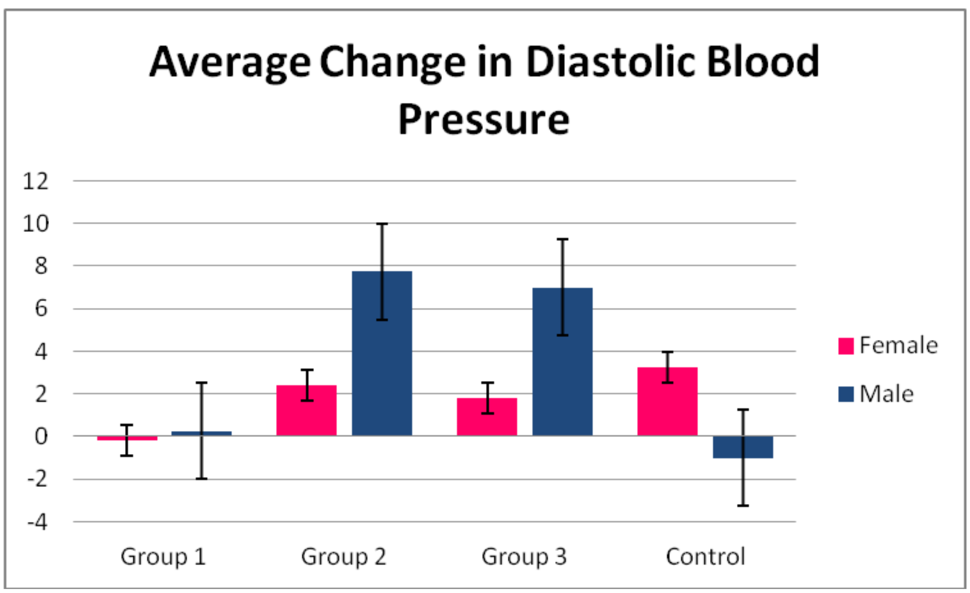

Figure 4 - A graph displaying the average change in systolic blood pressure for each group.

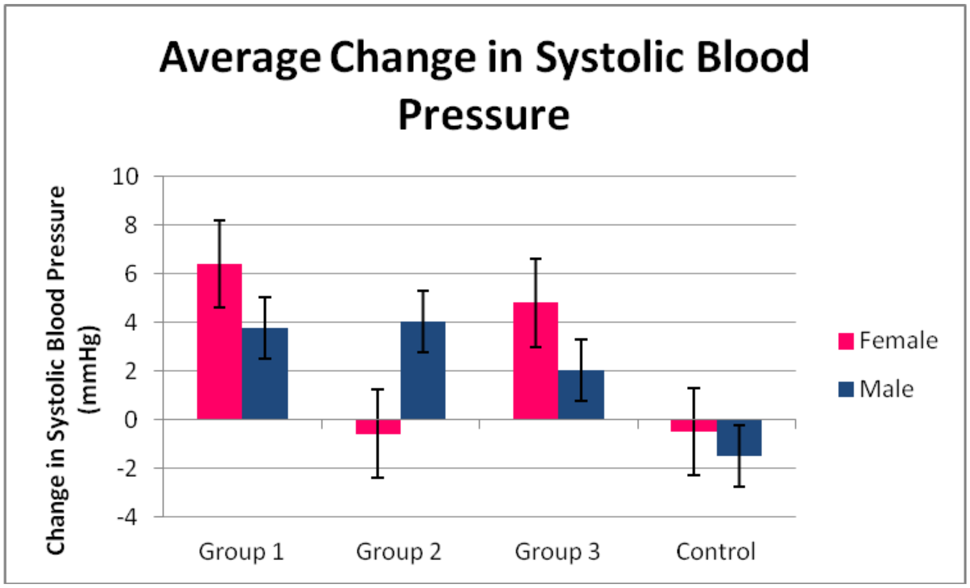

Figure 5 - A graph displaying the average change in diastolic blood pressure for each group.

Discussion

In response to anticipated exercise or physical activity, it has been found that signals arising from cortical regions can induce the sympathetic nervous system to increase the heart rate and blood pressure to prepare the body for a higher rate of activity.[2] We hypothesized that this central command activated via sympathetic stimulation of the heart, blood vessels, and lungs does not only occur, but also that it occurs on a graded scale in response to differing amounts of anticipated stress. Based on our data, our hypothesis is rejected for changes in respiration rate, and blood pressure, and is shown to be inconclusive for changes in heart rate between the groups. However, significant changes in heart rate were found when all experimental groups were combined. Any changes in respiration, blood pressure, or heart rate in the control group were not statistically significant. This suggests that the mere movement of subjects from one testing station to another did not alter recorded vitals enough to account for the differences found in the statistical analysis. Further tests will need to be done to determine, more clearly, the effects of differing amounts of stress on the feed forward response of the sympathetic nervous system acting on the heart rate.

A key reason why we did not find any significant changes in the cardiopulmonary system in anticipation to stressors could be explained by the degree of variability in our stressors. It could be argued that the difference in stress level between running against a clock versus running against another person is not as profound as we expected. Perhaps much more intense differences are needed before any gradient differences in the feed-forward response can be seen such as the anticipation of running a marathon versus running two miles.

Limitations

There were several limitations we encountered during our experiments that may have led to the results we reported. Due to the fact that the majority of our data collection took place in a weekly three hour lab period, we were limited to who we could recruit to participate in our study, the space and supplies available, and time to complete the study.

The first limiting factor was the sample population. The majority of participants were Physiology 435 lab members whom all have relatively similar lifestyles. Being college students, most participants were within a similar age range and they have been exposed to similar environmental factors such as the stress levels associated with higher-level education. In addition, the majority of Physiology 435 participants were science majors and therefore may have a greater understanding of physiology than the general population. This could have contributed to participants successfully predicting the physiological responses being tested, which could have altered the results. Furthermore the feed forward response, specifically, was a concept covered in class. Due to the fact that most of our participants were all in the same class it is possible that past participants may have given away the methodology of our experiment to future participants. Any participant that was aware of our methodology could have displayed a skewed response in comparison to those who were ignorant. It is possible that if we had access to a random population of participants with varying age ranges, and backgrounds we could have measured more genuine physiological responses.

The second limiting factor was the space and supplies available to conduct our study. We did not have access to an ideal space to facilitate a proper experimental environment. The obstacle course was in the hallway of a university building with many distractions and students walking past during the experimental measurements. For this reason, it is possible that participants may not have taken the running portion seriously. If we had the opportunity to set up the course in an empty facility solely intended for exercise, the course could have appeared more professional and individuals may have felt the pressure or anxiety to induce a feed forward response. Thus, the lab setting restricted our ability to create an ideal space for the study.

The limited supplies could have aided in the insignificant results due to human error and lack of high technological sensitivity. We had to take manual blood pressure of each volunteer with a blood pressure cuff and stethoscope so disparities between different recorders and any loud noises may have lead to inaccurate measurements. The oximeter used for measuring heart rate showed some inconsistencies. Perhaps a more accurate reading of heart rate (device or method) would have been more sensitive to slight changes. The respiratory transducer band used to measure respiration rates may not have been sensitive enough to detect subtle differences in respiration that could have been detected otherwise. The band may also have recorded variable responses depending on the thickness of clothing a participant was wearing or inadequate positioning and adjustment. The Tobin et al. (1986) study made use of a respiratory inductive plethysmograph that allowed them to detect CO_2 concentration at the nasal vestibule noninvasively. This equipment was sensitive enough to detect statistically significant increases to minute ventilation and mean inspiratory flow.[12] Had we had access to more accurate recording devices, it is possible that we could have detected measurable differences that were significant between baseline vitals and feed forward responses of the two genders among the different groups.

Lastly, we were presented with the limitation of time. The data collection times took place during a weekly three-hour laboratory session. This limited our ability to recruit more subjects that were not part of our Physiology 435 class. This also limited the number of participants we could realistically test during the time periods that were available to us. If we conducted this study over multiple months, we could have advertised the study, offered multiple sessions to accommodate more schedules, and recruited participants of varying ages, genders, and lifestyles.

Implications for clinical studies

Artificially inducing feed-forward responses by promoting appropriate stress conditions can lead to a greater understanding of the mechanisms that elicit the anticipation response. These findings could be translated onto the clinical setting to introduce more effective behavioral treatments for individuals with higher than normal anxiety that suffer from a stress related disorder. Due to the high stress societies in which individuals inhabit, it is imperative to understand the physiological responses in anticipation of a stressor event.

Previous studies have measured hourly levels of serum cholesterol over an eight-hour period in attempt to determine the nature of the stressor and factors involved to elicit changes in cholesterol.[10] The significant changes found in cholesterol levels were due to anticipation of stress or were a response to the event itself.

Abnormally high levels of cortisol can have adverse health effects and can permanently disrupt the HPA axis. This could present health difficulties to patients suffering from anxiety disorders or who are chronically stressed due to their difficulties in coping with anticipation of stressful events. Among these adverse health effects are early signs of diabetes, abdominal obesity and decreased secretion of sex steroids as well as growth hormone.[11]

Further research needs to be conducted to understand the degrees of stress and the environmental conditions that elicit the feed forward response to exertion anticipation. There is the possibility that exertion anticipation (a positive reason to exhibit a physiological response to anticipation) and anxiety could operate by a similar mechanism. Findings in these studies can shine light on more effective behavioral treatments to allow individuals who suffer from anxiety disorders find better alternatives to reacting in to stressors in a constructive manner instead of a debilitating and harmful response that can have adverse effects to individual’s health.

Although our study did not capture any significant results for feed forward responses for the anticipation of physical exercise, other studies show interesting outcomes that imply the importance of feed-forward response in athletics. In addition to the studies by Dampney, *et al.* (2002), Ulmer, *et al*. (1996), and Lambert, *et al*. (2005) discussed earlier, the continuing study of feed-forward response could lead to useful methods of improving athletic performance. If researchers can figure out new methods to prime our bodies for physical exertion, athletes can incorporate these into their training and reach new goals. A study done by Chimera, *et al.* (2004) supports the idea that training techniques involving feed-forward mechanisms can not only improve performance, but also protect athletes from injury. In this study, female athletes that incorporated plyometric training into their routines stimulated feed-forward responses that increased neurologic adaptations to motor programs in their lower extremities.[1] This improved coordination and dynamic restraint to protect their joints from the velocity and force of quick jumps and cuts.[1] Hewett, *et al.* (2005) did a similar study that produced comparable findings.

Continuing studies on feed-forward responses on performance and injury could not only be used in athletics, but also physical therapy and recovery, as well as training for other physically demanding activities. This may include occupations that include a large amount of physical labor or the training of troops in various positions.

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