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EMG AMPLITUDE IN MAXIMAL AND SUBMAXIMAL EXERCISE IS DEPENDENT ON SIGNAL CAPTURE RATE

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Running Head: Reliability of data capture in EMG

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ABSTRACT

Aim: This study analysed the effect of different electromyographic (EMG) capture rates during maximal voluntary contraction, submaximal and maximal dynamic cycling activity on EMG amplitude and signal characteristics.

Methods: Ten healthy subjects participated in this study. Peak power output (PPO) and maximal isometric force output (MVC) were measured, followed by a progressive cycle ride on a cycle ergometer. Electromyographic (EMG) data was simultaneously captured during the MVC and cycling activities at frequencies of 32, 64, 128, 256, 512, 1024 and 1984 Hz.

Results: Significant differences in amplitude were found ($P < 0.01$) between MVC, submaximal (SUB) and maximal cycling activities (PWATT) for all capture rates. Asymptote values for IEMG amplitude occurred at EMG capture rates of 1604 ± 235.6 Hz during MVC, 503.1 ± 236.2 Hz during PWATT and 326.2 ± 105.4 Hz during SUB cycling activity and were significantly different ($P < 0.01$). No significant differences were found for force/EMG ratios between PWATT and MVC at 1984 Hz capture rates (3.8 ± 1.7 N/V vs 2.5 ± 0.9 N/V) while significant differences occurred at 32 Hz capture rate (6.2 ± 3.8 vs 16.0 ± 8.0; $P < 0.01$). Low correlations were found between EMG activity captured at 1984 Hz during PWATT and lean thigh volume ($r = 0.36$) and MVC ($r = 0.32$).

Conclusion: Asymptote values indicate that data captured below 326 Hz for SUB, 503 Hz for PWATT and 1604 Hz for MVC are not reliable. Therefore apparatus capturing EMG data at low frequencies from these values cannot be used for quantitative data analyses.

Keywords: EMG, isometric contraction, cycling activity.

INTRODUCTION

Electromyography (EMG) is often used as a research tool by muscle physiologists, neuroscientists and clinicians (6) in clinical (3;4) and research fields (7;8;13). The surface EMG signal provides an expedient non-invasive approach to study the complexity of muscle neurophysiology throughout various types of contractions (12). The EMG signal is the electrical revelation of the neuromuscular activation affiliated with a contracting muscle. The signal is influenced by the anatomical and physiological properties of muscles and the type of instrumentation that is used to detect and observe it (1).

An important feature of EMG analyses is the rate at which the signal is captured. A number of commercially available EMG signal acquisition units used by researchers and physiotherapists will capture EMG at a rate ranging from 32 – 500 Hz (1). Most muscles in the human generate an EMG trace which has a bandwidth of 0 to 500 Hz. The Nyquist theorem states that the sampling rate should be twice the highest frequency generated by the muscle being sampled. If the Nyquist criterion is not met, a condition known as aliasing will occur due to under sampling (11). This occurs when upper frequencies get reflected into the lower frequencies, where in effect a high-frequency component takes on the identity of a lower frequency (15). Therefore the minimal frequency required to capture all the frequency content of the signal is suggested to be 1000 Hz (1).

Other researchers have found the range of signal frequencies for surface EMG's in certain instances to be between 1 to 3000 Hz (19). Applying the Nyquist sampling theorem, would advocate that in such cases a sampling frequency of 6000 Hz is necessary. Conversely, most of the power of the signal is in the range 50 to 150 Hz (17). For this reason, it has been suggested that a sampling frequency of 500 Hz would be more than sufficient for surface EMG (17).

There is, however still some confusion about what constitutes adequate capture rates for a functional, rehabilitative or sporting activity. Accordingly, the aim of this study was to assess the reliability of EMG data captured at different frequency capture rates by sampling surface EMG during fatiguing activities at a number of differing rates, and assessing the relationships between amplitudes recorded in each case.

METHODS

Subjects.

Ten healthy males volunteered for this study. The mean age, height and body mass of the subjects were 25.5 ± 3.5 yr, 180 ± 13 cm and 78.8 ± 16.0 kg respectively. All subjects were physically active and each signed an informed consent before the study. The Research and Ethics Committee of the University of Cape Town Medical School approved the study.

Experiment design.

Peak power output (PPO) was measured as described by Hawley and Noakes (10). Subjects began riding on an electrically braked cycle ergometer (Lode, Groningen, Netherlands) at a starting work rate of 2.5 $W.kg^{-1}$ for 150 s, after which the power output was increased by 25 W every 150 s until the subject became exhausted. Exhaustion was defined as a drop in the subject's pedalling frequency from ˜90 to <50 revolutions/minute. PPO was defined as the last completed work rate in W plus the fraction of time spent in the final non-completed work rate multiplied by 25 W. Mean PPO value for all the subjects were 347 $\pm$ 3 W

In order to compare cycling and maximal isometric voluntary contraction data, The following simplified relationship was used;

$P = Fv$

Where P is the power output (Watts), F is the force applied to the pedal (N), and V is the velocity (W/S) of the foot on the pedal. Rearranging this equation,

$$F = \frac{P}{V}$$

and since the length of the crank was 0.173 m and the pedal rate were 1.5 m revolutions per second (which is 3π radians per second),

$v = 0.173 \text{ m} \times 3\pi \text{ radians/s}$

$= 1.626 \text{ m/s}$

so $F = 0.615.P$

Maximal isometric voluntary contraction (MVC)

In the week after PPO testing, each subjects' right knee extensor strength capacity was measured on a dynamometer (Kin - Com, Chattanooga Group Inc., USA). Subjects sat on the dynamometer and their hips, thighs and upper bodies were firmly strapped to the seat. In this position their hip angle was at 100° flexion. The right lower leg was then attached to the arm of the dynamometer at a level slightly above the lateral malleolus and the axis of rotation of the arm was aligned with the lateral femoral condyle. The arm was then set so that the knee was at a 60° angle from full leg extension. Each subject performed four sub-maximal familiarisation contractions prior to performing two maximal MVC's, the latter of which were used for subsequent analyses. All subjects were encouraged verbally to exert maximal effort during both MVC'S.

Progressive Exercise Test

Following the MVC's, subjects performed a 45 minute ride on a cycle ergometer (Lode, Groningen, Netherlands) at increasing work rates. Work rate was started at 30% of PPO and increased to 50% (SUB) and then to 70%

of PPO for 15-minute periods. Immediately after these 15 minute rides at constant work rates, the work rate was progressively increased by 15 $W.min^{-1}$ until the subject reached the point of exhaustion and could no longer continue exercise (PWATT). PWATT, time taken to reach exhaustion (TIME) and peak VO_2 achieved (VO_{2peak}) were 330.3 $\pm$ 44.7 W, 49.5 $\pm$ 1.4 min and 50.7 $\pm$ 6.1. $ml.O_2.kg^{-1}.min^{-1}$. Individual physical performance values of the subjects are during this test described in Table 1.

Electromyographic (EMG) testing

During the MVC's and progressive cycling tests, the EMG activity of the rectus femoris muscle was recorded. The EMG electrode was placed over the 'belly' of the rectus femoris muscle approximately midway between the superior surface of the patella and the anterior superior iliac crest. Before placement of the electrode, the skin was shaved, abraded with sandpaper and cleaned with ethanol. A triode electrode was then attached to the leg, covered with cotton swabs to minimise interference from sweat and connected to a pre-amplifier. Outputs from the pre-amplifier were relayed to a Flexcomp/DSP EMG apparatus (Thought Technology USA) via a fiber optic cable and stored by an on line computer. EMG was recorded for 5 seconds during MVC, after 25 minutes during SUB and 30 seconds before reaching PWATT during the cycle ride. The same EMG signal was captured simultaneously on 7 channels programmed to record at frequencies of 32, 64, 128, 256, 512, 1024 and 1984 Hz. All the data for each subject was captured throughout one session with no change in electrode movement.

During recordings, EMG signals were notch filtered at 50 Hz to limit electrical interference and anti-aliasing filters were used for all 7 different channels.

Although Figure 1 shows raw signals, the EMG signals were subsequently converted to positive values by full-wave rectification. Post-hoc filtering was not possible on the data at low frequency capture rates and statistical differences in raw EMG amplitude for all capture rates were therefore assessed.

The spectra in Figure 4 were produced by fast fourier transform in MATLAB of the signal sampled at 1984. The frequencies up to 512 Hz are shown in A and C, and up to 32 Hz in B and D.

Data Statistics

Data statistics are presented as means and standard deviations. Significant differences between EMG amplitudes of MVC, PWATT and SUB were assessed by using analyses of variance with repeated measures. Where significant differences occurred, Scheffe's post hoc test was used to locate the differences between groups. Single comparisons between PWATT and MVC for N/V were analysed with a paired Students t-test.

Raw data for the 5s sample period for each subject was fitted to the optimal rectangular hyperbola for each capture rate. Using the Inplot GraphPad Programme, asymptote hyperbola values were determined by differentiating the hyperbola and determining where dEMG/dHz became 0/dkHz. The force output during the isometric test and cycle ride was calculated and related to the mean EMG activity during the 5 second time period when the data was captured. Pearson correlation coefficient was used to assess the relationships between the parametric data.

RESULTS

Figure 1 shows raw data for an individual subject for PWATT and MVC captured both at 32 Hz and 1984 Hz. This data demonstrates that the amplitude captured for both activities is considerably higher at 1984 Hz than 32 Hz. When comparing 32 Hz MVC (Figure1A) with PWATT (Figure 1C) the difference in amplitude appears to be marginal. However, visually there are marked differences at 1984 Hz between MVC (Figure 1B) and PWATT (Figure 1D) in this representative individual's data.

Figure 2 shows the effect of different EMG capture rates during MVC, PWATT and SUB. Highly significant differences ($P < 0.01$) were found for all frequencies during each activity. Highly significant differences ($P < 0.01$) are shown with asymptote values of 326.2 $\pm$ 105.4 Hz for Sub, 503.1 $\pm$ 236.2 Hz for PWATT and 1604 $\pm$ 235.6 Hz for MVC. The linearity above the asymptote value for MVC, PWATT and SUB indicates consistent and reliable recordings, whereas below shows differing profiles and wider variability, therefore unreliable recordings.

Figure 3 shows the comparison between PWATT and MVC of all the capture rates of each activity as a percentage of its' capture rate of 1984 Hz. The largest percentage difference at MVC, between 32Hz and 1984 Hz capture rate, was approximately 68%, as compared to the PWATT difference, which was less than 20%.

Figure 4 shows the individual frequency spectrum data sampled at 1984 Hz that is normalised to the maximum peak amplitude achieved within that activity, to enable comparison between MVC and PWATT. Figure 4 A and B describes an individual's data which was captured during MVC whilst Figure 4 C and Ds is captured throughout PWATT. Figure 4 B and D is a magnified version of A and C respectively and shows data up to 30 Hz. According to the Nyquist theorem (11), 16 Hz and below are the frequencies of data that are collected when using a capture rate of 32Hz.

Table 2 shows power expressed as force (N) to enable calculation of the force per voltage EMG (N/V) relationship from the varying rates. Subject 6 was omitted from the data because of unusually high amounts of EMG artifact recorded. There were no significant differences in the values captured at 1984 Hz (3.8 $\pm$ 1.7 N/V vs 2. $\pm$ 0.9 5N/V. However, significant differences found ($P < 0.01$) at 32Hz capture rate (6.2 $\pm$ 3.8 N/V vs 16 $\pm$ 8 N/V).

Low correlations were found between EMG activity and lean thigh volume, and MVC, whilst an insignificant negative correlation was seen for body fat percent (Table 3). Similarly, no correlations were found between EMG activity and PPO and PWATT.

DISCUSSION

The main findings of this study were, i) that significant differences in EMG amplitude were found for the different EMG capture rates, with varying EMG amplitudes from 32Hz to 1984 Hz capture rates; ii) that asymptote values for MVC (1604 $\pm$ 235.6 Hz), PWATT (503.1 $\pm$ 236.2 Hz) and SUB (326.2 $\pm$ 105.4 Hz) were significantly different; iii) the force / EMG relationship for PWATT and MVC was significantly different ($P < 0.01$) at 32 Hz capture rate but were similar at 1984 Hz capture rate.

For MVC, PWATT and SUB differences in EMG amplitudes were observed for all the capture rates. The absolute difference in amplitude between MVC, PWATT and SUB at all the capture rates is to be expected, as different activities and exercise intensities will result in different neuromuscular recruitment patterns. However, at the lower capture rates it is clear that significantly less amplitude is recorded. It is logical to conclude that when, for example, using a low capture rate of 32 Hz on an activity that is generating approximately 500 mV of amplitude, that only a small proportion of that signal will be recorded (see Figure 4). However, this may not be a limitation. In Figure 2, if the gradient of increase in generated amplitude with capture rates for MVC, PWATT and SUB were the same, it may be acceptable to use low capture rates for all activities and exercise intensities as the data would be comparable. Moreover, it would be possible to capture data at 32 Hz and by applying a formula based on the exponential rise in amplitude with capture rates, accurately predict what the amplitude would be if captured at 1984 Hz.

However, because asymptote values are significantly different between MVC, PWATT and SUB, means that the gradient rise in amplitude with capture rates is different between activities. This difference in gradient is described in Figure 3, which shows the percentage difference between 32 Hz and 1984 Hz capture rate was approximately 68% for MVC, while PWATT was less than 20% difference. This would therefore suggest that to use a capture rate of less than 1604 Hz for MVC, 503.1 Hz for PWATT and 326.2 Hz for SUB is unreliable because a different proportion of the signal is being captured. The cause of this difference at low capture rates could be that not sampling at rates that are twice that of the highest frequency generated will cause aliasing (11). For example, Figure 4 shows that if a capture rate of only 32 Hz is used, only 16 Hz will be captured and when comparing MVC with PWATT, the majority of the MVC data will not be captured at this low capture rate. However, in this study the EMG equipment used, employed the use of anti-aliaising filters, which will prevent aliasing from occurring. Therefore, some other condition is occurring which is causing such large variability at low capture rates between activities.

A possible cause of this large variability could be first, from motion artifact generated during cycling which is shown by the large spikes in Figure 4D. Motion artifact could be caused from any relative movement of the electrode and tissue, which would occur during the continual action of cycling, unlike the minimal movement during MVC. As the electrode and skin tissue have different electrical properties, contact between the two will cause general polarization potential, which occurs through a lack of chemical equilibrium (1).

When using high capture rates, it is possible to use a high pass filter, which will smooth and rectify the signal to take out the effects of motion artifact. However, when using low capture rates it is not possible to use a high pass filter, as there will be minimal signal left after the signal has been smoothed and rectified. For example, motion artifact is considered to occur at EMG signals of approximate frequencies <10 Hz, therefore, if according to Nyquist a capture rate of 32 Hz is used for SUB and PWATT, only 16 Hz of the signal is captured, 10 Hz of it will be motion artifact (Figure 4) (1), therefore resulting in a unreliable signal. However, this only explains the different asymptotes between MVC and cycling, but not between SUB and PWATT. If the difference in asymptote values were due to motion artifact, a lower asymptote value would be expected in PWATT than SUB because of a more aggressive motion producing extra motion artifact. A possible explanation for this occurrence is that in PWATT there is more amplitude generated than SUB, which is probably due to additional motor unit recruitment from the increase in force production (5;14). From this increase in motor unit recruitment, it can then be assumed that there is an accompanying rise in median frequency (2), which means higher frequencies in the spectrum therefore resulting in higher asymptote values in PWATT.

Second, the action of prolonged cycling during PWATT will increase the temperature of the muscle, resulting in decreased EMG amplitude (16) in comparison to MVC. This decrease could be as a result of altered tissue characteristics acting as a low pass filter (18). It is therefore possible that this “low pass filter” may filter out different portions of the PWATT signal received at low capture rates in comparison to the signal received at high capture rates.

Also, the force/EMG relationship displayed highly significant differences between PWATT and MVC at 32 Hz and no significant differences at 1984 Hz. The force/EMG signal should be similar for any given activity or intensity. Again, this suggests that to use a capture rate as low as 32 Hz is unreliable when comparing different activities and/or intensities for quantitative data assessment. Possible causes are by sampling at 32 Hz, which is below the 1604 Hz asymptote for MVC and 503.1 Hz asymptote for PWATT, results in capturing an unreliable portion of the signal, possibly due to motion artifact and increase in muscle temperature generated in PWATT or other reasons not elucidated in this study.

Finally, low correlations found between EMG activity at 1984 Hz during PWATT and lean thigh volume, MVC, PPO and PWATT, suggests that no regression formula can be applied to predict EMG activity at differing amounts of force output. This suggests that EMG amplitude amounts during cycling activity will represent the individual’s distinct neural recruitment pattern, which will only be proportionate to their own maximal amount of recruitment. The possible causes for these low correlations are first, lean thigh volume showed little correlation with total EMG activity because of varying quantities of subcutaneous fat deposits at the electrode placement site, which will invariably interfere with the level of EMG activity. Second, PWATT and PPO showed poor correlation with EMG activity, perhaps due to variables such as individual cardiorespiratory efficiency influencing the output at fatigue. Finally, MVC is affected by the position of the electrode, the fiber typing (proportion of fast twitch to slow twitch muscle fibers) and the inclusion of synergist muscle groups, which may be different to those used during cycling activity (9). Interestingly, although not significant, body fat percentage showed a negative correlation, meaning that the higher the individual's body fat the higher the amplitude recorded. More amplitude would be expected, when the individual's body fat is lower, due to less impedance of the signal. However, body fat percentage was predicted by means of skinfold calliper, which often serves as a poor calculation due to the variability of fat deposited in the skinfold site. Consequently a correlation was also done with the thigh skinfold measurement, but this also showed to be low due to the wide variability in fat deposits within each subject.

In summary, MVC, PWATT and SUB showed differences in all the EMG capture rates tested, differences in asymptote values and highly significant differences between PWATT and MVC at 32 Hz and no significant differences at 1984 Hz in the force/EMG relationship, which suggests that data captured at low frequencies is unreliable. Also, low correlations between EMG activity at 1984 Hz and lean thigh volume, MVC, PPO and PWATT and an insignificant negative correlation for body fat percentage, suggests that no regression formula can be applied to assume EMG activity at differing amounts of force output.

In conclusion this study shows that EMG data captured below the asymptote values 1604 Hz for MVC, 503.1 Hz for PWATT and 326.2 Hz for SUB at 32 Hz is unreliable. It is therefore suggested that EMG data for MVC, PWATT and SUB activity is captured above the aforementioned asymptote values for qualitative data analyses.

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REFERENCES

[1]Basmaijan JV and DeLuca CD. Muscles alive. Baltimore Md, Williams and Wilkins. 1985: 5.

[2]Bernardi M, Solomonow M, and Baratta RV. Motor unit recruitment strategy of antagonist muscle pair during linearly increasing contraction. Electromyogr Clin Neurophysiol 37: 3-12, 1997.

[3]Bulgheroni P, Bulgheroni MV, Andrini L, Guffanti P, and Giughello A. Gait patterns after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 5: 14-21, 1997.

[4]Ciccotti MG, Kerlan RK, Perry J, and Pink M. An electromyographic analysis of the knee during functional activities. II. The anterior cruciate ligament-deficient and -reconstructed profiles. Am J Sports Med 22: 651-658, 1994.

[5]DeVries HA. Method for evaluation of muscle fatigue and endurance from electromyographic fatigue curves. Am J Phys Med 47: 125-135, 1968.

[6]Gandevia SC, Enoka RM, McComas AJ, Stuart DG, and Thomas CK. Neurobiology of muscle fatigue. Advances and issues. Adv Exp Med Biol 384: 515-525, 1995.

[7]Gandevia SC, Herbert RD, and Leeper JB. Voluntary activation of human elbow flexor muscles during maximal concentric contractions. J Physiol (Lond) 512 (Pt 2): 595-602, 1998.

[8]Gerdle B, Karlsson S, Crenshaw AG, and Friden J. The relationships between EMG and muscle morphology throughout sustained static knee extension at two submaximal force levels. Acta Physiol Scand 160: 341-351, 1997.

[9]Gregor RJ, Broker JP, and Ryan MM. The biomechanics of cycling. Exerc Sport Sci Rev 19: 127-169, 1991.

[10]Hawley JA and Noakes TD. Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. Eur J Appl Physiol 65: 79-83, 1992.

[11]Horowitz P and Hill W. The art of electronics. New York, Cambridge University Press. 1989.

[12]McArdle WD., Katch FI, and Katch VL. Exercise Physiology. Lea and Febiger. 1991: 3

[13]Merletti R, Knaflitz M, and De Luca CJ. Myoelectric manifestations of fatigue in voluntary and electrically elicited contractions. J Appl Physiol 69: 1810-1820, 1990.

[14]Moritani T, Nagata A, and Muro M. Electromyographic manifestations of muscular fatigue. Med Sci Sports Exerc 14: 198-202, 1982.

[15]Oppenheim AV and Schafer RW. Digital signal processing. London, Prentice-Hall International. 1975.

[16]Petrofsky JS. Frequency and amplitude analysis of the EMG during exercise on the bicycle ergometer. *Eur J Appl Physiol* 41: 1-15, 1979.

[17]Vaughn CL, Davis BL, and O'Connor JC. Dynamics of Human Gait. Cape Town, Kiboho. 2000.

[18]Winkel J and Jorgensen K. Significance of skin temperature changes in surface electromyography. Eur J Appl Physiol 63: 345-348, 1991.

[19]Winter DA, Rau G, Kadefors R, Broman H, and DeLuca CJ. Units, terms, and standards in the reporting of EMG research. The International Society of Electrophysiological Kinesiology, 1980.

TABLES

Table 1. Subject information. Peak power output (PPO), peak watts reached at cycling exhaustion (PWATT), time taken to reach exhaustion (TIME), maximal volume of oxygen uptake (VO_{2PEAK}).

SUBJECT	PPO	P WATT	TIME	VO_{2PEAK}
1	346	347	51.1	43.7
2	311	329	50.3	57.5
3	356	359	49	51
4	373	347	49	52
5	343	346	51	46
6	364	377	50.3	51
7	357	340	50	53
8	312	248	46	40.5
9	298	250	49.2	52
10	408	360	49.4	61.2
Mean	346.8±33	330.3±44.7	49.5±1.4	50.7±6.1

All values are mean ± SD

Table 2. Newtons/volt (N/V) data of cycling at the point of exhaustion (PWATT) and maximal voluntary contraction (MVC) whilst captured at rates of 1984 Hz and 32 Hz.

Subject	PWATT N/V 1984	MVC N/V 1984	PWATT N/V 32	MVC N/V 32
1	2.4	3.4	3.1	31
2	2.7	1.1	3	3.7
3	4.5	2.5	3.2	11.2
4	6.5	3.8	14	24.5
5	2.5	3.1	2.8	18.4
6				
7	3.5	2.6	8.2	13.9
8	6	2.7	9.3	15.7
9	1.6	1.4	6	11.5
10	4.4	1.7	6.4	14.4
Mean	3.8 ± 1.7	2.5 ± 0.9	6.2 ± 3.8**	16.0 ± 8.0

All values are mean ± SD

** -P < 0.01 Ex N/V at 32 Hz vs MVC N/V at 32 Hz

Table 3. Mean lean thigh volume cc (LTV), body fat percentage (%), cycling exhaustion power output (PWATT), maximal voluntary contraction (MVC) and peak power output (PPO) correlated with IEMG amplitude captured at 1984Hz during cycling exhaustion (PWATT).

	r
LTV	-0.36
Body fat %	-0.63
PPO	-0.04
PWATT	-0.5
MVC	0.28

FIGURES

Figure 1. Individual raw data captured over a period of 5 seconds for MVC at (A) 32 Hz and at (B) 1984 Hz and cyclingexhaustion at (C) 32 Hz and (D) at 1984 Hz.

Figure 2. The effects of sampling frequency of mean EMG during maximal voluntary contraction (MVC), cycling exhaustion (PWATT), and 50% of peak power output (SUB). Highly significant differences ($P < 0.01$) are shown by the marked asymptote values of 326.2 ± 105.4 Hz for Sub, 503.1 ± 236.2 Hz for PWATT and 1604 ± 235.6 Hz for MVC.

Figure 3. Capture rates (32, 64, 128, 256, 512 and 1024 Hz) of cycling at exhaustion (PWATT) and maximal voluntary contraction (MVC) displayed as a percentage of their respective highest capture rate of 1984 Hz.

Figure 4. Individual data displaying frequency spectra normalized to the maximum. A and B is data captured during MVC, whilst C and D is data captured throughout PWATT. According to the Nyquist theorem, the arrow shows that while using a capture rate of 32 Hz, data will only be collected at <16 Hz (data to the left of the arrow).

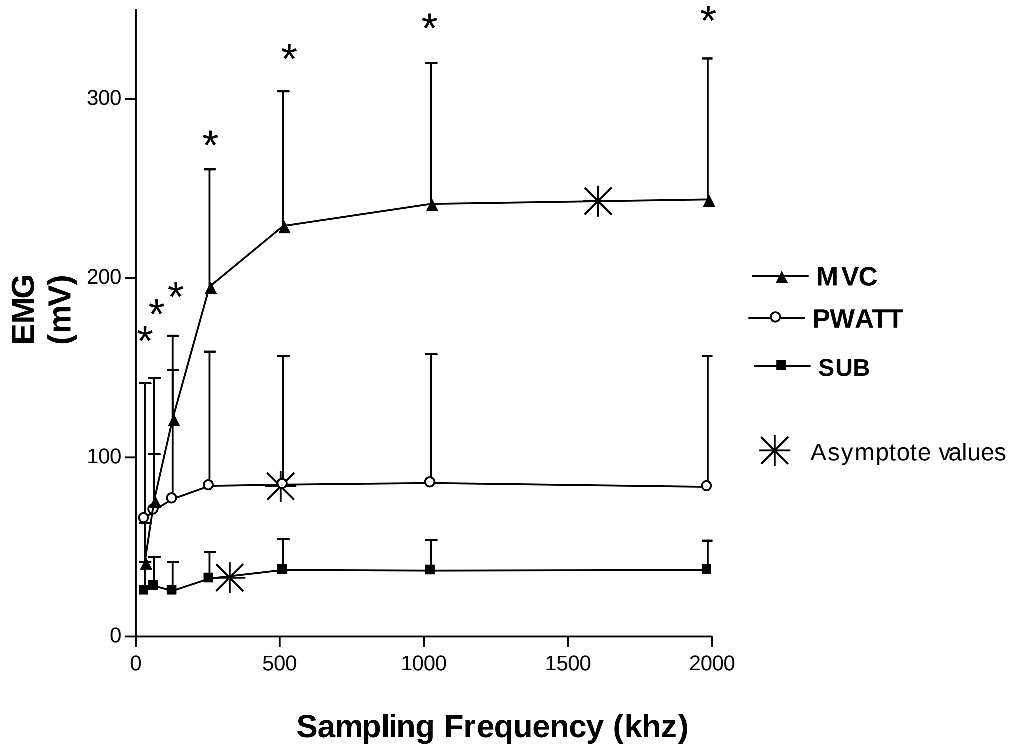
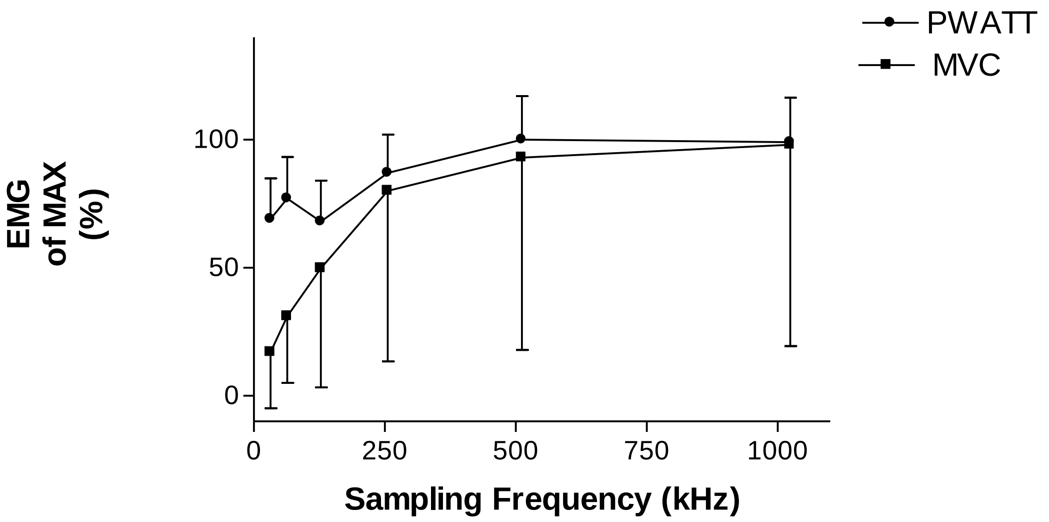


Figure 2. The effects of sampling frequency of mean EMG during maximal voluntary contraction (MVC), cycling exhaustion (PWATT), and 50% of peak power output (SUB) (* = P < 0.01 main effect). Highly significant differences (P < 0.01) are shown by the marked asymptote values of 326.2 ± 105.4 Hz for Sub, 503.1 ± 236.2 Hz for PWATT and 1604 ± 235.6 Hz for MVC.



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