Effect of Competition on Muscular Performance

University of Wisconsin-Madison, Department of Physiology

Physiology 435

Lab 601, Group 1

Allison Donhowe, Abbie Milski, Sophia Schmidt, Leon Yee Leong Tan, & Marcus Voigt

Keywords: Competition, Electromyography (EMG), Fatigue, Gender, Heart Rate, Muscle, Strength, Sympathetic Nervous System

Abstract

Competition is a prevalent motivator in everyday life. Previous studies have proven that competition influences hormonal levels and thus affect performance. The purpose of this study was to identify these physiological effects. This study was completed in two stages using a within-subject design. In both stages, participants were directed to clench a hand dynamometer as hard as possible for as long as possible. Stage one recorded baseline data from individuals completing the task alone. Stage two recorded experimental data from these same individuals competing against a same-gender peer. Individual differences between stages were attributed to the effects of competition. Four variables were measured in each stage: maximum clench force, fatigue time, electromyography, and change in heart rate. Fatigue time in male participants was found to increase significantly during competition; all other changes were statistically insignificant. Together, these results indicate that competition did not affect the physiological variables relative to the baseline. These results run contrary to numerous peer-reviewed publications, indicating a possible procedural problem.

Introduction

Competition has always been a part of human society. We experience competition in wars for resources, fights for mates, sporting events, and admission into schools. In a competitive setting, each individual or team attempts to outperform the opposition. The body often responds to this drive and performs differently than it would in non-competitive settings. Competitive performance, however, may vary between individuals and between situations.

Competition is often perceived as a stressor, causing the release of several hormones. Activation of the sympathetic nervous system, for example, stimulates the release of epinephrine and norepinephrine. These hormones are released from the adrenal medulla and act on

adrenergic receptors throughout the body. They elicit the "fight or flight" response that facilitates the change required for physical exertion (Yahyavi *et. al*, 2015). This leads to an increased heart rate, blood vessel dilation, respiratory airway dilation, and glucose mobilization (Roberts & Syme, 2018). Research has linked competition with this increase in sympathetic nervous system activity. In a study conducted on participants racing karts, average heart rate increased by 18 beats per minute, compared to driving the kart alone (Matsumara *et al.,* 2011). In a different study on race car drivers, post-race plasma epinephrine and norepinephrine concentrations were found to be 45% and 65% higher, respectively, than pre-race levels (Del Rosso *et al.,* 2016).

Typically, stimulation of the sympathetic nervous system is coupled with the release of cortisol. Cortisol is slower-acting than sympathetic hormones because it alters transcription rather than affecting a signaling cascade (Yahyavi *et. al*, 2015). Secreted by the adrenal cortex, cortisol prepares the body for disaster by mobilizing energy and suppressing the immune response (Yahyavi *et. al*, 2015). The exact trigger for cortisol release is unknown, but both anticipation of competition and competition itself have been shown to increase plasma cortisol levels (Zsofia *et al.*, 2016). Heightened cortisol levels during competition indicate that the body perceives competition as a physiological stressor.

The physiological response to competition is as much psychological as it is hormonal. A person who does not want to lose will often fight harder and perform better than a person who is unconcerned with the result. In many scenarios, mentality alone can alter circulating hormone levels (Yim, 2016). This runs contrary to the typical model in which hormones determine the physiological response and mindset. While hormone levels and mentality can both influence performance, they cannot be used to predict competitive results. In a study on kickboxers, there

were no significant hormonal differences between the winners and the losers of a given fight (Ouergui *et al.*, 2016). This highlights the importance of qualitative factors in competitive performance, including past experiences, genetics, personality, health conditions, and social influences.

The effect of competition on gender-specific performance is another gray area in physiology. An analysis of a dozen marathons found that men were more likely than women to slow their pace throughout the race (Deaner *et al*., 2015). Although this information alone is inconclusive, it indicates that gender differences in competitive performance may exist. While men and women may be equally competitive overall, the types of competition they engage in often differ. Men tend to experience more competition in physical contests and athletic events, whereas women generally experience more competition around physical attractiveness (Cashdan, 1998). This is likely the result of socialization differences rather than physiological differences. If, however, socialization does impact perception of competition, then men and women may respond differently to similar stimuli.

This study further investigates the effect of competition on muscle power, muscle fatigue, muscle electrical activity (electromyography or EMG), and heart rate. To assess the physiological effects of competition, participants were tested in both a non-competitive and a competitive scenario. Any difference between a participant's non-competitive baseline results and their competitive results can then be attributed to competition. Based on the hormonal release patterns of previous studies, we expect circulating levels of epinephrine and cortisol to be higher in competitive scenarios (Del Rosso *et al.,* 2016; Matsumara *et al.,* 2011; Ouergui *et al.*, 2016; Zsofia *et al.*, 2016). Given limited lab equipment, we were unable to directly measure hormone levels, so proxy measurements were chosen in place of direct hormone measurements.

Consequently, we expect larger muscle power output, reduced muscle fatigue, and increased heart rate during competition. Since EMG strongly correlates with muscular force, we also expect increased muscle electrical activity during competition (Helmi *et al.*, 2017; Roberts & Gabaldon, 2008). Any significant physiological change, relative to baseline, should reflect the effects of competition.

Methods

Participants

Thirty participants were selected from the Physiology 435 class at the University of Wisconsin-Madison during the spring 2018 semester. Of these participants, 12 were male and 18 were female. All participants were between the ages of 20 and 23. Subjects were informed of the terms and risks before consenting to participate in the experiment. To ensure confidentiality, participants were assigned random identification numbers and all data were de-identified.

Materials

Four variables were measured in this experiment: clench force, fatigue time, EMG, and heart rate. Data were collected and analyzed using Biopac Student Lab System (Model: MP36; Biopac Systems, Inc., Goleta, CA). Alcohol swab wipes (NCE-38936; Dynarex, India) were used to clean participants' skin before attaching three disposable electrodes to the forearm (Model: EL503, Biopac Systems, Inc., Goleta, CA). EMG was recorded using a three electrode lead set (Model: SS2L; SN: 711A14749, Biopac Systems, Inc., Goleta, CA), which were connected to the disposable electrodes. Clench force was tested using a hand dynamometer (Model: SS25LA; SN: 1506004319; Biopac Systems, Inc., Goleta, CA), which measured force in kilograms. Heart rate was measured using an Omron 10 series+ Blood Pressure Monitor (Model: BP791IT; Omron Healthcare Inc., Lake Forest, IL).

Procedure

This study was conducted in two stages. In each stage, a fatigue test was administered to test maximum clench force, time to 50% of the maximum clench force (referred to as "fatigue time"), EMG, and heart rate change. In stage one, participants were tested individually to establish a baseline for later comparison. In stage two, two same-gender participants competed at the same task performed in stage one. Stages were separated by at least one week to ensure that each trial was independent. An experiment outline with specific stage details can be found in **Figure 1**.

Stage One

In stage one, participants completed a fatigue test to obtain baseline physiological measurements. These baseline measurements were later used for comparison to the data collected in stage two. Prior to participant arrival, the Biopac equipment was prepared by attaching an electrode lead set and a hand dynamometer to the system. The hand dynamometer was calibrated to zero when lying flat on a level surface.

Upon arrival, participants were seated facing away from the connected computer monitor, unable to see any data collection. One researcher worked near the participant to administer the test while a second researcher worked from behind the computer.

The inside of the participant's dominant arm was cleaned from wrist to elbow using alcohol wipes. Three disposable electrodes were attached to the participants arm, as indicated in **Figure 2**. Electrode A was placed on the ulnar side of the inner arm, just above the wrist. Electrode B was placed on the radial side of the inner arm, about one inch proximal to electrode A. Electrode C was placed on the ulnar side of the subject's inner arm, about two inches below

the inner elbow. The black lead was connected to electrode A, the red to electrode B, and the white to electrode C.

Heart rate was measured before the test using a blood pressure cuff on the participant's non-dominant arm. The cuff remained on the participant's arm for the duration of the test. Participants were directed to squeeze the hand dynamometer with their dominant arm as hard and as long as possible. When the measured force had declined to less than 50% of the subject's maximum clench force, the participant was directed to stop. Immediately after the fatigue test, the participant's heart rate was again measured.

Stage Two

In stage two, two participants of the same gender completed a fatigue test at the same time to simulate competition. Subject pairs were randomly selected using participant identification numbers. The same physiological variables measured in stage one were again measured in stage two. Before participant arrival, two Biopac systems, each with an electrode lead set and a hand dynamometers, were set up on separate computers. The hand dynamometers were calibrated in the same manner as in stage one.

Upon arrival, participants were seated directly across from each other. Participants were again unable to see any data collection. Electrodes and leads were applied to each participant as they were in stage one. Heart rates were measured using separate machines and blood pressure cuffs for each participant. At this point, participants were explicitly told they would be competing against their opponent in the same fatigue test previously performed, with one declared as the winner. Again, participants were directed to squeeze the hand dynamometer as hard and as long as possible. Researchers directed both participants to stop squeezing at the same time, once each's clench force fell below 50% of their initial maximum value. This usually

required one participant to hold their grip past the 50% mark, as participants reached fatigue at different times. Immediately after the test, each participant's heart rate was again measured.

Data Analysis

This experiment used a within-subject design to compare each participant's physiological measurements under competitive scenarios to their baseline. Two sets of data for each participant were analyzed using the BioPac software, one from each stage of the experiment. From each data set, the maximum clench force, fatigue time, and area under the EMG were recorded. All area under the EMG curve was considered a positive value, even when the measured voltage was below zero. Because the area under the EMG curve always increases with time, "controlled EMG area" was calculated by dividing total area by fatigue time. This metric measures the amount of muscle electrical activity when controlled for time. Previous studies have validated this measurement by correlating muscle force with area under the EMG curve (Roberts & Gabaldon, 2008). Heart rate change was calculated by subtracting pre-test heart rate from post-test heart rate. This yielded four metrics to be analyzed: maximum clench force, fatigue time, controlled EMG area, and heart rate change.

In this experiment, negative control was indicated by a lack of physiological change when the participant did not prompt the equipment. Shown in **Figure 3** is evidence of negative control for the hand dynamometer and EMG. When a participant sits still with the dynamometer in hand, no force is registered and no change in EMG is recorded. The negative control for heart rate change follows similar logic, but is not shown.

Positive control was indicated by pilot testing on four team members. Compared to the negative control, all tools showed different results when prompted during a fatigue test. Data from these tests are shown in **Figure 4**. Pilot test results are shown in **Table 1**. A paired t-test

comparing each participant's positive control and negative control was calculated using an alpha value of 0.05. One-tailed t-tests were used to determine if our metrics increased during competition. A p-value of 0.014 was found for max clench force, 0.0051 for controlled EMG area, and 0.040 for heart rate change. Significant results ensure that the experimental design is feasible and that measurable changes occur during the fatigue test.

For each experimental participant, a separate analysis was conducted for each experimental stage. A participant's competitive results from stage two were compared to their baseline results from stage one. This data was expressed as a percent change. Individual results were compiled into groups for analysis. These groups were designated as:

- All participants (n=30)
- Male participants (n=12)
- Female participants (n=18)

A paired t-test comparing each participant's stage one (baseline) and stage two (competition) results was performed using an alpha value of 0.05. A statistically significant result implies that competition impacted the given physiological metric. This significance test was conducted for all four metrics in each of the three groups listed above, yielding 12 total p-values.

Results

Cumulative results for each metric are shown in **Table 2.** Additional results are detailed below.

<u>Maximum Clench Force</u>

Difference in maximum clench force between baseline and competition is shown in **Figure 5**. Maximum clench force increased by an average of 7.96% (SD=33.24) in the all participant group, by 13.06% (SD=37.82) in the male participant group, and by 4.56% (SD=30.48) in the

female participant group. No significant changes were found between a group's baseline and competitive results. The all participant group had a p-value of 0.099, the male group had a p-value of 0.128, and the female group had a p-value of 0.267. Non-significant results indicate no correlation between competition and maximum muscle power output.

Fatigue Time

Difference in muscle fatigue time between baseline and competition is shown in **Figure 6**. Fatigue time increased by an average of 11.72% (SD=58.89) in the all participant group, by 25.40% (SD=43.21) in the male participant group, and by 2.61% (SD=67.00) in the female participant group. These results indicate a significant change in the male participant group, but not in the other two groups. The male group had a p-value of 0.033, the all participant group had a p-value of 0.142, and the female group had a p-value of 0.435. A significant result indicates a correlation between competition and muscle fatigue in males.

Controlled EMG Area

Difference in controlled EMG area between baseline and competition is shown in **Figure 7**. Controlled EMG area increased by an average of 7.23% (SD=56.41) in the all participant group, by 11.03% (SD=67.54) in the male participant group, and by 4.69% (SD=49.59) in the female participant group. No significant changes in controlled EMG area were found between a group's baseline and competitive results. The all participant group had a p-value of 0.244, the male group had a p-value of 0.291, and the female group had a p-value of 0.347. Non-significant results indicate no correlation between competition and amount of muscle electrical activity.

Heart Rate Change

Difference in heart rate change between baseline and competition is shown in **Figure 8**. Heart rate change increased by an average of 0.20% (SD=9.15) in the all participant group, decreased by 2.70% (SD=9.29) in the male participant group, and increased by 2.13% (SD=9.15) in the female participant group. No significant changes in heart rate were found between a group's baseline and competitive results. The all participant group had a p-value of 0.453, the male group had a p-value of 0.847, and the female group had a p-value of 0.168. Non-significant results indicate no correlation between competition and heart rate change.

Discussion

Without having the ability to directly test hormone levels, the four metrics chosen serve as measurable physiological indicators of the body's response to competition. Maximum clench force measures muscle power output, fatigue time measures muscle fatigue, controlled EMG area measures muscle electrical activity, and heart rate change measures sympathetic nervous system activation. Any difference between the baseline and competitive tests can be attributed to competition. Based on the established effects of epinephrine and cortisol, we expected a larger maximum muscle power output, increased muscle fatigue time, increased muscle electrical activity, and increased heart rate change during competitive trials.

This study found only one statistically significant change in the four selected variables. This was male participant fatigue time (p=0.033), which increased by 25.40% (SD=43.21) during competition. Because the p-value was relatively close to the alpha value of 0.05, these results were further analyzed. Male fatigue time change was much larger than that of females, who only increased their fatigue time by 2.61% (SD= 67.00). Despite this apparent discrepancy, a t-test comparing these two populations yielded a p-value of 0.307. This indicates that gender

does not play a significant role in fatigue time during competition. Of the twelve male participants, nine increased their fatigue time during competition. If male fatigue time increased because of hormonal differences, as hypothesized, then increased fatigue time should correspond with increases in the other three metrics. Of the nine male participants who increased their fatigue time, only four increased their maximum clench force, two increased their heart rate change, and three increased their controlled EMG area. Because increases in fatigue time do not correlate well with the other three metrics, it is unlikely that hormones played a role. If competition were affecting epinephrine or cortisol levels, then all four metrics should increase together. Any increase in male fatigue time can likely be attributed to the small sample size or a mechanism outside of our hypothesis.

We calculated no other significant change in maximum clench force, fatigue time, controlled EMG area, nor heart rate change during competition. Because the hormonal effects of competition have been well established (Del Rosso *et al.,* 2016; Matsumara *et al.,* 2011; Ouergui *et al.*, 2016; Zsofia *et al.*, 2016), non-significant results likely indicate errors in the experimental procedure. Several factors could have produced these results. Influences that increased baseline sympathetic hormones or decreased competition sympathetic hormones would yield insignificant results.

One possible explanation is that subjects treated stage one as its own competition. If subjects felt they were being watched or tested, cortisol and epinephrine levels could have increased. Several participants asked to see their results after stage one, adding validity to this explanation. This phenomenon is known as "social facilitation," and often leads to improved performance at simple tasks (Demolliens *et al.*, 2017). Such scenario is quite possible, as all five experimenters watching were of similar age to the participant. If this were to occur, then stages

one and two would have similar hormonal profiles. We would then not expect to see significant differences in muscle performance.

A second possible explanation for our non-significant results is that subjects were not treating stage two as a real competition. Participants had no stake in the outcome, so they may not have performed as they would in a true competition. Because there was no extrinsic motivator, subjects complied solely based on intrinsic motivation, which greatly varies between individuals (Liang *et al.* 2018). Decreased competitive drive was evident in several participants during stage two. Some participants, for example, claimed that they knew their competitor would win. Other participants complained about the shape of the hand dynamometer. If incentive does play a role in effort, then a subject's thoughts on the competition are likely affected. Since cognition can itself affect circulating hormone levels (Yim, 2016), incentive could have had physiological effects during our experiment. If cortisol and epinephrine levels did not increase during stage two, then we would again have similar hormonal profiles and would not expect a difference in muscular performance.

Utilizing a larger sample size with a more diverse group of participants could produce more representative results. Of the 30 participants tested, 53% of participants increased their maximum clench force during competition, 57% increased their fatigue time, 47% increased their heart rate change, and 57% increased their controlled EMG area. Only 10% of participants increased all four metrics during competition. These unexpected results are indicative of a procedural problem than a sample size problem. It is also possible that the chosen variables were not reflective of hormone levels, invalidating the assumption our experiment was built upon.

The large error bars in **Figures 5-8** can partially be attributed to small sample size. With more participants, even the same data would have a smaller standard deviation. Due to time

constraints, our experiment was limited to 30 participants, the minimum to approximate a normal distribution in statistics. Sample size also explains why the male participant group (n=12) and female participant group (n=18) had larger standard error bars than the all participant group. Personal variation also played a role in the large error bars. For example, one participant's maximum clench force increased by 15.5 kg during competition, while another participant's maximum clench force actually decreased by 15.7 kg during competition. Similar variation was observed for all variables. This variation could be explained by the cognitive aspects previously described or by other procedural errors.

Future researchers should consider extrinsic motivation, such as a prize or monetary reward, to elicit more typical competition. Participants would likely take the competition more seriously, making hormonal changes more probable. Additional research is also needed to clarify competition's physiological effects on different genders. Likewise, it may be useful to study the physiological differences between same-gender and opposite-gender competition.

References

Cashdan, E. (1998). Are men more competitive than women?. *British Journal of Social Psychology*, *37*(2), 213-229.

Deaner, R. O., Carter, R. E., Joyner, M. J., & Hunter, S. K. (2015). Men are more likely than women to slow in the marathon. *Medicine and science in sports and exercise*, *47*(3), 607.

Del Rosso, S., Abreu, L., Webb, H. E., Zouhal, H., & Boullosa, D. A. (2016). Stress markers during a rally car competition. *The Journal of Strength & Conditioning Research*, *30*(3), 605-614.

Demolliens, M., Isbaine, F., Takerkart, S., Huguet, P., & Boussaoud, D. (2017). Social and asocial prefrontal cortex neurons: a new look at social facilitation and the social brain. *Social cognitive and affective neuroscience*, *12*(8), 1241-1248.

Helmi, M. H. B., Ping, C. S., Ishak, N. E. B., Saad, M. A. B. M., & Mokhtar, A. S. N. B. (2017). Assessment of muscle fatigue using electromygraphm sensing. In *AIP Conference Proceedings* (Vol. 1875, No. 1, p. 030019). AIP Publishing.

Liang, H., Wang, M. M., Wang, J. J., & Xue, Y. (2018). How intrinsic motivation and extrinsic incentives affect task effort in crowdsourcing contests: A mediated moderation model. *Computers in Human Behavior*, *81*, 168-176.

Matsumura, K., Yamakoshi, T., Yamakoshi, Y., & Rolfe, P. (2011). The effect of competition on heart rate during kart driving: A field study. *BMC research notes*, *4*(1), 342.

Ouergui, I., Davis, P., Houcine, N., Marzouki, H., Zaouali, M., Franchini, E., & Bouhlel, E. (2016). Hormonal, physiological, and physical performance during simulated kickboxing combat: differences between winners and losers. *International journal of sports physiology and performance*, *11*(4), 425-431.

Roberts, J. C., & Syme, D. A. (2018). Effects of epinephrine exposure on contractile performance of compact and spongy myocardium from rainbow trout (Oncorhynchus mykiss) during hypoxia. *Fish Physiology and Biochemistry*, *44*(1), 49-62.

Roberts, T. J., & Gabaldón, A. M. (2008). Interpreting muscle function from EMG: lessons learned from direct measurements of muscle force. *Integrative and comparative biology*, *48*(2), 312-320.

Yahyavi, S. T., Zarghami, M., Naghshvar, F., & Danesh, A. (2015). Relationship of cortisol, norepinephrine, and epinephrine levels with war-induced posttraumatic stress disorder in fathers and their offspring. *Revista Brasileira de Psiquiatria*, *37*(2), 93-98.

Yim, J. (2016). Therapeutic benefits of laughter in mental health: a theoretical review. *The Tohoku journal of experimental medicine*, *239*(3), 243-249.

Zsofia, N. B., Orsolya, K., & Otto, S. (2016). The role of cortisol hormone in equine exercise physiology. *MAGYAR ALLATORVOSOK LAPJA*, *138*(11), 643-652.

Figures and Tables

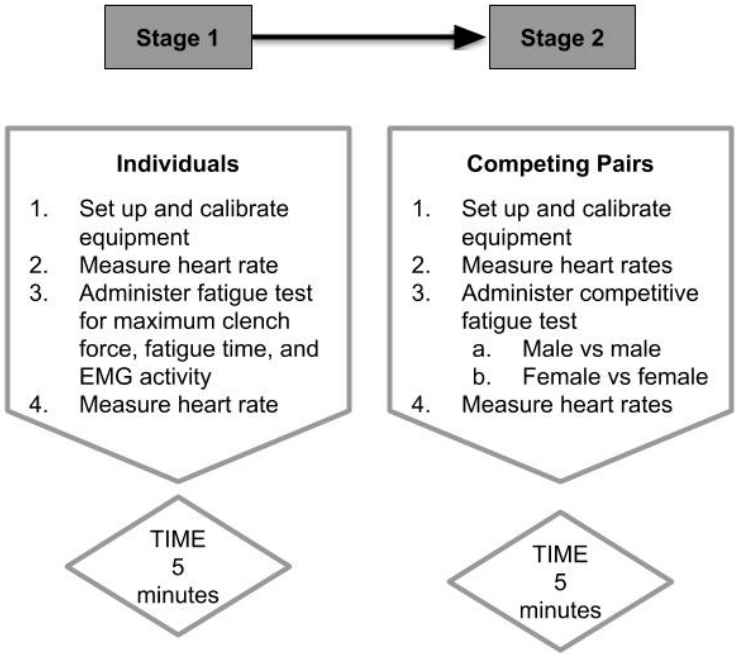

Figure 1. Experimental design overview. The same physiological measurements were made during a fatigue test administered in two different scenarios. In stage one, participants were tested alone. In stage two, participants were competing against another participant of the same gender.

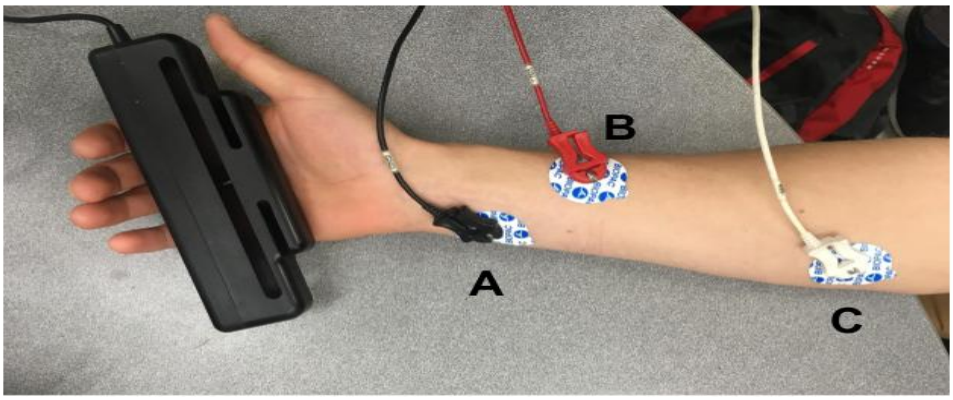

Figure 2. Example electrode setup for a right-handed subject. The black lead was connected to electrode A, the red to electrode B, and the white to electrode C.

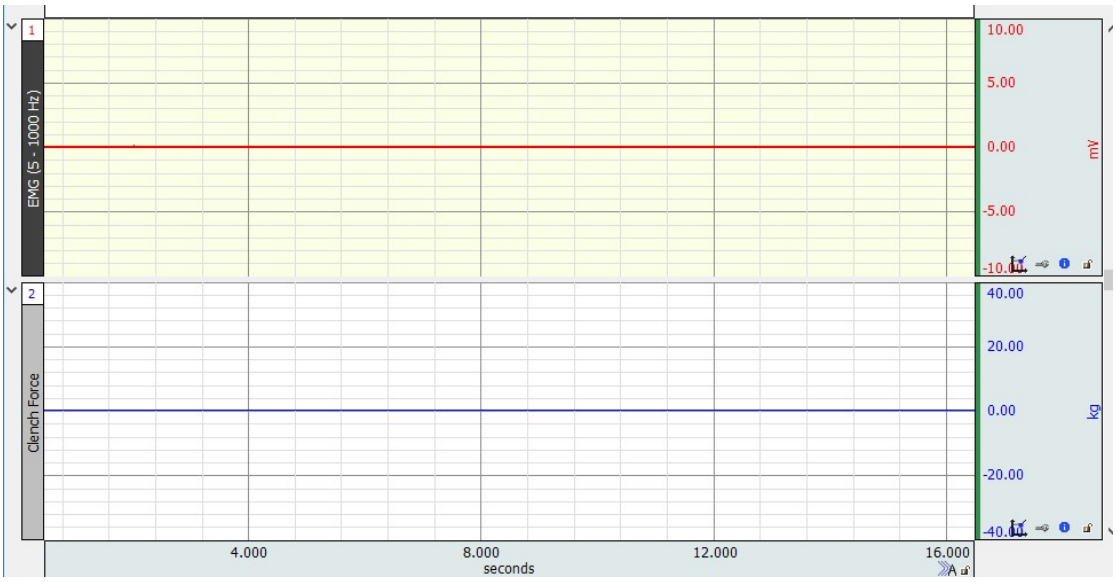

Figure 3. Negative control showing that each machine does not measure change when unprompted. When connected to a still patient, no change in clench force or EMG is recorded. Heart rate change follows the same pattern, but is not shown here.

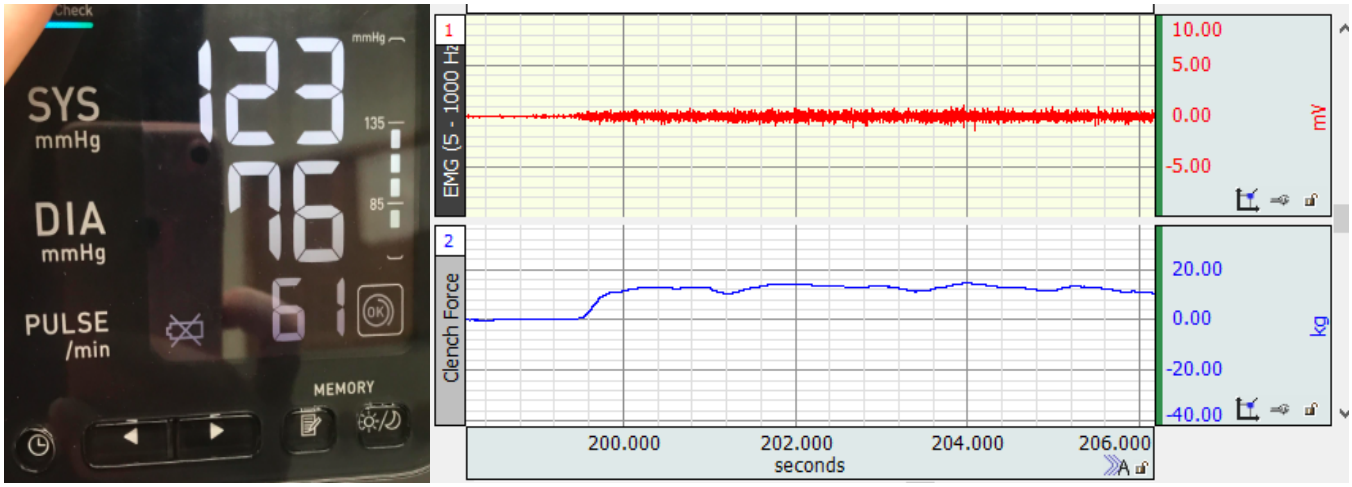

Figure 4. Positive control showing that each machine measures its intended metric in pilot testing. On the left, heart rate was monitored. On the right, EMG and clench force were measured during clenching.

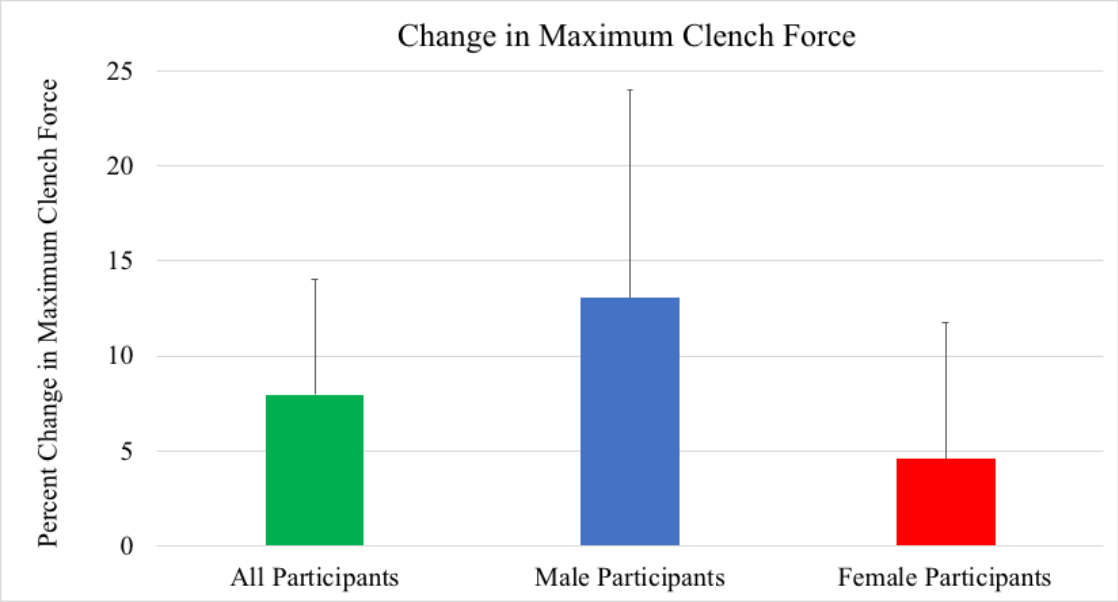

Figure 5. Percent change in experimental clench force between stage one (baseline) and stage two (competition). Difference between stages was not significant for all participants (p=0.099), male participants (p=0.128), or female participants (p=0.267).

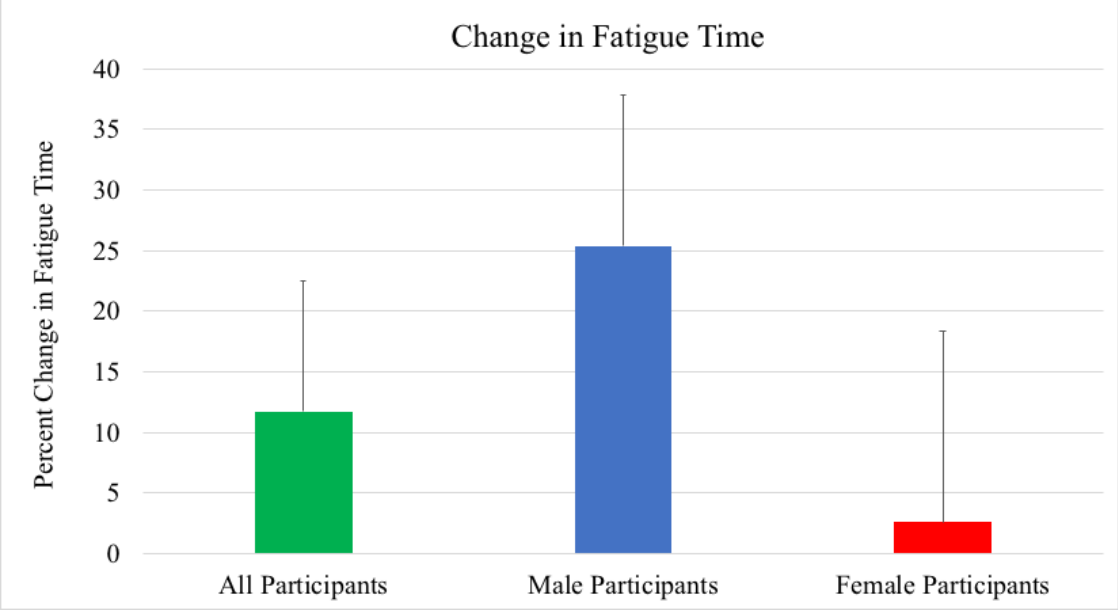

Figure 6. Percent change in experimental fatigue time between stage one (baseline) and stage two (competition). Fatigue time was measured as the time to reduce muscle power by 50%. Difference between stages was not significant for all participants (p=0.142) or female participants (p=0.435), but was significant for male participants (p=0.033).

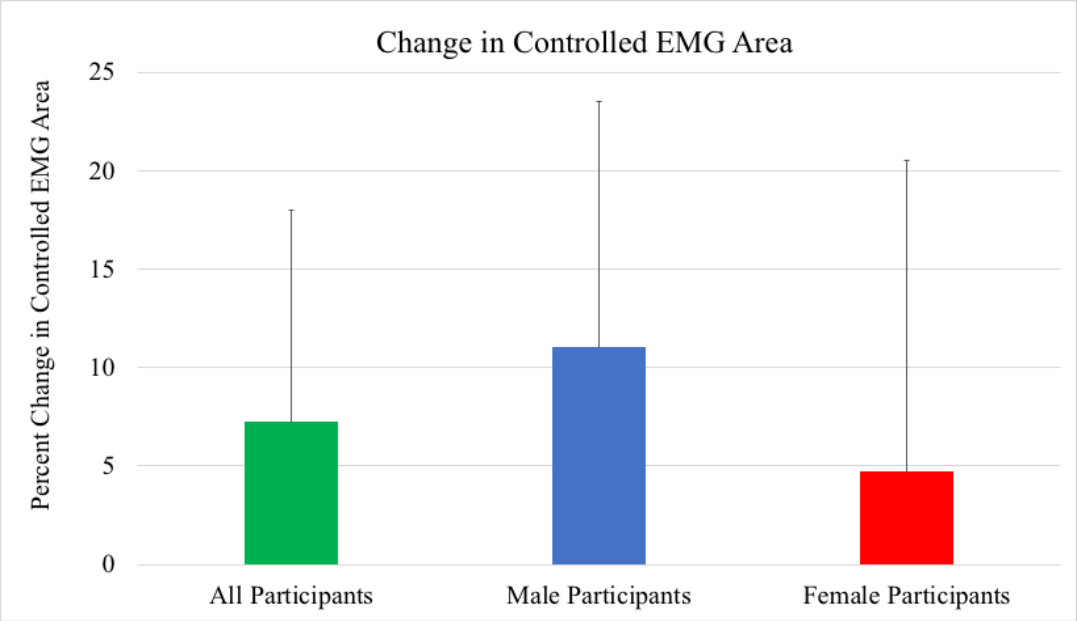

Figure 7. Percent change in experimental controlled EMG area between stage one (baseline) and stage two (competition). Controlled EMG area was used to approximate muscle electrical activity. It was measured by dividing area under the EMG curve by time. Difference between stages was not significant for all participants (p=0.244), male participants (p=0.291), or female participants (p=0.347).

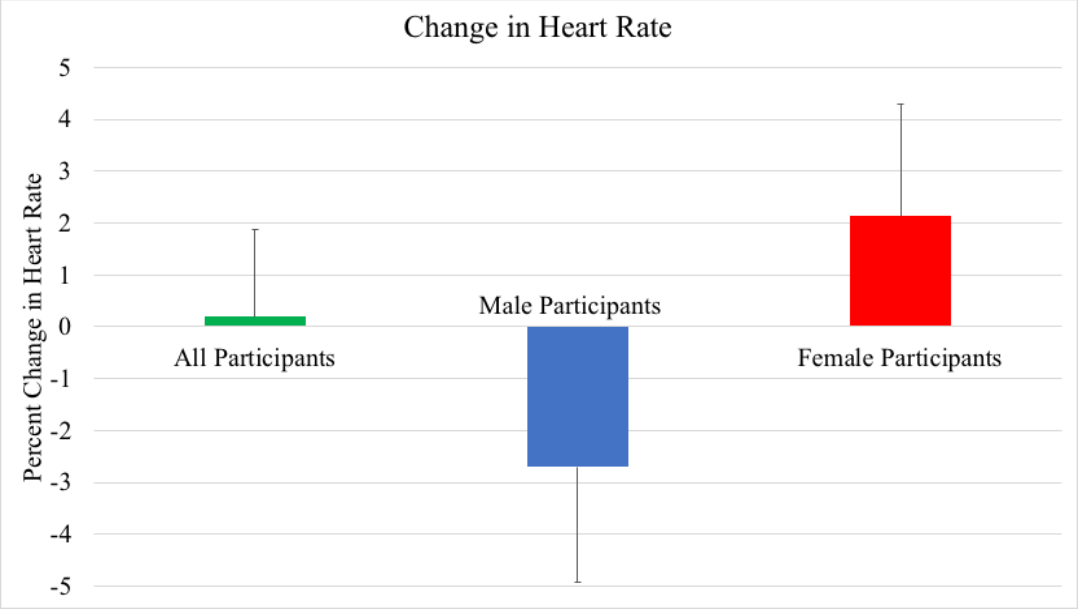

Figure 8. Percent change in experimental heart rate between stage one (baseline) and stage two (competition). Change was calculated by subtracting a pre-fatigue test heart rate from a post-fatigue test heart rate. Difference between stages was not significant for all participants (p=0.453), male participants (p=0.847), or female participants (p=0.168).

Group Member	Negative Control Max Clench Force (kg)	Positive Control Max Clench Force (kg)	Difference (kg)	Negative Control Controlled EMG Area (mV/s)	Positive Control Controlled EMG Area (mV/s)	Difference (mV/s)	Negative Control Heart Rate Change (BPM)	Positive Control Heart Rate Change (BPM)	Difference (BPM)
A	0.125	14.217	14.092	0.014	0.202	0.188	-5	5	10
B	0.188	19.698	19.510	0.012	0.496	0.484	-1	8	9
C	0.140	22.146	22.006	0.016	0.422	0.406	3	2	-1
D	0.028	41.828	41.800	0.035	0.408	0.373	0	9	9

Table 1. Results of pilot tests on group members. The average differences in metric between the two controls were all statistically significant.

Group	Max Clench Force	Standard Deviation	Fatigue Time	Standard Deviation	Controlled EMG Area	Standard Deviation	Heart Rate Change	Standard Deviation
All Participants: Percent Difference Between Baseline and Competition (n=30)	7.96	33.24	11.72	58.89	7.23	56.41	0.20	9.15
P-Value	0.099		0.142		0.244		0.453	
Male Participants: Percent Difference Between Baseline and Competition (n=12)	13.06	37.06	25.40	43.21	11.03	67.54	-2.70	8.73
P-Value	0.128		0.033		0.291		0.847	
Female Participants: Percent Difference Between Baseline and Competition (n=18)	4.56	30.48	2.61	67.00	4.69	49.59	2.13	9.15
P-Value	0.267		0.435		0.347		0.168	

Table 2. Experimental results for each of the four metrics tested. Positive values indicate higher levels during competition while negative values indicate lower levels during competition. One-tailed paired t-tests were performed between each group's results to determine the effect of competition.