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The Effects of Repetitive Bouts of a Fatiguing Exertion (with Breaks) on the Slope of EMG Measures of Localized Muscle Fatigue

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Disciplines

Ergonomics | Operations Research, Systems Engineering and Industrial Engineering

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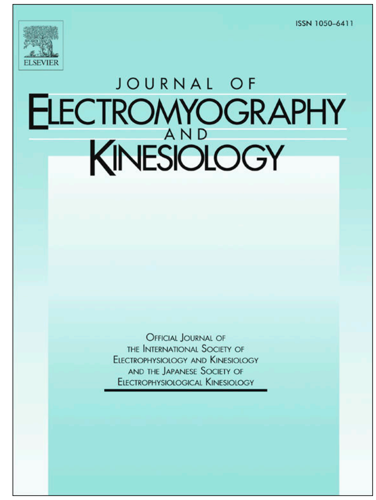

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Decreases in the median frequency of the power spectrum and increases in amplitude measures of an electromyographic signal have been used to assess localized muscle fatigue. How these responses are affected by repetitive bouts of exertions - separated by rest breaks - is not well understood. It was hypothesized that repetitive bouts of a fatiguing, isometric exertion, separated by periods of rest, would have cumulative effects (across bouts) on the slope of these EMG-based variables, with an expectation of a steeper rate of decline in the median frequency and a steeper rate of increase in amplitude measures in subsequent bouts. To test these hypotheses, 24 participants performed four bouts of an isometric (15% MVC) elbow flexion exertion. Each exertion lasted for four minutes and then a 15-minute break was provided between bouts. Surface electromyography was used to capture the activity of the biceps brachii at twenty-second intervals during the exertions. The median frequency and average rectified value were calculated, as were the slopes of these variables within each of the four-minute bouts. Contrary to the original hypotheses, the results showed that there were no statistically significant differences in the slopes of these EMG-based measures across bouts. One direction for future work is to explore different combinations of work-rest durations to refine this response while another may be to explore alternate EMG-based measures of muscular fatigue that may be more sensitive to this cumulative effect.

1. INTRODUCTION

Previous research has demonstrated that assessing localized muscle fatigue can be accomplished using electromyography (EMG). These techniques include both frequency domain measures (e.g. mean and median frequency of the EMG power spectrum) and time domain measures (e.g. root-mean-square values and average rectified values of the EMG). The fatigue-related changes in the frequency domain values can be traced to changes in muscle fiber conduction velocity due to decreases in the pH in the muscle with fatigue (Brody et al., 1991). Early work of Kadefors et al. (1968), showed a downward shift in median frequency of the EMG power spectrum of the biceps brachii muscle as it was fatigued. In a subsequent study, Lindström et al., (1977) again collected EMG data on the biceps brachii muscle, but this time they observed the continuous change in the median frequency and quantified the time-dependent, downward slope of the median frequency during the exertion. These authors performed a regression analysis on the value of the median frequency of the EMG power spectrum data and used the downward slope of the median frequency as a fatigue index. More recently studies have explored the relationship between this value of median frequency slope and joint angle (Doheny, et al., 2008); shoulder muscle coactivation (Evans et al., 2018); chronic back pain experience (da Silva et al., 2015); rotator cuff tear status (Hawkes et al., 2015); knee joint angles (Pereira et al., 2011).

Changes in the EMG amplitude have likewise been associated with muscle fatigue. The underlying physiology of these changes can be traced back to increased motor neuron stimulation and increased motor neuron recruitment in response to reduced muscle contractility needed to maintain a constant muscle force (Bigland-Ritchie et al., 1986). The two most popular parameters for quantification of EMG amplitude are root mean square and average rectified value of integrated EMG signal. A recent example of research that has employed this EMG amplitude measure to assess localized muscle fatigue was a by Vijendren et al., (2018) wherein the authors documented the increase in the amplitude of the surface EMG signal to show the effect of a specific rest break technique (the Ipswich Microbreak Technique) on the localized muscle fatigue of muscle of the neck and shoulder. By comparing the percentage increase in mean EMG amplitude, they concluded that this rest break technique can increase the time to fatigue. Since both time domain and frequency domain parameters provide insights into the muscular fatigue development process, Cifrek et al. (2009) advocated a joint analysis of spectrum and amplitude, noting that the joint analysis provides the necessary data to distinguish between muscle activity changes due to fatigue and those changes due to muscle force.

One area of the EMG fatigue response that has not yet been explored is the effect of repetitive bouts of a fatiguing exertion (with intermittent breaks) on the slope of these EMG-based measures of localized muscle fatigue. As noted above there have been a number of studies (e.g. Lindström et al., 1977; Doheny, et al., 2008; Evans et al., 2018; da Silva et al., 2015; Hawkes et al., 2015; Pereira et al., 2011; Merletti et al., 1984) that have considered the use of the time-dependent slope of these EMG parameters as a way of assessing the rate of development of fatigue. However, none of these studies have explored how intermittent breaks might influence the rate of fatigue development in individual bouts. The hypothesis of the current study is that with repeated bouts of an isometric exertion, the slope of these fatigue-indicating EMG measures will become steeper within a bout. The underlying muscle physiology that motivates this hypothesis focuses on the challenges of completely returning muscle to its original state after a period of fatiguing isometric contraction. Previous studies have shown that low-level muscle contractions (10-20% MVC) can create this circulatory compromise, negatively affecting blood flow in, and oxygenation of, muscular tissue (e.g. Griffin et al., 2001) thereby compromising muscle recovery during exertion. Several studies have attempted to explore the post-exertion recovery process and understand the relationship between fatigue-related EMG parameters and measures of muscle metabolites and processes including muscle pH (Béliveau et al., 1991; Béliveau et al., 1992) and changes to muscle fibre conduction velocity (Zwarts, et al., 1987). In the 1991 study, Béliveau and colleagues demonstrated that intra-muscular pH had not recovered to initial levels even though the median frequency had recovered to its initial value, indicating some residual fatigue that was not reflected in the MDF of the EMG signal. Therefore, the research question addressed in the current research is "Does the time-dependent fatigue response of a muscle vary depending on the number of fatiguing bouts previously experienced?". It is hypothesized that the time-dependent slopes of the median frequency of the EMG power spectrum and EMG amplitude within a bout will be steeper in later bouts as compared to the initial fatiguing bout.

2. METHODS

2.1 Participants

There were twenty-four participants (twelve men and twelve women) in this study and they had the following characteristics (mean ± SD): age (27.6 ± 6.6years), stature (168.8 ± 11.6cm), whole body mass (75.2 ± 20.3kg), standing elbow height (105 ± 20.8cm). Before participation, each participant provided written informed consent. Exclusion criteria were a history of chronic upper extremity pain/injury or current pain in the upper extremity, and less than 18 or greater than 65 years of age.

2.2 Apparatus

Surface electromyography of the dominant arm biceps brachii was captured using a DELSYS® Bagnoli-16 EMG system, (Massachusetts, USA). According to SENIAM standards, the electrode should be placed on the line between the medial acromion and the fossa cubit at 1/3 of the distance from the fossa cubit. The recording of upper arm length of the individual participant provided the data needed to establish this positioning. The choice of the dominant side biceps brachii as the muscle to be studied was motivated by the simplicity of the elbow flexion exertion, the level of control required from the exertions, as well as the availability of data from previous studies for exertion magnitude and duration (El Ahrache et al., 2006). Before attaching the electrode, the skin was cleaned with isopropyl alcohol. The EMG data were collected using a sampling frequency of 4096Hz for collection periods of four seconds, and these data collections occurred every twenty seconds during the fatiguing exertions.

A Kin-Com Isokinetic Dynamometer (125E, Chattanooga TN, USA), was employed to measure the maximum voluntary isometric contraction (MVIC) of the elbow flexors as well as provide the static resistance and video feedback that allowed the participants to control their elbow flexion moment at 15% of their MVIC during the submaximal trials (Figure 1).

Insert Figure 1 About Here

2.3 Experimental Tasks

Upon arrival, the experiment was described to the participant and the participant was asked to provide written informed consent. Basic anthropometric characteristics (stature, whole body weight, standing elbow height, upper elbow length, etc.) were then measured. Hand dominance was noted. The participant was then guided to the dynamometer where the axis of rotation of the dynamometer was aligned to the axis of rotation of the participant's dominant hand elbow joint with the elbow in a 90-degree elbow flexion posture. To maintain the required 90-degree elbow flexion angle during the exertions, the vertical distance of the center of location of the lever arm of dynamometer from the floor was adjusted to the individual subject's standing elbow height. Once aligned vertically, the handle of the dynamometer was positioned anteriorly/posteriorly so that the handle fit comfortably in the palm of the participant, and the forearm was secured in that position.

Once properly positioned, data collection began. To capture the participant-specific maximum elbow flexion moment, the participant was asked to exert maximum elbow flexion two times (exertions separated by one-minute rest), and if the maximum moments generated were within 10% of each other, the larger of the two was used as the maximum flexion moment. If they were not within 10% of each other, the participant was asked to perform a third maximum elbow flexion exertion and the largest of the three was used as the maximum flexion moment. The participant was then provided a five-minute rest. The participant then re-entered the apparatus and used the video feedback of the dynamometer to maintain an elbow flexion moment equal to 15% MVIC for four minutes. The level of 15% MVC and four-minute exertion duration were selected as our isometric exertion parameters based on the results of El Ahrache et al., (2006). This previous study developed a maximum endurance time model that it predicted that 95% of the population was able to maintain a 15% of MVC exertion of the upper extremity for 3.98 minutes. Upon completion of the four-minute exertion the participant was then provided a fifteen-minute rest, seated on a stool outside of the apparatus. This fifteen-minute break time was established through pilot studies that demonstrated that this duration of rest was necessary for the median frequency of the EMG power spectrum to return to its original value – a necessary condition for our hypotheses. The four-minute exertion then fifteen-minute rest sequence was repeated four times. Total experimental time was 57 minutes (4+15+4+15+4+15 minutes). Each of the four-minute segments of 15% MVIC exertion were considered a “BOUT” of the exertion.

2.4 Data Collection and Processing

Data were collected for four seconds every twenty seconds during the four-minute bouts. Data were processed in a MATLAB (MathWorks Inc., MA) code that utilized the Fast Fourier

Transform function convert to the frequency domain and then the code filtered (high-pass 10 Hz, low-pass 400, notch filter 60 Hz and harmonics) and then computed the median frequency of the EMG power spectrum. The median frequency of the EMG power spectrum and the average rectified value of the amplitude were calculated for each four second data collection period. Least squares regression was used to find the best fit line to these EMG data in each four-minute bout for each participant. The slopes of these lines were found for each bout for each participant and these slope values were the dependent variables in this experiment.

2.5 Experimental Design

2.5.1 Independent variables

The independent variable in this experiment was BOUT with values of 1, 2, 3, and 4.

2.5.2 Dependent Variables

The dependent variables of this experiment were the slope of 1) the median frequency of the EMG power spectrum and 2) the average rectified value of the time domain EMG signal, both of the dominant-hand, biceps brachii muscle.

2.5.3 Statistical analysis

The statistical software JMP was used to perform one-way ANOVA to assess the hypothesis that these slope values change (become steeper) as the value of BOUT increases. This was a randomized block design, with participant acting as the random-effects blocking variable and BOUT was considered the treatment. Assumptions of one-way ANOVA were confirmed (i.e., normality of residuals and homogeneity of variance). A significance level of 0.05 was used as the criteria value for statistical significance.

3. RESULTS

Figures 2-5 show the median frequency across each of the four bouts averaged across the 24 participants. The downward trend in these median frequency responses (Figures: 2-5) are consistent with the expected muscular fatigue and a statistical analysis (simple paired t-tests) confirmed that there is significant decrease in the value of EMG MDF ($p<0.0005$) and significant increase in the value of EMG amplitude ($p>0.0001$) from the beginning to the end of each bout. The average values of the slopes of the least squares fit lines of the median frequency of the EMG power spectrum were -0.006 Hz/sec, -0.014 Hz/sec, -0.015 Hz/sec, and -0.011 Hz/sec for BOUT 1, BOUT 2, BOUT 3, and BOUT 4, respectively. The statistical analysis from the ANOVA revealed an F-value of 0.35 which is less than F critical value of 2.74 ($F_{0.05, 3,69}$) signifying no significant differences ($p=0.77$) in the slopes across bouts, a result that does not support the original hypothesis. Figures 6-9 show the average rectified value across each of the four bouts averaged across the 24 participants. Consistent with the trends in the median frequency data, the positive slopes of the average rectified value are consistent with the expected fatigue response. Also consistent with the statistical analysis of the median frequency data, the statistical analysis from the ANOVA of the average rectified values showed that the computed F-value (1.25) was not statistically significant ($p=0.30$, F critical value of 2.74 ($F_{0.05, 3,69}$)). Therefore, there were no significant differences in the slope of the average rectified values from bout to bout.

Insert Figures 2-9 About Here

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4. DISCUSSION

Previous studies have established that a decrease in the median frequency is an indicator of peripheral muscle fatigue e.g. (Kadefros, Kaiser, & Petersen, 1968; Lindstrom et al., 1977; Merletti, Sabbahi, & De Luca, 1984), and subsequent studies have explored the slope of this decrease as a measure of rate of fatigue of the muscle. The current research sought to document the changes in this slope in repeated bouts of a fatiguing exertion with rest breaks in between the bouts of the fatiguing exertion, and it was hypothesized that measures of rate of fatigue development would increase in subsequent bouts due to residual muscular fatigue that was not captured by the value of the initial value of the median frequency of the EMG spectrum. The study hypotheses were not supported by the data in that these slope values (both frequency and time domain measures) did not change significantly as a function of bout number. The results of the current study demonstrate that, for this particular work-rest protocol, if a break is long enough to bring the median frequency and amplitude back to its initial value, the rate of change of these fatigue-related EMG measures does not significantly change across bouts.

There have been a number of studies that have explored the topic of slope of median frequency decline as a measure of rate of fatigue, and the comparison of the slope of the current study with those of previous research may be informative. These previous studies have typically focused on single bout exertions (i.e. without intervening rest breaks). A good example is a study by Hollman et al., (2013) who studied the slope of the median frequency of the gluteus maximus and semitendinosus as participants performed an isometric modified Biering–Sørensen test. Their participants held the trunk extension posture for five seconds and they used surface electrodes to sample these muscles. These authors found that the slopes of the median frequencies were -0.075 Hz/s for the gluteus maximus and -0.0166 Hz/s for the semitendinosus. These values are significantly larger than those seen in the current study, a direct result of the higher intensity exertions, as well as differences in the fiber type distributions in the muscles sampled. A study that evaluated the same muscle considered in the current study (bicep brachii) was performed by Kuthe et al., (2018). In their study they asked their participants (14 that participated in a daily structured training program and 14 untrained) to exert 50%, 75%, and 100% elbow flexion MVC for the 60s or until failure occurred. They then evaluated the slope of the median frequency through surface electromyography. They found that training did not have a consistent effect on the slope of the median frequency but did find that the slope become more negative as a function of increasing exertion level. Averaged across all participants, the slope of the 50%MVC exertion was -0.140Hz/sec, at 75%MVC the value of the slope was -0.255Hz/sec, and at 100%MVC the value of the slope was -0.294Hz/sec. The slopes seen in the current study are significantly lower, a result that is consistent with the exertion-level trends seen in this previous study.

The principal contribution of the current study was the exploration of the muscle fatigue response with the introduction of rest breaks into a fatigue protocol and evaluating the effects of these breaks on the slopes of established, fatigue-indicating EMG measures. Rest breaks are a particularly important and interesting aspect of the fatigue response particularly for ergonomic (i.e. occupational settings). As median frequency analysis is used to evaluate the development of fatigue in occupational scenarios, understanding the relationship between median frequency shift during a fatiguing exertion and the associated impacts of rest breaks is critical. By design, the recovery period considered in this study was sufficient to return the median frequency to its initial value (established in pilot studies). This was very important because Rashedi and Nussbaum (2017) demonstrated that the rate of fatigue reduction and recovery of a muscle depend on the initial condition. Since it was our objective to evaluate the changes in slope after periods of rest, initial conditions (i.e. initial median frequency) were critically important. As is evidenced in Figures 2-9, this objective was achieved. There have been a number of studies that have explored this topic of necessary (and sufficient) time for recovery and this was shown to vary both by muscle and exertion intensity level (e.g. Iguchi et al., 2008; Kroon et al., 1991), therefore we relied on the results of our pilot work to set the rest break duration.

There are two ways that these non-significant results of this study can be interpreted, and this dichotomy points to the principal limitation of the generalizability of our results. The first interpretation could be that the duration of the rest break was not only sufficient to return all EMG measures back their original values, but also sufficient to provide full recovery of all of the relevant muscle physiological parameters (e.g. muscle pH) so that there was no residual fatigue that would influence the subsequent responses in the following bouts. The second interpretation would be that the EMG measures chosen were not sensitive enough to capture this residual fatigue, if it existed. Anecdotally, the participants in this experiment were clearly subjectively more fatigued in the latter bouts as compared to the former, which might indicate support for the second of the two options presented above. Future research using different work-rests cycles and differing levels of work intensity along with the exploration of other EMG measures of fatigue may provide the data necessary to answer this question.

5. CONCLUSIONS

The focus of the current study was to explore the cumulative effects of multiple bouts of an isometric fatiguing exertion when inter-bout rest periods were provided. The results of this study with this particular repetitive four-minute work & fifteen-minute rest cycle profile did not show a cumulative effect on the responses of the median frequency of the EMG power spectrum or average rectified values on later bouts of a fatiguing exertion. Future work should explore varied work-rest cycles to better elucidate if localized muscle fatigue can be cumulative and, if so, what are the parameters that will lead to this response.

REFERENCES

Béliveau, L., Helal, JN., Gaillard, E., Hoecke, J.V., Atlan, G., and Bouissou, P. (1991) EMG Spectral Shift- and 31P-NMR-Determined Intracellular Ph in Fatigued Human Biceps Brachii Muscle. Neurology. 41(12):1998-2001.

Béliveau, L., Hoecke, J.V., Garapon-Bar, C., Gaillard, E., Herry, I P., Atlan, G., and P. Bouissou. (1992) Myoelectrical and Metabolic Changes in Muscle Fatigue. Int. J. Sports Med. 13, S153—S155.

Bigland-Ritchie, B., Cafarelli, E., and Vøllestad NK. (1986). Fatigue of Submaximal Static Contractions. Acta Physiologica Scandinavica. 128(Suppl 556), 137-148.

Brody, L.R., Pollock, M.T., Roy, S.H., De Luca, C.J., Celli, B. (1991). pH-Induced Effects on Median Frequency and Conduction-Velocity of the Myoelectric Signal, Journal of Applied Physiology, 71, 1878-1885.

Cifrek, M., Medved, V., Tonkovic´, S., and Ostojic´ S., (2009). Surface EMG based muscle fatigue evaluation in biomechanics. Clinical Biomechanics 24 (2009) 327–340.

da Silva, R.A., Vieira, E.R., Cabrera, M., Altimari, L.R., Aguiar, A.F., Nowotny, A.H., Carvalho, A.F. and Oliveira, M.R. (2015). Back muscle fatigue of younger and older adults with and without chronic low back pain using two protocols: A case-control study. Journal of Electromyography and Kinesiology. 25, 928- 936. https://doi.org/10.1016/j.jelekin.2015.10.003.

Doheny, E. P., Lowery, M. M., FitzPatrick, D. P. and O'Malley, M. J. (2008). Effect of elbow joint angle on force-EMG relationships in human elbow flexor and extensor muscles. Journal of Electromyography and Kinesiology. 18(5), 760–770. https://doi.org/10.1016/j.jelekin.2007.03.006.

El Ahrache, K., Imbeau, D., Farbos, B. (2006) Percentile values for determining maximum endurance times for static muscular work. International Journal of Industrial Ergonomics. 36, 99-108. https://doi.org/10.1016/j.ergon.2005.08.003.

Evans, N. A, Dressler, E. and Uhl, T. (2018). An electromyography study of muscular endurance during the posterior shoulder endurance test. Journal of Electromyography and Kinesiology. 41, 132–138. https://doi.org// 10.1016/j.jelekin.2018.05.01

Griffin, L., Garland S.J., Ivanova, T., Hughson, R.L. (2001). Blood flow in the triceps brachii muscle in humans during sustained submaximal isometric contractions. European Journal of Applied Physiology. 84, 432-437. https://doi.org/10.1007/s004210100397

Hawkes, D.H., Alizadehkhaiyat, O., Kemp, G.J., Fisher, A.C., Roebuck, M.M. and Frostick, S.P. (2015). Electromyographic assessment of muscle fatigue in massive rotator cuff tear. Journal of Electromyography and Kinesiology. 25, 93-99. https://doi.org/10.1016/j.jelekin.2014.09.010.

Hollman, J. H., Hohl, J. M., Kraft, J. L., Strauss, J. D. and Traver, K. J. (2013). Does the fast Fourier transformation window length affect the slope of an electromyogram's median frequency plot during a fatiguing isometric contraction? Gait and Posture. 38(1), 161–164. https://doi.org/10.1016/j.gaitpost.2012.10.028.

Iguchi, M., Baldwin, K., Boeyink, C., Engle, C., Kehoe, M., Ganju, A., Messaros A. J. and Shields, R. K. (2008). Low frequency fatigue in human quadriceps is fatigue dependent and not task dependent. Journal of Electromyography and Kinesiology. 18(2), 308–316. https://doi.org/10.1016/j.jelekin.2006.09.010.

Kadefors, R., Kaiser, E. and Petersen, I. (1968). Dynamic spectrum analysis of myo-potentials with special reference to muscle fatigue. Electromyography. 8(1), 39–74.

Kroon, G. W. and Naeije, M. (1991). Recovery of human after heavy eccentric, concentric or isometric exercise. Journal of European Applied Physiology and Occupational Physiology. 63, 444–448. https://doi.org/10.1007/BF00868076

Kuthe, C. D., Uddanwadiker, R. V. and Ramteke, A. A. (2018). Surface electromyography-based method for computing muscle strength and fatigue of biceps brachii muscle and its clinical implementation. Informatics in Medicine Unlocked. 12(March), 34–43. https://doi.org/10.1016/j.imu.2018.06.004.

Lindström, L., Kadefors, R. and Petersén, I. (1977). An electromyographic index for localized muscle fatigue. Journal of Applied Physiology Respiratory Environmental & Exercise Physiology. 43(4), 750–754. https://doi.org/10.1152/jappl.1977.43.4.750.

Merletti, R., Sabbahi, M. A. and De Luca, C. J., (1984). Median frequency of the myoelectric signal - Effects of muscle ischemia and cooling. European Journal of Applied Physiology and Occupational Physiology. 52(3), 258–265. https://doi.org/10.1007/BF01015206.

Pereira, G.R., de Oliveira, L.F. and Nadal, J. (2011) Isometric fatigue patterns in time and time–frequency domains of triceps surae muscle in different knee positions. Journal of Electromyography and Kinesiology. 21, 572–578. https://doi.org/10.1016/j.jelekin.2011.03.010.

Rashedi, E. and Nussbaum, M. A. (2017). Quantifying the history dependency of muscle recovery from a fatiguing intermittent task. Journal of Biomechanics. 51, 26–31. https://doi.org/10.1016/j.jbiomech.2016.11.061.

Vijendren, A., Devereux, G., Tietjen, A., Duffield, K., Van Rompaey, V., Van de Heyning, P., & Yung, M. (2018). The Ipswich Microbreak Technique to alleviate neck and shoulder discomfort during microscopic procedures. Applied Ergonomics. https://doi.org/10.1016/j.apergo.2018.04.013.

Zwarts, M. J., Weerden, T. W. V., and Haenen, H. T. M. (1987). Relationship between Average Muscle Fibre Conduction Velocity and EMG Power Spectra during Isometric Contraction, Recovery and Applied Ischemia. Eur J Appl Physiol. 56:212—216.

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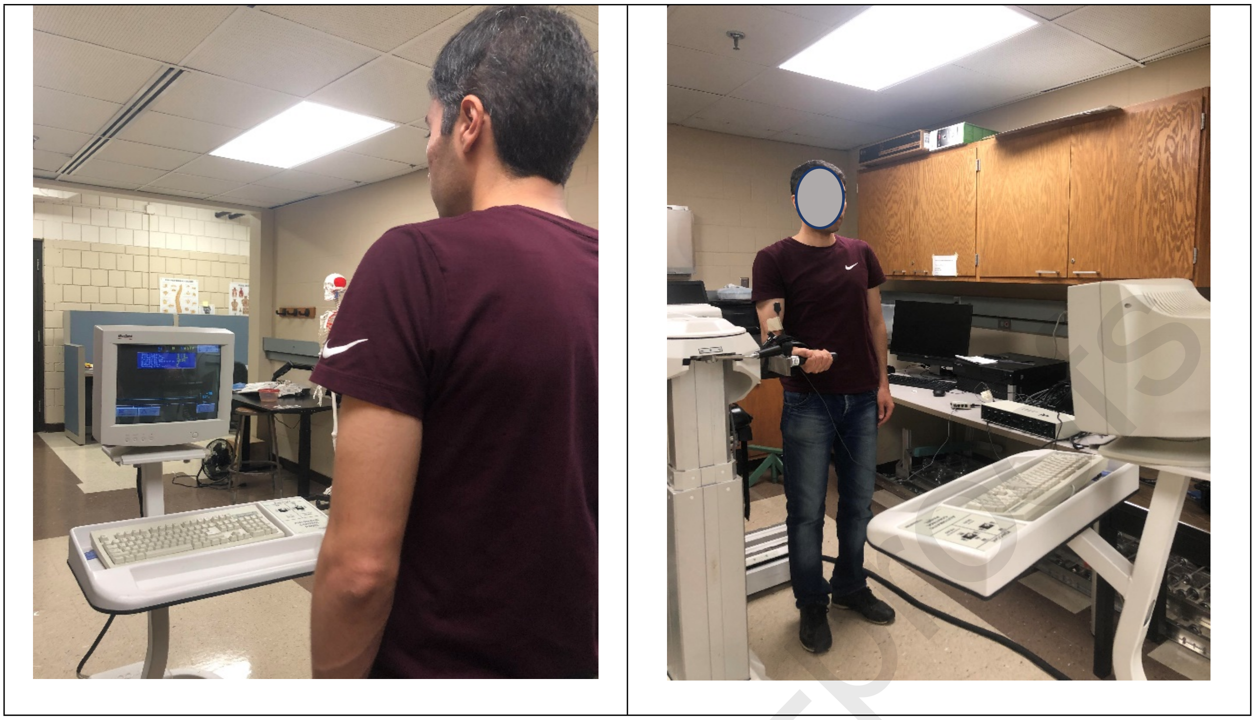

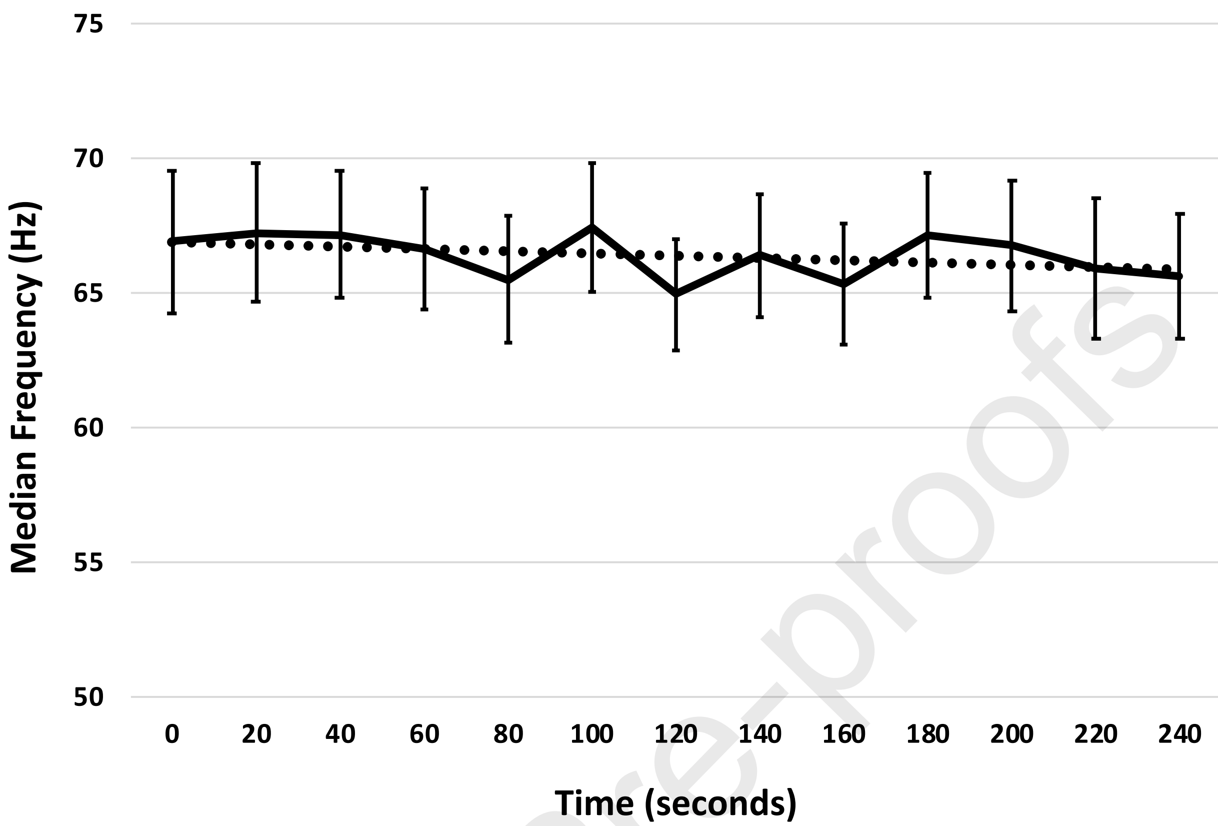
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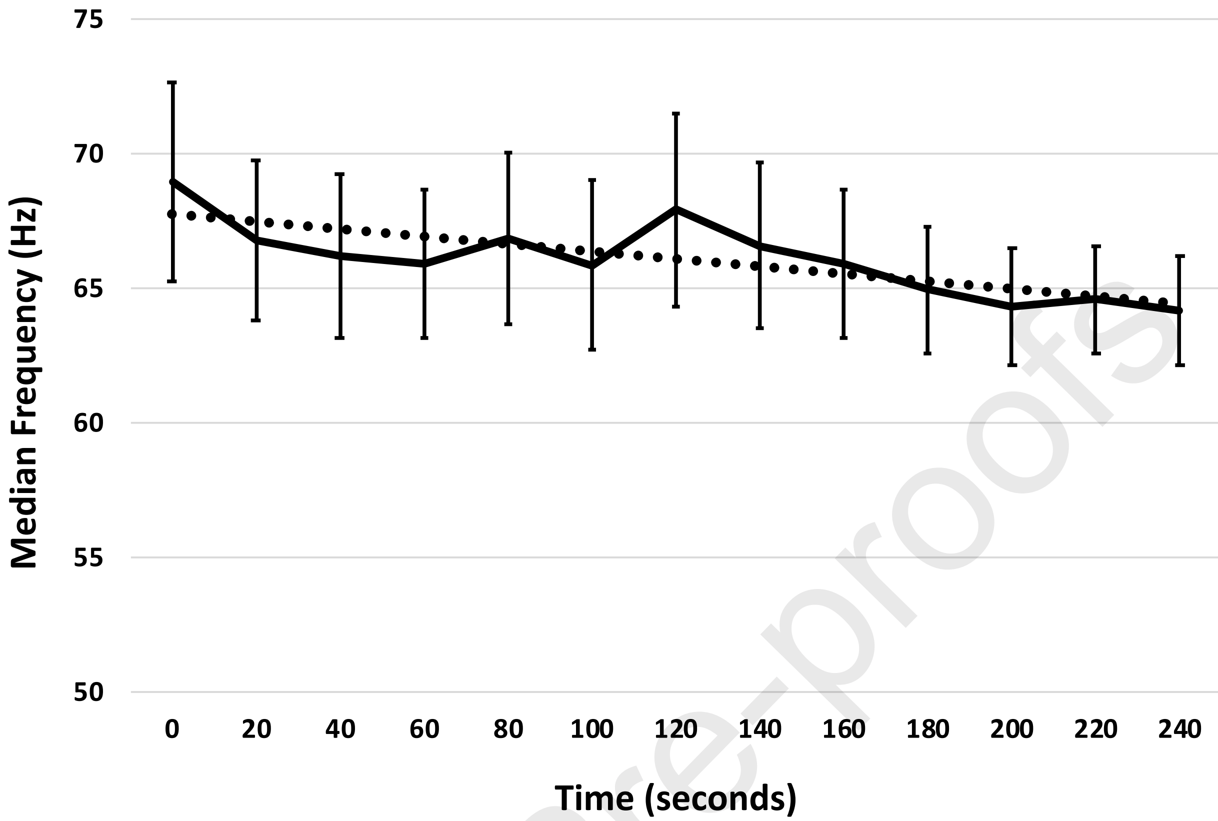
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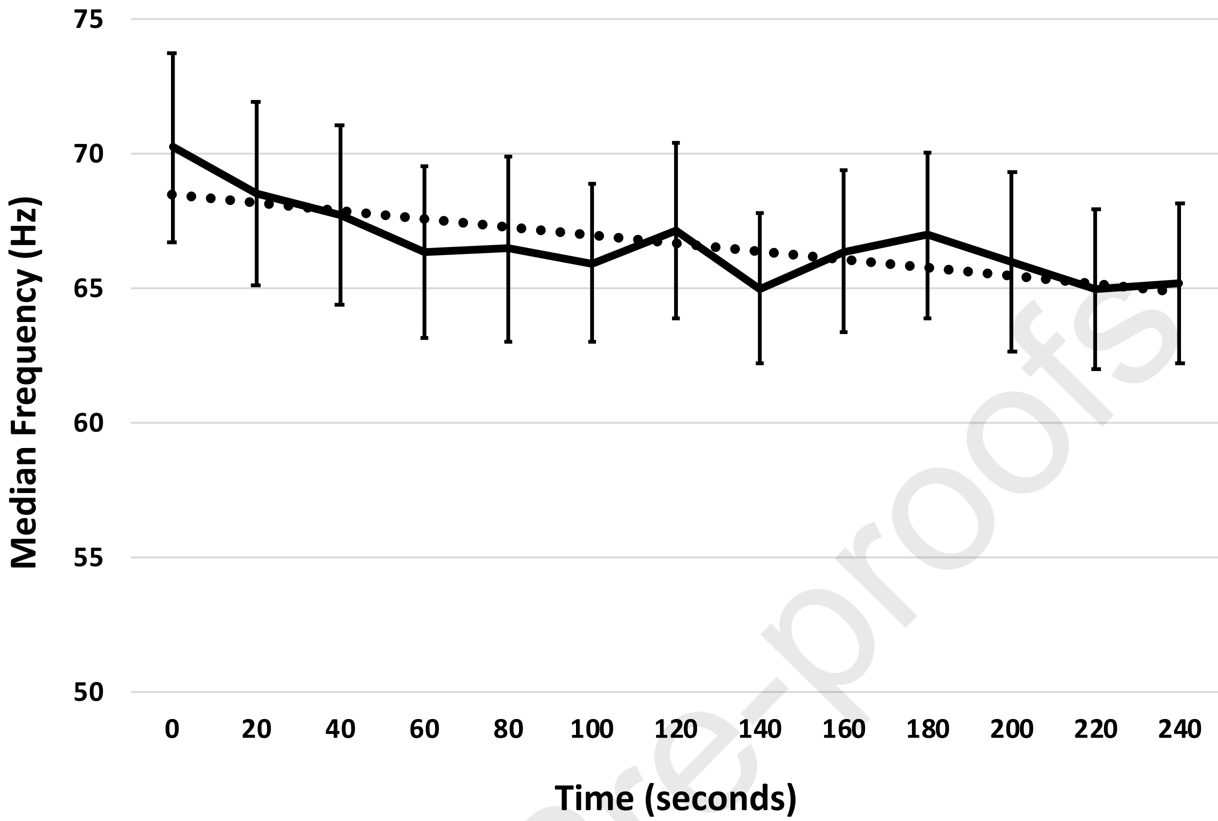
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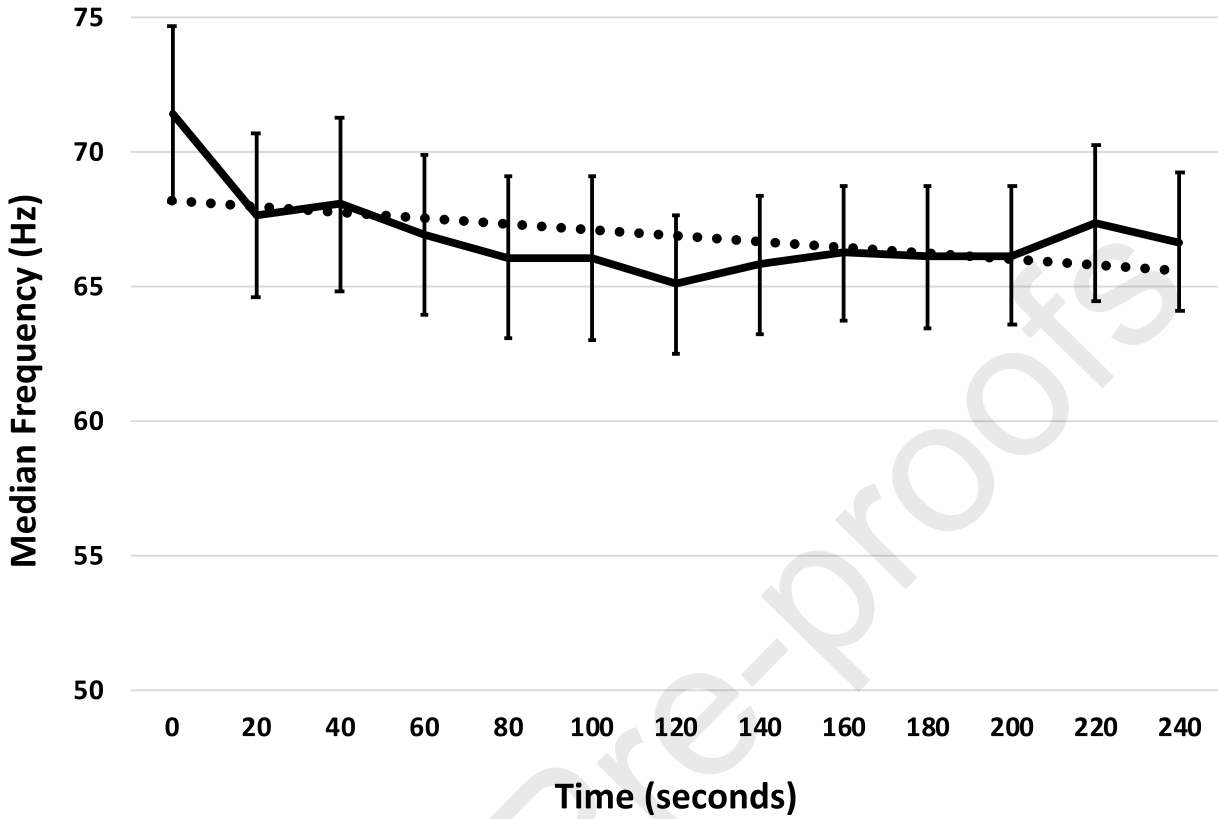
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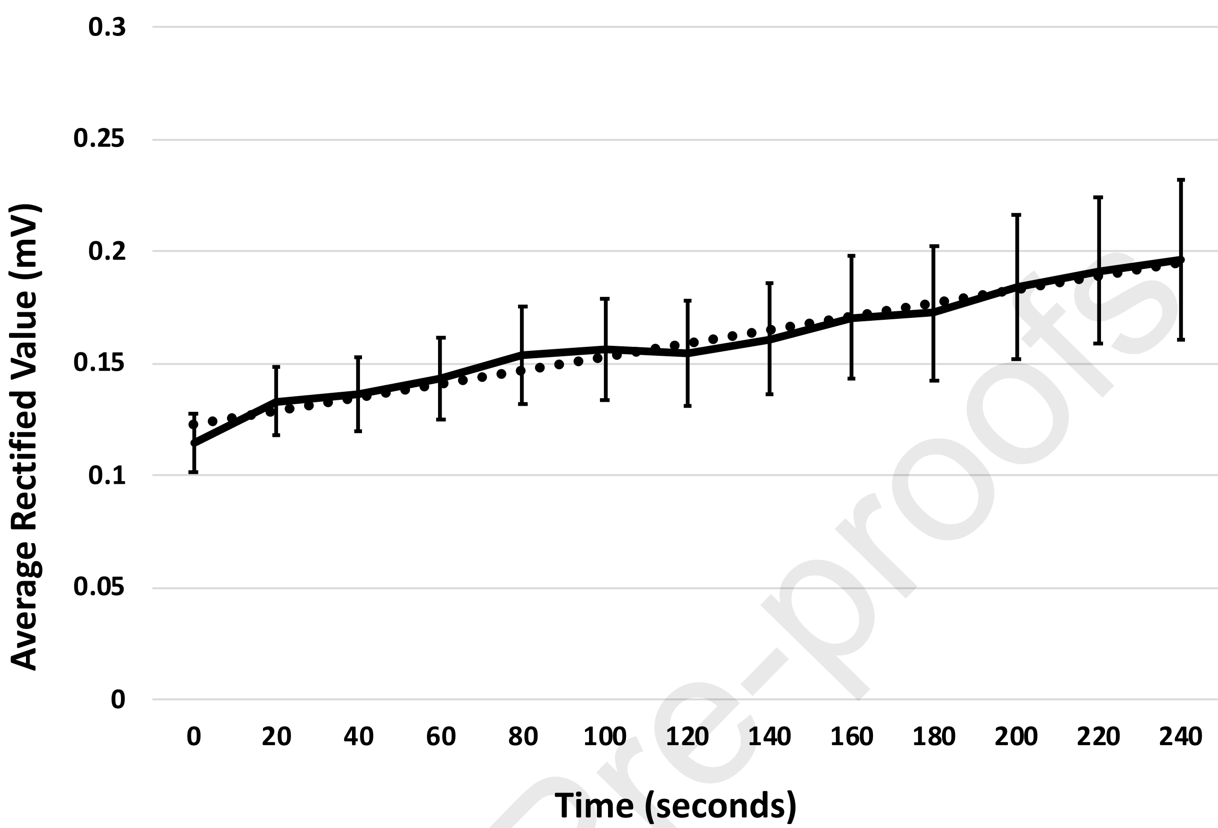
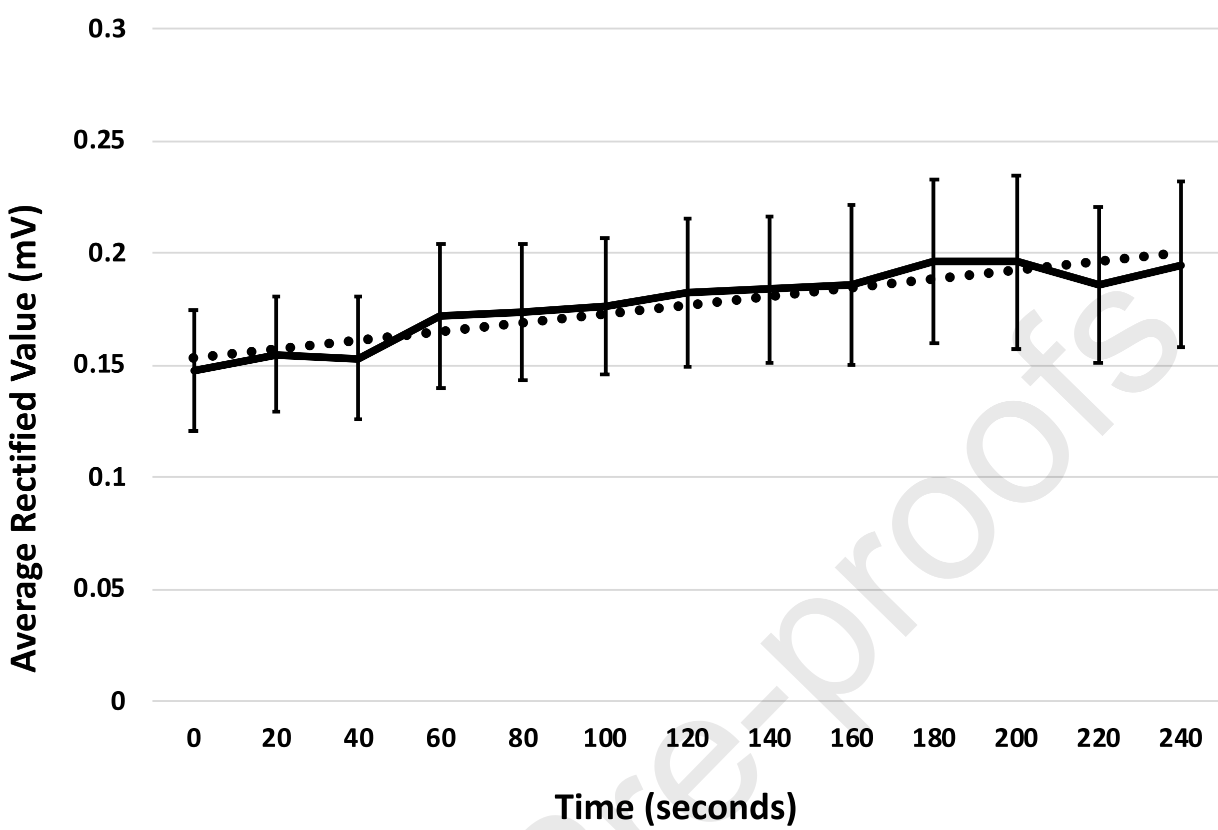
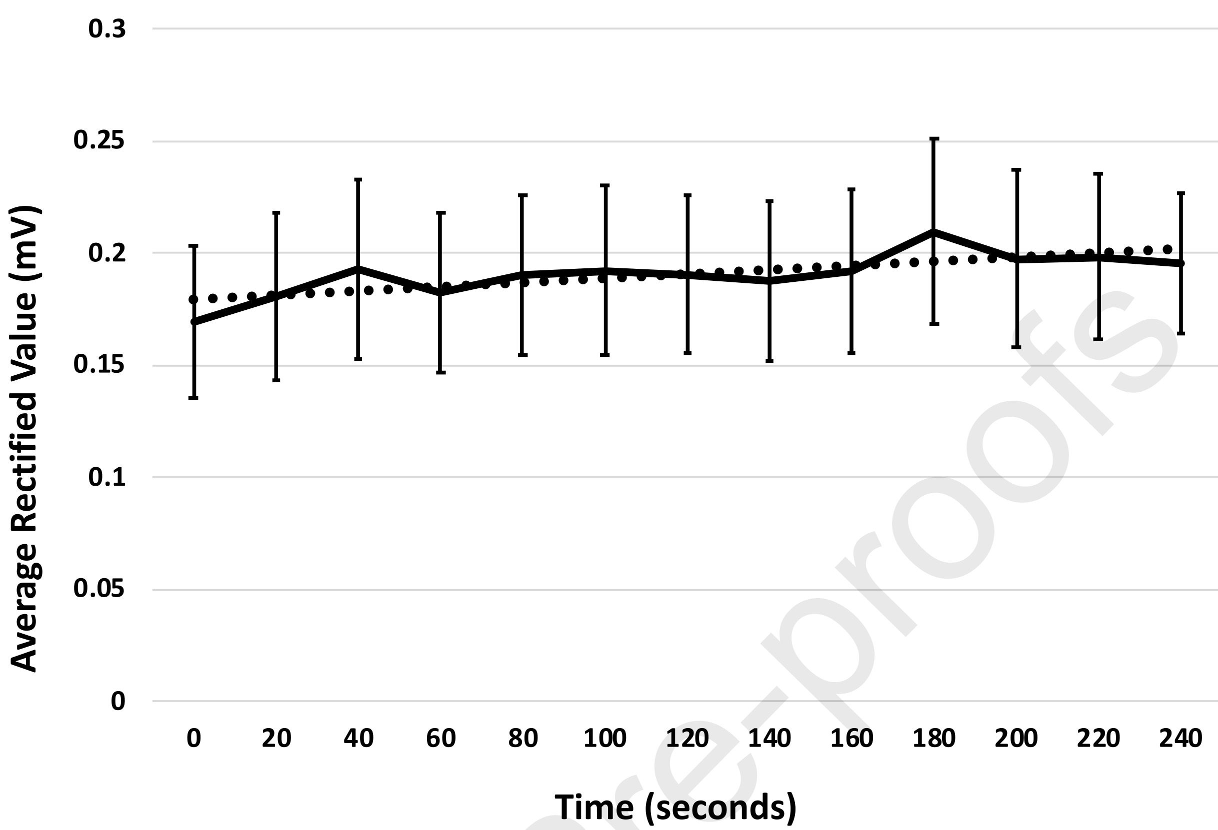
Median Frequency (Hz)
0
20
40
60
80
100
120
140
160
180
200
220
240
Time (seconds)


0.3
0.25
0.2
0.15
0.1
0.05
0
Average Rectified Value (mV)
0
20
40
60
80
100
120
140
160
180
200
220
240
Time (seconds)



0.3
0.25
0.2
0.15
0.1
0.05
0
Average Rectified Value (mV)
0
20
40
60
80
100
120
140
160
180
200
220
240
Time (seconds)


0.3
0.25
0.2
0.15
0.1
0.05
0
Average Rectified Value (mV)
0
20
40
60
80
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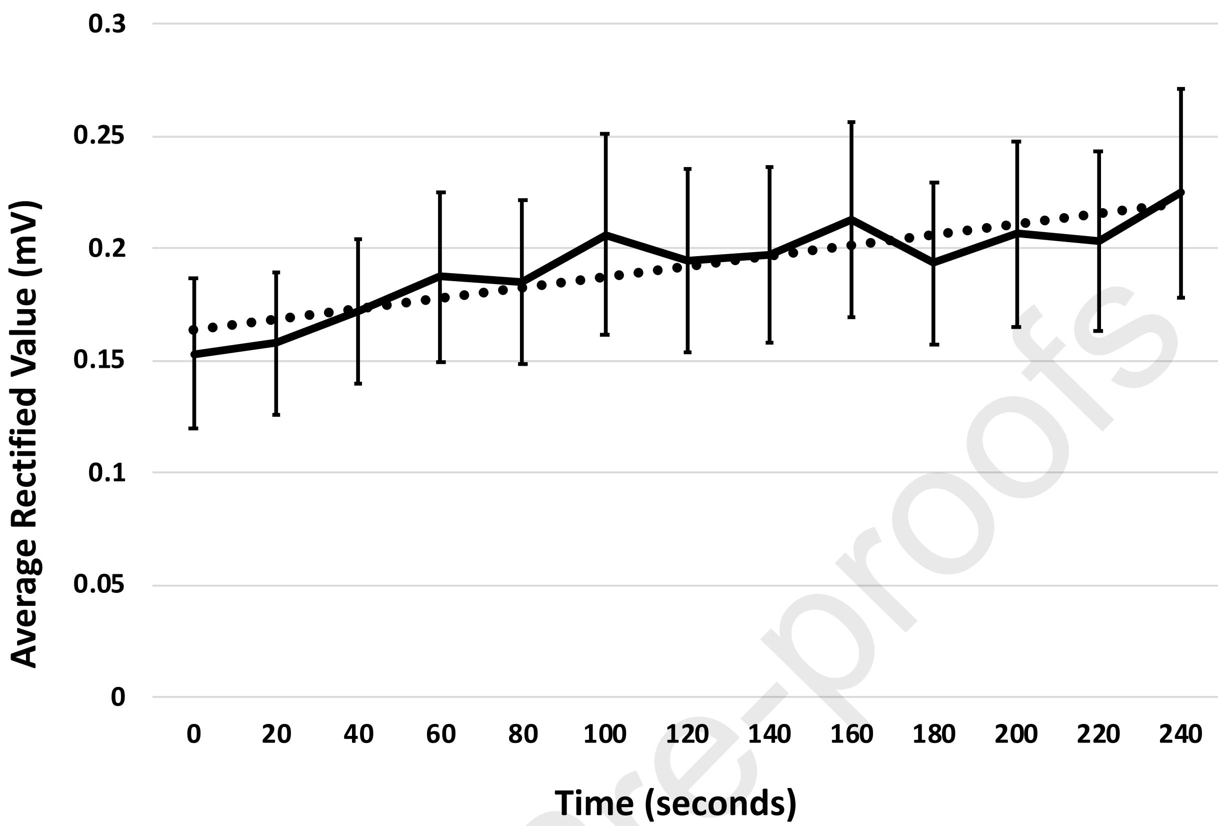
120
140
160
180
200
220
240
Time (seconds)


0.3
0.25
0.2
0.15
0.1
0.05
0
Average Rectified Value (mV)
0
20
40
60
80
100
120
140
160
180
200
220
240
Time (seconds)

Pramiti Sarker received her B.Sc. degree in 2015 and M. Sc. degree in 2017 in Industrial Engineering from Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. She is currently working as a graduate research assistant in Physical Ergonomics and Biomechanics Lab under department of Industrial Manufacturing and Systems Engineering in Iowa State University. She is doing her research to reduce the effect of fatigue on workers' performance in workplace.

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