Locomotion postural variability and coordination in boys with overweight

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Variability and coordination of locomotion postural in boys with overweight

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Abstract:

The purpose of this study was to examine the variability and coordination of postural adaptations in normal weight children and those with overweight in running and hopping. Fifty-six boys between 7-10 years were classified into groups as overweight (n=33) or normal-weight (n=23). They performed two trials of running and hopping over a 20-meter straight line distance. Accelerometers were attached on the trunk and head for collecting body movements in different directions from 15 strides. Postural variability and coordination were calculated by multiscale entropy and cross approximate entropy for the running and hopping trials, separately. Findings highlight overweight boys had significantly higher trunk-head coordination in mediolateral direction than normal-weight boys (0.72 vs. 0.68). The hopping movement pattern had highest variability (9.88 vs. 8.77) and trunk-head coordination (0.61 vs. 0.67) than running. Excess body mass demands additional postural adaptations to compensate for reducing the risk of losing balance laterally in boys with overweight.

Keywords: postural stability, locomotor skills, overweight children, adaptation.

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Introduction

Locomotor skills such as walking and running are present in countless activities of daily living. These skills along with other movement patterns such as jumping, hopping and leaping play an important role in the development of fundamental motor skills in early childhood (Haywood, Roberton, & Getchell, 2011).
Obesity and overweight during childhood adversely affect the structure and functions of the musculoskeletal system and subsequently the development of locomotor skills (Dietz, Gross, & Kirkpatrick, 1982). The changes due to increased body mass increase the risk of a stress fracture, foot discomforts and foot injury (Dowling, Steele, & Baur, 2004; Rubinstein et al., 2017) that can discourage children with overweight to participate in moderate to high-intensity physical activities involving fast walking and running or other locomotor skills. Previous studies have reported the changes in kinematics and kinetics of gait parameters in individuals with overweight such as reduced stride length, increased step width (de Souza et al., 2005), increased hip abduction (Russell & Hamill, 2011), reduced knee flexion (DeVita & Hortobágyi, 2003) and decreased peak ground reaction force (Lai, Leung, Li, & Zhang, 2008). In the running gait, children with overweight relative to normal-weight counterparts had greater contact area, contact time, peak pressure (Rubinstein et al., 2017) and impact shocks (Tirosh, Steinberg, Nemet, Eliakim, & Orland, 2019).

The differences in spatiotemporal gait parameters between children with overweight and normal-weight children are not consistent (Molina-Garcia et al., 2019). Besides, the kinematics and kinetics measures that are based on average performance (e.g. average of multiple strides or steps) need be complemented in order to better explain the organisation of the central nervous system (CNS) and underlying control mechanisms that are sensitive to musculoskeletal adaptations (Cimolin et al., 2019). Therefore, there is a need to look for other indicators that are more sensitive to organismic changes (e.g. increased body mass) during child development.

One of these methods involves non-linear analyses that allow accessing the interactions between the body systems, environment and the nature of the task (Stergiou, 2016). Instead of reducing the amount of information through central tendency measures (e.g. mean, median) and dispersion measures (e.g. standard deviation, variance), this method examines the system's adaptations in response to environmental and task changes (Stergiou, 2016). For example, coordination, variability, bilateral symmetry and regularity are hidden features of motor behaviours that are not recognised through the averaging methods and are measurable through advanced mathematical analysis methods such as entropy measures (Richman & Moorman, 2000), temporal analysis of multiple signals (e.g. relative phase) (Haddad, van Emmerik, Wheat, Hamill, & Snapp-Childs, 2010) and analysis of the frequency domain (e.g. harmonic ratio) (Bellanca, Lowry, VanSwearingen, Brach, & Redfern, 2013). Two candidate measures of entropy are multiscale entropy and cross approximate entropy, which allow accessing the structure of variability and coordination between different parts of the body, respectively (Costa, Peng, Goldberger, & Hausdorff, 2003; Harbourne & Stergiou, 2009; Kavanagh, Barrett, & Morrison, 2005; Martínez-Zarzuela, Gómez, Díaz-Pernas, Fernández, & Hornero, 2013).

Understanding the postural variability and coordination in children with overweight through non-linear methods could provide valuable insight regarding the nature of adaptations and possible functional constraints in the musculoskeletal system in locomotor skills. The presence or lack of such postural adaptations might be associated with the musculoskeletal discomforts or limitations in the trunk mobility (Park, Ramachandran, Weisman, & Jung, 2010) that restrict their participation in physical activity (Dusing & Harbourne, 2010). The importance of the current study is twofold. First, there are no studies regarding the roles of postural variability and coordination through non-linear analysis methods in children with overweight. The previous studies only used these methods in walking in overweight adults and normal-weight children (Bisi & Stagni, 2016, 2018) and their findings showed that individuals with overweight demonstrated higher symmetry in trunk (Cimolin et al., 2019) and greater coordination variability in lower extremities (Donini, Iavicoli, Pinto, & Draicchio, 2013) relative to normal-weight counterparts despite similarities on conventional spatiotemporal gait parameters between groups. These adaptations in people with overweight have been explained as necessary compensations for postural stability and prevention of falls (Rosenblatt & Grabiner, 2012; Wu, Lockhart, & Yeoh, 2012). Bisi and Stagni (2016) studied postural variability for understanding the motor development process and found that gait variability declines from childhood to adulthood due to the level of maturation and gait automaticity that is normally acquired in late childhood. Second, there are no studies regarding the roles of postural variability and coordination in the advanced locomotor patterns such as running and hopping that are used in sport and recreational activities. These skills have different mechanical demands for simultaneous upward and forward propulsion of the centre of mass (COM; the point of combined mass of the body) and maintaining the balance (Haywood et al., 2011) that should be understood during the development to facilitate the participation of overweight children in activities and sport games. Thus, the aim of this study was to compare the postural variability and coordination between children with overweight and normal-weight children in running and hopping.

Methods

Participants

The sample size was calculated by G*Power software with power of test equal to 0.80 and a large effect size (>0.40). Fifty-six boys aged between 7 and 10 years from a primary school volunteered for this study. Body mass index (BMI: body mass/height) is one of the criteria to differentiate between the individuals with overweight/obese groups and non-obese (Han, Fu, Cobly, & Saunders) and in this study it was used to allocate the participants into overweight and normal-weight groups. Overweight was defined as BMI > 20.20 kg/m^2 and normal weight was defined as BMI < 18 (Cole, Bellizzi, Flegal, & Dietz, 2000). In total, 33 overweight (OW) boys (age: 8.28 ± 1.02 years; height: 1.4 ± 0.09 kg; weight: 49.85 ± 11.71 kg; BMI: 25.1 ± 3.73 kg/m^2) and 23 normal-weight (NW) boys (age: 7.9 ± 1.32 years; height: 1.32 ± 0.07 kg; weight: 28.52 ± 6.3 kg; BMI: 16.14 ± 2.55 kg/m^2) completed all procedures. The participants were free of injuries and any orthopaedic or mechanical problems known to influence gait or posture. The research team requested parents/guardians review the participant information sheet and complete the consent form being made aware their child had the right to withdraw any time.

The study was carried out according to the regulations of ethics in human participants that was approved by a local research committee in Kharazmi university (protocol ID: RH/23826) and was required that the participants/ parents read the information sheet and sign the consent form. The research team also adhered to the data protection guidelines as a part of ethics in human subjects and kept the obtained data confidential in a password-protected PC that was only accessible by the research team.

Measurements

Two low-mass (3g) and 9-axis (3D accelerometer, 3D gyroscope and 3D magnetometer) inertial measurement unit (IMU) sensors (MetaMotion, Mbientlab, USA) were used for data collection. Only the accelerometer data was used at 200 Hz sampling frequency and 16g resolution. The IMU sensors were fixed by double-sided adhesive tapes and Velcro straps on middle-waist (L2-L3) and back of the head (the straight line from the forehead; parietal bone). The sensors were placed so that the +X was oriented upward (vertical), +Y was oriented left (mediolateral) and +Z was oriented anterior (anterior-posterior).

Procedure

The locomotor tasks in this study were normal running and hopping with preferred leg. Participants were asked to run and hop at their preferred speed in a 20m straight line that was set up using a measuring tape and was checked for accuracy by a second investigator. Each participant completed one running trial and after 15 min rest completed one hopping trial. All tests were completed individually to not be influenced by the child's peers in a clear space. One investigator prepared the participants at the start line.

The accelerometer data was manually captured by a mobile application (MetaBase). There was a button in the application that group the sensors together and synchronised the raw data on the timestamp. Before the data collection, the participants stood still behind the start line and moved after the investigator's "GO" signal.

Data analysis

Accelerometer raw data of the trunk and head were filtered using a 2^{nd} order Butterworth low-pass filter with a cut-off frequency of 10Hz after removing the gravity (g=9.81 m/s^2) in the raw signal. The dependent variables were postural variability and trunk-head coupling that were measured by MSE and Cross ApEn, respectively. To measure the dependent variables, 15 successive strides of each locomotor pattern were selected for further analysis. The initial contact of every stride was detected by peak acceleration value in the vertical direction (Jasiewicz et al. 2006). The nature of this study was exploratory and therefore the methods that were used for analysis are independent of the data length (number of steps).

Multiscale Entropy (MSE)

MSE is the degree of irregularity of a time series over multiple timescales. Time series that are highly irregular over a wide range of timescales are considered a more variable time series than the time series that shows irregular behaviour at only a single timescale. To calculate the MSE, coarse-graining of the raw signal is calculated to derive multiple signals, each of which captures the system dynamics on a given scale, then a sample entropy (SampEn) was calculated and an index of variability (C_I) is obtained through integrating the entropy values over a predefined range of scales. The SampEn quantifies the likelihood that if a vector with m data points matches, within a tolerance r, a template of the same length, then the vector and the template will still match when their length increases from m to $m + 1$ data points. The MSE curve is obtained by plotting SampEn for each coarse-grained time series (ordinate) as a function of scale. The C_I is the area under the MSE curve. The length of the original time series, N, determines the largest scale factor, n, analysed (Costa et al., 2003). In this study, we used n=10, m=2 and r=20% of the standard deviation of the original signal. The high C_I indicates high variability and vice versa.

Cross Approximate Entropy (Cross ApEn)

The degree of coupling between trunk and head in different directions was calculated by applying Cross ApEn to the trunk and head acceleration signals. To calculate Cross ApEn, two equal signals in terms of length (N) were considered as master (x) and follower (y), then they were divided into the vectors of length m=2 and decorrelation index k=1. The distance between two x and y vectors was calculated as a maximal absolute sample difference. The Cross ApEn is calculated as the number of patterns similar to the one beginning at interval i/total number of pattern with the same length m. The lower Cross ApEn value (close to zero) indicates stronger coupling between paired acceleration signals (Kavanagh et al., 2005). A Matlab code was used to calculate the MSE and Cross ApEn (https://www.mathworks.com/matlabcentral/fileexchange/33203).

After checking the assumptions of parametric tests, the dependent variables were analysed by 2 (group) × 2 (movement task) multivariate analysis of variance (MANOVA) with repeated measures on the last factor. If the result was significant, a Bonferroni post-hoc test was carried out. The confidence interval was set at 95% (two-tailed). The effect size was calculated by lambda square (η^2) in SPSS package (IBM, v 22).

Results

MSE

The results of MANOVA showed a significant main effect of the task (λ=0.55, $F_{3,52}$=13.94, $p<0.05$, η^2=0.44), but not group and group ($p>0.05$, η^2=0.002) and task interaction ($p>0.05$, η^2=0.04). The follow-up tests showed that the hopping task had significantly more complex movement patterns than running (see Figure 1) in MSE_X ($F_{1,54}$=34.66, $p<0.05$), MSE_Y ($F_{1,54}$=6.64, $p<0.05$) and MSE_Z ($F_{1,54}$=30.62, $p<0.05$).

---Insert Figure 1 here---

Cross ApEn

The MANOVA results showed a significant interaction between group and task (λ=0.80, $F_{3,52}$=4.33, $p<0.05$, η^2=0.20) and significant group (λ=0.74, $F_{3,52}$=6.1, $p<0.05$, η^2=0.26) and task main effects (λ=0.36, $F_{3,52}$=29.84, $p<0.05$, η^2=0.63) on head and pelvis coupling. The follow-up results showed that NW boys in running had significantly lower coupling in cross $ApEn_Y$ ($F_{1,54}$=34.66, $p<0.05$) than OW boys in both running and hopping (see Figure 2). In addition, running pattern had lower coupling than hopping pattern in cross $ApEn_X$ ($F_{1,54}$=82.7, $p<0.05$) and cross $ApEn_Y$ ($F_{1,54}$=11.47, $p<0.05$).

---Insert Figure 2 here---

Discussion

The aim of this study was to compare the postural variability and coordination between OW and NW boys when running and hopping. The findings identified important differences between two groups and postural coordination in OW boys in running and hopping was greater than NW boys in running but not hopping in the medio lateral direction. Regardless of group differences, the hopping pattern requires higher degrees of postural variability and coordination than the running pattern, especially in vertical and mediolateral directions.

Our findings did not show any significant differences between groups. Despite differences between people with overweight and normal-weight people on the trunk smoothness during walking (Cimolin et al., 2019), our findings contradict this. Conversely, we showed that the postural variability was not affected by obesity even in more difficult locomotor patterns. Postural variability and coordination have been recognized as an adaptation during locomotion that is sensitive to age-related changes in the neuromusculoskeletal system (Bisi & Stagni, 2018; Costa et al., 2003; Kavanagh et al., 2005). The low variability and high coordination indicate the rigid coordination that plays an important role in body stability (Costa et al., 2003; Martínez-Zarzuela et al., 2013).

Although, the number of studies regarding the impacts of increased body mass on the postural adaptations through nonlinear analysis methods is limited, we only found differences in postural coordination in the mediolateral direction. The different effects of overweight on postural adaptations (significant effect in cross ApEn but not MSE) in locomotion might be explained by increased degrees of freedom and redundancy. OW boys typically showed a different strategy than NW boys when the variability of body movements was increased from three DoFs of the trunk (in MSE analysis) to six DoFs of head-trunk (in cross ApEn). Thus, the OW boys selected a more conservative strategy to increase the coupled units between the independent body parts to maintain the body stability (Rosenblatt & Grabiner, 2012; Wu et al., 2012). A previous study showed that people with overweight have high smoothness (less variability) in trunk motion that is used as a compensation for postural stability (Cimolin et al., 2019). Another reason for a different coordination might be due to limited trunk mobility in OW boys (Park et al., 2010) that naturally freeze the degrees of freedom in the upper body parts. Because running and hopping require significant work rate to propel the COM and maintain balance, it is more challenging for OW boys due to lower strength-to-weight ratio (Haywood et al., 2011). The lateral stability during walking inherently is more challenging for a system with more constraints such as older adults (Kavanagh et al., 2005), children (Haywood et al., 2011) and people with overweight (Cimolin et al., 2019) and the amount of task difficulty in running and hopping might further destabilise the lateral balance that requires postural compensations in OW boys.

The nature of the locomotor task was a significant discriminant factor in postural variability and coordination. Hopping had significantly greater variability in all movement directions and required strong coupling between head and trunk in vertical and mediolateral directions. Thus, children during motor development of locomotor patterns effectively use adaptive mechanisms (variability and coordination) to stabilize the posture when the body travels forward. Running and hopping, unlike walking require higher leg strength, balance and inter-limb coordination due to a short stance phase and the addition of a flight phase (Haywood et al., 2011). The vertical displacement in the hopping pattern is higher than the running pattern, and as a mass-spring system, taking advantage of elastic properties of leg muscles, stiffness, in preparation for the flight phase requires more physical efforts in the hopping pattern (Blickhan, 1989). These biomechanical constraints might explain the findings of this study regarding the needs for more postural adaptations in the hopping pattern than in the running pattern through employing more variable (irregular) and more coordinated trunk-head pattern in response to the task demands.

Another reason for inter-task variations on postural adaptations is related to the level of motor development. Running pattern reaches an advanced level earlier and faster than the hopping pattern, and it is expected that children at ages 3-5 years can master the necessary postural control mechanisms in locomotion (Haywood et al., 2011). Hence, the needs for using more compensations, high variability and rigidity, in the upper body parts depend on the task difficulty and child’s readiness to adapt with the requirements of more advanced locomotor patterns. For example, a decline in gait variability was referred to the level of maturation and automaticity (Bisi & Stagni, 2018).

The findings of this study have important implications for practitioners who work with children such as physical education teachers. Despite the negative impacts of increased body mass on the musculoskeletal system and performance of locomotor movement patterns, postural adaptations such as creating a coupled unit during the motor development process are effective to minimise the risk of falling and losing balance when the body accelerates. Thus, it is safe to encourage children with overweight to practice advanced locomotor patterns such as hopping without unnecessary concerns regarding their safety.

Whilst inter-task variation is a good model of practice for facilitating motor development in children, the needs to plan the exercises based on the difficulty of the locomotor task should be considered for children with overweight. In addition, the coordination of both upper and lower body parts is important in designing the locomotor task practice and the focus of the practice should be beyond the current developmental models that only include the legs and arms during running and hopping and include other body components such as the trunk and head that have a crucial role in postural stability.

We acknowledge some limitations in this study. Firstly, the travel distance for straight running and hopping was short therefore limiting the number of strides for analysis of sprint or distance running. It is recommended to use longer distance trials in sample entropy analysis to get a better insight regarding the locomotor postural adaptations due to the nature of task. Secondly, findings may not be generalisable to girls. Sex differences in the development of locomotor skills and postural stability strategies requires further investigation. Lastly, we are aware of the roles of some physical constraints such as strength and balance ability on locomotor patterns that might affect the postural adaptations that were not assessed or controlled for in the current study. Future studies can include these mediating variables in the model of analysis and examine the effects of task and increased body mass on postural stability strategies. An investigation examining girls is also warranted to identify any sex differences.

Conclusion

In conclusion, OW boys in both running and hopping applied a head-trunk coordination pattern more efficiently than NW boys in running for lateral stability. Due to task difficulty, the hopping pattern uses more complex (chaotic) adaptation and higher degrees of coupling between head and trunk to stabilise the posture. Children with overweight or obesity can safely participate in hopping exercise.

Declaration of interest

The authors report no declarations of interest.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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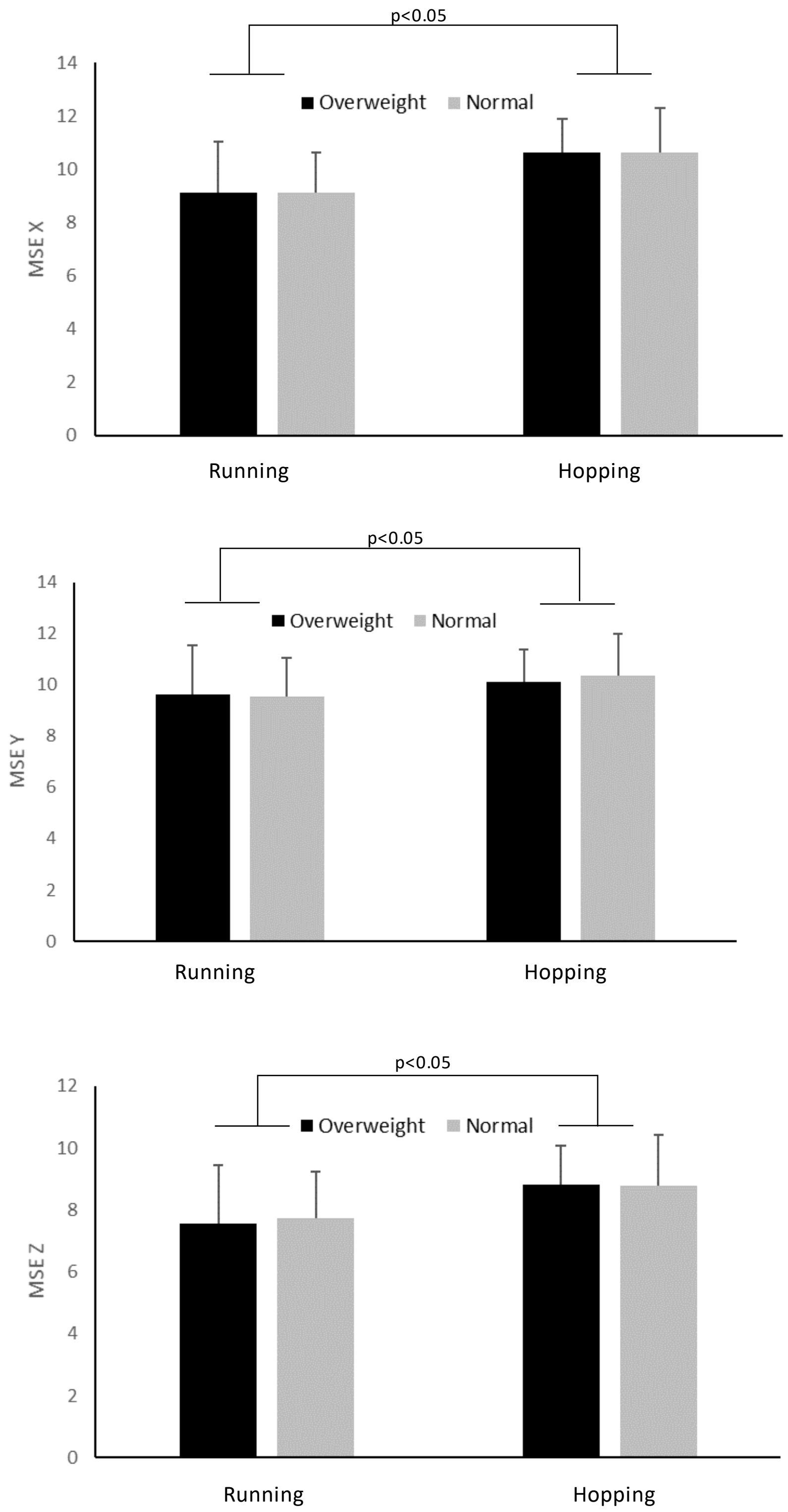

Figure 1- Postural variability in different axes in OW and NW boys in running and hop.

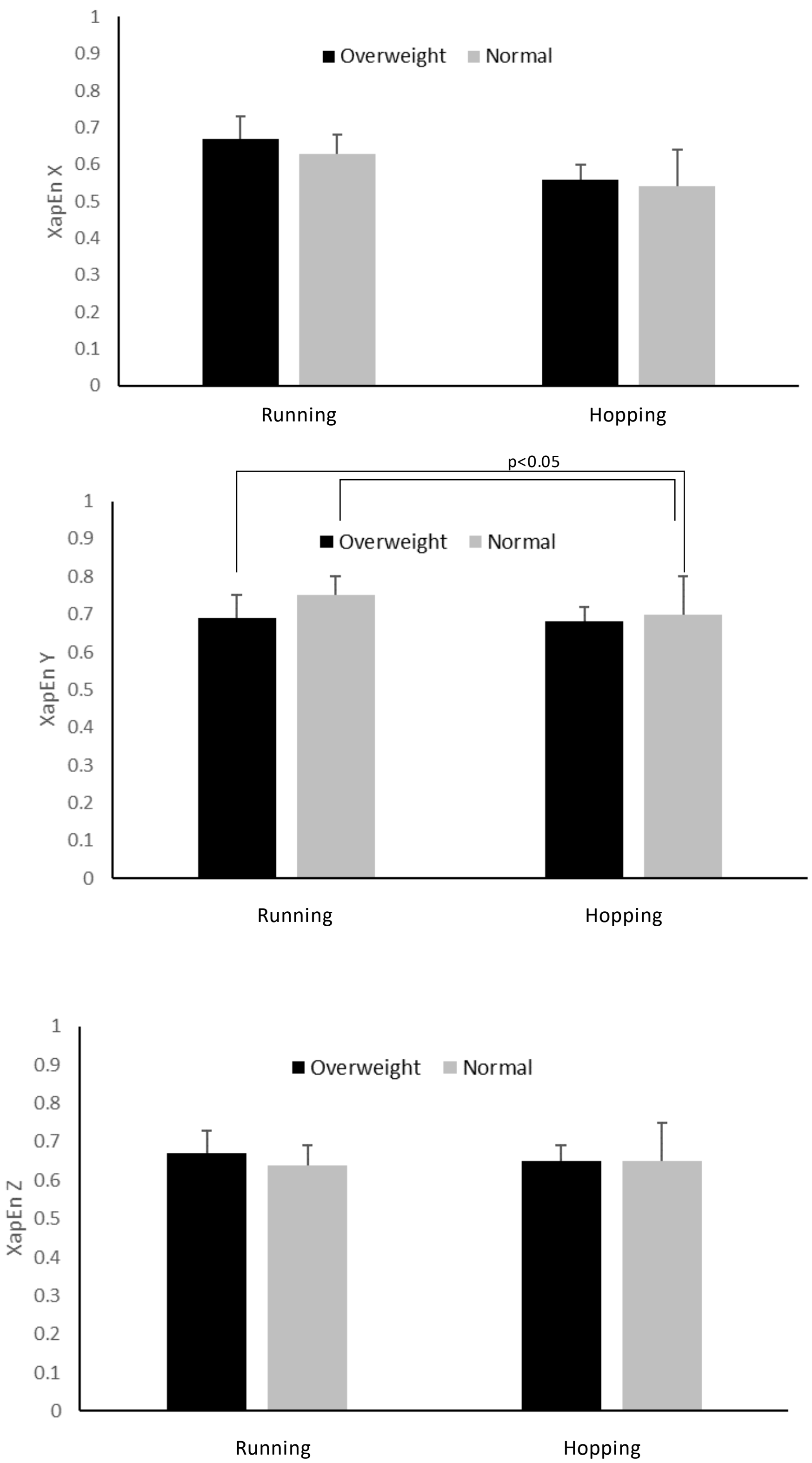

Figure 2- Postural coordination in different axes in OW and NW boys in running and hop.