

Article

Does sex dimorphism exist in dysfunctional movement patterns during sensitive period of adolescence?

Josip Karuc ^{1*}, Mario Jelčić², Maroje Sorić ¹, Marjeta Mišigoj-Duraković ¹, and Goran Marković ^{1,2}

¹ Faculty of Kinesiology, University of Zagreb, Croatia; mjelcic1@gmail.com (M.J.); maroje.soric@kif.unizg.hr (M.S.); marjeta.misigoj-durakovic@kif.unizg.hr (M.M.-D.); goran.markovic@kif.unizg.hr (G.M.)

² Motus Melior, Zagreb, Croatia

* Correspondence: josip.karuc@kif.unizg.hr (J.K.)

Abstract: This study aimed to investigate sex difference in the functional movement in adolescent period. Seven hundred and thirty adolescents (365 boys) aged 16–17 years participated in the study. The participants performed standardized Functional Movement Screen™ (FMS™) protocol and t-test was used to examine sex differences in the total functional movement screen score while chi-square test was used to determine sex difference in the proportion of dysfunctional movement and movement asymmetries within the individual FMS™ tests. Girls demonstrated higher total FMS™ score compared to boys (12.7 ± 2.3 and 12.2 ± 2.4 , respectively; $F=8.26$, $p=0.0054$). Also, sex differences were present in several individual functional movement patterns where boys demonstrated higher prevalence of dysfunctional movement compared to girls in patterns that challenges mobility and flexibility of the body, while girls underperformed in tests that have higher demands for upper-body strength and abdominal stabilization. Findings of this study suggest that sex dimorphism exist in functional movement patterns in the period of mid-adolescence. The results of this research need to be considered while using FMS™ as a screening tool as well as the reference standard for exercise intervention among secondary school-aged population.

Keywords: FMS™; pubescence; maturation; fundamental movement patterns; functional movement; gender difference

1. Introduction

Physical inactivity represents global health problem and it is related to higher risk for morbidity and mortality [1]. Evidence have shown that inactive children are exposed to increased metabolic [2] and cardiovascular risk [3]. Physical activity in childhood and adolescence is also important to attain appropriate bone mineral content [4]. Therefore, promoting physical activity has become a public priority in developed countries worldwide. Although the influence of physical activity as a measure of movement quantity has been examined extensively, very few studies have examined the movement quality through the period of the adolescence [5-16]. Although functional movement is considered as the clinical measure of movement quality [17,18], the true impact of the optimal functional movement on the musculoskeletal health remains unknown.

Functional movement can be defined as optimal flexibility of the soft tissue, mobility of the joints, and neuromuscular control of the body regions involved in the particular motor task [17,18]. On the other hand, dysfunctional movement (DFM) is characterized with movement compensations evident across the kinematic chain with significant loss in the mobility, observed asymmetry, and poor movement control of the particular motor task [17,18]. Importance of functional movement patterns has been studied widely [19-21] and they represent basic foundation for execution of more complex motor tasks [17,18]. Also, higher incidence of musculoskeletal injury incidence has been associated with DFM patterns among athletic population [19-21], while some studies reported opposite [22-24]. The most common diagnostic tool to assess functional movement is Functional Movement Screen (FMSTM) which evaluates mobility and stability in seven functional movement patterns: deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise (ASLR), trunk stability push-up, and rotary stability [17,18]. Also, FMSTM can detect movement asymmetries if difference between right and left side of the uni/contralateral movement patterns is observed [17,18]. What is more, literature show that movement asymmetries detected via FMSTM have been associated with higher injury risk [25] which could possibly contribute to the development of the musculoskeletal deformities in later life.

Presence of the DFM patterns and movement asymmetries in the childhood could facilitate postural abnormalities in the period of mid-adolescence. Indeed, evidence shows that neuromuscular control of the movement is not properly developed by the time of the adolescent period [26]. Therefore, identifying DFM patterns and movement asymmetries in this period of child's growth needs special attention. Still, only few studies investigated sex difference in functional movement in the group of average or athletic adolescent population. These studies suggest that, in both general and athletic population, girls exhibit better functional movement compared to boys [8-10,12,15,16] while some studies reported opposite or no difference between sexes [6,11,13,14]. However, these were either small scale studies [11,12,13] or included only active adolescents [5-10,14] or adolescents with overweight/obesity [7] and did not analyze movement asymmetries.

However, to this date, none of the study investigated sex differences in functional movement and movement asymmetries in a large representative sample of school-aged mid-adolescents. Therefore, the purpose of this study was to examine sex dimorphism in functional movement patterns and movement asymmetries in the representative sample of mid-adolescents.

2. Materials and Methods

2.1. Participants

This investigation is a part of the Croatian physical activity in adolescence longitudinal study (CRO-PALS) conducted in a representative sample of urban youth (city of Zagreb, Croatia). This study was performed during the 2nd wave of assessments, and all measurements were taken in 2015, during March, April, and May. Information about the procedures of the CRO-PALS longitudinal study have been documented in previous research [27]. In brief, using stratified two-stage random sampling procedures (school level and class level), 54 classes in 14 secondary schools were selected to participate in the CRO-PALS study (schools were stratified by type: grammar schools/vocational schools/private schools). All 1408 students in the selected classes were approached, and 903 agreed to participate (response rate=64%). One hundred and twenty participants were unavailable on the day of testing or did not complete the FMSTM screening. As a consequence, we included data from

783 adolescents. All the participants had to meet certain criteria for the medical doctor to perform the screening process, specifically: 1) not having any pain during the movement screening (i.e. FMS™ testing procedures), 2) not having an acute medical condition that precluded FMS™ testing (neurologic disorders or serious orthopedic trauma such as bone fractures or complete muscle ruptures). Accordingly, 53 subjects were excluded. Therefore, the total number of participants that was analyzed was 730 (girls, n=368, mean age \pm SD=16.6 \pm 0.4 yo, mean weight \pm SD=60.1 \pm 9.3, mean height \pm SD=166.3 \pm 6.4; boys, n=362, mean age \pm SD=16.7 \pm 0.4 yo, mean weight \pm SD=71.7 \pm 12.5, mean height \pm SD=179.0 \pm 7.2). The flowchart of the included participants is shown in Figure 1.

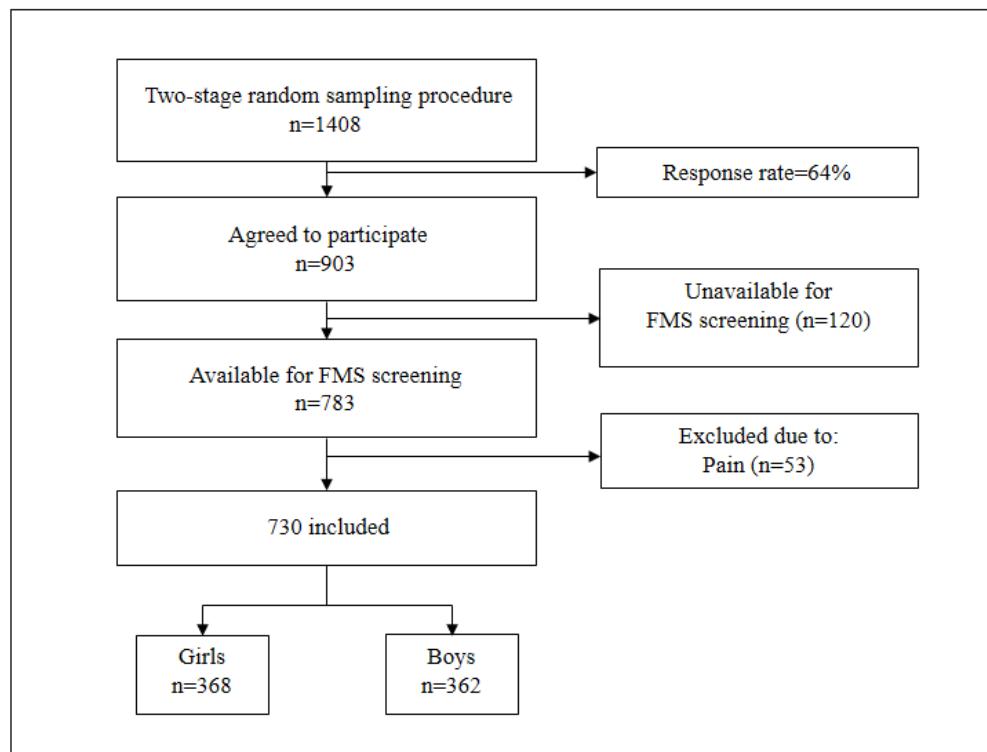


Figure 1. Flowchart of included participants.

Children and their parents were fully informed about the purposes of the research, its protocols, possible hazards and discomforts related to the procedures used. Also, written consent was obtained from both children and their parents or legal guardians. The study was performed according to the Declaration of Helsinki and the procedures were approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (No: 1009-2014).

2.2. Functional Movement Screen

FMS™ is an instrument designed for evaluation of mobility and stability of 7 functional movement tests: the deep squat, hurdle step, inline lunge, shoulder mobility, ASLR, trunk stability push-up, and rotary stability [17,18]. In the current study, ten novice trained raters used FMS™ according to the official guidelines. All ten raters passed two-day FMS™ education course by FMS™ certified practitioner. Despite large number of raters recruited in this study, previous researches reported moderate to good interrater and intrarater reliability of the FMS™ among novice raters [28,29]. Participants had a maximum of 3 trials for each test in accordance with the recommended protocol [17,18] while each test was scored on a three-point scale, from 0 to 3, with higher scores

indicating better functional movement. Evidence shows that pain can alter movement control [30]. Therefore, subjects were asked if they felt pain during the FMS™ assessment, and were subsequently scored with the score of 0 and excluded if answered positively to this question (n=53). In the current study, functional movement was defined as the movement with a given score of 2 or 3 during FMS™ testing. In addition, a score of 1 was recorded when the participant was unable to perform movement task due to the number of movement compensation present which reflects the DFM pattern [17,18]. This means that score of 2 and 3 was an indicator of functional movement, whereas a score of 1 was an indicator of DFM for each of 7 individual FMS™ tests. If discrepancy in the scores between right and left side of the contra/unilateral FMS™ test was observed, movement asymmetry was documented for that specific FMS™ test. We analyzed movement asymmetries for five contra/unilateral FMS™ tests (i.e. hurdle step, inline lunge, shoulder mobility, ASLR, and rotary stability). Accordingly, number (n) and proportion (%) of subjects that performed DFM or showed movement asymmetry could be calculated in each of the seven or five individual FMS™ movement patterns, respectively. This was the basic step for analyzing the differences in the proportion of participants that performed DFM or demonstrated any asymmetry between girls and boys for individual FMS™ tests (i.e. using chi-square tests). In addition, total FMS™ score was set as an outcome continuous variable and was calculated according to literature [17,18].

2.3. Statistical Analysis

Independent t-test was used to examine difference between sexes in total FMS™ score. Chi-square test was performed to investigate difference between girls and boys in the proportion of DFM in 7 individual FMS™ tests and for the movement asymmetries exhibited in the 5 contralateral FMS™ tests. Data are presented as mean \pm SD. All analyses were performed using Statistica (version 13.0) and the level of statistical significance was set at $p < 0.05$.

3. Results

Basic characteristics of participants are shown in Table 1. Result demonstrated that girls slightly outperformed boys in total FMS™ score (12.7 ± 2.4 and 12.2 ± 2.5 , respectively; $p=0.0054$).

Table 1. Basic characteristics of participants by sex.

	Girls	Boys
BMI (kg/m2)		
mean (SD)	21.7 (3.2)	22.4 (3.5)
Waist circumference(cm)		
mean (SD)	68.7 (6.4)	76.0 (7.5)
Hips circumference (cm)		
mean (SD)	96.7 (7.5)	98.0 (7.5)
Sum of four skinfolds (mm)		
mean (SD)	48.8 (15.0)	37.1 (18.1)
Functional Movement Asymmetries		
0	76 (21)	86 (23)
1	128 (35)	126 (34)
2	98 (27)	111 (30)
3	51 (14)	38 (10)
n (%)		
4	7 (2)	7 (2)
5	2 (0.5)	0 (0)
Sport participation		
n (%)	93 (25)	173 (48)
SES		
median (IQR)	3 (1)	2 (1)

Note: BMI: Body Mass Index; Functional Movement Asymmetries n (%): Number (n) and percentage (%) of participants that exhibited Functional Movement Asymmetries within each sex group; Sport Participation n (%): Number (n) and percentage (%) of participants that participated in sport activity; SES: Socioeconomic status (1 - Much lower than average, 2 - Lower than average, 3 - Average, 4 - Higher than average, 5 - Much higher than average); IQR: Interquartile Range; SD: Standard Deviation.

Figure 2 depicts proportion (%) of DFM patterns among girls and boys in all seven FMS™ tests. Girls demonstrated higher proportion of DFM patterns compared to boys in trunk stability push-up (81% vs 44%, df=1, p<0.0001) and rotary stability (54% vs 44%, df=1, p=0.0075). However, boys showed higher proportion of DFM in inline lunge (32% vs 22%, df=1, p=0.0009), shoulder mobility (47% vs 26%, df=1, p<0.0001), and ASLR (31% vs 9%, df=1, p<0.0001), while scores in deep squat and hurdle step were similar in both sexes (see Figure 2).

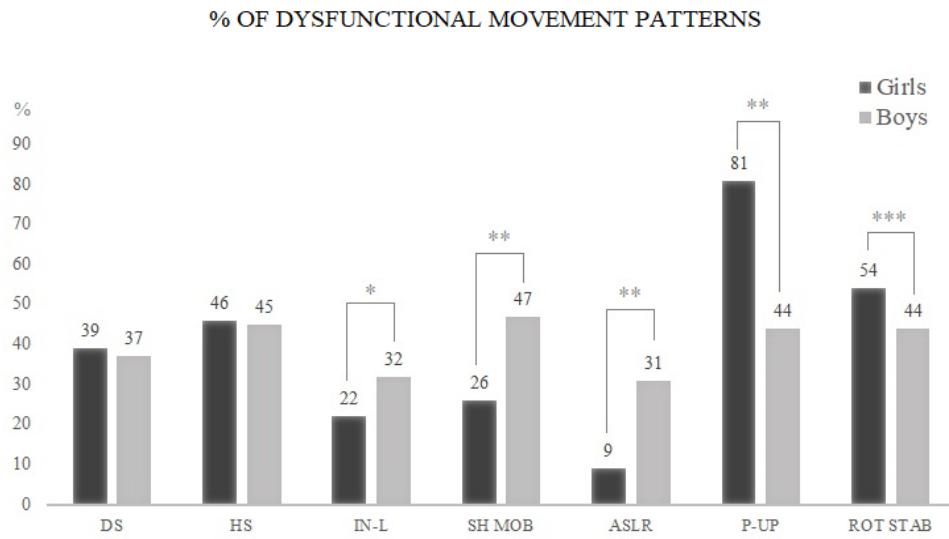


Figure 2. Proportion (%) of adolescent girls and boys that performed dysfunctional movement (DFM) in each FMS™ test. Note: DS: deep squat; HS: hurdle step; IN-L: inline lunge; SHO MOB: shoulder mobility; ASLR: active straight leg raise; P-UP: Trunk stability push-up; ROT STAB: rotary stability. *p=0.0009; **p<0.0001; ***p=0.0075.

Boys demonstrated higher proportion of movement asymmetries compared to girls in shoulder mobility (45% vs 36%, df=1, p=0.0218) and ASLR (21% vs 13%, df=1, p=0.008). However, no significant difference between girls and boys in the proportion of the movement asymmetries were found for the other FMS™ tests; hurdle step (27% vs 24%, df=1, df=1, p=0.331), inline lunge (31% vs 31%, df=1, p=0.95), and rotary stability (26% vs 22%, df=1, p=0.237) (see Figure 3).

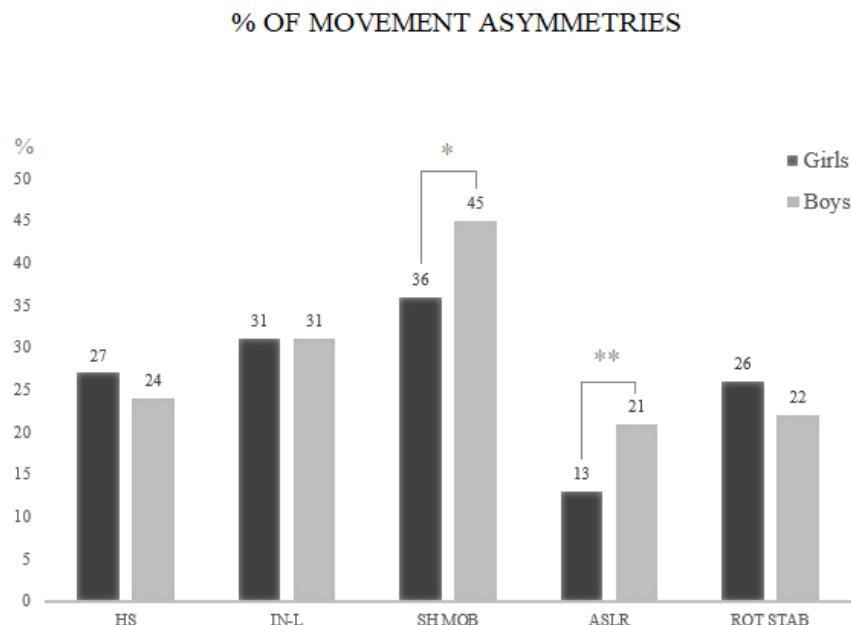


Figure 3. Proportion (%) of adolescent girls and boys that demonstrated movement asymmetries in each FMS™ test. Note: HS: hurdle step; IN-L: inline lunge; SHO MOB: shoulder mobility; ASLR: active straight leg raise; ROT STAB: rotary stability. *p=0.0218; **p=0.008.

4. Discussion

This study aimed to determine functional movement status in general adolescent population. The main finding of this study is that adolescent boys showed higher proportion of DFM and movement asymmetries in the larger number of FMS™ tests compared to adolescent girls. More specifically, boys demonstrated higher proportion of DFM and movement asymmetries in the inline lunge, shoulder mobility and ASLR tests which could potentially predispose them to higher injury for lower and upper extremities [25]. On the other hand, girls demonstrated higher prevalence of DFM in the push-up and rotary stability tests. Low score in trunk stability pushup test and rotary stability could indicate inadequate reactive stabilization of the trunk muscles and deficit in the upper-body strength in the female adolescent population [18]. For this reason, adolescent girls in the current study, could be more prone to suffer from higher risk of lower back injury [31]. On the other hand, girls slightly outperformed boys in total FMS™ score (12.7 vs. 12.3 points) which further emphasize aforementioned sex difference in the functional movement during mid-adolescent period.

According to the current literature, in both general and athletic adolescent population, most evidence demonstrate that females have higher total FMS™ score compared to males [8,9,10,12,15,16] although two studies reported opposite results [6,14]. In the study done by Abraham et al. [14], large age span (10-17 y) among participants reveals that pre-pubertal and pubertal subject were included in the sample where all inactive children were excluded what could potentially lead to higher mean values. Also, some researchers found no sex difference in total FMS™ score [11,13] which could be potentially contributed to different population studied (8-11 yo) and much smaller sample size (n=77 and n=58, respectively). Concerning individual FMS™ patterns, evidence almost consistently show that, in both general and athletic adolescents, same sex differences are present. More specifically, female adolescents generally show better quality of movement in flexibility/mobility tests [10,11,13,16] while boys are better at push up and rotary stability [6,11,13-16]. It could be concluded that behind mechanism of observed sex dimorphism in functional movement cannot be contributed to participation in particular sport activity since same sex differences in functional movement are present in both athletic and general population of adolescents [6,10,11,13-16]. Reported results from previous studies are in the line with findings of our study. What our study adds to the existing body of knowledge is that the same sex differences in functional movement exist in the population of mid-adolescents.

Still, it remains unanswered why these sex differences in the functional movement patterns are present in adolescent period. Therefore, three possible explanations for observed phenomena should be considered: 1) *Physiological - potential effect of maturation on muscle performance*: girls scored higher in inline lunge, shoulder mobility and ASLR which could be due to higher mobility/flexibility demands of these movements [17,18]. This could be further explained with previous findings that reported greater mobility among girls compared to boys during adolescent period of growth [32]; Since higher values of upper-body strength are reported in boys compared to girls during adolescence [33], this could explain discrepancy that was found in upper-body test (i.e. trunk stability pushup); 2) *Anatomical - potential effect of sex on joint morphology*: reported differences in aforementioned FMS™ patterns could be possibly due to different architecture of the pelvis, hip, and shoulder since adolescent girls demonstrate more general joint laxity, hip anteversion, and tibiofemoral angels compared to adolescent boys [34]. Furthermore, development of the adolescent female pelvis from fifteen years of age and onward differs considerably from males which can

contribute to observed discrepancies in reported DFM in the current study [35]. Also, difference in the proportion of DFM in lower-body patterns reported in the current study could be due to different hip architecture since it has been shown that adolescent girls have different orientation of the acetabulum compared to boys [36]. More specifically, girls from age of 13 to 17 have increased acetabular anteversion compared to boys [36]. This could possibly explain why girls performed better on tasks that demands active hip flexion (i.e. inline lunge and ASLR), where different orientation of acetabulum in boys could limit hip flexion movements. What could be concerning is that higher prevalence of DFM observed in lower-body patterns among boys could predispose them to higher risk for developing hip orthopedic abnormalities (i.e. femoroacetabular impingement) [37]. 3) *Sociocultural – potential effect of cultural engagement in specific sport activity:* adolescent boys tend to engage more in sports such as soccer and basketball which have high prevalence of unilateral and asymmetrical movement patterns [38]. This could further facilitate movement asymmetries as seen in shoulder mobility and ASLR tests. On the other hand, girls participate more in sport activities that have aesthetic component (i.e. dance, ballet, etc.) where specific unilateral movement patterns are not emphasized or trained in isolation [38]. Given the fact that in the current study more boys are engaged in sport activity compared to girls (48% vs 25%, respectively), aforementioned explanations could be possible behind mechanism for observed discrepancies between adolescent girls and boys in movement asymmetries.

This study has several strengths. First, this is the only study which provided information about dysfunctional movement as well as movement asymmetries assessed by FMS™ in a large sample of urban adolescents. Second, this is the first study that investigated highly age-homogenized adolescent population (16-17 y). Third, current research is based on a reasonably large number of participants (n=733). All this allows more precise information about sex differences in functional movement that had been investigated. However, there are also several limitations that need to be considered while interpreting this data. This study investigated population in the urban area, thus excluding children from rural areas which may affect the generalizability of the results in the context of the whole adolescent population. Also, a large number of raters used in this study can be a potential drawback, although good inter-rater agreement in FMS™ scores has been repeatedly reported [28,29]. Despite all this, the results of the present study give comprehensive data about functional movement among adolescent population.

5. Conclusions

The results of this study confirmed some previous findings and offer a new perspective in the context of functional movement in adolescent population. In the current study total functional movement screen score was higher in girls compared to boys. Also, sex differences were present in several individual functional movement patterns where boys demonstrated higher prevalence of DFM in patterns that challenges mobility and flexibility of the body, while girls underperformed in tests that have higher demands for upper-body strength and abdominal stabilization. The results of the present study need to be considered while implementing data into practical usage and while using FMS™ as a screening tool among adolescent school-aged population. Future research should focus on investigating sex dimorphism in functional movement in other population of children and adolescents.

Author Contributions: Conceptualization: J. Karuc, M. Jelčić, M. Sorić, M. Mišigoj-Duraković and G. Markovic; Data curation: M. Sorić and M. Mišigoj-Duraković; Formal analysis: J. Karuc, M. Jelčić, M. Sorić and G. Markovic; Funding acquisition: M. Sorić and M. Mišigoj-Duraković; Investigation: J. Karuc, M. Jelčić, M. Sorić, M. Mišigoj-Duraković and G. Markovic; Methodology: J. Karuc, M. Jelčić, M. Sorić, M. Mišigoj-Duraković and G. Markovic; Project administration: M. Sorić and M. Mišigoj-Duraković; Resources: M. Sorić, M. Mišigoj-Duraković and G. Markovic; Software: J. Karuc, M. Sorić and G. Markovic; Supervision: M. Sorić, Marjeta Mišigoj-Duraković and Goran Markovic; Validation, Josip Karuc, Mario Jelčić, Maroje Sorić, M. Mišigoj-Duraković and G. Markovic; Visualization: J. Karuc and M. Jelčić; Writing – original draft: J. Karuc, M. Jelčić and M. Sorić; Writing – review & editing: J. Karuc, M. Jelčić, M. Sorić, M. Mišigoj-Duraković and G. Markovic.

Funding: This work is a part of the Croatian physical activity in adolescence longitudinal study (CRO-PALS), funded by the Croatian Science Foundation under the grant no. IP-2016-06-9926, and grant no: DOK-2018-01-2328.

Acknowledgments: The authors would like to thank L. Blažević, M. Stepić, Pašuld S. Venier M., A. Trbojević, F. Bolčević, M. Bičanić and R. Buljanović, for help concerning the FMS™ assessment.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Warburton, D.; Charlesworth, S.; Ivey, A.; Nettlefold, L.; Bredin, S.S. A systematic review of the evidence for Canada's Physical Activity Guidelines for Adults. *Int. J. Behav. Nutr. Phys. Act.* **2010**, *7*: 39. doi: 10.1186/1479-5868-7-39.
2. Ekelund, U.; Anderssen, S.A.; Froberg, K.; Sardinha, L.N.; Andersen, L.B.; Brage, S. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: The European youth heart study. *Diabetologia* **2007**, *50*, 18320-18400. doi: 10.1007/s00125-007-0762-5.
3. Andersen, L.B.; Harro, M.; Sardinha, L.B.; Froberg, K.; Ekelund, U.; Brage, S.; Alfred Anderssen, S. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet* **2006**, *368*, 299-304. doi: 10.1016/S0140-6736(06)69075-2.
4. Ondrak, K.S.; Morgan, D.W. Physical activity, calcium intake and bone health in children and adolescents. *Sports Med.* **2007**, *37*, 587-600. doi: 10.2165/00007256-200737070-00003.
5. Chalmers, S.; Fuller, J.T.; Debenedictis, T.A.; Townsley, S.; Lynagh, M.; Gleeson, C.; Zacharia, A.; Thomson, S.; Magarey, M. Asymmetry during preseason Functional Movement Screen testing is associated with injury during a junior Australian football season. *J. Sci. Med. Sport* **2017**, *20*, 653–657. doi: 10.1016/j.jsams.2016.12.076.
6. Anderson, B.E.; Neumann, M.L.; Huxel Bliven, K.C. Functional Movement Screen Differences Between Male and Female Secondary School Athletes. *J. Strength Cond. Res.* **2015**, *29*, 1098–1106. doi: 10.1519/JSC.0000000000000733.
7. Molina-Garcia, P.; H. Miguel, J.; Cadenas-Sanchez, C.; Esteban-Cornejo, I.; Mora-Gonzalez, J.; Rodriguez-Ayllon, M.; Plaza-Florido, A.; Molina-Molina, A.; Garcia-Delgado, G.; D'Hondt, E.; Vanrenterghem, J.; Ortega, F.B. Fatness and fitness in relation to functional movement quality in overweight and obese children. *J. Sports Sci.* **2019**, *37*, 878–885. doi: 10.1080/02640414.2018.1532152.
8. Paszkewicz, J.R.; McCarty, C.W.; Van Lunen, B. Comparison of functional and static evaluation tools among adolescent athletes. *J. Strength Cond. Res.* **2013**, *27*, 2842-2850. doi: 10.1519/JSC.0b013e3182815770.

9. Kramer, T.A.; Sacko, R.S.; Pfeifer, C.E.; Gatens, D.R.; Goins, J.M.; Stodden, D.F. The association between the Functional Movement Screen™, Y-balance test, and physical performance tests in male and female high school athletes. *Int. J. Sports Phys. Ther.* **2019**, *14*, 6, 911–919.
10. Pfeifer, C.E.; Sacko, R.S.; Ortaglia, A.; Monsma, E.V.; Beattie, P.F.; Goins, J.; Stodden, D.F. Functional Movement Screen™ in youth sport participants: evaluating the proficiency barrier for injury. *Int. J. Sports Phys. Ther.* **2019**, *14*, 436–444. doi: 10.26603/ijsp20190436.
11. Mitchell, U.H.; Johnson, A.W.; Adamson, B. Relationship between functional movement screen scores, core strength, posture, and body mass index in school children in moldova. *J. Strength Cond. Res.* **2015**, *29*, 1172–1179. doi: 10.1519/JSC.0000000000000722.
12. Duncan, M.J.; Stanley, M. Functional movement is negatively associated with weight status and positively associated with physical activity in British primary school children. *J. Obes.* **2012**, *2012*, 1–5. doi: 10.1155/2012/697563.
13. Duncan, M.J.; Stanley, M.; Leddington Wright, S. The association between functional movement and overweight and obesity in British primary school children. *Sport. Med. Arthrosc. Rehabil. Ther. Technol.* **2013**, *5*, 1–8. doi: 10.1186/2052-1847-5-11.
14. Abraham, A.; Sannasi, R.; Nair, R. Normative values for the functional movement screen™ in adolescent school aged children. *Int. J. Sports Phys. Ther.* **2015**, *10*, 29–36.
15. García-Pinillos, F.; Roche-Seruendo, L.E.; Delgado-Floody, P.; Mayorga, D.J.; Latorre-Román, P.Á. Original Is there any relationship between functional movement and weight status. *Nutr. Hosp.* **2018**, *35*, 805–810. doi:10.20960/nh.1670.
16. O'Brien, W.; Duncan, M.J.; Farmer, O.; Lester, D. Do Irish Adolescents Have Adequate Functional Movement Skill and Confidence? *Journal of Motor Learning and Development* **2018**, *6*, S301-S319. doi: 10.1123/jmld.2016-0067.
17. Cook, G.; Burton, L.; Hoogenboom, B. Pre-Participation Screening: The Use of Fundamental Movements As An Assessment of Function–Part 1. *North Am. J. Sport. Phys. Ther.* **2006**, *1*, 62–72. doi: 10.1055/s-0034-1382055.
18. Cook, G.; Burton, L.; Hoogenboom, B. Pre-Participation Screening: The Use of Fundamental Movements As An Assessment of Function–Part 2. *North Am. J. Sport. Phys. Ther.* **2006**, *1*, 62, 132–139. doi: 10.1055/s-0034-1382055.
19. Kiesel, K.B.; Butler, R.J.; Plisky, P.J. Prediction of Injury by Limited and Asymmetrical Fundamental Movement Patterns in American Football Players. *J. Sport Rehabil.* **2014**, *23*, 88–94.. doi: 10.1123/jsr.2012-0130. doi: 10.1123/jsr.2012-0130.
20. Garrison, M.; Westrick, R.; Johnson, M.R.; Benenson, J. Association between the functional movement screen and injury development in college athletes. *Int. J. Sports Phys. Ther.* **2015**, *10*, 21–8.
21. Letafatkar, A.; Hadadnezhad, M.; Shojaedin, S.; Mohamadi, E. Relationship Between Functional Movement Screening Score and History of Injury. *Int. J. Sports. Phys. Ther.* **2014**, *9*, 21–27.
22. Dossa, K.; Cashman, G; Howitt, S.; West, B.; Murray, N. Can injury in major junior hockey players be predicted by a pre-season functional movement screen – a prospective cohort study. *J. Can. Chiropr. Assoc.* **2014**, *58*, 421–427.
23. Bardenett, S.M.; Micca, J.J.; DeNoyelles, J.T.; Miller, S.D.; Jenk, D.T.; Brooks, G.S. Functional Movement Screen Normative Values and Validity in High School Athletes: Can the Fms™ Be Used As a Predictor of Injury? *Int. J. Sports Phys. Ther.* **2015**, *10*, 303–308.
24. Dorrel, B.S.; Long, T.; Shaffe, S.; Myer, G.D. Evaluation of the Functional Movement Screen as an Injury Prediction Tool Among Active Adult Populations: A Systematic Review and Meta-analysis. *Sports health* **2015**, *7*, 532–537. doi: 10.1177/1941738115607445.
25. Chalmers, S.; Fuller, J.T.; Debenedictis, T.A.; Townsley, S.; Lynagh, M.; Gleeson, C.; Zacharia, A.; Thomson, S.; Magarey, M. Asymmetry during preseason Functional Movement Screen testing is associated with injury during a junior Australian football season. *J. Sci. Med. Sport.* **2017**, *20*, 653–657. doi: 10.1016/j.jsams.2016.12.076.
26. Quatman-Yates, C.C.; Quatman, C.E.; Meszaros, A.J.; Paterno, M.V.; Hewett, T.E. A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness? *Br. J. Sports. Med.* **2012**, *46*, 649–655. doi:10.1136/bjsm.2010.079616.

27. Štefan, L.; Sorić, M.; Devrnja, A.; Podnar, H.; Mišigoj-Duraković, M. Is school type associated with objectively measured physical activity in 15-year-olds? *Int. J. Environ. Res. Public Health* **2017**, *14*, 1417. doi: 10.3390/su12166392.

28. Gulgin, H.; Hoogenboom, B. The Functional Movement screening (FMSTM): An Inter-rater Reliability Study Between Raters of Varied Experience. *Int. J. Sports. Phys. Ther.* **2014**, *9*, 14–20.

29. Teyhen, D.S.; Shaffer, S.W.; Lorenson, C.L.; Halfpap, J.P.; Donofry, D.F.; Walker, M.J.; Dugan, J.L.; Childs, J.D. The Functional Movement Screen: A Reliability Study. *J. Orthop. Sport. Phys. Ther.* **2012**, *42*, 530–540. doi: 10.2519/jospt.2012.3838.

30. Sterling, M.; Jull, G.; Wright, A. The effect of musculoskeletal pain on motor activity and control. *J. Pain* **2001**, *2*, 135–145. doi: 10.1054/jpai.2001.19951. doi: 10.1054/jpai.2001.19951.

31. Bernard, J.; Bard, R.; Pujol, À.; Combey, A.; Boussard, D.; Begué, C.; Salghetti, A. Muscle assessment in healthy teenagers, Comparison with teenagers with low back pain. *Ann. Readapt. Med. Phys.* **2008**, *51*, 263–83. doi: 10.1016/j.annrmp.2008.03.010.

32. Jansson, A.; Saartok, T.; Werner, S.; Renstrom, P. General joint laxity in 1845 Swedish school children of different ages: Ageand gender-specific distributions. *Acta Paediatr.* **2004**, *93*, 1202–1206. doi: 10.1080/08035250410023971.

33. Gómez-Campos, R.; Andruske, C.L.; Arruda, M.; Sulla-Torres, J.; Pacheco-Carrillo, J.; Urra-Albornoz, C.; Cossio-Bolaños, M. Normative data for handgrip strength in children and adolescents in the Maule Region, Chile: Evaluation based on chronological and biological age. *PLoS one* **2018**, *13*, e0201033. doi: 10.1371/journal.pone.0201033.

34. Shultz, S.J.; Nguyen, A.D.; Schmitz, R.J. Differences in lower extremity anatomical and postural characteristics in males and females between maturation groups. *J. Orthop. Sports. Phys. Ther.* **2008**, *38*, 137–149. doi: 10.2519/jospt.2008.2645.

35. Huseynov, A.; Zollikofer, C.P.; Coudyzer, W.; Gascho, D.; Kellenberger, C.; Hinzpeter, R.; Ponce de León, M.S. Developmental evidence for obstetric adaptation of the human female pelvis. *Proc. Natl. Acad. Sci. U.S.A.* **2016**, *113*, 5227–5232. doi: 10.1073/pnas.1517085113.

36. Peterson, J.B.; Doan, J.; Bomar, J.D.; Wenger, D.R.; Pennock, A.T.; Upasani, V.V. Sex Differences in Cartilage Topography and Orientation of the Developing Acetabulum: Implications for Hip Preservation Surgery. *Clin. Orthop. Relat. Res.* **2015**, *473*, 2489–2494. doi: 10.1007/s11999-014-4109-5.

37. Hooper, P.; Oak, S.R.; Lynch, T.S.; Ibrahim, G.; Goodwin, R.; Rosneck, J. Adolescent Femoroacetabular Impingement: Gender Differences in Hip Morphology. *Arthroscopy* **2016**, *32*, 2495–2502.

38. Slater, A.; Tiggemann, M. Gender differences in adolescent sport participation, teasing, self-objectification and body image concerns. *J. Adolesc.* **2011**, *34*, 455–463. doi: 10.1016/j.adolescence.2010.06.007.