Effects of locomotion task constraints on running in boys with overweight/obesity: the mediating role of developmental delays

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Abstract:

Background: Childhood obesity adversely affects the musculoskeletal system and is accompanied with motor development delays. Movement interventions that change the body composition and movement patterns is suggested as an effective way to minimise the childhood obesity adverse effects.

Research question: whether a locomotion task constraints intervention is effective to change body composition, motor performance and running efficiency in overweight/obese boys with different levels of motor development.

Methods: Forty young boys (age: 8.21 ± 1.01 years) whose body mass index (BMI) was above the 85th normative ranked score were divided into 4 independent groups according to their development and BMI: intervention-typical, intervention-delay, control-typical and control-delay. A 6-week task constraints intervention with an emphasis on improving locomotion skills such as fast walking, running, jumping, hopping, skipping and leaping were carried out in the intervention group.

Results: The pre and post-intervention difference score on the sample dependent variables showed decreases in body mass and BMI and improvements in agility, joint kinematics and running economy in the intervention-typical group relative to other groups.

Significance*:* the findings highlight that the boys with overweight/obesity and typical development can benefit more from a short-term developmentally-appropriate intervention to refine the running pattern and agility skill that was accompanied by positive changes in body composition.

Keywords: boys with overweight/obesity. fundamental movement pattern. running performance. locomotion intervention. body composition.

Introduction

Overweight and obesity in childhood has significant adverse effects on cardiovascular health indices that track into adulthood [1]. Childhood obesity also adversely affects the musculoskeletal system [2]. Some studies have reported structural changes in children with obesity in the lower extremities causing increased foot length and width, decreased navicular height [3], lower medial arch height and higher plantar pressure [4]. This leads to an increased prevalence of foot and ankle problems during childhood and adulthood [5] and more referrals to physicians due to increased foot pressure and lower extremity complaints in overweight/obese children compared to non-overweight/obese children.

The mastery of the fundamental motor skills (FMS) has been associated with healthy development during childhood in different domains [6]. Movement competency may be viewed as a predictor for future participation in sport and physical activity. Competency in FMS was associated with better health outcomes, such as a lower body mass index and greater aerobic fitness [7].

Childhood obesity could affect the mastery of FMS that require whole body movements, agility and coordination [8]. Reduced motor performance has been associated with a decreased level of physical activity [9]. Cliff, Okely, Morgan, Jones, Steele and Baur [10] showed that the deficiency in FMS in overweight/obese children was significantly higher than the normal counterparts in locomotor and manipulative skills. Participation in physical activity is positively associated with reductions in metabolic risk factors [11]. The mastery of locomotor skills and improving neuromotor fitness are also related to organismic, environment and the nature of the intervention [12]. It is highlighted that if children were not exposed to rich learning environments, they display motor delays in the development of FMS [13], consequently leaving them at greater risk of health problems [14]. In a meta-analysis, it was shown that the combination of aerobic and resistance training exercise resulted in greater reductions in body mass, fat mass and LDL specifically in studies where the duration of the intervention was longer than 6 months [15]. The effectiveness of specialised interventions designed to improve motor skills and FMS have also been reported previously in normal [16] and overweight/obese children [17]. D'hondt, Gentier, Deforche, Tanghe, De Bourdeaudhuij and Lenoir [17] implemented a multidisciplinary intervention that was a combination of regular physical activity, nutritional intervention and psychological support and found that the children with obesity significantly reduced body mass and improved locomotor skills. They also demonstrated that the increased mastery in locomotor skills was associated with decreased body mass.

In another study in pre-school children [18], it was shown that long-term interventions encouraging structured and unstructured motor skills activities and games significantly improved motor performance, physical fitness and motor dexterity, but without any effect on body composition. Recently in a systematic review, the effectiveness of exercise interventions on improving FMS and motor performance in children with obesity were studied [19]. The review of 17 studies showed that exercise interventions ranging between 6 and 208 weeks (average of 36 weeks) and focused on FMS activities, whole body movements (e.g. aerobic, gymnastics and strength-flexibility) and sport activities strongly improved the FMS mastery in locomotor and object control skills; however, their effectiveness on dynamic balance were equivocal.

Despite the abundance of studies that have investigated the effects of different types of physical activity on FMS and motor performance in children with obesity, their effects on running efficiency has not been studied to the authors knowledge. In fact, the conclusive evidence suggests that the running gait in children with overweight/obesity is different from their normal-weight counterparts and they have greater contact area, contact time, peak pressure and peak tibia acceleration (impact shock) during stance phase [20].

The biomechanical adaptations following development and task constraints have some implications for practitioners. First, these biomechanical changes due to increased body mass could increase the risk of a stress fracture, foot discomforts and foot injury that might discourage them from participating in high intensity physical activities such as fast walking and running or other locomotor skills that are require for sport games. Second, the running pattern is subject to motor development in terms of kinematic changes and the obesity might affect the biomechanical parameters that are involved in running development in children. For example, one kinematic measure is the amount of knee flexion in the stance phase that plays a significant role in shock absorption [21]. It is not clear whether delay in running development in children with overweight/obesity is related to efficiency in such kinematic measure that might further cause foot discomfort due to insufficient shock absorption. Lastly, the level of motor development was not taken into account in the studies that examined the effect of physical activity on the FMS, body composition and motor performance in children with overweight/obesity. In other words, whether the benefits of a specialised intervention to improve FMS and running pattern are different between typical-development children with overweight/obesity and children with developmental delays is unknown. Thus, the aim of this study was to examine the effects of a locomotion task constraints intervention on body composition, motor performance and running efficiency in children with overweight/obesity with different developmental levels. It is hypothesised that participation in the locomotion task intervention will significantly change the body composition, motor performance and running efficiency in overweight/obese boys.

Methods

Participants

The initial sample that was recruited included 56 boys aged between 7-9.5 years from a primary school. The cohort was screened for motor development level by trained practitioners and BMI was calculated before allocation to independent groups. In total, 40 overweight/obese participants (age: 8.21 ± 1.01 years; BMI: 24.48 ± 3.3 kg/m^2) were selected according to their scores on motor development and BMI and randomly allocated into the intervention or control groups. Overweight/obesity was defined as BMI > 20.20 kg/m^2 [22]. The participants' parents were asked to read the participant information sheet and complete the consent form. They had the right to withdraw at any stage of the study. The study was approved by the Faculty of Health and Wellbeing ethics committee.

Measurements

Motor performance tests

Motor development. The locomotor subscale of Test of Gross Motor Development (TGMD-2) was used to determine the proficiency of participants in locomotor patterns including running, hopping, galloping, jumping, leaping and sliding [23]. The locomotor subtests were videotaped individually by a digital camera (Canon PC1742, Japan) and the patterns were scored by two experts in motor development. Running was assessed based on four criteria; 1) arms move in opposition to legs; 2) brief period where both feet are off the ground; 3) narrow foot placement landing on heel or toe; 4) non-support leg bent approximately 90 degrees. If a child met each performance criteria, he scored one point. The ranges of scores for two trials were 0-8, with 0 reflecting lack of development and 8 representing a mature level running pattern. Children who were ranked below the 30th percentile in locomotor subtests of the TGMD-2 were categorised as children with developmental delays [23].
Motor fitness. A 4×10m shuttle-run test was used to assess agility. Participants ran10m to pick up small beanbags. The time taken to complete the 40m distance was measured. Leg power was assessed by the standing long jump test in which participants jumped with both feet simultaneously as far as possible. The measurement was taken from the take-off line to the nearest point of contact on the landing (back of the heels) in centimetres.

Running impact shock and kinematic. A 3D wireless motion capture system (MyoMotion system, Noraxon, USA) was used to analyse the joint angular displacements of participants during running. The 9-axis (3D accelerometer, 3D gyroscope and 3D magnometer) inertial measurement units sensors were fixed by Velcro straps in the distal tibia, middle-shank, middle-thigh, middle-waist and forehead. The sensors sampled movements at a frequency of 200 Hz. For detecting the stance phase, the gyroscope and accelerometer of the tibia sensor were synchronized.

Procedure

Participants were requested to undertake the 6-week intervention not inclusive of pre-post intervention assessments. The intervention was based on the principles of nonlinear pedagogy that emphasised manipulating task constraints as forms of locomotor skills with minimum explicit instructions [24]. The length of the intervention period was 6 weeks, 3 sessions per week, 50 minutes per session. In each session, and after a 10 minute standardised warm up, the intervention group took part in specific tasks that provided more opportunities to explore body movements. The type of task was changed weekly (see Figure 1 for details of the intervention each week). The main aim of all tasks was constraining children to move in all three dimensions with different paces. One experienced staff member in motor development and physical education at early childhood supervised the intervention programme to engage the children in different tasks.

The control group participated in typical physical education sessions throughout the 6-week intervention period. The sessions were the same as the intervention group in terms of frequency, number of sessions and duration but were different in terms of the type of tasks which mainly included training in basic association football skills. After the intervention, all tests were repeated in all participants, in the same order and in the same location in the school yard. Each participant was assessed individually. For running kinematic assessments, each participant ran at their preferred speed in a distance between two cones that were separated 10 meters apart. Parents were informed to avoid any change in the child's physical activity level during the intervention period.

Data analysis

Accelerometer data were analysed during the stance phase of running. The stance phase, initial contact to toe-off events, was determined by the gyroscope of the tibia sensor. To measure the impact shock, 15 strides were selected for further analysis. The dependent variables in running mechanics were impact shock magnitude, frequency domain and shock transfer function (TF). The resultant raw acceleration (g) of tibia, pelvis and head were filtered using a 2nd order Butterworth low-pass filter with a cut-off frequency of 20Hz after removing the gravity (g=9.81 m/s2) in the raw signal. The stance phase shock magnitude was calculated as peak positive tibia acceleration (PTacc), peak positive pelvis acceleration (PPacc) and peak positive head acceleration (PHacc). The power of tibia, pelvis and head acceleration during the stance phase was calculated through Fast Fourier Transformation (FFT) for the power spectral density (PSD) analysis [21]. Because the impact shock magnitude could be different during the stance phase due to different adopted shock absorption strategies by the participants [25], using the PSD analysis could provide a sensitive metrics regarding the impact shock absorption in a frequency window. The amount of shock that is transmitted from the tibia to pelvic and head is defined as shock transfer function [21], and it represents the ability of the musculoskeletal system to absorb the impact shock. The TF was calculated as the ratio between $PSD_{proximal}$ to PSD_{distal}:

$$TF = 10 \times \log_{10}(PSD_{proximal}/PSD_{distal})$$

Positive values indicate a gain or increase in the signal strength, whereas negative values indicates the attenuation or decrease in signal strength.

Week	Equipment	Tasks	Variations
1	• Tape • Chalk • Ladder • Hoops of 1 m diameter	• Children should move in a circular designed environment which was included of some motor stations full of equipment to constrain them perform skills like walk, run, hop and jump	• Distance between objects
2	• Thick rope • Foam board • Hoops of 0.5 m diameter	• Children should passed through the motor stations with skills like hop, jump and Diagonal run	• Distance between objects • Form of the objects
3	• Balance beam • Cons • Hive like ladder • Aerobic step	• The stations were designed and included of equipment which constrain children to act with skills like run, vertical and horizontal jump, slide and balance walk	• Distance between objects • Direction of performance
4	• Patterned baner • Archery barrier • Hurdles in different heights	• Children were encouraged to passed through the motor stations which this time were more challenging and needed more power and precise	• Speed of performance • Direction of performance
5	• Arrows • Aerobic step • Cons in different sizes • Agility poles	• Moreover than pass through the challenging stations, children participated in some individual games which were designed by the equipment to encourage them perform a variety of locomotor activities	• Speed of performance • Direction of performance • Challenge of the games
6	• Colored plastic tape • Wooden barriers in different heights • Yoga brick	• Children should passed through new stations which this time needed some degree of balance when performing locomotor skills. Moreover they participated in some cooperative games	• Speed of performance • Direction of performance • Challenge of the games

Figure 1. Equipment, tasks and variations of the intervention

Knee and hip angles were measured by the adjacent IMU sensors (shank, thigh and waist) as indicators of kinematic adaptations during running.

The stance phase of successive strides in each walking condition was normalised (0-100%) by a spline interpolation method in a custom-written Matlab programme (MatWorks, Inc. 2016).

The dependent variables, pre-post difference score, were analysed by one-way analysis of variance (ANOVA) after the parametric assumptions such as normality and homogeneity of variance were met. If the result was significant, a Bonferroni post-hoc test was carried out. The confidence interval was set at 95% (two-tailed). The Cohen's effect size [26] was used to interpret the clinical significance of the intervention using small (<0.20), medium (0.50) and large (>0.80) cut offs.

Results

Body composition and motor performance measures

The body and performance measures of different groups before and after the intervention are presented in Table 1. Results of the ANOVA showed that there were significant differences among the groups on pre-post changes in body mass, BMI and agility ($p<0.05$) but not on the long jump. Post hoc tests showed that the intervention-typical group had lower body mass and BMI than other groups after the intervention period. In addition, the intervention groups improved agility significantly greater than the control groups.

Impact shock and kinematic measures

Results of ANOVA showed that there was a significant difference among the groups on peak $Head_{acc}$ and peak knee angle at initial contact ($p<0.05$). The intervention-delay group reduced the head shock, but the intervention-typical group increased knee angle greater than other groups (see Table 2).

Shock adaptation measures

Results of the impact shock in the frequency domain in different body parts are presented in Table 3. Results of ANOVA showed that the intervention-typical group relative to other groups showed a significantly greater

Table 1- Body composition and motor performance measures pre and post intervention in different groups

	Intervention-Typical		Intervention-Delay		Control-Typical		Control-Delay		*F*	*ES*
	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention		
Body Mass (kg)	46.66(12.22)	44.33(10.7)	48.85(15)	49.78(15.71)	46.83(6.11)	47.16(7.25)	52.6(7.97)	53.2(7.34)	3.72**	0.19
Body Mass Index (kg/m^2)	23.85 (2.28)	22.87 (1.93)	24.79 (4.53)	25.88 (5.05)	22.94 (1.09)	23.29 (1.61)	25.17(2.51)	25.76(2.26)	2.85**	0.12
BMI Z-Score	2.98(0.4)	2.77(0.39)	3(0.51)	3.2(0.52)	2.69(0.13)	2.76(0.21)	2.97(0.42)	3.08(0.48)	2.78**	0.11
Agility (time)	16.13(0.28)	14.54(0.42)	17.63(1.9)	14.91(1.1)	15.54(1.76)	15.02(1.22)	17.77(3.2)	17.43(3.15)	6.24**	0.31
Long Jump (cm)	111.33(11.84)	115(30.41)	85.35(18.4)	96.07(15.21)	96.83(13.1)	105(22.8)	90.4(18.16)	89(23.9)	0.66	0.03

Table 2- Kinematic and impact shock measures before and after the intervention in different groups

	Intervention-Typical		Intervention-Delay		Control-Typical		Control-Delay		*F*	*ES*
	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention		
Peak Hip Flexion (deg)	16.22(6.15)	21.64(2.06)	9.77(9.59)	9.03(12.3)	14.76(9.22)	9.54(4.16)	16.97(3.67)	6.88(10.73)	0.13	0.08
Peak Knee Flexion (deg)	37.13(1.95)	34.54(4.57)	29.43(13.07)	27.01(11.51)	27.14(6.66)	33.35(9.22)	26.3(12.47)	33(5)	2.81**	0.14
Peak Head Acceleration (g)	1.21(0.16)	2.07(1.03)	1.53(0.7)	1.25(0.27)	1.46(0.36)	1.72(0.51)	1.21(0.17)	1.32(0.2)	3.53**	0.19
Peak Pelvis Acceleration (g)	3.05(0.76)	4.37(1.44)	3.32(0.92)	3.71(1.05)	2.8(0.5)	3.65(1.08)	3.22(0.8)	4(0.83)	1.65	0.05
Peak Tibia Acceleration (g)	6.98(1.06)	9.93(4.5)	6.7(1.8)	7.77(2.3)	5.82(1.01)	8.34(2.3)	5.52(1.17)	9.18(2.41)	1.67	0.05

Table 3- Impact shock adaptation measures before and after the intervention in different groups

	Intervention-Typical		Intervention-Delay		Control-Typical		Control-Delay		*F*	*ES*
	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention		
PSD Head $_{Low}$ (g^2/Hz)*	2.99(0.93)	14.04(14.36)	7.14(7.67)	3.95(2.31)	5.71(3.45)	9.18(7.27)	6.49(3.1)	4.68(2.6)	3.75**	0.21
PSD Head $_{High}$ (g^2/Hz)*	0.05(0.01)	0.02(0.02)	0.08(0.15)	0.03(0.04)	0.03(0.02)	0.05(0.05)	0.06(0.05)	0.04(0.03)	0.41	0.05
PSD Pelvis $_{Low}$ (g^2/Hz)*	18.76(8.27)	81.5(56.2)	29.92(19.62)	23.65(40)	16.22(11.21)	35.15(33.73)	25.02(18.1)	33.73(20)	5.01**	0.27
PSD Pelvis $_{High}$ (g^2/Hz)*	0.31(0.18)	0.91(0.93)	0.31(0.29)	0.3(0.26)	0.14(0.07)	0.3(0.18)	0.31(0.29)	0.41(0.35)	3.1**	0.16
PSD Tibia $_{Low}$ (g^2/Hz)*	89.43(53.12)	502(432)	123(94.5)	189(162)	62.3(25.95)	247(209)	61.7(29.9)	257(188)	3.09**	0.11
PSD Tibia $_{High}$ (g^2/Hz)*	3.7(2.33)	8.9(14.2)	3.32(2.63)	3.83(3)	2.41(1.98)	3.67(2)	2.56(1.9)	4.3(2.9)	0.74	0.02
TF-HT $_{Low}$ (dB)	-17.43(5)	-15.54(1.67)	-15.08(5.46)	-16.76(4.9)	-14.76(4.76)	-12.77(3.91)	-11.72(2.82)	-18.18(3.61)	2.11	0.09
TF-HT $_{High}$ (dB)	-16.66(3.22)	-18.86(8.09)	-18.02(4.69)	-21.74(6.02)	-17.03(5.42)	-18.96(2.44)	-13.75(5.12)	-20.34(5.45)	0.89	0.01
TF-PH $_{Low}$ (dB)	-9.86(4.05)	-5.67(5.81)	-8.64(4.84)	-7.59(5.36)	-9.02(3.86)	-7.59(3.07)	-5.8(3.68)	-.9.54(3.23)	0.96	0.1
TF-PH $_{High}$ (dB)	-10.25(3.56)	-8.51(11.51)	-11.7(5.73)	-11.05(4.4)	-10(7.12)	-14(2.51)	-8.23(5.15)	-10.94(5.26)	0.16	0.01

* The actual values were multiplied by 1000 (10^{-3}).

** p value significant at <0.05.

increase in low frequency shock at the PSD_{head}, PSD_{pelvis} and PSD_{tibia} ($p<0.05$). The same difference between the groups was also evident on high frequency shock at the PSD_{pelvis}. The TF was absorbed from the tibia to the pelvis and to the head during running in all groups.

Discussion

The aim of this study was to examine the effects of a locomotion task constraints intervention on body composition, motor performance and running efficiency in boys with overweight/obesity and with different developmental levels. The findings of this study showed that the effectiveness of the locomotion intervention depends on the level of motor development. Boys with overweight/obesity and typical development can benefit more than developmentally delayed boys from a short-term intervention to lose body mass and improve their running pattern.

Participation in structured physical activity and exercise has significant benefits for children with overweight/obesity to lose body mass and improve their motor function [11]. Previous studies have used different forms of activity including aerobic exercise, resistance training [15] and FMS activities [17] for changing the body composition and improving motor fitness. Despite the general belief regarding the association between losing body mass and improving fundamental locomotor skills in children with obesity [17], this relationship was not conclusive [18]. However, the results of the current study demonstrated that task constraints that focus on whole body movements would be beneficial for weight management and agility skills as parts of behaviour change strategies in boys with overweight/obesity. Nevertheless, this effectiveness was not observed in the intervention-delayed group which further emphasises the mediating role of motor development. In fact, despite an improvement in agility in both intervention groups, the improvement was not associated with the changes in body composition. Results of additional correlation analysis failed to show associations between body mass changes and motor performance and running mechanics in the whole cohort. An inverse relationship between motor proficiency and excessive body mass in children can advocates that developmental factors such as motor competence and perceived competence might constrain the effectiveness of the physical activity at this stage of child development.

The same interactive effect of intervention and development level was found on running mechanics in this study. Specifically, the results showed a movement adaptation following the intervention in the typical development group regarding shock power (PSD) in the tibia, pelvis and head in low frequency ranges was greater than other groups. These findings are more interesting considering the changes in peak impact shock and shock transfer attenuation were not different among groups. Thus, the intervention-typical group executed a running pattern with an effective employment of motor control mechanisms that were responsible to maximise running efficiency. The increased shock power at the tibia and pelvis in the low frequency range representing the ground reaction force and active movements of the foot, leg and the whole centre of mass during the stance phase [25, 27]. This suggests a new adaptive response following the task constraints intervention in children with overweight/obesity who reached the advanced level in locomotor development and this intervention gave them an opportunity to fine tune their movement patterns. The improvement in running efficiency following physical activity interventions generally and locomotor task intervention specifically in boys with overweight/obesity is not studied extensively. For example, a previous study that examined the benefits of weight loss on locomotor skills in children with obesity showed that decreases in lateral kinetic and vertical potential energy and kinematic changes such as hip and knee extension were body weight-related changes following a specific intervention in walking pattern [28]. Other types of intervention were changes in the task such as stride length, shoe insoles [28, 29] and using online tibia shock biofeedback [20] to change the locomotor skills in people with obesity.

Another reason for the changes in the shock power because of the intervention and motor development is pertinent to the kinematic changes. In adult runners, the greater knee flexion excursion and velocity and a greater contact time were possible kinematic adaptations for greater tibial signal power magnitude of frequencies below 10 Hz [30]. Thus, the current intervention resulted in movement refinements, increased knee angle, in typically development boys with overweight/obesity that had a significant role in running economy. One key factor that might obscure the same effects of the intervention in intervention-delayed group was the duration of intervention. Future studies could examine the long-term adaptations of the intervention in children with overweight/obesity in running and other locomotor skills. In addition, the current findings are applicable in boys and further studies are required to examine any potential differences in girls.

Conclusion

The findings of this study showed that the boys with overweight/obesity and with typical development can benefit more from the developmentally-appropriate interventions to refine the running efficiency such as knee joint angle during stance phase and shock absorption ability.

Declaration of interest

The authors report no declarations of interest.

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