**Long, D, Dotan, R, Pitt, B, McKinlay, B, O'Brien, TD, Tokuno, C and Falk, B**

**The Electromyographic Threshold in Girls and Women.**

**http://researchonline.ljmu.ac.uk/id/eprint/4792/**

**Article**

**Citation** (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

**Long, D, Dotan, R, Pitt, B, McKinlay, B, O'Brien, TD, Tokuno, C and Falk, B (2016) The Electromyographic Threshold in Girls and Women. Pediatric Exercise Science. ISSN 1543-2920**

# The Electromyographic Threshold in Girls and Women

Devon Long[1], Raffy Dotan[1], Brynlynn Pitt[1], Brandon McKinlay[1], Thomas D. O'Brien[2], Craig Tokuno[1], and Bareket Falk[1]

[1] – Faculty of Applied Health Sciences, Brock University, St Catharines, ON, Canada, L2S 3A1

[2] – Research Institute for Sport & Exercise Science, Faculty of Science, Liverpool John Moores University, UK L3 5UA

**Corresponding author**:

Raffy Dotan,
Faculty of Applied Health Sciences
Brock University
500 Glenridge Ave
St. Catharines, ON, Canada
L2T 2Y1
Tel: 905 688 5550 x5257
Email: rdotan@brocku.ca

**Running title**: Electromyographic threshold in girls and women

**Subject area**: Exercise physiology

**Word count** (excluding Abstract, Tables, Acknowledgements, and References): 3983

## Abstract

***Background***: The electromyographic threshold ($EMG_{Th}$) is thought to reflect increased high-threshold/type-II motor-unit (MU) recruitment and was shown higher in boys than in men. Women differ from men in muscular function. ***Purpose***: Establish whether females' $EMG_{Th}$ and girls–women differences are different than males'. ***Methods***: Nineteen women (22.9±3.3yrs) and 20 girls (10.3±1.1yrs) had surface EMG recorded from the right and left vastus lateralis muscles during ramped cycle-ergometry to exhaustion. EMG root-mean-squares were averaged per pedal revolution. $EMG_{Th}$ was determined as the least residual sum of squares for any two regression-line data divisions, if the trace rose ≥3SD above its regression line. $EMG_{Th}$ was expressed as % final power-output (%Pmax) and %$VO_2$pk power (%$P_{VO2pk}$). ***Results***: $EMG_{Th}$ was detected in 13 (68%) of women, but only 9 (45%) of girls ($p<0.005$) and tended to be higher in the girls (%Pmax= 88.6±7.0 *vs.* 83.0±6.9%, p=0.080; %$P_{VO2pk}$= (101.6±17.6 *vs.* 90.6±7.8%, p=0.063). When $EMG_{Th}$ was undetected it was assumed to occur at 100%Pmax or beyond. Consequently, $EMG_{Th}$ values turned significantly higher in girls than in women (94.8±7.4 *vs.* 88.4±9.9 %Pmax, p=0.026; and 103.2±11.7 *vs.* 95.2±9.9 %$P_{VO2pk}$, p=0.028). ***Conclusions***: During progressive exercise, girls appear to rely less on higher-threshold/type-II MUs than do women, suggesting differential muscle activation strategy.

**Keywords:** Muscle activation, Muscle function, child–adult differences

## Introduction

Children's response to exercise is often different than that of adults'. Their maximal voluntary force, even when body-mass-normalized, is lower (14) and their force kinetics are slower (1, 14) than in adults. Yet, children's muscular endurance is greater (37, 51) and their recovery from intense exercise is faster (13) than adults'. Metabolically, children demonstrate a more oxidative profile with greater reliance on fat metabolism during submaximal exercise (40), lower blood lactate concentrations during exercise (11), and their ventilatory and lactate thresholds occur at higher exercise intensities compared with adults (25, 42, 45). It has been suggested that numerous child–adult differences can be wholly or partly explained by children's lesser utilization of higher-threshold motor units (MUs) relative to lower-threshold units, whether due to lesser recruitment or lower prevalence (10).

The EMG threshold ($EMG_{Th}$), measured during progressive exercise, is widely considered as indicating the onset of accelerated recruitment of the higher-threshold/type-II MUs (4, 12, 22, 23, 29, 30, 32-35, 38, 48), or possibly, just the $II_X$ and/or $II_{AX}$ sub-groups thereof. This accelerated recruitment is viewed as necessary for maintaining or increasing power or force output. The interpretation of the $EMG_{Th}$ as reflecting an increase in utilization of type-II MUs is supported by glycogen-depletion measurements in different muscle-fibre types (49) and by findings of increasing conduction velocities with progressive recruitment of higher threshold MUs (15). The $EMG_{Th}$ has been widely investigated in adults, athletes and non-athletes, in order to quantify muscle activation during exercise and elucidate issues related to neuromuscular fatigue (6, 12, 22, 23, 29, 30, 32-35, 38, 48). Based on this, we used the $EMG_{Th}$ as a proxy for investigating the recruitment of type-II MUs in girls and women, with the aim of elucidating developmental changes in muscle function. $EMG_{Th}$ in children has previously been studied only by Pitt *et al.* (39), demonstrating it to occur at higher relative exercise intensities in boys than in men. This finding suggested that in ramped, exhaustive cycling exercise, boys recruit type-II MUs later and to a lesser extent than do men.

While EMG amplitude is notoriously sensitive to factors such as temperature, muscle size, cutaneous/adipose thickness and others, it is noteworthy that the $\mathrm{EMG_{Th}}$ method is independent of the specific EMG-amplitude since its criterion is a *slope change* (threshold) rather than the attainment of particular amplitude.

Prepubescent girls and boys have similar muscle strength and aerobic capacity, as well as metabolic responses to exercise (*e.g.*, (3, 18, 28)). Male–female differences become most distinct by mid-to-late adolescence and early adulthood (3, 8, 9, 47). Consequently, various child–adult muscular differences are distinct in males but are smaller or undetectable in females (3, 8).

O'Brien *et al*. (36) showed that children could not voluntarily activate their muscles to the extent typical of adults, and that the girls' activation level was lower than the boys'. In accordance with the size principle (Henneman 1965), un-recruited MUs are expected to be of higher recruitment thresholds than the recruited ones. Thus, the boy–girl activation difference, as observed by O'Brien *et al*., may directly affect the intensity at which $\mathrm{EMG_{Th}}$ occurs in each of the groups.

As no $\mathrm{EMG_{Th}}$ data exist for females, it was our purpose to examine the relative exercise intensity at which the $\mathrm{EMG_{Th}}$ occurs in girls compared with women, employing the same protocol recently used in males (39). It was hypothesized that girls' $\mathrm{EMG_{Th}}$ would occur at higher relative exercise intensities compared with women. Since women's muscular performance has been shown to be lower than men's but higher than boys', it was further hypothesized that these girls–women differences would be smaller than previously observed in males.

# Methods

## Participants

Nineteen women, aged 19–34 years, and 20 girls, aged 8–11 years, volunteered for this study. The groups had similar training histories and physical fitness. Their characteristics are listed in Table 1. All tests and procedures were carried out in accordance with the Helsinki declaration and were cleared by the institutional Research Ethics Board. Prior to participation, informed consent was obtained from all women and from each girl's parent or guardian. An informed assent was obtained from all of the girls.

[ **Table 1** ]

## Experimental Protocol

Participants were invited for two visits to the laboratory, separated by a minimum of two days and a maximum of two weeks. The first visit began with an overview of the two testing sessions, followed by signing the informed consent/assent forms, medical screening, filling out physical activity/training-history questionnaires, and anthropometric measurements (see below). The crank-length of the cycle-ergometer (Excalibur Sport, Lode, Groningen, The Netherlands) was individually adjusted in 5 mm increments based on body height. Handlebar position and saddle height were established for comfort and proper knee angles prior to testing and recorded for replication in the second visit ($EMG_{Th}$ test). The participant was familiarized with the cycle-ergometer and practiced keeping a steady cadence at ≥80rpm. Peak $O_2$ uptake ($VO_2pk$) and the $VO_2pk$-corresponding mechanical power output ($P_{VO2pk}$) were determined through submaximal and maximal $VO_2$ tests. The second visit, to determine the $EMG_{Th}$, took place 2−7 days following the first visit (see below).

## Measurements

*Anthropometry*. Height and weight were measured and adiposity (% body fat) assessed using gender- and age-specific skinfold formulae (43). Right triceps and subscapular skinfold thicknesses were measured in triplicate using Harpenden calipers (British Indicators, Herts, England).

*Maturity*. Girls' maturity was estimated by the years-to-peak-height-velocity (PHV) equation (31). The girls self-assessed their sexual maturity using a graphical questionnaire (46).

*Physical activity*. Physical activity and training history were recorded using a questionnaire (16) and an interview.

## Visit 1: Submaximal $VO_2$ and $VO_2$pk tests

Participants began with a 3–5-minute warm-up and cadence familiarization. The submaximal protocol included 3–5 incremental stages to establish a $VO_2$–power regression. Stages were 3.5- and 4-min long for the girls and women, respectively. Girls typically started at 25–35W and increased by 10–20W per stage. Women typically started at 40–60W, incremented by 20–30W per stage. Participants were allowed ~10-min break before commencing the graded exercise test to exhaustion to determine $VO_2$pk. The maximal test typically began at 40–50 and 60–70W and incremented by 10 and $20W•min^{-1}$ for girls and women, respectively, and continued to volitional exhaustion. As has previously demonstrated by Barker *et al*. (2), we did not rely on the commonly-used fixed criteria for $VO_2$pk attainment (*e.g.*, 90% predicted max HR, or respiratory exchange ratio of 1.05), but rather exceeded them in motivating the participants and verbally encouraging them to reach their respective utmost exhaustion. To verify that the testing protocol indeed elicited highest possible values, supra-maximal testing at 105% of the $VO_2$pk test's final power, was administered to a sample of the first ~15 women and girls, ~10 min post $VO_2$pk test (as suggested by Barker *et al*. (2)). In no case was an improvement observed relative to the preceding $VO_2$pk test. $VO_2$pk was recorded as the average of the highest three consecutive 15-s intervals near the end of the volitional exercise test. The above protocol allowed for the determination of steady-state $VO_2$ at submaximal, 3.5–4-min workloads, as well as $VO_2$pk determination in closely subsequent test to exhaustion. However, the protocol's discontinuous nature was incompatible with gas-exchange-threshold determination.

HR was determined using a HR monitor (Timex Personal Heart Rate Monitor, Timex Group Inc., Toronto, ON, Canada). Expired gas was collected and analyzed using the Moxus metabolic cart (AEI Technologies, PA, USA), calibrated prior to each test. A cadence of 80rpm or higher was required throughout each test. The metabolic cart could be switched between standard (adult) and small (pediatric) mixing chambers. The latter was used for girls of less than ~40 kg body mass.

$VO_2$pk value was then placed on the individual's $VO_2$–power regression line, derived from the graded submaximal test. The mechanical-power equivalent of the $VO_2$pk value (*i.e.*, net-aerobic peak power, free of anaerobic contribution) was then determined and defined (calculated) from that plot and termed as $P_{VO2pk}$. While response linearity may not be identical, non-linearity (plateauing effect) in adults is considerably less significant in cycling than in running, due to cycling's lower $VO_2$pk.

### Visit 2: $EMG_{Th}$ test

Surface EMG was used to continuously monitor m. vastus lateralis (VL) EMG of each leg, using 10-$mm^2$ bipolar Ag/Ag surface electrodes (Delsys 2.1, Delsys Inc., Boston, MA). An area of each thigh, at two-thirds of the line between the anterior spina iliaca superior and the superior border of the patella, was shaved (if necessary), abraded with skin preparation gel (Nuprep, Weaver & Co., Aurora, CO), and cleaned with rubbing alcohol. Electrodes were placed parallel to the direction of muscle fibres on the medial aspect of the VL and affixed with proprietary double-sided tape. Reference electrode was placed over the spinous process of the 7th cervical vertebra.

The VL muscle was chosen since it is a chief cycling agonist and had previously been shown to be the most reliable of the major cycling muscles in exhibiting $EMG_{Th}$ (22). The choice of the VL-midpoint for electrode placement was based on earlier testing (39) that showed it to produce the clearest signal. If necessary, electrode position was further tweaked for each participant to attain the cleanest possible baseline between successive EMG bursts (minimal cross-talk with adjacent muscles).

The ramped cycle-ergometer test was started at the individual's 40 %$P_{VO2pk}$ (determined during the first visit). This starting power averaged 39.3±8.3W and 74.7±15.1W for girls and women, respectively. Exercise intensity was increased by 1W every 4–10s so as to reach $P_{VO2pk}$ output in ~10min, for both girls and women. A cadence of 80±1 rpm was required and maintained throughout the test. The protocol for this progressive test was based on previous studies in adults (22, 23) as well as extensive pilot testing to ensure suitability for both children and adults (39). The test was terminated upon volitional exhaustion, or when the participant could no longer raise her cadence above 76 rpm in the test's final seconds. The power output at test cessation, or when the cadence reached 78 rpm on its way down in the final seconds, was defined as the test's maximal power output (Pmax).

**EMG data reduction**

EMG signals were sampled at 1kHz and band-pass filtered (20–450 Hz) using the Bagnoli-4 bioamplifier (Delsys Inc., Boston, MA) using a computer-based oscillograph and Data Acquisition System (EMGworks Acquisition, Delsys Inc., Boston, MA). A dedicated MATLAB (2013 version; MathWorks Inc., Natick, MA) computer algorithm was used for EMG data analysis. EMG bursts were recorded for each pedal stroke, separately for each leg (Figure 1). The recorded trace was then pruned at the beginning and end to remove any partial or incomplete bursts, if any, and the trace was de-trended to offset any baseline drift. The EMG root-mean-square ($EMG_{RMS}$) was calculated for each burst and its onset and offset were defined as the points where the $EMG_{RMS}$ rose or fell, respectively, above or below 10% of the mean $EMG_{RMS}$ value of the entire test record. The mean $EMG_{RMS}$ of each burst (*i.e.*, between the onset and offset) was then extracted for $EMG_{Th}$ determination.

### $EMG_{Th}$ Determination

A composite plot of the averaged $EMG_{RMS}$ traces of both legs, was constructed for each participant and plotted *vs*. test duration. To reduce internal fluctuations, a trimmed moving average (a 30-point averaging window in which the lowest 10 and highest 10 values were trimmed off) was applied to the plot (Figure 2). Where a drop in the $EMG_{RMS}$ was observed at the end of the test in conjunction with a sustained cadence fall below 80 rpm, the plot was truncated at the point where cadence began to fall. The $EMG_{Th}$ was then determined by computer algorithm as the point of least residual sum of squares (LRSS) for any two linear-regression-line divisions of the data, similar to Hug *et al.*'s approach (21).

[ **Figures 2** & **3** ]

Since a LRSS can always be determined, even when no actual threshold exists, an additional criterion was used to qualify a physiologically-meaningful threshold. As $EMG_{Th}$ was expected to occur at relative power outputs of ~80% Pmax or higher in adults (22) and likely higher than that in the children, a linear regression line was determined for the initial 70% of the test duration (corresponding to ~80% of Pmax). The line was then extrapolated to the test's end and a 3-SD confidence interval was applied above it and extended to the end of the trace. An $EMG_{Th}$ was confirmed only if the $EMG_{RMS}$ plot rose and remained above the confidence limit (Fig. 2), without descending back to within the confidence interval until the end of the test. The power output at the $EMG_{Th}$ was determined from the power–time relationship and was expressed as a percentage of the peak power output reached at test's end (%Pmax) and as percentage of $P_{VO2pk}$ (%$P_{VO2pk}$), based on the $VO_2$–power data obtained at the first session.

**Statistical analysis:**

All statistical analysis was performed using SPSS v.20 (SPSS Inc., Chicago, IL). The data for all groups are presented as means ±1SD. Differences in the observed number (or percentage) of detectable $EMG_{Th}$ between groups were examined using a Chi-squared test. Group differences in physical characteristics and $EMG_{Th}$ as a %Pmax and %$VO_2$pk were assessed using a two-tailed Student's *t* test. Additionally, differences between the 'Responder' and 'Non-Responder' groups (defined below) were examined using a two-tailed Student's *t* test. The acceptable level of significance for all tests was set at $p<0.05$.

## Results

Girls were estimated to be 4.48±0.46 years before the age of PHV. The girls' sexual maturity ranged between stages 1 and 3 (46), with 15 girls at stage 1, two at stage 2, and two at stage 3 (one refused to complete the self-assessment). Although the girls had higher activity scores than the women, they had similar training histories and their aerobic capacities were similar (Table 1).

Peak net-aerobic power output in the $VO_2$pk test ($P_{VO2pk}$) averaged 2.93±0.44 and 2.65±0.69 W/kg for the women and the girls, respectively. Peak power output upon exhaustion at the $EMG_{Th}$ test (Pmax) averaged 3.16±0.48 and 2.89±0.72 W/kg for the women and girls, respectively.

The $EMG_{Th}$ test's duration was quite variable across all participants, but statistically similar for the two groups (617.0±60.5 and 588.5±70.4 s for the women and girls, respectively; $p=0.183$). The $EMG_{Th}$ could be detected in only 9 (45%) of the 20 girls and in 13 (68%) of the 19 women ($\chi^2_{(1,\, n=39)}$ =7.945; $p<0.005$). There were no significant differences in training history, or physical characteristics between those in whom $EMG_{Th}$ was detected ('Responders') and those in whom it was not ('Non-Responders').

Figures 2 and 3 provide typical examples of $EMG_{Th}$ detection (in a woman; Figure 2) and no detection (in a girl; Figure 3).

Mean $EMG_{Th}$ intensity (%) in the girl 'Responders' tended to be higher than among the women (Table 2). Assuming that 'Non-Responders' would have demonstrated $EMG_{Th}$ at higher contractile forces than those reached at the ramped-test's end, we assigned them $EMG_{Th}$ values of 100 %Pmax (an under-estimate; see Discussion). When 'Responders' and 'Non-Responders' were thus pooled together, the girls–women differences in relative $EMG_{Th}$ intensities were statistically significant (Table 2).

## Discussion

This is the first study to investigate $EMG_{Th}$ specifically in females. A significantly smaller proportion of the girls (45%) demonstrated $EMG_{Th}$ during the progressive exercise, compared with women (68%). Among those 'Responders', the $EMG_{Th}$ tended to occur at higher relative intensities in the girls than in the women. When 'Non-Responders' were considered as having reached $EMG_{Th}$ at the point of exhaustion (*i.e.*, $EMG_{Th}$ = 100% Pmax), the girls–women $EMG_{Th}$ differences were statistically significant, whether expressed in terms of %Pmax (p=0.026) or %$P_{VO2pk}$ (p=0.028) (Table 2).

As the $EMG_{Th}$ is widely accepted as indicating the onset of accelerated recruitment of higher-threshold, type-II MUs (4, 12, 22, 23, 29, 30, 32-35, 38, 39, 48), the results suggest that during ramped exercise to exhaustion, girls recruit higher-threshold/type-II MUs later and therefore also to a lesser extent than do women.

Pertinent to our $EMG_{Th}$ determination is the rationale for assigning 'Non-Responders' $EMG_{Th}$ values equal to their power output at exhaustion (100% Pmax). When exhaustion is reached at the end of an incremental cycling test, such as that used in the present study, the force applied to the pedals is estimated to be ~50% of the maximal force the legs are capable of momentarily producing at the given pedalling cadence (17, 41). That is, at the time the participant reaches her maximal cycling power, her maximal leg-extension force is only ~50% of her current MVC. This means that for $EMG_{Th}$ to be detected during incremental cycling, it must occur below ~50% of the tested muscle's maximal force at the contraction velocity associated with the 80-rpm cycling cadence. Since higher-threshold, type-II MUs are typically recruited at the higher ranges of muscular exertion (20, 50), it stands to reason that these high-threshold MUs (and particularly type $II_{AX}$ and type $II_X$ muscle fibres) would be recruited near or beyond exhaustion in our incremental test (had increasing contractile force been further sustained).

Support for the above claim is provided in Figure 4, depicting the relationship (r = –0.93) between the %Pmax at which the $EMG_{Th}$ was detected and the proportion of $EMG_{Th}$ detection (% 'Responders') in the girls' and women's groups of the present study and the boys' and men's groups of the earlier males' study (39). Generally, the higher the $EMG_{Th}$ intensity in a given group, the lower the percentage of 'Responders'. Thus, the higher one's $EMG_{Th}$ is, the less likely it is to be detected within the scope of contractile intensities of the employed progressive cycling test. It is noteworthy that most of the previously mentioned $EMG_{Th}$ studies in men had nearly 100% detection rate, which corresponds to our men's 95.2% detection rate (Pitt *et al*. 2015) (Figure 4).

[ **Figure 4** ]

The possibility of the $EMG_{Th}$ residing beyond the exhaustion point of incremental exercise, means that for 'non-responders', 100% Pmax may be an underestimate of their true $EMG_{Th}$ intensity. It can be reasonably presumed that all individuals would eventually recruit their higher-threshold or type-II MUs (including type $II_{AX}$ and $II_X$) and would therefore demonstrate an $EMG_{Th}$ at one point or another. Thus, adopting the above rationale has the advantage of including all participants in the comparison and restoring its statistical power. The limitation, of course, is that assigning $EMG_{Th}$=100% Pmax under-estimates the true $EMG_{Th}$ mean for groups in which not all participants demonstrate an actual threshold prior to exhaustion. Therefore, since $EMG_{Th}$ was undetected in considerably more girls than women (55 *vs*. 32%, respectively), it can be suggested that true girls–women (or generally, child–adult) $EMG_{Th}$ differences would be larger than those reported in this and the previous (39) male's studies.

We compared the characteristics of 'Responders' *vs*. 'Non-Responders' and found the latter to be slightly younger, lighter, and less mature (Tanner's secondary sex characteristics), which is in line with our hypothesis. However, none of the differences was statistically significant, possibly due to the high variability and low participant numbers, but also to the possibility that the increase in MU activation during maturation might not exactly parallel other somatic changes

The fact that the present study's results are in line with the earlier findings in boys *vs.* men, supports the child–adult differential MU activation hypothesis (10), which suggests a child–adult difference in the capacity to recruit higher-threshold motor units. That is, the involvement of higher-threshold MUs, during high-intensity contractions, is lower in children compared with adults. This difference may be due to maturation-related changes in neural activity, or in muscle composition (see below). The magnitude of the girls–women $EMG_{Th}$ difference (6.5 %Pmax), although smaller than the corresponding boys–men difference (11.5 %Pmax), is consistent with the reported child–adult differences in the ventilatory- ($Ve_{Th}$) or lactate- ($La_{Th}$) thresholds (1, 25, 37, 42, 45, 51). However, as in males, the absolute intensities at which $EMG_{Th}$ occurs (>90 $\%VO_2pk$) are considerably higher than the corresponding intensity for the $Ve_{Th}$ and $La_{Th}$ (>50–60 $\%VO_2pk$). This is likely due to the fact that both $Ve_{Th}$ and $La_{Th}$ thresholds are metabolic and systemic in nature and limited by aerobic capacity, while the $EMG_{Th}$ is localized to the working muscles and is more related to their maximal force, which is never approached at exhaustion in progressive exercise. This large $Ve_{Th}/La_{Th}$–$EMG_{Th}$ difference can be further accounted for by considering the possibility that the $EMG_{Th}$ reflects the recruitment onset of specifically type $II_X$ and/or $II_{AX}$ MUs rather than the entire type-II MU pool.

Differences in muscle-fibre composition could also directly affect the type-II/type-I MU recruitment proportion at any given time or exercise intensity. While there is some evidence to the contrary, two of the most comprehensive studies suggest that, compared with adults, prepubertal children have as much as 10–15% higher type-I (lower type-II) muscle-fibre composition (24, 27). Male–female differences are not as clear. Some studies show no differences while others find women as having slightly lower type-II fibre composition than men (7, 44). Komi and Karlsson (26), on the other hand, found opposite fibre-compositional differences (somewhat higher percentage of type-II in the women). However, the women's contraction velocity, as defined by the time to attain 70% MVC, was nearly half that of the men, a characteristic typically associated with higher type-I fibre composition. There are no specific data for boys and girls. Overall, therefore, differential muscle composition does not appear to be a major factor in affecting the observed male–female $EMG_{Th}$ differences.

It should be noted that, similar to previous studies (21-23), we examined EMG activity in the vastus lateralis, using a single measurement site. The vastus lateralis is a very dominant cycling muscle, shown to be the most consistent and reliable for $EMG_{Th}$ determination (22). Nevertheless, it is conceivable that its contribution to the pedalling cycle is different in children than in adults. Breese *et al.*'s study (5) is the only one to have suggested child–adult difference in vastus lateralis activation during high-intensity cycling exercise. However, the study's findings were based on MRI imaging obtained ~2 min post exercise – a time gap that has been shown sufficient for complete or nearly-complete recovery in children, but not in adults (*e.g.*, (13, 19)). Thus, the available evidence justifies vastus-lateralis-based child–adult $EMG_{Th}$ comparison. It may be beneficial, however, to examine the $EMG_{Th}$ in more than a single muscle in future studies. Further, Hug *et al.* (22) demonstrated that in non-cyclist adults, $EMG_{Th}$ detection was not 100% consistent in cycling agonists, other than the vastus lateralis. It is a possibility that this is also the case in children's vastus lateralis. Beyond our extensive pilot testing, we did not conduct an $EMG_{Th}$ reliability study in children. Future reliability studies can clear up this doubt.

The child–adult $EMG_{Th}$ differences, observed in this and the earlier male study (39), as well as other previously-observed age-related differences, suggest a close relationship with the maturational process. This, in turn, begs the question of whether the increasing levels of sex-hormones (testosterone, estrogen) associated with maturation, directly affect neuromuscular activation, akin to their effect on muscle strength or sex characteristics.

Our findings would have benefited from direct measurements of force applied to the pedals. However, the fact that cycling cadence was strictly controlled at 80 rpm meant that the only factor changing with increasing power output was pedal force, which in turn meant that at exhaustion the force applied to the pedals was directly proportional to the final power output. A direct force measurement was not possible in the present study, but if done in conjunction with maximal pedalling-force measurement (MVC) in future studies, it could facilitate the calculation and child–adult comparison of %MVC at exhaustion.

Future studies ought to examine the $EMG_{Th}$ using different exercise modes, allowing for higher contractile forces prior to exhaustion in children and adults of both sexes. The sex-hormone connection could be explored by correlating sex-hormone levels, in a wide age and maturational range, with the $EMG_{Th}$ as well as other neuro-motor performance criteria. Additionally, cardiorespiratory and metabolic measurements during exercise may improve our understanding of the $EMG_{Th}$ in general, and perhaps contribute to the explanation of the observed child–adult $EMG_{Th}$ difference.

## Acknowledgements

The authors gratefully acknowledge the women, the girls, and the parents who volunteered their time and effort and made this study possible.

# References

1. Asai H, Aoki J. Force development of dynamic and static contractions in children and adults. *Int J Sports Med.* 1996; 17(3):170–174.
2. Barker AR, Williams CA, Jones AM, Armstrong N. Establishing maximal oxygen uptake in young people during a ramp cycle test to exhaustion. *Br J Sports Med.* 2011; 45(6):498–503.
3. Blimkie CJ. Age- and sex-associated variation in strength during childhood: Anthropometric, morphologic, neurologic, biomechanical, endocrinologic, genetic, and physical activity correlates, in *Perspectives in Exercise Science and Sports Medicine, Vol. 2: Youth, Exercise and Sports*. vol. 2, Gisolfi CV, (Ed. Indianapolis, IN: Benchmark Press, 1989, p. 99–163.
4. Boone J, Barstow TJ, Celie B, Prieur F, Bourgois J. The impact of pedal rate on muscle oxygenation, muscle activation and whole-body VO(2) during ramp exercise in healthy subjects. *Eur J Appl Physiol.* 2015; 115(1):57–70.
5. Breese BC, Barker AR, Armstrong N, Fulford J, Williams CA. Influence of thigh activation on the VO(2) slow component in boys and men. *Eur J Appl Physiol.* 2014; 114(11):2309–2319.
6. Candotti CT, Loss JF, Melo Mde O, La Torre M, Pasini M, Dutra LA, de Oliveira JL, de Oliveira LP. Comparing the lactate and EMG thresholds of recreational cyclists during incremental pedaling exercise. *Can J Physiol Pharmacol.* 2008; 86(5):272–278.
7. Carter SL, Rennie CD, Hamilton SJ, Tarnopolsky MA. Changes in skeletal muscle in males and females following endurance training. *Can J Physiol Pharmacol.* 2001; 79(5):386–392.
8. De Ste Croix MB, Deighan MA, Ratel S, Armstrong N. Age- and sex-associated differences in isokinetic knee muscle endurance between young children and adults. *Appl Physiol Nutr Metab.* 2009; 34(4):725–731.
9. Demello JJ, Cureton KJ, Boineau RE, Singh MM. Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. *Med Sci Sports Exerc.* 1987; 19(4):354–362.
10. Dotan R, Mitchell C, Cohen R, Klentrou P, Gabriel D, Falk B. Child-adult differences in muscle activation – a review. *Pediatr Exerc Sci.* 2012; 24(1):2–21.

11. Dotan R, Ohana S, Bediz C, Falk B. Blood lactate disappearance dynamics in boys and men following exercise of similar and dissimilar peak-lactate concentrations. *J Pediatr Endocrinol Metab.* 2003; 16(3):419–429.

12. Edwards RG, Lippold OC. The relation between force and integrated electrical activity in fatigued muscle. *J Physiol.* 1956; 132(3):677–681.

13. Falk B, Dotan R. Child–adult differences in the recovery from high-intensity exercise. *Exerc Sport Sci Rev.* 2006; 34(3):107–112.

14. Falk B, Usselman C, Dotan R, Brunton L, Klentrou P, Shaw J, Gabriel D. Child–adult differences in muscle strength and activation pattern during isometric elbow flexion and extension. *Appl Physiol Nutr Metab.* 2009; 34(4):609–615.

15. Farina D, Macaluso A, Ferguson RA, De Vito G. Effect of power, pedal rate, and force on average muscle fiber conduction velocity during cycling. *J Appl Physiol.* 2004; 97(6):2035–2041.

16. Godin G, Shephard RJ. A simple method to assess exercise behavior in the community. *Can. J Appl Sport Sci.* 1985; 10(3):141–146.

17. Greig C, Sargeant AJ, Vollestad NK. Muscle force and fibre recruitment during dynamic exercise in man. *J Physiol London* 1985; 371(176P).

18. Grosset JF, Mora I, Lambertz D, Perot C. Voluntary activation of the triceps surae in prepubertal children. *J Electromyogr Kinesiol.* 2008; 18(3):455–465.

19. Hebestreit H, Mimura K, Bar-Or O. Recovery of muscle power after high-intensity short-term exercise: comparing boys and men. *J Appl Physiol*. 1993; 74:2875–2880.

20. Henneman E, Somjen G, Carpenter DO. Functional Significance of Cell Size in Spinal Motoneurons. *J Neurophysiol.* 1965; 28:560–580.

21. Hug F, Laplaud D, Lucia A, Grelot L. A comparison of visual and mathematical detection of the electromyographic threshold during incremental pedaling exercise: a pilot study. *J Strength Cond Res.* 2006; 20(3):704–708.

22. Hug F, Laplaud D, Lucia A, Grelot L. EMG threshold determination in eight lower limb muscles during cycling exercise: a pilot study. *Int J Sports Med.* 2006; 27(6):456–462.

23. Hug F, Laplaud D, Savin B, Grelot L. Occurrence of electromyographic and ventilatory thresholds in professional road cyclists. *Eur J Appl Physiol.* 2003; 90(5-6):643–646.

24. Jansson E. Age-related fiber type changes in human skeletal muscle, in *Biochemistry of Exercise IX*, Maughan RJ and Shirreffs SM, Eds.). Champaign, IL: Human Kinetics, 1996, p. 297–307.

25. Klentrou N, Nishio M-L, Plyley M. Ventilatory breakpoints in boys and men. *Pediatr Exerc Sci.* 2006; 18(2):216–225.

26. Komi PV, Karlsson J. Skeletal muscle fibre types, enzyme activities and physical performance in young males and females. *Acta Physiol Scand.* 1978; 103(2):210–218.

27. Lexell J, Sjostrom M, Nordlund AS, Taylor CC. Growth and development of human muscle: a quantitative morphological study of whole vastus lateralis from childhood to adult age. *Muscle Nerve* 1992; 15(3):404–409.

28. Lillegard WA, Brown EW, Wilson DJ, Henderson R, Lewis E. Efficacy of strength training in prepubescent to early postpubescent males and females: effects of gender and maturity. *Pediatr Rehabil.* 1997; 1(3):147–157.

29. Lucia A, Sanchez O, Carvajal A, Chicharro JL. Analysis of the aerobic-anaerobic transition in elite cyclists during incremental exercise with the use of electromyography. *Br J Sports Med.* 1999; 33(3):178–185.

30. Maestu J, Cicchella A, Purge P, Ruosi S, Jurimae J, Jurimae T. Electromyographic and neuromuscular fatigue thresholds as concepts of fatigue. *J Strength Cond Res.* 2006; 20(4):824–828.

31. Mirwald RL, Baxter-Jones AD, Bailey DA, Beunen GP. An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc.* 2002; 34(4):689–694.

32. Moritani T, deVries HA. Reexamination of the relationship between the surface integrated electromyogram (IEMG) and force of isometric contraction. *Am J Phys Med.* 1978; 57(6):263–277.

33. Moritani T, Takaishi T, Matsumoto T. Determination of maximal power output at neuromuscular fatigue threshold. *J Appl Physiol.* 1993; 74(4):1729–1734.

34. Moritani T, Tanaka H, Yoshida T, Ishii C, Yoshida T, Shindo M. Relationship between myoelectric signals and blood lactate during incremental forearm exercise. *Am J Phys Med.* 1984; 63(3):122–132.

35. Nagata A, Muro M, Moritani T, Yoshida T. Anaerobic threshold determination by blood lactate and myoelectric signals. *Jpn J Physiol.* 1981; 31(4):585–597.

36. O'Brien TD, Reeves ND, Baltzopoulos V, Jones DA, Maganaris CN. In vivo measurements of muscle specific tension in adults and children. *Exp Physiol.* 2010; 95(1):202–210.

37. Paraschos I, Hassani A, Bassa E, Hatzikotoulas K, Patikas D, Kotzamanidis C. Fatigue differences between adults and prepubertal males. *Int J Sports Med.* 2007; 28(11):958–963.

38. Petrofsky JS. Frequency and amplitude analysis of the EMG during exercise on the bicycle ergometer. *Eur J Appl Physiol Occup Physiol.* 1979; 41(1):1–15.

39. Pitt B, Dotan R, Millar J, Long D, Tokuno C, O'Brien T, Falk B. The electromyographic threshold in boys and men. *Eur J Appl Physiol.* 2015; 115(6):1273–1281.

40. Riddell MC, Jamnik VK, Iscoe KE, Timmons BW, Gledhill N. Fat oxidation rate and the exercise intensity that elicits maximal fat oxidation decreases with pubertal status in young male subjects. *J Appl Physiol.* 2008; 105(2):742–748.

41. Sargeant AJ, Hoinville E, Young A. Maximum leg force and power output during short-term dynamic exercise. *J Appl Physiol Respir Environ Exerc Physiol.* 1981; 51(5):1175–1182.

42. Simon G, Berg A, Simon-Alt A, Keul J. Determination of the anaerobic threshold depending on age and performance potential. *Dtsch Z Sportsmed.* 1981; 32:7–14.

43. Slaughter MH, Lohman, TG, Boileau, BA. Skinfold equations for estimation of body fatness in children and youth. *Hum Biol.* 1988; 60:709–723.

44. Staron RS, Hagerman FC, Hikida RS, Murray TF, Hostler DP, Crill MT, Ragg KE, Toma K. Fiber type composition of the vastus lateralis muscle of young men and women. *J. Histochem Cytochem.* 2000; 48(5):623–629.

45. Tanaka H, Shindo M. Running velocity at blood lactate threshold of boys aged 6-15 years compared with untrained and trained young males. *Int J Sports Med.* 1985; 6(2):90–94.

46. Tanner JM *Growth at Adolescence* 2nd ed. Oxford: Blackwell Scientific Publications, 1962.

47. Tarnopolsky LJ, MacDougall JD, Atkinson SA, Tarnopolsky MA, Sutton JR. Gender differences in substrate for endurance exercise. *J Appl Physiol.* 1990; 68(1):302–308.

48. Tikkanen O, Hu M, Vilavuo T, Tolvanen P, Cheng S, Finni T. Ventilatory threshold during incremental running can be estimated using EMG shorts. *Physiol Meas.* 2012; 33(4):603–614.

49. Vollestad NK, Blom PC. Effect of varying exercise intensity on glycogen depletion in human muscle fibres. *Acta Physiol Scand.* 1985; 125(3):395–405.

50. Vollestad NK, Vaage O, Hermansen L. Muscle glycogen depletion patterns in type I and subgroups of type II fibres during prolonged severe exercise in man. *Acta Physiol Scand.* 1984; 122(4):433–441.

51. Zafeiridis A, Dalamitros A, Dipla K, Manou V, Galanis N, Kellis S. Recovery during high-intensity intermittent anaerobic exercise in boys, teens, and men. *Med Sci Sports Exerc.* 2005; 37(3):505–512.

**Table 1** – Participants' physical characteristics and training histories

| | **Women** | **Girls** |
|---|---|---|
| **n** | **19** | **20** |
| **Age** (year) | **22.9** ±3.3 | **10.3** ±1.1* |
| **Mass** (kg) | **62.68** ±6.64 | **39.2** ±9.1* |
| **Height** (cm) | **167.5** ±8.0 | **142.5** ±8.5* |
| **Body Fat** (%) | **24.0** ±3.9 | **22.5** ±8.7 |
| **Activity score** | **56.4** ±21.3 | **93.0** ±31.2* |
| **Training** ($hrs \cdot wk^{-1}$) | **2.7** ±1.8 | **3.1** ±2.2 |
| **VO$_2$pk** ($ml \cdot kg^{-1} \cdot min^{-1}$) | **37.6** ±4.4 | **37.2** ±7.0 |
| **HR at VO$_2$pk** (bpm) | **193** ±10 | **202** ±9* |
| **RER at VO$_2$pk** | **1.19** ±0.08 | **1.13** ±0.08* |

Values are means ±1SD

* – Significant difference; $p<0.05$

**Table 2** – Comparisons of EMG$_{Th}$ intensities between the women and girls groups for the ‘Responders’ and for the entire groups (‘Non-Responders’ being assigned EMG$_{Th}$ = 100% Pmax)

| | **‘Responders’** | | **All**<br>(‘Responders’ + ‘Non-Responders’) | |
|---|---|---|---|---|
| **EMG$_{Th}$ type** | %P$_{VO2pk}$ | %Pmax | %P$_{VO2pk}$ | %Pmax |
| **Women** | **90.6** ±7.8<br>n=13 (68%) | **83.0** ±6.9<br>n=13 (68%) | **95.2** ±9.9<br>n=19 | **88.4** ±9.9<br>n=19 |
| **Girls** | **101.6** ±17.6<br>n=9 (45%) | **88. 6** ±7.0<br>n=9 (45%) | **103.2** ±11.7<br>n=20 | **94.8** ±7.4<br>n=20 |
| **Δ**<br>(Women – Girls) | **–11.0** | **–5.6** | **–8.0** | **–6.5** |
| **p** | 0.063 | 0.080 | **0.028** | **0.026** |

## Figure Legend

1. Sample segment of the EMG trace of one leg demonstrating onset and offset determination for each burst. The corresponding bursts for the opposite leg would show between the bursts shown here, in the off segment. The composite right-left trace was created only after the root mean square was calculated for each trace.

2. Sample $EMG_{RMS}$ trace of a woman with a clearly detectible $EMG_{Th}$. Note the persistent rise of the trimmed $EMG_{RMS}$ mean trace above the +3SD confidence interval beyond the detected $EMG_{Th}$.

3. Sample $EMG_{RMS}$ trace of a girl in which $EMG_{Th}$ could not be detected. Note that the trimmed $EMG_{RMS}$ mean does not exceed the +3SD confidence interval by end of test.

4. The relationship between $EMG_{Th}$ intensity (%Pmax) and the proportion of $EMG_{Th}$ detection (% ‘Responders’) in the girls and women of the present study as well as the boys and men of the earlier male study (Pitt *et al*. 2015). Generally, the higher the $EMG_{Th}$ intensity, the lower the $EMG_{Th}$ detection rate.