The Effects of Posture Difficulty and Gender on Biomechanical Characteristics of Balance in School-Aged Children

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Abstract

The purpose of this study was to investigate the biomechanical characteristics of balance and postural control in three stances and based on gender. Postural sway parameters and centre of pressure (CoP) variations and kinematic data were calculated for 45 school-aged children (7-10 years), (n=20 females and n=25 males), who did not participate in sports, during three stances (normal quiet (NQS); Romberg-sharpened (RS); and one-legged (OLS)). Both groups demonstrated increased postural sway when the base of support was narrowed; however, boys exhibited greater CoP movement compared to girls while girls demonstrated better postural control. The results of our research could be useful to examine the specialized use of physical education in kindergarten and first grades of elementary school.

Keywords: Gender; Children; Static balance; Postural sway; Biomechanics.

1. *Introduction*

Skills of balance constitute a basic element of coordination which according to the model for childhood proposed by Hirtz and Greifswald's scientific team and based on the general ideas of Bernstein, comprises five skills: kinesthetic skill, space orientation skill, balance skill, skill of reaction and rhythm (Hirtz, 1985). The development of these skills which composes coordination is a precondition for learning, refining, stabilizing and applying sport skills performance (Gallahue, 1996). Also, in sport, the creation of unstable balance conditions for the performance of dynamic movements is often pursued. The balance or stabilization skill is regarded to significantly influence the learning and performance of new skills and it is a basic factor in success for all sport activities (Meinel & Schnabel, 1998). Besides, it is not infrequent in sport training that problems, which initially were attributed to lack of strength, speed etc., in reality were due to lack of balance. Balance can be defined as the ability to maintain the body's centre of gravity over its base of support with minimal sway or maximal steadiness (Horak, 1987; Shumway-Cook, Anon, & Hailer, 1988).

Most developmental motor tests include a measure of static balance, which refers to the ability to maintain an upright posture and maintain the centre of gravity within the limits of support (Geuze, 2003). Afferent information from proprioceptive, visual, vestibular, and cognitive systems is integrated and evaluated to maintain static balance (Winter, Prince, Frank, Powell, & Jabjek, 1996). Stabilometric measures using a force platform are the most common means of evaluating static balance because of being sensitive to age differences (Geuze, 2003; Riach, & Hayes, 1987).

To coordinate the forces required to remain stable when perturbed or when using a limb (e.g., holding a book while reading) or the entire body (e.g., walking), an individual must organize visual, proprioceptive, and vestibular information (Peterson, Christou, & Rosengren, 2006; Shumway-Cook & Woollacott, 2007). The development of the necessary systems to do this occurs at different ages: the proprioceptive system matures first, followed by the visual and vestibular systems (Geuze, 2003). The greatest development in sensory integration occurs between 4 and 6 years, and responses to altered sensory conditions become similar to those exhibited by adults when a child is 7 to 10 years old (Nolan, Grigorenko, & Thorstensson, 2005; Shumway-Cook, & Woollacott, 1985).

The different components of postural control in children have been studied extensively. Riach & Hayes (1987) assessed quiet stance in 2- to 14 years old and found that amplitude of postural sway decreases with age, as does the variability in postural responses. Postural control, assessed by movement of the centre of pressure (CoP), has been documented in a number of studies investigating the development of balance in children. Movement of the CoP, calculated by postural sway parameters (e.g. standard deviation (SD) and root mean square (RMS)) has been found to stabilize earlier in girls than boys (Shumway-Cook, & Woollacott, 1985). Odenrick, & Sandstedt, (1984) and Riach & Hayes (1987) found that boys under age 10 have a greater SD and RMS than girls, and that girls enter the adult RMS range earlier than boys. Taguchi & Tada (1988) reported that spontaneous sway during quiet stance in children aged 9 to 12 years old with eyes open was comparable to that of adults. Studies have also assessed compensatory postural control to perturbations and generally reported that children exhibit well organized muscular responses to perturbations by 7 to 10 years of age (Peterson, et al., 2006; Steindl, Kunz, Scholtz, & Schrott-Fischer, 2006).

In a study which was conducted in laboratory conditions, in which balance was disturbed by moving the surface of the base of support, it was ascertained that the examiners used all the known strategies of maintaining balance: ankle or hip strategy or stepping (Creath, Kiemela, Horak, Peterka, & Jeka, 2005). Other factors such as the length of the base of support, the central position, and the kind of a potential nervous condition affect on the dominance of either the ankle or the hip strategy (Park, Horak, & Kuo, 2004; Horak, Nashner, & Diener, 1990). Sensory information, area of support, musculoskeletal characteristics, degrees of freedom, and task constraints are important for the selection of ankle and hip postural movement patterns (Maurer, Mergner, Bolha, & Hlavacka, 2000). A mixed strategy, with contributions from hip and ankle muscles, has been also reported (Horak, et al., 2004). The three afferent sensory systems (proprioceptive, visual, and vestibular) develop more slowly than hierarchically lower reflexive motor processes that mature early in childhood (Steindl, et al., 2006). What is unclear is why school-aged girls seem to have better equilibrium than boys of the same age; Lebiedowska & Syczewska (2000) investigated the roles of age, gender, height, and body mass on the ability of 7- to 18-year-olds to maintain static posture. They found no gender differences on any variables in their sample of 25 males and 32 females. Furthermore, there were no correlations between sway parameters (i.e., total path, length of sagittal and lateral sway, velocity) and anthropometric characteristics when subjects were asked to maintain static posture with or without visual feedback, and only weak negative correlations between age and sway parameters when subjects were provided with visual feedback or visual information (to have eyes open or close), (Shumway-Cook & Woollacott, 2007; Lebiedowska & Syczewska, 2000). Odenrick & Sandstedt (1984) found greater sway amplitude, in a similar study of postural sway with static posture, in males (n=11) than females (n=10) under 10 years of age.

Investigating developmental changes in postural control in children with respect to standing balance, Rival, Ceyte, & Olivier, (2005) found that a transition phase, from the phase of beginner to postural maturation, should occur at around 7 to 8 years; in 9- to 10- year-olds, standing balance appeared to be adult-like. Two recent studies found significantly lower sway velocities and total path length of static standing balance in girls compared with boys (Nolan, et al., 2005; Geldhof, Cardon, De Bourdeaudhuij, Danneels, Coorevits, Vanderstraeten, & De Clercq, 2006), indicating better postural control in girls at the age of 9 to 10 years. Some studies, in attempting to identify aspects of neural control of posture and balance, specifically in children, calculate postural sway parameters, while others analyze the frequency content of the CoP. Using these methods to document balance control in children, most studies report a relationship between sway parameters and age (Riach, & Hayes, 1987; Odenrick, & Sandstedt, 1984; Taguchi, & Tada, 1988; Portfors-Yeomans, & Riach, 1995). Riach, & Hayes (1987) reported that younger children had greater high-frequency sway that diminishes with age, but they did not distinguish between girls and boys.

The majority of studies into the development of postural control in children have evaluated mixed-sex groups; consequently, few have reported sex differences.

The only study reporting summary sway parameters for girls and boys separately found age-related differences for boys but not girls (Portfors-Yeomans, & Riach, 1995). Therefore, the use of mixed-sex groups may mask age differences in increasing postural demands during quiet standing. Thus, the purpose of the present study was twofold: to investigate differences in postural requirements in three postural conditions, including (a) normal quiet stance (NQS), (b) sharpened or tandem Romberg stance (RS), and (c) one legged stance (OLS), as reflected in CoP variations and kinematics; and to investigate gender differences in the three stances in girls and boys with the mean age of 8.5 years. The aim of the present study was to investigate whether we would accept the null hypothesis, which was that no significant difference in the values of the biomechanical characteristics of the conditions of static balance, or between genders, would exist. We defined the alternative hypothesis as the existence of significant differences in the values of the biomechanical characteristics of the conditions of static balance and between genders.

2. *Methods*

2.1 Subjects

Forty-five healthy children (mean ± SD; age 8.54 ± 0.69 years; height 139 ± 5 cm and weight 33.38 ± 5.72 kg, (n=25) for girls and age 8.44 ± 0.78 years; height 143 ± 6 cm and weight 37.56 ± 6.40 kg, (n=20) for boys), free of any neurological and musculoskeletal diseases and impairments and who were not involved in sports activities, voluntarily participated in the study. Children with mental developmental disabilities, such as excessive clumsiness, mental or motor deficit, attention-deficit, or poor academic achievement, were not included. None of the children, who were chosen to participate in the study, had been defined to have had at least one of these impairments by the specific authority of the Greek Education Ministry. Participants were randomly chosen from the third grade of four primary schools, where physical education is taught at all the grades according to the primary school program, in the city of Serres/Greece. Parents or guardians provided written informed consent for children's participation in the research. The children formed two groups: one of 20 girls and one of 25 boys (Table 1). The testing protocol was approved by the local university ethics committee.

Table 1. Subject characteristics

		Mean ± SD		
Gender	*N*	Age (years)	Height (cm)	Weight (kg)
Girls	20	8.54 ± 0.69	139 ± 5	33.38 ± 5.72
Boys	25	8.44 ± 0.78	143 ± 6	37.56 ± 6.40

2.2 Procedures

Kinematic data were collected using Video camcorder (Panasonic, PV-900, 60 Hz, Osaka, Japan) placed perpendicularly to the A/P (antero-posterior) plane of motion. Spherical landmarks covered by retro-reflective tape (3M^{TM} high gain 7610) were affixed over the fifth metatarsal head, lateral malleolus, lateral femoral epicondyle, greater trochanter, acromion, and lateral forehead on all participants' right side (Ariel, 1990; Lohmann, Roche, & Martorell, 1988). This type of marker allowed automated digitization of the video frames and derivation of the x- & z-position coordinates after noise reduction (cut-off frequency, 5 Hz) using APAS motion analysis (Ariel Dynamics, Inc.), (Ariel, 1990). Subjects were wearing proper athletic attire. Four control landmarks with known locations were used for the appropriate 2D spatial calibration, and an additional external point was the benchmark (Ariel, 1990). In addition, a spotlight (Reflecta 3002, with a lamp of 300 watts at 220 volts) was used to achieve ideal lighting conditions; the spotlight assured good quality to capture the landmarks placed on the subjects during the examined tasks. To avoid capturing incorrect kinematic data, all landmarks were placed on the naked skin (Nigg, 1985).

The body was modeled as a five-segment (foot, shank, thigh, trunk, and head) rigid linked system (Winter, 1991). To assess the angular kinematic characteristics of the static conditions of balance, a cartesian coordinate system of reference of the motion was used (Ariel, 1990). Zero time was defined with the use of a light, which allowed synchronization of the kinetics and kinematic data required to validate the evaluation. The CoP oscillations along the anteroposterior (A/P, x) and medial/lateral (M/L, mediolateral, y) axes were calculated from the ground reaction forces' data recorded on force plate software (Kistler 9281CA, Winterthur, Switzerland, 1000Hz).

2.3 Experimental Postural Conditions

At the beginning of the experimental session, participants were asked to identify their dominant kicking leg. All balance exercises that required subjects to balance on one leg were performed with the non-dominant kicking leg. The following posture tasks, from the easiest to most difficult (Rowland, 1993), were assessed: NQS, intermalleolar distance 10-15cm, arms freely hanging; RS, non-dominant heel in front of the dominant toe, hands on the hips; and OLS, standing on the leg, contra lateral to the dominant kicking leg, with the non-support leg flexed and stabilized on the standing leg, hands also on the hips. Five minutes was provided for subjects to become familiar with each stance and children were asked to stay stable in each stance for 5sec. Critical stance duration of 5sec was considered appropriate because children of this age have difficulty remaining in a one-legged or heel-to-toe stance for more than 5sec (Pangrazi, 1998). The time of 5sec was defined by the software that the data of the force plate was recorded on, in order to provide the values of the CoP variables. As far as the synchronization is concerned between the force plate and the video camera, a synchronization system was used; so as to be defined e.g. at which moment there was stabilization or first contact of the right foot with the force plate and which were its kinematic characteristics at that moment. The synchronization system used worked as follows: a MOFSET switch had been adapted to the mouse and allowed the passage of current through 12 Volt feeder to a lamp, which was lit when opening the switch and at the same time started. In this way, the lamp provided the necessary optical signal for the synchronization of the two cameras (synchronization fact).

Data recording began once the subject was stable in the required posture and continued for 5sec. Participants were instructed to look straight ahead and fixe their gaze on a 3cm diameter marker positioned at eye level 150cm in front of them. Subjects performed three trials in each stance, and data were averaged across the three trials (Riach, & Hayes, 1987). During the tasks, the rules, which were related to the children's development and the laboratory conditions, were strictly abide by Rowland (1993). Results confirm that task selection was sufficient to distinguish postural responses in boys and girls.

2.4 Data processing

The acquired images were then transferred to a personal computer and the APAS software package was used for data digitization (Ariel, 1990). A 2D kinematic analysis was used for all the performed trials. The independent variables were a) gender (boys and girls) and b) balance condition (as presented in the test protocol). The dependent variables measured were (1) SD and range of A/P sway of the CoP during each trial; (2) SD and range of M/L sway of the CoP during each trial; (3) SD and range of angular displacement in the sagittal plane, defined by the foot, ankle, and knee markers; (4) SD and range of angular displacement of the knee in the sagittal plane, defined by the ankle, knee, and hip markers; and (5) SD and range of angular displacement of the hip in the sagittal plane, defined by the knee, hip, and shoulder markers. The mean and SD of each measure for each condition were calculated. SD is numerically equivalent to the RMS of a signal that has a mean value of zero (Riach, & Hayes, 1987). The measures of angular motion were chosen to obtain data for coordination of body parts in addition to CoP motion data (Gatev, Thomas, Kepple, & Hallett, 1999). An initial frame and a final frame from the video recording of any given trial were defined based on the beginning and the end of the lateral malleolus horizontal displacement. During the interval between the initial and final frames, compensatory postural adjustments helped maintain the participant's equilibrium. The initial frame represents the NQS posture, and the final frame represents the extent of compensatory postural adjustment.

2.5 Statistical Analysis

The multivariate statistical analysis of variance was used to identify gender differences in CoP and kinematic measures of the two groups. The repeated measures' analysis of variance was used to identify balance differences between the examined posture conditions. When F ratios were significant, *post hoc* analysis was performed using Bonferroni's multiple comparison tests. Statistical significance was accepted at $p<0.05$. All analyses were performed with SPSS (version 17.0) for Windows. The Kolmogorov-Smirnov is one sample test performed to measure if the particular distribution of the values of the dependent variables differed significantly from a normal distribution. The results showed no significant difference from the normal distribution ($p>0.05$).

3. *Results*

3.1 Postural parameters

Significant differences were observed between the range of angular displacement of the hip during a) NQS (5.69±2.66grad) and RS (9.0±5.05grad) and during NQS (5.69±2.66grad) and OLS (7.54±5.16grad), (F2,36=5.952, p=0.006), (Fig.1); b) between the CoP oscillations along the x axis during NQS (0.27±0.28cm) and OLS (0.38±0.19cm) and during RS (0.28±0.15cm) and OLS (0.38±0.19cm), (F2,40=7.023, p=0.003), (Fig. 2); and c) between the CoP oscillations along the y axis during NQS (0.29±0.13cm) and OLS (0.42±0.21cm) and during RS (0.34±0.14cm**)** and OLS (0.42±0.21cm), (F2,40=11.149, p=0.000), (Fig. 3).

3.2 Sex differences

The multivariate statistical analysis revealed significant gender differences in the CoP oscillations along the y axis during NQS (girls 0.197±0.17 vs. boys 0.352±0.22cm), (F1,35=3.954, p=0.050), (Fig. 4).

4. Discussion

The primary purpose of the present study was to investigate the control of static balance and gender differences in postural control in children with a mean age of 8.5 years. The difference reflects a smaller range of angular displacement of the hip during NQS and a greater range of hip displacement during RS and OLS, which are more difficult balancing postures and no significant differences in the range of angular hip displacement during the RS and the OLS. The x-y axis of balance control is protected in the RS balancing posture, and the difficulty of a particular posture does not allow increases in the range of angular displacement of the hip.

Furthermore, children of a particular age demonstrate significant differences in the range of the CoP oscillations along the x and y axes, suggesting that OLS presents greater difficulty than NQS and RS. While differences were not significant in the range of angular hip displacement during the RS and the OLS, the range of A/P sway of the CoP provides information about the difficulty of the OLS compared to RS. The kinematics data of girls and boys did not differ during the NQS, RS and OLS.

Nevertheless, the results reveal that girls are more stable than boys in the NQS and that they have almost the same difficulty as boys in terms of being stable as the base of support narrows. In NQS both feet is the base of support for the upper body and in RS or OLS the base narrowed as only one foot support the body. Our results demonstrate that, narrowing the base of support during the three postural control stances results in greater postural sway in school-aged children. The present study demonstrated gender differences in M/L sway, indicating that at an average age of 8.5 years, girls have better postural control than boys.

No gender differences were observed in A/P sway when children stood with their eyes open, but when standing with their eyes closed, boys had increased A/P sway velocity and total path length compared to girls at 9 to 10 years of age. It may be that by the time they are 9 to 10 years old, boys use a control strategy similar to that of girls to monitor A/P sway when standing with their eyes open, but in the absence of visual control, they use a different strategy (Nolan, et al., 2005). Visual feedback mechanisms develop more slowly in children and 14 to 15 years old have the same level of visual feedback as adults. Vestibular function develops more slowly than visual function: even at 14 to 15 years it has not reached that of an adult (Hirabayashi, & Iwasaki, 1995). It has been proposed in some studies that, between the ages of 7 and 9, children progress to an integrated open- and closed-loop strategy whereby they make more controlled and accurate corrections in their CoP (Kirshenbaum, Riach, & Starkes, 2001).

However, these studies examined mixed-sex groups, and it may be possible that boys develop the integrated open- and closed-loop strategy later than girls (Nolan, et al., 2005). This suggests that, when standing, vestibular processing in 9 to 10 years old boys differs from that of girls. Thus, at 9 to 10 years of age, the vestibular system may still be developing in boys. Another study designed to report test-retest reliability and reference values for postural stability in 9 to 10 years old schoolchildren using the Balance Master System revealed that girls perform better on all the composite balance parameters compared to boys, with the exception of reaction time and movement velocity. No differences were found in standing balance scores between 9- and 10-year-olds (Geldhof, et al., 2006).

During development, dominant sensory inputs for postural control shift, and at 7 to 10 years old, postural response patterns become comparable to those of adults. This suggests that by 7 to 10, the integrative processes required to integrate sensory inputs have developed (Shumway-Cook, & Woollacott, 1985). Children under 7.5 years were unable to suppress the influence of visual or proprioceptive input derived from the support surface in a systematic way when they were provided inappropriate information about orientation (Steindl, et al., 2006).

Riach & Hayes (1987) note that boys under 10 years-old sway substantially more than girls of the same age, suggesting a greater level of postural instability in boys of that age. These facts support the clinical impression that young boys at low primary school level are less stable than girls of the same age.

This study showed the significance of sensory integration, in which vestibular function is considered to play a critical role in motor adjustment and in higher functions, such as attention and cognition essential for learning (Ayres, 1978). It is possible that the maturational slowness of vestibular function in young boys is one factor responsible for the fact that boys are prone to be less attentive and more hyperactive than girls and that attention deficit hyperactivity disorder (ADHD) and learning disabilities are more preponderant in males (Hirabayashi, & Iwasaki, 1995). In another study, females showed a greater rate of improvement in stability compared to males up to the age of 11 to 12 (Steindl, et al., 2006). These results also demonstrated that males under age 10 are less attentive and more agitated than females of the same age. The ongoing maturation of the nervous system and postural experience acquired during childhood are explanations for the age dependence decrease in boys (Riach, & Hayes, 1987; Odenrick, & Sandstedt, 1984).

Peeters, Breslau, Mol, & Caberg (1984) showed that girls 6 to 10 years old demonstrate better postural stability than boys. In contrary, boys 11 to 15 years demonstrate better postural stability than girls. The sensory system, in conjunction with the vestibular system, is important for balance control and for higher central nervous functions, such as attention and cognition (Ayres, 1978). Delayed vestibular development could also have a significant role in children with ADHD (Hirabayashi, & Iwasaki, 1995). In conclusion, the present study demonstrated gender differences in balance parameters in the absence of external perturbations. Furthermore, narrowing the base of support resulted in greater postural sway in school-aged children, and significant gender differences were observed in M/L sway, with girls having better postural control than boys of the same age. Age-related improvements in sway parameters were observed primarily in boys, indicating that they lag girls in terms of developing postural control. When investigating balance in normally developing children, boys and girls should be assessed separately.

According to Roth & Winter (1994), the basic factors affecting the development of coordination and consequently of static and dynamic balance are three: 1. Physical activity (degree of difficulty, kind of exercise, requirements in speed or accuracy), 2. Personal factor (gender, motor, cognitive and psychic characteristics), and 3. Environment (sport training & intervention programs). Analyzing postural mechanisms in children and adolescents will provide a better understanding of the development of sensory systems. Characterizing balance impairments will contribute to diagnostic evaluations of neuromotor disorders.

Children develop at different rates, and differences in balance due to maturation may have been overlooked. Differences in levels of maturation within the same age group may also be responsible for the high variability in some of the measured parameters. Two potential limitations of this study warrant discussion. First, the individual levels of maturation, as distinct from chronological age, were not measured. Second, due to the methodological limitations of this study, we cannot directly infer the underlying mechanism or learning effects responsible for the observed results. Therefore, future studies should involve retention tests to elucidate whether mechanism or learning effects account for the observed findings.

In summary, static balance conditions are included in coordination skills. Their effective practice and performance is vital for the development of fundamental motor skills of pre-school or school-aged children (Gallahue, 1996). It is recommended that children can start practicing in balance skills as young as the age of 4; however, the crucial developmental age for girls is 7 to 11 and for boys 7 to 12 years; thus, practicing older children in balance skills would not be beneficial (Roth, 1998). The development of coordination skills (static and dynamic balance) contributes to the easier learning of and development of motor abilities, which can motivate children to be more active in physical activities and sports (Bouffard, Watkinson, Thomson, Causegrove, & Romanow, 1996). Hirtz (1985) consider that if the coordination and balance skills remain unimproved in these ages (4-7years), their development, in later ages, is going to be a very difficult process. Consequently, not only their training in early ages is recommended, but is it essential during childhood. Furthermore, physical education programs, applied to school-aged children, are directed to start practice in balance skills and abilities from these ages. At any rate, the results of our research on these static and dynamic balance conditions in children aged about 8,5 years could be useful in other studies that may examine the specialized use of physical education in kindergarten (4-6 years) and first grades of elementary school (7-9 years).

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Authors' Notes

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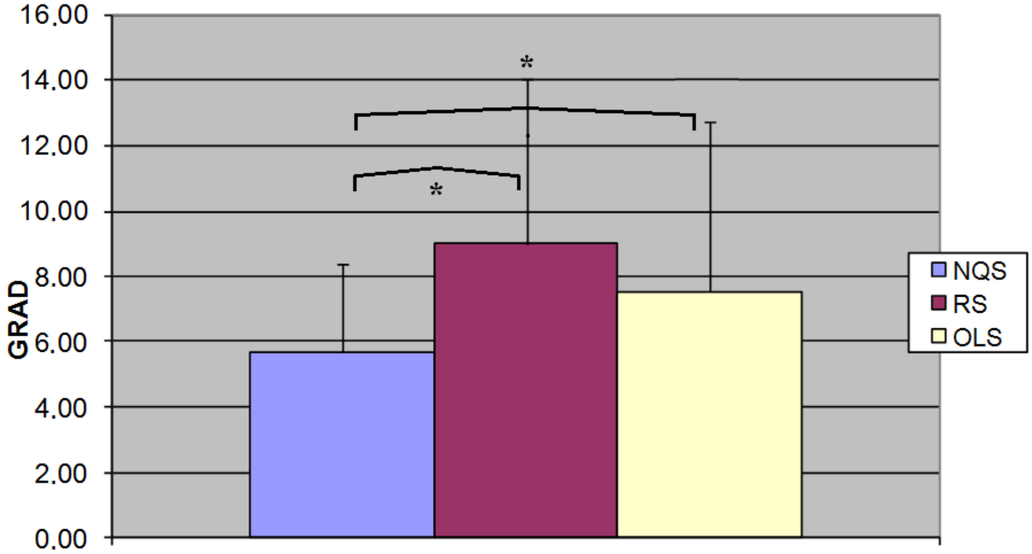

Fig. 1. Significant differences in the range of angular hip displacement during normal quiet stance (NQS), Romberg stance (RS) and One-legged stance (OLS); (Values and error bars represent mean ± SD; * represents $p = 0.006$).

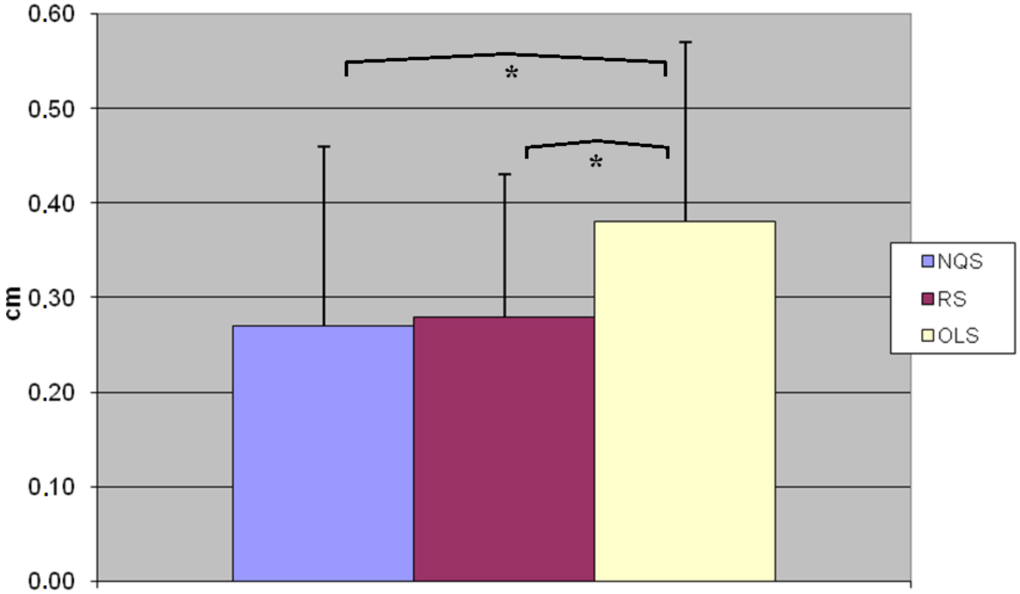

Fig. 2. Significant differences in the CoP oscillations along the x axis during normal quiet stance (NQS), Romberg stance (RS) and one-legged stance (OLS); (Values and error bars represent mean ± SD; * represents $p = 0.003$).

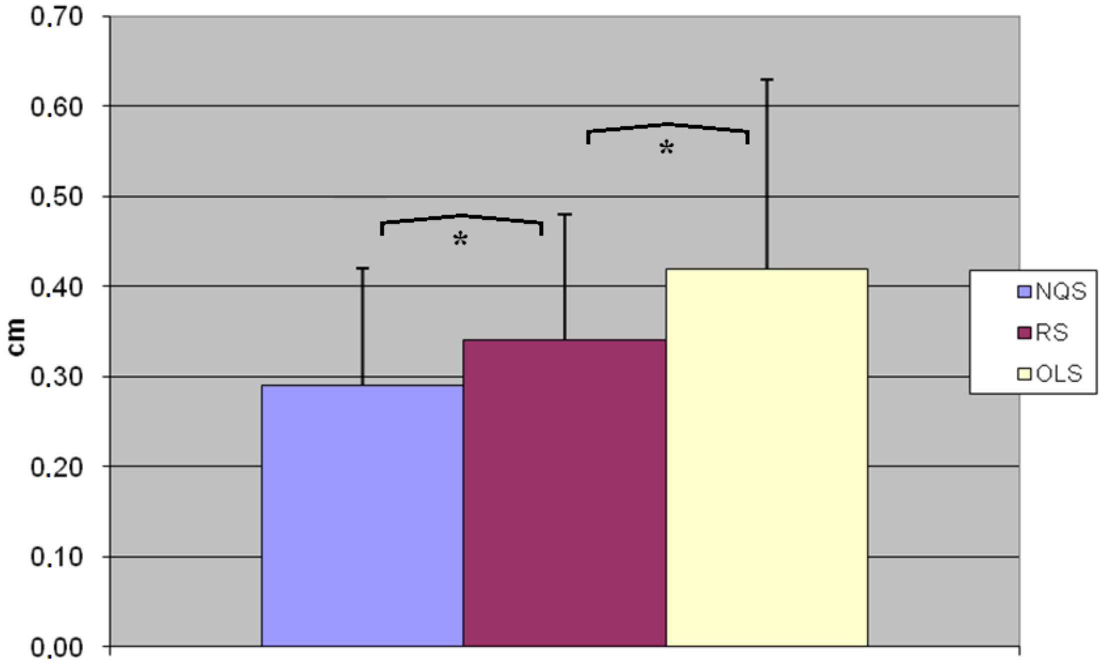

Fig. 3. Significant differences in the CoP oscillations along the y axis during normal quiet stance (NQS), Romberg stance (RS) and one-legged stance (OLS); (Values and error bars represent mean ± SD; * represents $p = 0.000$).

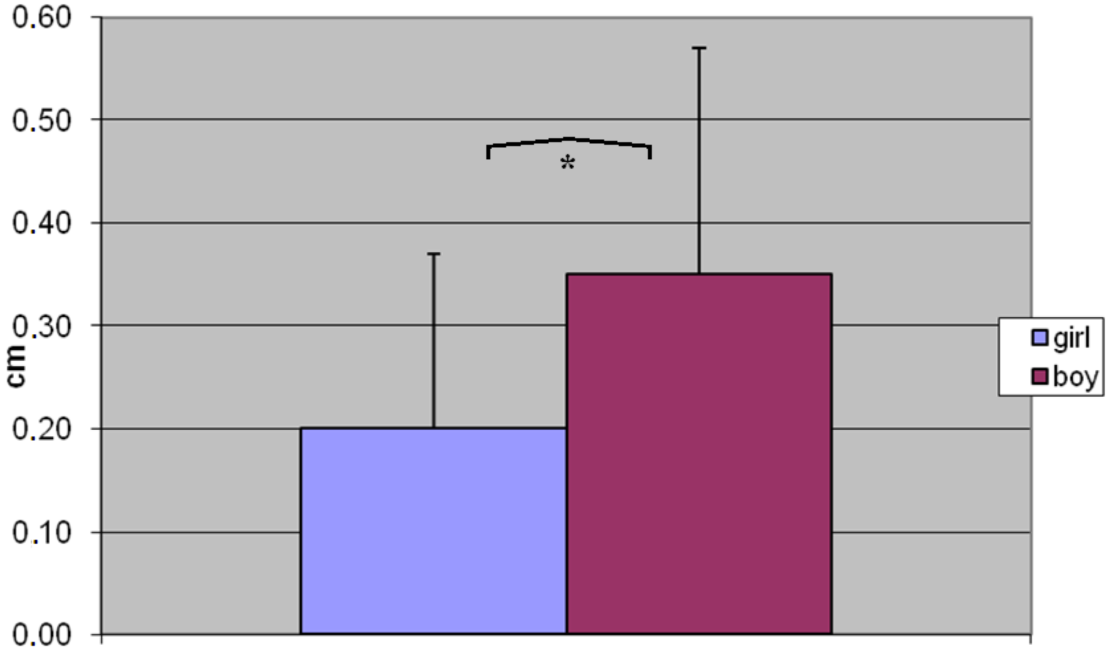

Fig. 4. Significant gender differences between girls and boys in the CoP oscillations along the y axis during normal quiet stance (NQS); (Values and error bars represent mean ± SD; * represents $p = 0.050$).