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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

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The Electromyographic Threshold in Girls and Women

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Running title: Electromyographic threshold in girls and women

Subject area: Exercise physiology

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

27 **Abstract**

28 **Background:** The electromyographic threshold (EMG_{Th}) is thought to reflect increased high-
29 threshold/type-II motor-unit (MU) recruitment and was shown higher in boys than in men. Women
30 differ from men in muscular function. **Purpose:** Establish whether females' EMG_{Th} and
31 girls–women differences are different than males'. **Methods:** Nineteen women (22.9 ± 3.3 yrs) and
32 20 girls (10.3 ± 1.1 yrs) had surface EMG recorded from the right and left vastus lateralis muscles
33 during ramped cycle-ergometry to exhaustion. EMG root-mean-squares were averaged per pedal
34 revolution. EMG_{Th} was determined as the least residual sum of squares for any two regression-line
35 data divisions, if the trace rose $\geq 3SD$ above its regression line. EMG_{Th} was expressed as % final
36 power-output (% P_{max}) and % VO_{2pk} power (% $P_{VO_{2pk}}$). **Results:** EMG_{Th} was detected in 13 (68%)
37 of women, but only 9 (45%) of girls ($p < 0.005$) and tended to be higher in the girls (% $P_{max} =$
38 88.6 ± 7.0 vs. $83.0 \pm 6.9\%$, $p = 0.080$; % $P_{VO_{2pk}} = (101.6 \pm 17.6$ vs. $90.6 \pm 7.8\%$, $p = 0.063$). When EMG_{Th}
39 was undetected it was assumed to occur at 100% P_{max} or beyond. Consequently, EMG_{Th} values
40 turned significantly higher in girls than in women (94.8 ± 7.4 vs. 88.4 ± 9.9 % P_{max} , $p = 0.026$; and
41 103.2 ± 11.7 vs. 95.2 ± 9.9 % $P_{VO_{2pk}}$, $p = 0.028$). **Conclusions:** During progressive exercise, girls
42 appear to rely less on higher-threshold/type-II MUs than do women, suggesting differential muscle
43 activation strategy.

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

45 **Introduction**

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

56 The EMG threshold (EMG_{Th}), measured during progressive exercise, is widely considered as
57 indicating the onset of accelerated recruitment of the higher-threshold/type-II MUs (4, 12, 22, 23,
58 29, 30, 32-35, 38, 48), or possibly, just the II_X and/or II_{AX} sub-groups thereof. This accelerated
59 recruitment is viewed as necessary for maintaining or increasing power or force output. The
60 interpretation of the EMG_{Th} as reflecting an increase in utilization of type-II MUs is supported by
61 glycogen-depletion measurements in different muscle-fibre types (49) and by findings of increasing
62 conduction velocities with progressive recruitment of higher threshold MUs (15). The EMG_{Th} has
63 been widely investigated in adults, athletes and non-athletes, in order to quantify muscle activation
64 during exercise and elucidate issues related to neuromuscular fatigue (6, 12, 22, 23, 29, 30, 32-35,
65 38, 48). Based on this, we used the EMG_{Th} as a proxy for investigating the recruitment of type-II
66 MUs in girls and women, with the aim of elucidating developmental changes in muscle function.
67 EMG_{Th} in children has previously been studied only by Pitt *et al.* (39), demonstrating it to occur at

68 higher relative exercise intensities in boys than in men. This finding suggested that in ramped,
69 exhaustive cycling exercise, boys recruit type-II MUs later and to a lesser extent than do men.

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

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

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

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

89

90 **Methods**

91 **Participants**

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

98 [**Table 1**]

99 **Experimental Protocol**

100 Participants were invited for two visits to the laboratory, separated by a minimum of two days
101 and a maximum of two weeks. The first visit began with an overview of the two testing sessions,
102 followed by signing the informed consent/assent forms, medical screening, filling out physical
103 activity/training-history questionnaires, and anthropometric measurements (see below). The crank-
104 length of the cycle-ergometer (Excalibur Sport, Lode, Groningen, The Netherlands) was
105 individually adjusted in 5 mm increments based on body height. Handlebar position and saddle
106 height were established for comfort and proper knee angles prior to testing and recorded for
107 replication in the second visit (EMG_{Th} test). The participant was familiarized with the cycle-
108 ergometer and practiced keeping a steady cadence at ≥ 80 rpm. Peak O₂ uptake (VO_{2pk}) and the
109 VO_{2pk}-corresponding mechanical power output (P_{VO_{2pk}}) were determined through submaximal and
110 maximal VO₂ tests. The second visit, to determine the EMG_{Th}, took place 2–7 days following the
111 first visit (see below).

112 **Measurements**

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

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

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

120 **Visit 1: Submaximal VO₂ and VO₂pk tests**

121 Participants began with a 3–5-minute warm-up and cadence familiarization. The submaximal
122 protocol included 3–5 incremental stages to establish a VO₂–power regression. Stages were 3.5- and
123 4-min long for the girls and women, respectively. Girls typically started at 25–35W and increased
124 by 10–20W per stage. Women typically started at 40–60W, incremented by 20–30W per stage.
125 Participants were allowed ~10-min break before commencing the graded exercise test to exhaustion
126 to determine VO₂pk. The maximal test typically began at 40–50 and 60–70W and incremented by
127 10 and 20W•min⁻¹ for girls and women, respectively, and continued to volitional exhaustion. As
128 has previously demonstrated by Barker *et al.* (2), we did not rely on the commonly-used fixed
129 criteria for VO₂pk attainment (*e.g.*, 90% predicted max HR, or respiratory exchange ratio of 1.05),
130 but rather exceeded them in motivating the participants and verbally encouraging them to reach
131 their respective utmost exhaustion. To verify that the testing protocol indeed elicited highest
132 possible values, supra-maximal testing at 105% of the VO₂pk test's final power, was administered
133 to a sample of the first ~15 women and girls, ~10 min post VO₂pk test (as suggested by Barker *et*
134 *al.* (2)). In no case was an improvement observed relative to the preceding VO₂pk test. VO₂pk was

135 recorded as the average of the highest three consecutive 15-s intervals near the end of the volitional
136 exercise test. The above protocol allowed for the determination of steady-state VO_2 at submaximal,
137 3.5–4-min workloads, as well as $\text{VO}_{2\text{pk}}$ determination in closely subsequent test to exhaustion.
138 However, the protocol's discontinuous nature was incompatible with gas-exchange-threshold
139 determination.

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

145 $\text{VO}_{2\text{pk}}$ value was then placed on the individual's VO_2 -power regression line, derived from the
146 graded submaximal test. The mechanical-power equivalent of the $\text{VO}_{2\text{pk}}$ value (*i.e.*, net-aerobic
147 peak power, free of anaerobic contribution) was then determined and defined (calculated) from that
148 plot and termed as $P_{\text{VO}_{2\text{pk}}}$. While response linearity may not be identical, non-linearity (plateauing
149 effect) in adults is considerably less significant in cycling than in running, due to cycling's lower
150 $\text{VO}_{2\text{pk}}$.

151 **Visit 2: EMG_{Th} test**

152 Surface EMG was used to continuously monitor m. vastus lateralis (VL) EMG of each leg,
153 using 10-mm² bipolar Ag/Ag surface electrodes (Delsys 2.1, Delsys Inc., Boston, MA). An area of
154 each thigh, at two-thirds of the line between the anterior spina iliaca superior and the superior
155 border of the patella, was shaved (if necessary), abraded with skin preparation gel (Nuprep, Weaver
156 & Co., Aurora, CO), and cleaned with rubbing alcohol. Electrodes were placed parallel to the

157 direction of muscle fibres on the medial aspect of the VL and affixed with proprietary double-sided
158 tape. Reference electrode was placed over the spinous process of the 7th cervical vertebra.

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

165 The ramped cycle-ergometer test was started at the individual's 40 %P_{VO2pk} (determined during
166 the first visit). This starting power averaged 39.3±8.3W and 74.7±15.1W for girls and women,
167 respectively. Exercise intensity was increased by 1W every 4–10s so as to reach P_{VO2pk} output in
168 ~10min, for both girls and women. A cadence of 80±1 rpm was required and maintained throughout
169 the test. The protocol for this progressive test was based on previous studies in adults (22, 23) as
170 well as extensive pilot testing to ensure suitability for both children and adults (39). The test was
171 terminated upon volitional exhaustion, or when the participant could no longer raise her cadence
172 above 76 rpm in the test's final seconds. The power output at test cessation, or when the cadence
173 reached 78 rpm on its way down in the final seconds, was defined as the test's maximal power
174 output (P_{max}).

175 **EMG data reduction**

176 EMG signals were sampled at 1kHz and band-pass filtered (20–450 Hz) using the Bagnoli-4
177 bioamplifier (Delsys Inc., Boston, MA) using a computer-based oscillograph and Data Acquisition
178 System (EMGworks Acquisition, Delsys Inc., Boston, MA). A dedicated MATLAB (2013 version;
179 MathWorks Inc., Natick, MA) computer algorithm was used for EMG data analysis. EMG bursts

180 were recorded for each pedal stroke, separately for each leg (Figure 1). The recorded trace was then
181 pruned at the beginning and end to remove any partial or incomplete bursts, if any, and the trace
182 was de-trended to offset any baseline drift. The EMG root-mean-square (EMG_{RMS}) was calculated
183 for each burst and its onset and offset were defined as the points where the EMG_{RMS} rose or fell,
184 respectively, above or below 10% of the mean EMG_{RMS} value of the entire test record. The mean
185 EMG_{RMS} of each burst (*i.e.*, between the onset and offset) was then extracted for EMG_{Th}
186 determination.

187 **EMG_{Th} Determination**

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

196 [**Figures 2 & 3**]

197 Since a LRSS can always be determined, even when no actual threshold exists, an additional
198 criterion was used to qualify a physiologically-meaningful threshold. As EMG_{Th} was expected to
199 occur at relative power outputs of ~80% P_{max} or higher in adults (22) and likely higher than that in
200 the children, a linear regression line was determined for the initial 70% of the test duration
201 (corresponding to ~80% of P_{max}). The line was then extrapolated to the test's end and a 3-SD
202 confidence interval was applied above it and extended to the end of the trace. An EMG_{Th} was

203 confirmed only if the EMG_{RMS} plot rose and remained above the confidence limit (Fig. 2), without
204 descending back to within the confidence interval until the end of the test. The power output at the
205 EMG_{Th} was determined from the power–time relationship and was expressed as a percentage of the
206 peak power output reached at test’s end (%Pmax) and as percentage of P_{VO_2pk} (% P_{VO_2pk}), based on
207 the VO_2 –power data obtained at the first session.

208 **Statistical analysis:**

209 All statistical analysis was performed using SPSS v.20 (SPSS Inc., Chicago, IL). The data for
210 all groups are presented as means \pm 1SD. Differences in the observed number (or percentage) of
211 detectable EMG_{Th} between groups were examined using a Chi-squared test. Group differences in
212 physical characteristics and EMG_{Th} as a %Pmax and % VO_2pk were assessed using a two-tailed
213 Student’s *t* test. Additionally, differences between the ‘Responder’ and ‘Non-Responder’ groups
214 (defined below) were examined using a two-tailed Student’s *t* test. The acceptable level of
215 significance for all tests was set at $p<0.05$.

216

217 **Results**

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

222 Peak net-aerobic power output in the VO_2pk test (P_{VO_2pk}) averaged 2.93 ± 0.44 and 2.65 ± 0.69
223 W/kg for the women and the girls, respectively. Peak power output upon exhaustion at the EMG_{Th}
224 test (Pmax) averaged 3.16 ± 0.48 and 2.89 ± 0.72 W/kg for the women and girls, respectively.

225 The EMG_{Th} test's duration was quite variable across all participants, but statistically similar for
226 the two groups (617.0±60.5 and 588.5±70.4 s for the women and girls, respectively; p=0.183). The
227 EMG_{Th} could be detected in only 9 (45%) of the 20 girls and in 13 (68%) of the 19 women ($\chi^2_{(1, n=39)}$
228 =7.945; p<0.005). There were no significant differences in training history, or physical
229 characteristics between those in whom EMG_{Th} was detected ('Responders') and those in whom it
230 was not ('Non-Responders').

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

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

239

240 **Discussion**

241 This is the first study to investigate EMG_{Th} specifically in females. A significantly smaller
242 proportion of the girls (45%) demonstrated EMG_{Th} during the progressive exercise, compared with
243 women (68%). Among those 'Responders', the EMG_{Th} tended to occur at higher relative intensities
244 in the girls than in the women. When 'Non-Responders' were considered as having reached EMG_{Th}
245 at the point of exhaustion (*i.e.*, EMG_{Th} = 100% Pmax), the girls–women EMG_{Th} differences were

246 statistically significant, whether expressed in terms of %Pmax ($p=0.026$) or %P_{VO2pk} ($p=0.028$)
247 (Table 2).

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

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

264 Support for the above claim is provided in Figure 4, depicting the relationship ($r = -0.93$)
265 between the %Pmax at which the EMG_{Th} was detected and the proportion of EMG_{Th} detection (%
266 'Responders') in the girls' and women's groups of the present study and the boys' and men's
267 groups of the earlier males' study (39). Generally, the higher the EMG_{Th} intensity in a given group,
268 the lower the percentage of 'Responders'. Thus, the higher one's EMG_{Th} is, the less likely it is to be

269 detected within the scope of contractile intensities of the employed progressive cycling test. It is
270 noteworthy that most of the previously mentioned EMG_{Th} studies in men had nearly 100%
271 detection rate, which corresponds to our men's 95.2% detection rate (Pitt *et al.* 2015) (Figure 4).

272 [**Figure 4**]

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

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

289 The fact that the present study's results are in line with the earlier findings in boys *vs.* men,
290 supports the child-adult differential MU activation hypothesis (10), which suggests a child-adult
291 difference in the capacity to recruit higher-threshold motor units. That is, the involvement of

292 higher-threshold MUs, during high-intensity contractions, is lower in children compared with
293 adults. This difference may be due to maturation-related changes in neural activity, or in muscle
294 composition (see below). The magnitude of the girls–women EMG_{Th} difference (6.5 %Pmax),
295 although smaller than the corresponding boys–men difference (11.5 %Pmax), is consistent with the
296 reported child–adult differences in the ventilatory- (V_{eTh}) or lactate- (La_{Th}) thresholds (1, 25, 37,
297 42, 45, 51). However, as in males, the absolute intensities at which EMG_{Th} occurs ($>90\% VO_{2pk}$)
298 are considerably higher than the corresponding intensity for the V_{eTh} and La_{Th} ($>50\text{--}60\% VO_{2pk}$).
299 This is likely due to the fact that both V_{eTh} and La_{Th} thresholds are metabolic and systemic in nature
300 and limited by aerobic capacity, while the EMG_{Th} is localized to the working muscles and is more
301 related to their maximal force, which is never approached at exhaustion in progressive exercise.
302 This large $V_{eTh}/La_{Th}\text{--}EMG_{Th}$ difference can be further accounted for by considering the possibility
303 that the EMG_{Th} reflects the recruitment onset of specifically type II_X and/or II_{AX} MUs rather than
304 the entire type-II MU pool.

305 Differences in muscle-fibre composition could also directly affect the type-II/type-I MU
306 recruitment proportion at any given time or exercise intensity. While there is [some](#) evidence to the
307 contrary, two of the most comprehensive studies suggest that, compared with adults, prepubertal
308 children have as much as 10–15% higher type-I (lower type-II) muscle-fibre composition (24, 27).
309 Male–female differences are not as clear. Some studies show no differences while others find
310 women as having slightly lower type-II fibre composition than men (7, 44). Komi and Karlsson
311 (26), on the other hand, found opposite fibre-compositional differences (somewhat higher
312 percentage of type-II in the women). However, the women’s contraction velocity, as defined by the
313 time to attain 70% MVC, was nearly half that of the men, a characteristic typically associated with
314 higher type-I fibre composition. There are no specific data for boys and girls. Overall, therefore,

315 differential muscle composition does not appear to be a major factor in affecting the observed
316 male–female EMG_{Th} differences.

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

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

336 Our findings would have benefited from direct measurements of force applied to the pedals.
337 However, the fact that cycling cadence was strictly controlled at 80 rpm meant that the only factor

338 changing with increasing power output was pedal force, which in turn meant that at exhaustion the
339 force applied to the pedals was directly proportional to the final power output. A direct force
340 measurement was not possible in the present study, but if done in conjunction with maximal
341 pedalling-force measurement (MVC) in future studies, it could facilitate the calculation and
342 child–adult comparison of %MVC at exhaustion.

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

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353 **Acknowledgements**

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

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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·wk ⁻¹)	2.7 ±1.8	3.1 ±2.2
VO_{2pk} (ml·kg ⁻¹ ·min ⁻¹)	37.6 ±4.4	37.2 ±7.0
HR at VO_{2pk} (bpm)	193 ±10	202 ±9*
RER at VO_{2pk}	1.19 ±0.08	1.13 ±0.08*

Values are means ±1SD

* – Significant difference; p<0.05

486 **Table 2** – Comparisons of EMG_{Th} intensities between the women and girls groups for the
 487 ‘Responders’ and for the entire groups (‘Non-Responders’ being assigned EMG_{Th} =
 488 100% P_{max})

	‘Responders’		All (‘Responders’ + ‘Non-Responders’)	
EMG_{Th} type	%P_{VO2pk}	%P_{max}	%P_{VO2pk}	%P_{max}
Women	90.6 ±7.8 n=13 (68%)	83.0 ±6.9 n=13 (68%)	95.2 ±9.9 n=19	88.4 ±9.9 n=19
Girls	101.6 ±17.6 n=9 (45%)	88.6 ±7.0 n=9 (45%)	103.2 ±11.7 n=20	94.8 ±7.4 n=20
Δ (Women – Girls)	-11.0	-5.6	-8.0	-6.5
p	0.063	0.080	0.028	0.026

489

490 **Figure Legend**

- 491 1. Sample segment of the EMG trace of one leg demonstrating onset and offset determination for
492 each burst. The corresponding bursts for the opposite leg would show between the bursts shown
493 here, in the off segment. The composite right-left trace was created only after the root mean
494 square was calculated for each trace.
- 495 2. Sample EMG_{RMS} trace of a woman with a clearly detectable EMG_{Th} . Note the persistent rise of
496 the trimmed EMG_{RMS} mean trace above the +3SD confidence interval beyond the detected
497 EMG_{Th} .
- 498 3. Sample EMG_{RMS} trace of a girl in which EMG_{Th} could not be detected. Note that the trimmed
499 EMG_{RMS} mean does not exceed the +3SD confidence interval by end of test.
- 500 4. The relationship between EMG_{Th} intensity (%Pmax) and the proportion of EMG_{Th} detection (%
501 ‘Responders’) in the girls and women of the present study as well as the boys and men of the
502 earlier male study (Pitt *et al.* 2015). Generally, the higher the EMG_{Th} intensity, the lower the
503 EMG_{Th} detection rate.