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Joint position sense and balance in children with hemiplegia in comparison with typically developing controls: A cross-sectional study

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Abstract:
This study aimed to assess the joint position sense (JPS) of trunk, hip, knee and ankle joints and balance deficits in hemiplegic children, comparing these findings with typically developing (TD) controls and to detect the relation between JPS and balance in hemiplegic children. 42 hemiplegic children and 42 TD children participated in this study. Their age range from 8-12 years old. Digital goniometer and Kids-Balance Evaluation System Test (Kids-BESTest) were used for assessment. There was statistically significant increase in the mean values of the trunk, hip, knee and ankle joints repositioning errors in hemiplegic children than TD controls (p < 0.005) and there was statistically significant decrease in the mean values of all scores of Kids-BESTest scale in hemiplegic children than TD children (p < 0.005). There was statistically significant negative moderate correlation between trunk JPS and Kids- BESTest score (r= -0.583) (p=0.001). Statistically non-significant negative weak correlation was found between hip, knee JPS from (weight bearing and non-weight bearing positions), ankle JPS and Kids-BESTest score (r= -0.135)(p=0.392),(r= -0.055and-0.197) (p=0.727and0.212) r, (r= -0.271) (p=0.082) respectively. The JPS and balance were affected in hemiplegic children compared to TD controls. The trunk position sense was strongly related to balance in hemiplegic children.

Keywords: Cerebral palsy, Hemiplegia, Joint repositioning error, Proprioception**,** Balance.

Introduction

Hemiplegic CP is an impairment which is localized unilaterally in the the brain and leads to hypertonicity of the muscles and hyperreflexia **(Papadelis et al., 2017)**. Children with hemiplegia often have balance problems and affected postural responses.

The asymmetric alignment of the posture results in atypical posture in these children **(Li, 2020)**. This poor posture is caused by impairment in the development of the neural control mechanisms as well as secondary musculoskeletal problems like spasticity, weakness of the muscles, and slow proprioception which decrease the capacity to symmetrically transfer the weight of the body in reponse to movement to maitain posture **(Kenis-Coskun et al., 2016).** Because of deficiencies in their ability to react and anticipate postural reactions, as well as changes in ground reaction force during postural adjustment, these children exhibit poor trunk control and inadequate preservation of neutral posture. They also have sensory-motor integration and muscular coordination deficits which affects negatively postural control and balance **(Rojas et al., 2013).**

Proprioception is a sensory-motor perception that includes the feeling of limb movement (kinesthesia) and the feeling of static limb position (JPS) in the absence of vision. The capacity to recognize joint position without the aid of vision is known as joint position sense (JPS). It is essential for maintaining postural stability and gait and greatly enhances joint coordination and the creation of natural movement for suitable task **(Damiano et al., 2013; Madhavan and Shields, 2005).**

It was reported that children with hemiplegia have worse proprioception, and there are findings that the affected side has lower proprioception compared to the less-affected side **(Goble et al., 2009).** The degree and timing of muscle activation may be affected by impaired proprioception **(Tuthill and Azim, 2018).** These results suggest that compensatory gait modifications, poor postural control and balance abnormalities in CP may be related to long-term proprioceptive problems. All of these constraints may lead to numerous restrictions in everyday tasks and negatively affect children's engagement in learning and recreational activities (**Yardımcı-Lokmanoğlu et al., 2020).**

Overall, deficiencies in sensory input and processing lead to motor abnormalities; however, further investigations are needed to determine the relation between sensory function and motor ability in CP. The relationship between trunk position sense and lower limb somatosensory functions and balance performance is still not clear. So, this study attempted to evaluate the JPS of trunk and lower limb joints and balance in children with hemiplegia and compare these findings with age matched

TD children, and detect the relationship between the trunk and lower limb joints' position sense and balance function in HCP children.

Methods

Study design

This cross-section study was approved by Research Ethical Committee of the Faculty of Physical Therapy, Cairo University (P.T.REC/012/003680). Before conducting this study, all children and their parents were informed about the goal and procedure of this study, and all caregivers of participants provided informed consent.

Participants

Eighty-four children from both sexes with ages ranged from 8-12 years old participated in this study. Forty-two TD children enrolled in this study from governmental primary schools at Cairo Governorate and Forty-two children with hemiplegic CP were recruited from outpatient clinic of Faculty of Physical Therapy, Cairo University, and Abo-El Reesh Hospital, with mild degree of spasticity graded 1 to 1+ according to Modified Ashworth Scale **(Bohannon and Smith, 1987).** Their motor function was at level I and II according to Gross Motor Function Classification System (GMFCS) **(Palisano et al., 2008)** and they were able to follow instructions. Children with visual or auditory problems, musculoskeletal issues or definite deformities in the spine and/or the lower limbs, as well as children who experienced lower limb or spine operation or received botox injections within the previous six months excluded from the study.

Outcome measures

The following assessments were completed by all of the children including; assessment of trunk and lower limb (hip, knee and ankle) JPS using digital goniometer. Kids-Balance Evaluation System test (Kids-BESTest) was used to evaluate balance abilities.

Procedures

Assessment of joint position sense

Joint position sense assessed by digital goniometer through the reproduction of active joint positioning (**Lokhande et al., 2013)**. The digital goniometer has validity for assessment of joint ROM and equivalent inter- and intra-rater reliability to the universal goniometer. The absolute axis goniometer eliminates the need to manually score each measurement that decreases the errors **(Carey et al., 2010).**

Assessment of trunk position sense

Each child was instructed to keep standing, extend his knees, neutralize his hips and feet and support his pelvis against the wall **(Monica et al., 2021).** The fulcrum of goniometer was positioned at the iliac crest, the movable arm was coincided with the mid axillary line and the fixed arm was maintained lateral to the trunk in the center (bisecting ASIS and PSIS) **(Chertman et al., 2015).**

Each child was given two practice trials after being given an explanation of the testing procedure. First, the trunk was flexed to the target angle of 30 degrees passively, they were told to maintain this position and memorize it for 10 seconds while keeping their eyes opened. Then they return back to the initial position and they were informed to reproduce the target position actively while keeping their eyes closed. An angle of 30 degrees was chosen in this study as large degrees could lead to more pressure on the muscle and adversely affect the test results **(Monica et al., 2021).**

Assessment of lower limb joints' position sense

a. Hip joint

Each child was asked to stand with minimal support for balance (a chair in front of him).The goniometer's axis was positioned at the greater trochanter of the femur, while the movable arm was directed towards the longitudinal axis of the femur and the fixed arm was parallel to the trunk. The hip joint of each child was flexed passively to the target angle (30 degrees). Then the child was informed to maintain this position and memorize it for 10 seconds while keeping their eyes opened, then went back to the starting position and was informed to reproduce the target angle actively while keeping their eyes closed **(Kiefer et al., 2013).**

b. Knee joint

- Non-weight bearing position:

Each child was informed to sit on a firm chair, their thigh fully supported and knees extended **(Lokhande et al., 2013)**. The goniometer's axis was located at the lateral epicondyle of the femur, while the fixed arm was pointed to the greater trochanter of the femur and the movable arm was pointed to the lateral malleolus of the fibula **(Norkin and White, 2003)**. The knee joint was passively flexed to the target angle of 30 degrees **(Lokhande et al., 2013).** After holding this position for 10 seconds, the child was asked to return back to their starting position. Then they were requested to actively replicate the target angle while keeping their eyes closed **(Lokhande et al., 2013 ; El Shemy, 2018).**

- **Weight bearing position:**

Each child was informed to stand on one limb with minimal support for balance (a chair in front of the child), with keeping the other side off the ground and slowly flexed the weight bearing extremity (affected side) till the target angle 30 degrees. The child was informed to keep this position 10 seconds, and then returned back to bilateral weight bearing. Finally, the child was asked to actively reproduce the target angle without the dependence on their vision **(Lokhande et al., 2013).**

c. Ankle joint

Each child was given instructions to sit on a chair with their hips and knees were flexed in ninety degrees. The ankle joint was in zero degree planter flexion **(Chen and Qu, 2019)**. The stationary arm was pointed to the outside of the calf muscles ,the movable arm was directed to the outer line of the fifth metatarsal bone, and the goniometer's axis was located at the lateral malleolus **(Kiefer et al., 2013).** The child was moved to the target angle of 15 degree planter flexion passively, he was told to keep this position for 10 seconds while his eyes opened then return back to its initial position. After that, the child was informed to actively reproduce the target angle while keeping their eyes closed **(Chen and Qu, 2019).**

Assessment of balance

Balance abilities were assessed by the Kids-Balance Evaluation System Test (kids-BESTest). The Kids-BESTest is a comprehensive postural control assessment modified for children from adult BESTest (**Horak et al., 2009).** It is the first assessment tool that evaluate all systems contributing to postural control in children with CP; it shows excellent ability to distinguish between different levels of postural control abilities for school-aged children with CP from 8 to 14 years **(Dewar et al., 2019)**.

The Kids-BESTest total score showed good intra-rater agreement (89%) and excellent intra-rater reliability (ICC=0.99, 95%CI 0.97 to 1.00), the intra-rater reliability of all domains was also excellent (ICC=0.93-0.98), the SDC for the total score was excellent (5.5 points or 5%). It showed good inter-rater agreement (83%) and excellent inter-rater reliability (ICC=0.97, 95%CI 0.94 to 1.00), the Test-retest reliability for total score was excellent (ICC=0.96, 95% CI 0.92 to 1.00) **(Dewar et al., 2019).** It has 36 tasks that categorize and detect postural control in six different domains: biomechanical constraints, stability limits, reactive postural responses, anticipatory postural adjustment, sensory orientation, stability in gait. The total score ranged from 0-108, every task was graded from 0 (lowest performance) to 3 (best performance) on a four-point scale and for every domain, a percentage that the child understood each task, instructions were given and each task was demonstrated. Each child received a practice trial on each item and two attempts were allowed for each child and recorded the best **(Dewar et al., 2017).**

Statistical analysis

Statistical package for the social sciences computer program (version 20 for Windows; SPSS Inc., Chicago, Illinois, USA) was used for data analysis. Data were presented as mean± SD. Unpaired t-test was used to compare between subjects' characteristics of the two groups. The chi squared test was employed to compare the distribution of sexes among the groups. Data were checked for normality assumption, variance homogeneity and presence of extreme scores. Shapiro-Wilk test for normality revealed that all measured variables were normally distributed, so one-way MANOVA was used to compare the measured variables between both groups. Pearson correlation coefficient was used to find the relation between joint position sense and balance in children with hemiplegia. *P*-value less than 0.05 was considered significant.

Results

There were statistically non-significant differences between both groups in the mean values of age, weight, height and BMI (P >0.05) (table 1). The frequency distribution of sex and affected side were presented in table (2).

As shown in table (3), there was statistically significant increase in the mean values of trunk, hip, knee, ankle joints repositioning error in children with hemiplegia than TD controls (P=0.001). As shown in table (4), there was statistically significant decrease in the mean values of all domains and total score of KIDS-BESTest in children with hemiplegia than TD children (P=0.001).

Regarding correlation between JPS and balance abilities in hemiplegic children as shown in table (5), there was statistically significant negative moderate correlation between trunk JPS and Kids-BESTest score (r= -0.583) (p=0.001). Statistically non-significant negative weak correlation was found between hip JPS and Kids- BESTest score (r= -0.135) (p=0.392). Also, non-significant negative weak correlation was found between knee JPS from (weight bearing and non-weight bearing positions) and Kids-BESTest score (r= -0.055 and -0.197) (p=0.727 and 0.212) respectively, and between ankle JPS and Kids- BESTest score (r= -0.271) (p=0.082).

Table (1): Demographic characteristics of children of each group

	Hemiplegic group	**TD Group**	**p-value**
	± SD $\boxed{\bar{X}}$	**± SD** $\boxed{\bar{X}}$	
Age (years)	9.64±1.59	10.05±1.55	0.240
Weight (kg)	33.43±11.83	36.79±9.12	0.149
Height (cm)	133±13.67	137.76±10.31	0.075
BMI (kg/m^2)	18.13±3.73	19.24±3.21	0.145

$\bar{X}$: Mean SD: Standard deviation p values: Probability values

Table (2): Frequency distribution of sex and affected side

	Hemiplegic group	**TD Group**	**p-value**
Sex distribution	N (%)	N (%)	
Males	21(50%)	29(69%)	0.075
Femlaes	21(50%)	13(31%)	
Affected side			
Right side	26 (62%)		
Left side	16 (38%)		

Data was expressed as number (percentage), χ^2 : chi square, p- value: significance.

Table (3): Comparison of the mean values of joint repositioning error between both groups

Joint repositioning error (degrees)	**Hemiplegic group**	**TD Group**	**P-value**
	± SD $\bar{X}$	**± SD** $\bar{X}$	
Trunk	8.17 ± 4.5	3.36 ± 1.64	0.001*
Hip	3.63 ± 2.06	2.5 ± 1.4	0.001*
Knee (Weight bearing)	6.97 ± 2.6	2.1 ± 1	0.001*
Knee (non-weight bearing**)**	2.85 ± 1.27	2.14 ± 1.2	0.011*
Ankle	2.97 ± 1.3	1.73 ± 0.87	0.001*

$\bar{X}$: Mean SD: Standard deviation p values: Probability values

*p: significant

Table (4): Comparison of the mean values of Kids-BESTest score between both groups

Kids-BESTest score	**Hemiplegic group**	**TD Group**	**P-value**
	± SD $\bar{X}$	**± SD** $\bar{X}$	
Biomechanical constraints	11.55 ± 1.93	14.02 ± 1.05	0.001*
Stability limits	18.83 ± 1.67	20.67 ± 0.65	0.001*
Reactive postural responses	14.07 ± 2.12	17.71 ± 0.51	0.001*
Anticipatory postural adjustment	13.62 ± 1.85	17.14 ± 0.72	0.001*
Sensory orientation	12.95± 1.29	14.42 ± 0.74	0.001*
Stability in gait	18.05 ± 1.99	20.83 ± 0.44	0.001*
Total Kids- BESTest score	89.48 ± 9.85	105.43 ± 2.09	0.001*

$\bar{X}$: Mean SD: Standard deviation p values: Probability values
*p: significant

Table (5): Correlation between joint position sense and balance in hemiplegic group

	Joint position sense	r-value	p-value
Total Kids- BESTest score	Trunk	-0.583	0.001*
	Hip	-0.135	0.392
	Knee (weight bearing)	-0.055	0.727
	Knee (non-weight bearing)	-0.197	0.212
	Ankle	-0.271	0.082

r value: Pearson correlation coefficient p value: Probability value *p: significant

Discussion

Children with CP exhibit poor posture maintenance due to impaired anticipatory and reactive postural adjustments as well as alterations in ground reaction force during postural correction. Their weak trunk muscles, impaired neural control and poor position sensing all contribute to their poor trunk control **(Seyyar et al., 2019).**

Balance is essential while carrying out all functional activities. Postural control aids in maintaining the one’s position in space, which is crucial for orientation and stabilization. Keeping for stable position requires extensive connections between the musculoskeletal and neurological systems **(Shumway-Cook and Woollacott, 2014).** Proprioception plays an important role in motor planning and execution, movement fluidity and precision **(Zarkou et al., 2020).** Deficits in proprioception can cause problems for children's gross and fine motor skills, making it difficult for them to run, jump and modify their movement's speed, timing, and direction **(Yardımcı-Lokmanoğlu et al., 2020)**. So investigating the relation between JPS and balance is crucial because the postural modifications required for a particular motor task are produced by combining information from the proprioception, sensory, and visual systems **(Juras et al., 2008).**

This study presented that the trunk position sense was more affected in children with hemiplegia compared to normal children. This can be explained as children with spastic CP have abnormal neural control, insufficient trunk muscle strength, and poor trunk control. Although they can accomplish motor activities, the quality of their movements is degraded, and their goal-directed motions are not executed precisely **(Monica et al 2021).** This finding was corroborated by the study of **Monika et al., (2021)** who found that errors in repositioning the trunk which was greater in CP than the normal individuals.

It was found that the hip JPS was more affected in children with hemiplegia which could affect their balance abilities as they depend on this joint in their balance strategies **(Rha et al., 2010)**. This finding agrees with results of **Wingert et al., (2009)** who found that the hemiplegic group showed higher hip joint position sense errors than controls.

Additionally, the knee JPS in the current study was more affected in children with hemiplegia than normal children. This finding may be related to muscle weakness that present in CP children as the innervated knee extensor muscles' activity was found to have a sufficient influence on the ability to recognize knee position. It was found that there might be a compensating effect on JPS due to the increased activity of the muscle spindles **(Manikowska et al., 2015).** This finding disagrees with **Chen et al., (2020)** who reported that the JPS error in CP group was not affected at 30° knee flexion than in TD subjects. Also, **Bartonek et al., (2023)** found that children with TD, CP, myelomeningocele, and arthrogryposis multiplex congenita did not differ in their knee JPS errors.

According to the results of this study the ankle JPS was more affected in children with hemiplegia than TD children. This can be clarified through the study of **Stolk-Hornsveld et al., (2006)** who reported that proprioceptive impairment is found to be greater in distal joints than proximal joints and tactile and proprioceptive deficiencies are found in the feet and ankles of CP. The results agrees with that of **Zarkou et al., (2021)** who found that ankle joint position sense were decreased in CP children.

The mean values of all domains of Kids-BESTest in hemiplegic children in the current study showed significant decrease compared to normal children. This is because hemiplegic children experience difficulties with balance as a result of reduced muscle strength, limited joint mobility, muscular stiffness, inadequate ankle, hip, and stepping strategies, and insufficient postural adjustments **(Kiefer et al., 2021).** The results come in agreement with **Billen and Laure (2022)** who found the children with CP exhibited considerably worse performance on the total Kids-BESTest score and in every domain score with the exception of the fifth domain compared to their TD peers.

Regarding the results of hemiplegic children in domain I of Kids-BESTest (biomechanical constraints), this may be due to many issues that presented in CP. The main issues arise from the neural injury, secondary issues arise from the primary issues when combined with growth and abnormal mobility, and tertiary issues arise from coping responses employed to get over the primary and secondary issues. For instance, one of the primary issues is a lack of muscle strength. Moreover, the performance may be impacted by spasticity, reduced muscle strength, and passive stiff contractures **(Koman et al., 2004).**

The results of hemiplegic group in domain II of Kids-BESTest (limits of stability) can be explained by the presence of hypertonicity, joint mobility restriction, muscle weakness, and insufficient dynamic postural adjustment. These factors may have been brought on by an abnormal recruitment sequence in the muscles and impairing muscle recruitment, which are linked to upper motor neuron injury **(Bigongiari et al., 2011).**

The results of hemiplegic group in anticipatory postural adjustments and transitions (domain III) may result from pre-tensioning the muscle throughout any task in these children (**Bigongiari et al., 2011).** The findings concerning domain IV (reactive postural responses) indicate that children with CP have a poor postural emergency backup system, which increases their risk of falling. This result agrees with **Woollacott and Shumway-Cook (2005)** who found that children with CP had less effective reactive balance, as evidenced by their higher sway during balance restoration, longer times were needed to restore their balance, and delayed recruitment of the ankle muscles.

The significant differences between hemiplegic and TD children in domain V (sensory orientation), agrees with **Kenis-Coskun et al., (2016)** who found that there were variations between sway velocities among typically developing children and CP children under both the eye opened and eye closed situations. This finding disagrees with **Billen and Laure (2022)** who found that there were no differerncesbetween both groups in the scores of sensory orientation domain. In domain VI (stability in gait), the result of the study was supported by **Billen and Laure (2022)** who reported that CP children revealed a slightly abnormal gait pattern and indications of instability, although they can change gait velocity and walk over barriers, they lack their stability which detected in a wider step and abnormal trunk and pelvis movement.

Regarding the correlation between JPS and balance in children with hemiplegia, there was a negative moderate correlation between the repositioning error of trunk joint and Kids-BESTest. These results may be due to poor trunk position sense of these children which affect negatively on their balance and their functional mobility. Also, this finding agrees with the work of **Monica et al., (2021)** who found that the trunk position sense revealed a moderate negative correlation with static sitting balance, which indicate that children with spastic CP who had improved trunk position sense also had improved trunk control. Also, children exhibiting greater functional performance showed improved trunk control and lesser errors in trunk position sense.

In the present study, it was found that there was a negative weak correlation between the repositioning error of hip joint position sense and Kids-BESTest total score. This result is consistent with the work of **Damiano et al., (2013)** who found that hip proprioception error was related to balance in people with both unilateral and bilateral CP. This finding could be attributed to mild motor affection in hemiplegic children participated in this study that may prevent these children from losing their balance during assessment.

The finding of this study declared that there was negative weak correlation between the repositioning error of knee joint position sense from (weight bearing and non-weight bearing positions) and Kids- BESTest total score. This finding is in line with the findings of **Fujisawa et al., (2005)** who reported that ankle and hip strategies were most responsible for maintaining postural control during bilateral static standing**.** This result was supported by the findings of **Jain et al., (2017)** who found weak negative correlation between knee joint proprioception error and dynamic balance.

They explained that this weak correlation because multiple signals from the visual, somatosensory, and vestibular systems interact to control balance and every sensory system is necessary for balance regulation. So proprioception is not the only component that is necessary for maintaining balance there are other elements also play a role in balance.

Moreover, there was negative weak correlation between the repositioning error of ankle joint position sense and Kids-BESTest score in hemiplegic children. This result agrees with that of **Zarkou et al., (2020)** who found that balance performance was highly correlated with vibration and two-point discrimination, while ankle JPS was only correlated with one subdomain of the BESTest (Postural Responses). These results suggested that balance problems may be partially associated with defects in ankle proprioception.

Conclusion

The findings of this study showed that children with hemiplegic CP have greater impairments to their trunk and lower limb JPS as well as balance in comparison to TDC. Trunk position sense error was strongly related to balance deficits while lower limb JPS error was partially related in children with hemiplegic CP. These findings imply that proprioceptive training of the trunk and lower limbs is crucial for enhancing balance performance in hemiplegic children.

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Conflicts of interest:

No conflict of interest.

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