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UPPER LIMB RELATED FACTORS IN DETERMINING POSTURAL CONTROL

DEJAVNIKI POVEZANI Z ZGORNJIMI OKONČINAMI, PRI DOLOČANJU POSTURALNE KONTROLE

ABSTRACT

Postural control is an outcome of complex interactions between many systems and structures to control body position in space. Appropriate postural control is necessary for the initiation and continuation of movements in different body parts, such as the upper limbs. Although the importance of maintaining postural control for movement is well recognized, its relationship with upper limb functions is unknown. The present study investigated the factors related to the upper limb in determining postural control in healthy young adults. We included 68 non-symptomatic individuals in this cross-sectional study. The static and dynamic postural stability and upper limb performance parameters of the participants were evaluated. Multiple Linear Regression analysis was performed to determine the independent determinants of postural control. According to the results of the analysis, Six Minute Peg Board Ring Test (6PBRT) explaining 11% of the variance was the independent determinant of static general stability index ($p < 0.05$). Nine-Hole Peg Test (9HPT) explaining 5.3% of the variance was the independent determinant of static anterior-posterior stability index ($p < 0.05$). The 6PBRT and Medicine Ball Chest Launch Test (MBCLT) explaining 16.5% of the variance were found as independent determinants of static medial-lateral stability index ($p < 0.05$). There was no significant relationship between dynamic stability indices and upper extremity functional parameters ($p > 0.05$). It was concluded that upper limb functions were a determinant of static postural control in non-symptomatic young adults.

Keywords: Upper Limb, Balance, Postural Control

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IZVLEČEK

Ravnotežje je rezultat zapletenih interakcij med številnimi sistemi in strukturami za nadzor položaja telesa. Za začetek in nadaljevanje gibov v različnih delih telesa, na primer v zgornjih okončinah, je potrebno ustrezno ravnotežje. Pomen ohranjanja ravnotežja je za gibanje dobro prepoznavno, njegov odnos s funkcijami zgornjih okončin pa še ni znan. V študijo smo preučevali dejavnike povezane z zgornjimi okončinami pri določanju kontrole telesa pri zdravih mladih odraslih. V presečno študijo smo vključili 68 oseb zdravih oseb. Ocenili smo statično in dinamično ravnotežje ter parametre delovanja zgornjih okončin udeležencev. Ugotovili smo, da šestminutni test obroča (6PBRT), ki je neodvisen dejavnik statičnega indeksa splošne stabilnosti ($p<0,05$) pojasnjuje 11% variance. Test z devetimi luknjami (9HPT), ki je neodvisen dejavnik statičnega indeksa stabilnosti ($p<0,05$), pojasnjuje 5,3% skupne variance. Testa 6PBRT in test met medicinke (MBCLT), pojasnjujeta 16,5% skupne variance ($p <0,05$). Med indeksi dinamične stabilnosti in funkcionalnimi parametri zgornjih okončin nismo našli pomembnih povezav ($p> 0,05$). Ugotovili smo, da so funkcije zgornjih okončin determinanta statičnega ravnotežja mlajših zdravih odraslih.

Ključne besede: zgornji udi, ravnotežje, posturalni nadzor

INTRODUCTION

Postural control is the ability to maintain equilibrium in a gravitational field by keeping or returning the center of body mass over its base of support (Horak, 1987). Postural control is an outcome of complex interactions between many systems and structures, especially the nervous and musculoskeletal systems, to control body position in space (Ivanenko & Gurfinkel, 2018). In maintaining postural control; sensory (vestibular, visual and proprioceptive systems), perceptual (nervous system), and motor processes (musculoskeletal system) play important roles (Massion, 1994). Pertinent postural control is required to produce and maintain body movements (Feldman, 2016). Although a movement may seem like a simple process, it emerges as a result of the complex integration of many structures and systems (Winter, 2009). Motor movements can be successfully performed by means of precise cooperation between the nervous system (both peripheral and central nervous system) and the musculoskeletal system (Alexander, DeLong, Crutcher, & Sciences, 1992; Winter, 2009). During movements, the body constantly adapts to postural changes; these adaptations are characterized by low amplitude and slow oscillating movements involving whole body (Newell & Pacheco, 2019).

Upper limb movements are basic motor abilities for all activities, especially for activities of daily living. Body segments are organized to adapt to changing conditions during various activities, such as holding an object, launching and catching a ball, dressing, and cooking (Rau, Disselhorst-Klug, & Schmidt, 2000). Besides cerebellum, cortex, subcortical structures and peripheral nerves, which are main regulators, postural muscles also play an important role in fulfilling upper limb functions (R. Lalonde & C. Strazielle, 2007). Before the movement is initiated, core muscles contract to provide the stabilization necessary for the movement (Larson & Brown, 2018). Prior to the movement, preparative postural arrangements contribute to the initiation and maintenance of the movement (Larson & Brown, 2018; Mesquita Montes et al., 2017). Therefore, any insufficiency in postural control leads to problems in initiating and maintaining movements (Emami, Yoosefinejad, & Razeghi, 2018).

The ability of the upper limbs to perform various tasks depends on their ability to work away from the trunk; an ability that is in close relationship with the stability of the scapulothoracic joint (Meadows, Raine, & Lynch-Ellerington, 2009; Raine et al., 2012). The scapular muscles must stabilize the scapulothoracic joint before any functional movement in the upper limb. Attached to the trunk through scapulothoracic joints, upper limbs can function more effectively in a better state of postural control (Mottram, 1997; Voight & Thomson, 2000). Therefore, postural control is in a dynamic relationship with the upper limbs. This relationship between upper limb movements and postural control is based on neuronal connections (R. Lalonde & C. J. P. i. n. Strazielle, 2007; Schepens, Stapley, & Drew, 2008).

Knowing the determinants of postural control in relation with the independent upper extremity functions will assist with planning tailored rehabilitation programs to improve the independence level and performance of individuals, especially during activities of daily living. Although the impact of postural control to upper extremities movements is well recognized in research, it is yet unknown whether upper extremities movements are a determinant factor for postural control.

The aim of this study was to examine the relationship between postural control and upper limb functions and to determine whether these functions can be a determinant factor for postural control. It was hypothesized that upper extremity functions would be the determinant of postural control.

METHODS

Study Design and Participants

A total of 68 individuals (30 men, 38 women) were included in this cross-sectional study. Individuals over 18 years of age who had no known health and communication problems were included in the study. Individuals with neurological or orthopedic problems or cognitive impairments, those with a history of surgery in lower or upper limbs, and individuals with a history of malignancy were excluded. Ethics approval was obtained from the Clinical Research Ethics Committee of University (approval no. 2019-21/206). All participants signed an informed consent form.

Outcome Measures

The participants' demographic data, including age, height, body weight, and medical background were recorded.

Evaluating Postural Control

The participants' postural control was evaluated via Biodex Balance System (BBS, a commercially available balance device, Biodex Medical Systems, Shirley, NY, USA). BBS is a commonly used method to evaluate postural control (Arnold & Schmitz, 1998; Aydog,

Aydog, Çakci, & Doral, 2004). BBS consists of a mobile platform capable of tilting up to 20° in 360° range of motion. The platform provides objective evaluation data using a computerized software (Upper display module-firmware version 1.09, Lower control board-firmware version 1.03, Biodex Medical Systems). Postural control can be evaluated over different difficulty levels ranging from 1 (the hardest) to 12 (the easiest). Based on the relevant literature, in the present study, postural control was evaluated both dynamically and statically in three measurements. Higher scores in each index indicate poor postural control. With their feet shoulder-width apart, the participants were asked to stand upright on the BBS platform in a comfortable position and look ahead. Participants were trained about 1 minute to adapt to BBS to reduce learning effects. Each measurement lasted for 20 seconds with a 10-second rest interval between the measurements. To evaluate dynamic postural control 2 levels were used and the evaluations were made with eyes open. For each participant, general stability index, anteroposterior stability index and mediolateral stability index scores were recorded for both static and dynamic postural control (Akhbari, Salavati, Mohammadi, & Safavi-Farokhi, 2015; Arnold & Schmitz, 1998; Pickerill & Harter, 2011; Testerman, Griend, & international, 1999).

Evaluating Upper Limb Functions

Upper Limb Exercise Capacity: Six-Minute Pegboard Ring Test (6PBRT) was used and the evaluation was based on the protocol by Zhan et al, (Zhan et al., 2006). Higher scores indicate low upper extremity exercise capacity.

Evaluating Dexterity: Nine-Hole Peg Test (9HPT) was used to evaluate dexterity. The participants were asked to insert the pegs into the holes using their dominant hand. Time was recorded in seconds using a stopwatch (Poole et al., 2005). A high score in 9HPT indicates low dexterity.

Evaluating Functionality: Closed Kinetic Chain Upper Extremity Stabilization Test (CKCUES) was used for evaluating functionality. Since the participants were sedentary individuals, the modified push-up position was used as testing position. The evaluation consisted of counting how many times, in 15 seconds, each participant assuming the modified push-up position was able to touch his/her supporting hand with the swinging hand (de Oliveira et al., 2017). A high score in CKCUES indicates higher upper extremity functionality.

Evaluating Muscle Endurance: Muscle endurance was evaluated both statically and dynamically. The evaluation of static endurance consisted of recording the duration each participant was able to hold a training ball of 5 kilograms with the shoulder in 45° of flexion and 45° of abduction. To evaluate dynamic endurance, the participants were asked to hold a training ball of 5 kilograms, lift it to 45° of flexion and 45° of abduction in their shoulder, and return to the initial position. The number of repetitions within 30 seconds was recorded as the test score. Both evaluations were made with the participant sitting on a chair. Higher scores indicate better muscle endurance.

Evaluating Upper Limb Muscle Power: Performed in standing position, Medicine Ball Chest Launch Test (MBCLT) was used to evaluate upper limb power. The participants were asked to hold a 2-kilogram med ball at their chest and then explosively throw the ball forward as far as they could. Each participant had 3 test throws and the best throw was recorded as the test score. Larger throw distance scores indicate greater upper extremity muscle power.

Evaluating Upper Limb Flexibility: Active Internal Rotation Test (IRT), Horizontal Adduction Test (HAT) and goniometric measurement methods were used for the evaluations. For IRT, the participants were asked to stand in an upright position and reach with their thumb to their back with shoulder adduction and internal rotation. The distance between the spinous process of the seventh cervical vertebra and the thumb was recorded in centimeters (Granata & Orishimo, 2001). For HAT, the participants were asked to actively move their arm from 90° of flexion to the maximum of horizontal adduction. Once at the final position, the distance between the lateral epicondyle and the opposite acromion was measured and recorded in centimeters (Kugler, Krüger-Franke, Reininger, Trouillier, & Rosemeyer, 1996). Low scores (smaller distances) indicate greater upper extremity flexibility. Goniometric evaluations consisted of measuring internal and external rotation range of motion of the shoulder joint.

Sample Size

To the best of our knowledge, no study in the literature has investigated whether upper limb can be a possible factor for static and dynamic balance measured using postural control index. However, a previous study has reported body weight as a significant predictor of postural stability ($R^2 = 0.10$, $p < 0.05$) [24]. Based on the results of that study, the minimum required sample size for a multiple regression analysis was calculated as 60 participants for the probability level of 0.05, ten predictors in the model, the anticipated effect size as 0.14, and the statistical power level as 80% using G*Power Software (Version 3.1.9.2, Düsseldorf University, Düsseldorf, Germany). Allowing for a 10% dropout rate, 67 subjects were recruited into the study.

Data Analysis

SPSS 22.0 for Windows was used to analyze the data. Visual (histogram) and analytical (Shapiro-Wilk test) methods were used to examine whether the data were normally distributed. Values are given as mean ± standard deviation. Since the data had normal distribution, Pearson Correlation analysis was used to investigate the correlation between variables. Correlation coefficients of > 0.5 were considered as strong, 0.3–0.5 as moderate, and 0.2–0.3 as weak correlations (Cohen, 1988). Multiple Linear Regression was used to determine the independent determinants of postural control. Significance level was set as $p < 0.05$.

RESULTS

Demographic data and evaluation parameters of the participants are given in Table 1.

Table 1. Demographic and clinical characteristics of the participants.

	Mean	Standard Deviation	Minimum	Maximum
Age (years)	21.19	1.56	18	25
Height(cm)	169.09	8.73	149	187
Weight(kg)	64.35	10.69	47	90
BMI (kg/m²)	22.80	2.50	18.44	29.39

A statistically significant negative moderate correlation was found between the 6PBRT score and static general stability index ($r = -0.352$, $p = 0.003$, Table 2). A positive weak correlation was found between static general stability index and 9HPT ($r = 0.289$, $p = 0.017$, Table 2). There was no significant relationship between static general stability index and upper limb functions ($p > 0.05$, Table 2). According to the results of Multiple Linear Regression analysis, the 6PBRT was found as an independent determinant of static general stability index explaining 11% of the variance ($p < 0.05$, Table 3).

Table 2. Correlation between postural control score score and other assessments.

		6PBRT	9HPT	CKCUES	SEC	DES	MBCLT	IRT	HAT	IRT	ER
SOS	**p**	-0,352**	0,289*	-0,150	-0,009	-0,197	-0,224	-0,027	-0,182	0,133	0,131
	r	0,003	0,017	0,223	0,943	0,106	0,067	0,824	0,138	0,280	0,285
SAPS	**p**	-0,214	0,258*	-0,113	0,017	-0,082	-0,058	0,023	-0,077	0,073	0,057
	r	0,080	0,034	0,359	0,890	0,505	0,641	0,852	0,534	0,556	0,642
SMLS	**p**	-0,321**	0,176	-0,159	0,013	-0,200	-0,252*	-0,061	-0,191	0,175	0,128
	r	0,008	0,151	0,195	0,917	0,102	0,038	0,622	0,119	0,152	0,297
DGS	**p**	-0,191	0,238	-0,127	0,056	-0,105	0,105	0,122	0,039	-0,051	-0,121
	r	0,118	0,051	0,300	0,650	0,393	0,393	0,321	0,749	0,679	0,327
DAPS	**p**	-0,199	0,207	-0,122	0,005	-0,105	0,043	0,128	0,035	-0,040	-0,126
	r	0,104	0,090	0,320	0,967	0,396	0,727	0,297	0,777	0,745	0,308
DMLS	**p**	-0,102	0,220	-0,111	0,099	-0,092	0,193	0,097	0,062	-0,055	-0,079
	r	0,408	0,072	0,369	0,420	0,454	0,114	0,433	0,613	0,657	0,520

SOS: Static Overall Stability Index, SAPS: Static Anterior/Posterior Stability Index, SMLS: Static Medial/Lateral Stability Index, DOS: Dynamic Overall Stability Index, DAPS: Dynamic Anterior/Posterior Stability Index, DMLS: Dynamic Medial/Lateral Stability Index, 6PBRT: 6-Minute Pegboard and Ring Test, 9HPT: Nine-Hole Peg Test, CKCUES: Closed Kinetic Chain Upper Extremity Stabilization Test, SEC: Static Endurance Score, DES: Dynamic Endurance Score, MBCLT: Medicine Ball Chest Launch Test, IRT: Active Internal Rotation Test, HAT: Horizontal Adduction Test, IR: Internal Rotation, ER : External Rotation

A positive weak correlation was found between static anterior-posterior stability index and 9HPT score ($r = 0.258$, $p = 0.034$, Table 2). There was no significant relationship between static anterior-posterior stability index and upper limb functions ($p > 0.05$, Table 2). According to the results of Multiple Linear Regression analysis, the 9HPT was found as an independent determinant of static anterior-posterior stability index explaining 5.3% of the variance ($p < 0.05$, Table 3).

There was a significant negative moderate correlation between static medial-lateral stability index and 6PBRT score ($r = -0.321$, $p = 0.008$, Table 2). A significant negative weak correlation was found between the static medial-lateral stability index and MBCLT score ($r = -0.252$, $p = 0.038$, Table 2). There was no significant relationship between static medial-lateral stability index and upper limb functions ($p > 0.05$, Table 2). According to the results of Multiple Linear Regression analysis, 6PBRT (score) and MBCLT (m) explaining 16.5% of the variance were found as independent determinants of static medial-lateral stability index ($p < 0.05$, Table 3).

There was no significant correlation between dynamic stability indices and upper limb functions (p> 0.05, Table 2).

Table 3. Stepwise multiple linear regression model of postural control.

	B	SH	Beta	p	adjusted R^2
		Determinants of Static Overall Stability Index			
Constant	2.825	0.588	-	<0.001	0.110
6PBRT (score)	-0.01	0.003	-0.352	0.003	
		Determinants of Static Anterior/Posterior Stability Index			
Constant	-0.641	0.592	-	0.283	0.053
9HPT (sn)	0.077	0.036	0.258	0.034	
		Determinants of Static Medial/Lateral Stability Index			
Constant	2.710	0.529	-	<0.001	0.165
6PBRT (score)	-0.008	0.002	-0.358	0.002	
MBCLT (m)	-0.001	<0.001	-0.297	0.010	

6PBRT: 6-Minute Pegboard and Ring Test, MBCLT: Medicine Ball Chest Launch Test,
9HPT: Nine-Hole Peg Test

DISCUSSION

Postural control is an output of the interaction between the nervous and musculoskeletal systems (Ivanenko & Gurfinkel, 2018). Through this interaction, the muscular system enables individuals to perform all their activities (Ivanenko & Gurfinkel, 2018). Upper limb functions form the basis for important motor skills, which are required for daily living. Studies on postural control mainly focus on activities such as gait and balance; yet, it is important to know the relationship between postural control and upper extremities, which play a prominent role in the performance of daily activities. Therefore, as the first study in the literature, we examined whether upper extremity functions are determinants of postural control. According to the results, upper extremity functions are indeed a determinant of static postural control. Our results also indicated that upper limb exercise capacity and dexterity were the determinants of general static postural control, dexterity was the determinant of static anterior-posterior postural control, and upper limb exercise capacity and upper limb power were the determinants of static medial-lateral postural control. In the relevant literature, the concepts of postural control and postural stability are commonly used interchangeably. Postural control is defined as the ability to keep or regain the center of body mass over the base of support (Horak, 1987). Postural stability is the stable position of the body mass center within the base of support to maintain an upright posture (Westcott, Lowes, & Richardson, 1997) (Iqbal, 2011). These two definitions show how intertwined the two concepts are. In our study, the term 'postural control' is used as it is more comprehensive than 'postural stability'.

Core muscles are involved in maintaining postural control. These muscles have been shown to improve upper limb functions by increasing trunk stabilization. In their study, Miyake et al. reported that increased core endurance and trunk stabilization lead to improved upper extremity functions (increase in the Purdue Pegboard score) and daily living activities (Miyake, Kobayashi, Kelepecz, & Nakajima, 2013). A study investigating the relationship between dexterity and postural control in children between five and six years of age reported a relationship between dexterity and postural control (Rosenblum & Josman, 2003). In a study conducted on individuals with Parkinson, the relationship between dexterity and postural control differed according to age. While there was a relationship between dexterity and postural control in Parkinson patients over 65 years of age, no significant relationship was observed in patients below 65 years old [6]. Furthermore, a relationship is reported between hand functions and postural control in individuals over 65 years of age (Fatih et al.). In line with these studies, our results also revealed a significant relationship between manual skills and SOS and SAPS indices. Moreover, 9HPT was found to be the independent determinant of SAPS index explaining 5.3% of the variance, indicating that dexterity is a determining factor of postural control. Static postural control is the ability to control the center of mass within the base of support during normal posture (Shumway-Cook & Woollacott, 2007). Based on our results, we can assume that 9HPT can be a factor in determining static postural control as this test is performed in static sitting position. There is a need for future studies to further investigate this finding.

Upper limb exercise capacity is another important aspect in performing and maintaining upper limb functions. Unsupported upper limb movements are needed for most of the daily living activities (Takeda et al., 2013). To the best of our knowledge, our study is the first study in the literature that examines whether upper extremity exercise capacity is a determinant of postural control. Therefore, there is no study in the relevant literature to compare our results with. According to our results, there was a relationship between upper limb exercise capacity and SOS and SMLS indices. Moreover, 6PBRT was found to be an independent determinant of static general stability and static medial-lateral stability indices. Hence, it is thought that increasing upper extremity exercise capacity can have a positive effect on static postural control. Further studies are needed to examine this relationship between upper limb exercise capacity and postural control, and to investigate evaluation and intervention approaches.

It has been reported in several studies that upper limbs are functionally involved in maintaining and restoring disturbed postural control (Marigold, Bethune, & Patla, 2003; Roos, McGuigan, Kerwin, Trewartha, & posture, 2008). According to Gracovetsky's spinal machine theorem, the abdominal oblique muscles work in coordination with other central column muscles to create kinetic and potential energy and generate a rotating torque. As a result of this rotator torque, spiral motion system is activated and many functional movements originating from the central column (such as walking and rolling) can be performed. Maximum force is created when the force generated from the trunk and lower limbs is combined -through the thoracolumbar fascia- with the force produced in the upper limbs. According to the researcher, during baseball ball launch, the appropriate trunk position required for the upper limb is maintained with the coactivation of bilateral hip adductors together with ipsilateral internal and contralateral external oblique abdominals (Marcus, 2010). This explains the relationship between upper extremity functions and trunk stabilization. Previous studies have reported significant correlations between trunk stabilization and upper limb power in different sports such as baseball, handball, and football (Lust, Sandrey, Bulger, & Wilder, 2009; Saeterbakken, Van den Tillaar, Seiler, & Research, 2011; Sharrock, Cropper, Mostad, Johnson, & Malone, 2011; Shinkle, Nesser, Demchak, McMannus, & Research, 2012). In their study on 35 athletes, Sharrock C et al. (Sharrock et al., 2011) investigated the relationship between trunk stabilization and upper limb power. The researchers used double leg jump test to evaluate trunk stabilization and Medicine Ball Chest Launch Test to evaluate upper limb power. They reported a significant relationship between trunk stabilization and upper limb power (Sharrock et al., 2011). In another study on 25 football players, Shinkle J. et al. (Shinkle et al., 2012) examined the relationship between trunk stabilization and upper limb functional performance. They reported a significant relationship between trunk stabilization and upper limb performance, and concluded that this relationship was important in transferring power to the upper limbs and generating force (Shinkle et al., 2012). In their study on functional reactions of the lower and upper limb muscles to postural changes, Mcllroy et al. used EMG to evaluate muscle functions. They examined the response of the posterior deltoid muscle to the disrupted postural control and observed that in case of any loss in postural control, posterior deltoid responded together with the muscles of lower limbs. They also reported that when postural control is medio-laterally disrupted, the posterior deltoid muscle responded even more than the lower limbs (McIlroy & Maki, 1995). In the present study, a significant relationship was found between upper limb power and static medial-lateral stability index. Moreover, upper limb muscle power was found to be an independent determinant of static medial-lateral stability. In a study on elite volleyball players, no relationship was found between upper extremity functional performance and dynamic postural control (Kugler et al., 1996). Similarly, we found no significant relationship between upper extremity power and dynamic postural control parameters. This might be due to the MBCLT protocol that we used to evaluate upper extremity power. In our protocol, the participants were asked to launch the ball using only their upper extremities without any swing in their trunk. So, it is normal for the results to be related to static postural control.

Maintaining posture during voluntary movements and reactions against external forces in unexpected situations are considered as dynamic postural control (Shumway-Cook & Woollacott, 2007). Dynamic postural control is the state of realignment of the body or regaining balance after a fall. Dynamic postural control ensures the maintenance of postural control during activities in which the body is no longer in contact with the base of support, such as running and jumping (Travis, 1945). A study conducted with dancers found a relationship between shoulder flexibility and dynamic postural control. In our study, there was no significant relationship between upper limb functions and dynamic postural control. This might be due to the fact that all upper extremity function tests were performed in static positions such as sitting and standing. If tests involving more dynamic stability were used to evaluate upper extremity functions, the results could be different. Moreover, lower limb functions could be more effective in determining dynamic postural control. In this context, future studies are recommended to separately examine the effects of upper and lower limb functions on static and dynamic postural control.

The study has some limitations. Healthy individuals were included and evaluated in the present study. Including different specific populations could also yield useful results. Future studies may examine the relationship between upper limb functions and postural control in more specific groups.

CONCLUSION

The present study is the first in the literature to examine and identify the determinants of postural control in non-symptomatic young adults. According to the results, upper limb functions are an independent determinant of static postural control. It is recommended to include upper extremity exercises to the rehabilitation programs that aim to improve postural control.

Declaration of Conflicting Interests

No conflict of interest was reported.

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