

Sensory processing abilities, postural stability, and selective motor control in children with hemiplegic cerebral palsy: a cross-sectional study

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ABSTRACT

This study aimed to assess sensory processing abilities, selective voluntary motor control (SVMC) and postural stability among children with hemiplegic cerebral palsy (CP) and to compare hemiplegic CP and age-matched typically developing children (TDC). The ages of the children that took part in the study varied from 6 to 10 years old, and they included 30 TDC and 30 hemiplegic CP. Outcomes were assessed using: (a) the Child Sensory Profile 2 (CSP-2) to evaluate sensory processing; (b) the Test of Arm Selective Control (TASC) and the Selective Control Assessment of the Lower Extremity (SCALE) to assess selective voluntary motor control (SVMC) of the upper and lower extremities, respectively; and (c) the HUMAC Balance System to evaluate postural stability. The findings of the current study revealed statistically substantial reduction in HUMAC Balance System test scores of modified clinical test of sensory integration and balance (mCTSIB), center of pressure (COP) and limit of stability (LOS) 4 and 6 in children having hemiplegic CP in comparison with TDC ($p < 0.001$) respectively. A substantial decline was found in SCALE and TASC scores among children having hemiplegia in comparison with that of TDC ($p < 0.001$) while children with hemiplegic CP exhibited significantly higher scores compared to TDC across various sections of CSP-2. These findings may help guide clinical practice and inform decision-making to improve rehabilitation outcomes.

KEYWORDS

Sensory Processing Abilities; Postural Stability; Selective Voluntary Motor Control; Hemiplegia; Cerebral Palsy

1. INTRODUCTION

Cerebral palsy (CP) is a neurodevelopmental disorder that impacts motor skills, posture, and muscle tone. It constitutes the primary cause of motor impairment in newborns and young children. Motor impairments frequently correlate with disruptions in sensory processing, perception, cognition, communication, alongside behavior, in addition to epilepsy and subsequent musculoskeletal complications (Patel et al., 2020; Gulati & Sondhi, 2018).

Hemiplegic CP is defined by unilateral spastic weakness or paralysis resulting from a contralateral brain injury. Children with hemiplegia exhibit a delay in the attainment of motor milestones along with deficiencies in the coordination of body movements in the upper and the lower extremities (Fontes et al., 2017).

Sensory processing is the process by which brain systems process sensory information through neural systems, which includes the functioning of receptor organs in addition to the peripheral and central nerve systems. The brain processes, integrates, synthesizes, and utilizes information to understand experiences and formulate appropriate responses. Atypical connectivity and conductivity among brain regions associated with sensory processing and integration have been correlated with sensory modulation disorders (Bundy & Lanc, 2020).

Sensory processing disorders impair the ability to detect, modify, interpret, and react to sensory stimuli. Sensory modulation disorders are characterized by irregularities in the regulation of the degree, intensity, and nature of responses to sensory stimuli, leading to considerable challenges in daily tasks and routines (Jorquera-Cabrera et al., 2017).

Postural stability, or balance, is a multidimensional domain that encompasses the body's capacity to interact with disruptions, move effortlessly, and avoid falling. It is the capacity to maintain or restore the body's center of gravity (COG) perpendicular to the base of support (BOS), allowing for the safe and accurate execution of smooth coordinated motions (Patel et al., 2017). Postural stabilization involves a complex interplay of sensory information mechanisms, including the vestibular, visual, and proprioceptive systems. These systems convey information to the somatosensory cortex, where it is integrated to facilitate neuromuscular control, maintain equilibrium, and enable appropriate motor responses (Almeida et al., 2017).

Spastic CP is associated with damage to the corticospinal tract (CST) in addition to other motor pathways involved in SVMC. The SVMC refers to the capacity to carry out isolated, skilled, and accurate joint or limb movements with regulated force and speed in response to a command.

Deficits in SVMC impair coordination among lower limb joints, leading to varying degrees of coupling between the hip, knee, and ankle. SVMC has been shown to significantly influence gait patterns and mobility in children with spastic CP (Vuong et al., 2021).

Impaired SVMC refers to the diminished capacity to isolate muscle activation in a specific pattern in response to the requirements of a voluntary posture or movement. A synergistic mass movement pattern denotes an involuntary, simultaneous flexor or extensor response that takes place at two or more joints. Flexor or extensor synergies interfere with isolated joint movement, resulting in mandatory co-activation of muscle groups during functional activities like gait (Zhou et al., 2019). Individuals with CP may struggle to execute isolated joint movements without resorting to mass flexor or extensor patterns and mirroring, often due to accompanying impairments such as spasticity, diminished voluntary motor control, and altered sensory processing (Newell et al., 2020).

Limited upper extremity function is the most observed motor impairment in children with hemiplegia and has a significant impact on daily activities. These children exhibit disrupted sensorimotor integration, muscle weakness, abnormal tone, reduced motor selectivity, and spasticity - all of which restrict the functional use of the affected upper limb (El-Shamy, 2018).

Tactile sensory dysfunction also diminishes upper limb function among children with CP. Subsequently, the child often exhibits ineffective integration of tactile and proprioceptive sensory information due to both motor and sensory impairments. They exhibit deficits in visual motor integration (VMI) that impact the interplay between motor, visual perceptual (VP), along with visual skills. Deficient VP together with eye-hand coordination are prevalent among children having hemiplegic CP (Kuo et al., 2016).

A deeper understanding of sensory function and processing among children having CP is crucial, as sensory inputs are fundamental to motor function, control, in addition to development. Therefore, the purposes of this study are to examine sensory processing abilities, SVMC and postural stability in children with hemiplegia.

2. METHODS

2.1. Design and Participants

This cross-sectional study design included thirty children with hemiplegic CP from both sexes recruited randomly from outpatient clinic of Faculty of Physical Therapy Cairo University. Also, Thirty-age matched TDC participated in this study selected from primary schools in Luxor. Sample

size calculation was performed using G*POWER statistical software (version 3.1; Franz Faul, Universität Kiel, Germany) based on data from Jovellar-Isiegas et al. (2020) who examined sensory processing in children with unilateral cerebral palsy. Assuming a power of 80%, a significance level (α) of 0.05, an effect size of 0.8, and an allocation ratio of 1:1, the estimated required sample size was approximately 30 typically developing children and 30 children with hemiplegic cerebral palsy.

They were between the ages of 6 and 10, and their Modified Ashworth Scale scores for spasticity were 1 to 1+ (Bahanoon & Smith, 1987). Their motor function classification level was I–II according to Gross Motor Function Classification System (GMFCS) (Palisano et al., 2008). They were capable of following instructions throughout the evaluation procedures, and their caregivers possessed a sufficient command of the English language. Children were excluded from participation in this study if they have visual or auditory impairments, musculoskeletal problems or fixed deformities, surgical interference in upper, lower limbs and/or spine, seizures or received a Botulinum toxin injection within a six-month period prior to the study.

The Research Ethics Committee of the Faculty of Physical Therapy, Cairo University, granted approval for this investigation (P.T.REC/012/004244) with Clinical Registration Number NCT06989034. Prior to the study, all participants, including their parents, were briefed on the study's goals and procedures. Before the trial began, all participants' caregivers gave their consent.

2.2. Procedures

All children were assessed for sensory processing abilities using Child sensory profile 2 (CSP-2), postural stability using HUMAC balance and tilt system, and SVMC of upper extremity and lower extremity was assessed using test of arm selective control (TASC) and selective control assessment of lower extremity scale (SCALE).

Assessment of sensory processing abilities

All children were assessed using the CSP-2 which is a caregiver questionnaire consists of 86 items, designed for children aged 3:00 to 14:11 years. The parent or caregiver fills out the CSP-2 by assessing the frequency of the child's reactions to different sensory experiences, utilizing a five-point scale: (5 = almost always, 4 = frequently, 3 = about half of the time, 2 = occasionally, 1 = almost never, and 0 = does not apply). When a question is irrelevant to the child or the caregiver has never seen the behavior, they use the "does not apply" option. The questionnaire takes approximately 15 to 20 minutes to complete (Dunn, 2014).

The CSP-2 assesses four sensory processing patterns categorized into quadrants: seeking, avoidance, sensitivity, and registration. Furthermore, the CSP-2 assesses children's reactions to routine events in six sensory domains (auditory, visual, touch, movement, body position, and oral) along with three behaviors associated with sensory processing (behavioral, socio-emotional, and attentional) (Dunn, 2014).

The test-retest reliability of Sensory Profile 2 is rated as good to excellent. Most inter-rater reliability coefficients were deemed acceptable to good, with diminished coefficients noted in the domains of visual and tactile processing. There was a moderate to high level of validity among the Sensory Profile (SP) as well as SP2 (Louwrens, 2018). Sensory Profile 2 exhibits strong construct validity (Dean et al., 2016).

Assessment of postural stability

All children underwent evaluation utilizing the HUMAC balance along with tilt system, which assesses both static and dynamic balance components. Balance was evaluated on the force platform using three tests: the modified clinical test of sensory integration of balance (mCTSIB), center of pressure (COP), as well as limits of stability (LOS). The platform's horizontal and vertical lines were utilized to define the anatomical zero point before commencing any tests. In the beginning, children were instructed to assume their natural posture, after which their foot positioning was recorded utilizing the scales of the HUMAC balancing board (Koltermann et al., 2017).

Modified Clinical Test of Sensory Integration and Balance (mCTSIB): This assessment was formulated to evaluate sensory integration of balance on both firm and foam surfaces in open and closed eye conditions, specifically: Eyes Open Firm Surface (EOFS), Eyes Closed Firm Surface (ECFS), Eyes Open Soft Surface (EOSS), in addition to Eyes Closed Soft Surface (ECSS). The child's feet were placed on the hard platform, and he was told to look at a mark on the wall at eye level for 30 seconds. This was done because 30 to 60 seconds was a good amount of time for data analysis (Dounskaia et al., 2018). The procedure was conducted twice on a foam surface, first with the eyes open and then with them closed, prior to being instructed to close his eyes for an additional 30 seconds. For each condition, three tests were performed, and the optimal value from each set of results was employed (Lotfi et al., 2018).

The center of pressure test (COP) was conducted to assess the child's ability to sustain static balance. The child was directed to position themselves on the platform. Upon evaluating his foot position, he learned that the purple point displayed on the screen indicated his body movement. He

was subsequently directed to maintain this point at the center of the X and Y axes by stopping any body movement and ensuring maximum stability. The testing procedure had a duration of 30 seconds and was conducted three times. The average value was determined based on the outcomes of each trial, reflecting the percentage of stability observed in each instance (Qu et al., 2015).

The limit of stability test (LOS): This test evaluated the dynamic balance (Alsalaheen et al., 2015). The child was directed to stand on a platform and was trained to figure out the test prior to measurement. Participants were instructed to track an illuminated purple point indicative of their body's movement and to maintain stability for one second until a new target was illuminated. After then, the target was moved to catch it and hold it steady until another target was lighted. The test measures body movement in eight directions: front, back, front/right, back/left, right, left, back/right, and front/left. The mean value is calculated from three repetitions. The test is conducted at levels 4 and 6, representing the distance to the farthest target. Level 4 is simpler, with relatively small distances between center targets and surrounding targets. Level 6 has larger distances, indicating better performance. Higher values indicate better performance (Yassin et al., 2020).

Selective motor control assessment

The Test of Arm Selective Control (TASC) is a reliable as well as valid assessment tool used to evaluate the selectivity of upper extremity movements, encompassing the shoulder, elbow, wrist, fingers, and thumb extension (key grip), as detailed in the administration and scoring guide. The assessments were conducted while seated in a comfortable chair with feet positioned on the floor. The examiner illustrated the test requirements for the two primary starting positions and joint movements to the child. With the shoulder in mid-rotation, (1) extend the elbow, wrist, and fingers; (2) flex the elbow 90 degrees, place the forearm in mid-position, and extend the wrist and fingers. The examiner would passively guide the tested upper extremity through its entire range of motion as they demonstrated the appropriate action for each test. Subsequently, the participant was directed to actively mobilize the tested extremity, utilizing a three-second verbal count. Positions were assigned scores of 'unable' (0), 'impaired' (1), or 'normal selective voluntary motor control (SVMC)' (2). The total score for each upper extremity was 16, with a maximum possible score of 32 for both tested extremities, indicating that a higher score reflects better performance (Sukal-Moulton et al., 2018).

The Selective Control Assessment of Lower Extremity Scale (SCALE) was utilized to assess the capability of children with CP to execute SVMC movements across various joints. The subject was instructed to execute the subsequent reciprocal movement patterns: (1) hip flexion and extension

with the knee in an extended position, (2) knee extension and flexion, (3) ankle dorsiflexion and plantarflexion while the knee remains extended, (4) subtalar inversion and eversion, in common with (5) toe flexion and extension. All measurements were conducted in the sitting position, apart from hip joint flexion, which was assessed in the side-lying position to ensure adequate joint excursion. The participants were directed to execute the task by counting for 3 seconds as the examiner passively manipulated their extremities through the specified ROM.

If the child successfully completed the movement within the given time without moving any untested ipsilateral or contralateral lower extremity (LE) joints, a score of 2 points (normal) was assigned. A score of 1 (impaired) was given if the child made one of the following errors: performing only one directional movement, achieving less than 50% of the movement, moving a non-tested joint (including mirror motions), or exceeding the three-second verbal count. A score of 0 (unable) was assigned if the child did not initiate the required movement or displayed a mass extensor or flexor synergistic pattern. This process was repeated for each joint in the lower extremities (Fowler et al., 2010).

2.3. Statistical Analyses

All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 25 for Windows. Levene's test for homogeneity of variances was performed to assess the homogeneity of variances across groups. An unpaired t-test was performed to compare the demographic features of children among groups. A chi-squared test was performed to compare the sex distribution among groups. An unpaired t-test was performed to compare all outcome measures among the groups. The alpha level for the statistical tests was established at $p < 0.05$.

3. RESULTS

Table 1 presents a comparison of the demographic and anthropometric characteristics of typically developing children (TD/TDC) and children with hemiplegia. It compares the two groups in terms of age, weight, height, and body mass index (BMI), using mean values and standard deviations. Table 2 presents the frequency distribution of sex in the typically developing (TD) group and the hemiplegic group, as well as the distribution of the affected side among children with hemiplegia. No substantial difference was noted among both groups in age, weight, height, BMI as well as sex distribution ($p > 0.05$) as shown in table 1 and 2.

Table 1. Comparison of demographic characteristics between TDC and children with hemiplegia

	TD group	Children with hemiplegia	MD	p value
	Mean $\pm$SD	Mean $\pm$SD		
Age (years)	8.37 $\pm$ 1.25	7.86 $\pm$ 1.32	0.54	0.12
Weight (kg)	24.60 $\pm$ 3.20	23.76 $\pm$ 4.46	0.84	0.41
Height (cm)	127.23 $\pm$ 6.84	125.93 $\pm$ 7.46	1.3	0.48
BMI (kg/m²)	15.25 $\pm$ 2.10	14.99 $\pm$ 2.56	0.25	0.66

Note. MD: Mean difference; SD: Standard deviation; p value: Probability value

Table 2. Frequency distribution of sex and affected side

	TD Group	Hemiplegic group	p value
Sex distribution	N (%)	N (%)	
Males	15(50%)	17(57%)	0.61
Females	15(50%)	13(43%)	
Affected side			
Right side	18(60%)		
Left side	12(40%)		

Note. Data was expressed as number (percentage), p- value: Probability value

The analysis of the Child Sensory Profile 2 (CSP-2) scores revealed that children having hemiplegic CP exhibited significantly higher scores compared to TDC across various sections. In the sensory sections, significant increase was observed in auditory, visual, touch, movement, body position, as well as oral sensory processing ($p < 0.01$). Similarly, in the behavioral sections, significant increases were noted in conduct, social emotion, and attention ($p < 0.001$). In the quadrants, children having hemiplegic CP had higher scores in seeking, avoiding, sensitivity, in addition to registration ($p < 0.001$) compared with TDC as shown in table 3.

Table 3. Comparison of sensory processing scores by domains between TDC and children with hemiplegia

	CSP-2 domains	TDC	Children with hemiplegia	MD	p	D
		Mean $\pm$ SD	Mean $\pm$ SD			
Sensory domains	Auditory	19.90 $\pm$ 4.28	26.20 $\pm$ 3.22	-6.3	0.001*	1.65
	Visual	12.00 $\pm$ 2.37	14.40 $\pm$ 2.38	-2.4	0.001*	1.01
	Touch	14.50 $\pm$ 3.09	21.66 $\pm$ 4.94	-7.16	0.001*	1.72
	Movement	16.00 $\pm$ 2.53	20.46 $\pm$ 2.34	-4.46	0.001*	1.83

Behavior's domains	Body position	11.70 ± 2.27	15.96 ± 2.49	-4.26	0.001*	1.79
	Oral sensory	17.40 ± 5.64	21.63 ± 5.10	-4.23	0.004*	0.79
	Conduct	17.96 ± 4.70	24.56 ± 6.26	-6.6	0.001*	1.19
	Socio-emotional	25.73 ± 3.49	29.93 ± 5.40	-4.2	0.001*	0.92
	Attentional	20.23 ± 4.31	26.20 ± 3.51	-5.97	0.001*	1.52
Quadrants	Seeking	41.10 ± 7.47	54.53 ± 9.74	-13.43	0.001*	1.54
	Avoiding	38.03 ± 3.83	46.20 ± 4.08	-8.17	0.001*	2.06
	Sensitivity	34.93 ± 6.90	49.70 ± 6.85	-14.77	0.001*	2.15
	Registration	36.10 ± 3.82	48.10 ± 2.82	-12	0.001*	3.57

Note. MD: Mean difference; SD: Standard deviation; *p* value: Probability value; **p*: Significant; D: Effect size

Table 4 compares the HUMAC balance system test scores between typically developing children (TDC) and children with hemiplegia across sensory integration, center of pressure (COP), and limits of stability (LOS) measures.

Table 4. Comparison of HUMAC balance system test scores between TDC and children with hemiplegia

	Tests	TDC	Children with hemiplegia	MD	<i>p</i>	D
		Mean ± SD	Mean ± SD			
Modified clinical test of sensory integration and balance	Eyes open firm surface	86.86 ± 3.13	83.20 ± 4.22	3.66	0.001*	0.98
	Eyes closed firm surface	85.00 ± 6.04	76.10 ± 9.72	8.9	0.001*	1.10
	Eyes open foam surface	78.86 ± 6.15	70.76 ± 9.51	8.1	0.001*	1.01
	Eyes closed foam surface	70.43 ± 5.28	62.70 ± 5.33	7.73	0.001*	1.46
Center of pressure	COP	89.10 ± 3.95	85.03 ± 5.22	4.07	0.001*	0.88
Limits of stability	LOS 4	36.66 ± 5.93	22.60 ± 4.14	14.06	0.001*	2.73
	LOS 6	31.66 ± 2.05	22.16 ± 1.41	9.5	0.001*	5.37

Note. MD: Mean difference; SD: Standard deviation; *p* value: Probability value; **p*: Significant; D: Effect size

There was a substantial reduction in HUMAC balance system tests' scores of eyes open firm surface, eyes closed firm surface, eyes open foam surface, eyes closed foam surface, COP, LOS 4 and LOS 6 among children having hemiplegic CP in comparison with TDC ($p < 0.001$) as presented in table (4).

The analysis of test of arm selective control (TASC) scores together with selective control assessment of lower extremity scale (SCALE) revealed that there was a substantial reduction among children having hemiplegia in comparison with TDC ($p < 0.001$) as presented in table (5).

Table 5. Comparison of SCALE and TASC scores between TDC and children with hemiplegia

	TDC	Children with hemiplegia	MD	p value	D
	Mean $\pm$ SD	Mean $\pm$ SD			
SCALE	19.33 $\pm$ 1.77	12.37 $\pm$ 2.08	6.97	0.001*	3.61
TASC	30.73 $\pm$ 2.95	22.40 $\pm$ 3.31	8.33	0.001*	2.66

Note. MD: Mean difference; SD: Standard deviation; p value: Probability value; *p: Significant; D: Effect size

4. DISCUSSION

The purpose of this study was to assess sensory processing abilities, postural stability and SVMC among children with hemiplegic CP and to compare hemiplegic CP and age- matched TDC. Sixty children, aged from 6 to 10 years, collaborated in the study, 30 TDC and 30 children with hemiplegia.

It was reported that children with CP reveal that 45% of neuroimaging exams show white matter damage, potentially impacting sensory processing development in cortical and thalamic areas. This could help identify potential causes of sensory processing deficiencies, motor coordination, fine along with gross motor function, in addition to motor control issues among CP. Primary dysfunctions from CNS injury contribute to sensory impairment, while functional impairments in activity together with social participation may increase sensory processing abnormalities due to restricted sensory exploration (Pavão & Rocha, 2017).

Children with CP often face challenges in exploring their environment and participating in activities that require diverse movements. Proprioceptive as well as vestibular sensory input can be influenced by motor difficulties, such as uncontrolled movement patterns and deficient postural control, which can lead to secondary impairments along with atypical sensory responses. In addition to sensory issues, they also face functional challenges because of muscle tone abnormalities and insufficient postural control. Children suffering from CP frequently exhibit sensory-processing

disorders; however, they frequently go undiagnosed. The emotional well-being, motor functions, along with daily activities of a child can be impacted by these sensory-processing difficulties (Erkek & Cekmece, 2023).

Most of the research regarding sensory processing among children with CP employs sophisticated neuroimaging methods that are not easily available in clinical environments. The application of clinical measures to evaluate sensory processing among children with CP is still relatively rare (Pavão et al., 2021). Choosing CSP-2 as a tool used for assessment of sensory processing abilities in this study as it has many advantages including it focuses on sensory modulation; it belongs to the latest version of the Sensory Profile (SP); and it is a comprehensive tool that can be easily used clinically (Park, 2017).

Choosing balance and SVMC as an outcome measure of the current study because they affect the functional performance of children having CP. This is corroborated by Gan et al. (2008) who demonstrated that balance as well as upright postural control are essential elements of movement aside from functional activities, since they encompass the capacity to recover from instability and to predict it. They stated that diminished SVMC hinders functional movements, including gait and reaching, when flexor or extensor synergies hinder isolated joint movement.

The balance abnormalities that are observed in CP are the result of an early brain lesion that occurs during pregnancy or birth. The exact cause of these balance abnormalities is dependent upon the brain region that is affected. Spastic CP, the most prevalent form, results in injury to the motor cortex in addition to the white matter that surrounds it. Hypertonicity of the injured muscle groups is one of the signs of this condition. Spasticity directly affects balance by limiting one's capacity to respond to postural perturbations or by modifying gait kinematics (Niiler, 2018).

Selective voluntary motor control, enabling rapid and independent regulation of joint motion, is a fundamental aspect of normal human movement. Children having spastic CP exhibit compromised SVMC as one of four interrelated neuromuscular deficits that frequently combine with muscle weakness, spasticity, and reduced muscle-tendon length. All four motor deficits share a common denominator: damage to the CST and other descending motor tracts, which leads to a lack of excitatory and inhibitory descending signals (Cahill-Rowley & Rose, 2014).

The SVMC assessment and the distribution of impairment in young children with CP can aid in treatment planning and motor function development. A deeper understanding of sensory function

and processing among children with CP is crucial, as sensory inputs are fundamental to motor function, control, in addition to development.

Data obtained from both groups regarding demographic characteristics, sensory processing abilities, postural stability and SVMC were statistically analyzed. The findings indicated that the mean values for age, weight, height, BMI, and gender did not substantially differ between the two groups, attributable to the sample's homogeneity.

Regarding the analysis of the study's results, a significant decrease was found in postural stability scores of mCTSIB, COP along with LOS among children having hemiplegic CP in comparison with TDC while regarding sensory processing abilities scores revealed that children having hemiplegic CP exhibited substantially higher scores in comparison with TDC across various sections. For selective motor control of upper extremity and lower extremity, a substantial reduction was found in SCALE and TASC of children having hemiplegic CP in comparison with TDC.

The significant differences between hemiplegic and TDC in sensory processing abilities tests scores, aligns with the findings of Jovellar-Isiegas et al. (2020) who found that UCP children often exhibit avoidance in addition to registration sensory profile patterns, with greater difficulties in sensory processing and functional performance in mobility, social/cognitive function, along with everyday activities. The processing of auditory, visual, along with tactile information is associated with engagement in educational settings and psychological health.

Considering sensory processing, the significant differences between hemiplegic and TD children in sensory processing abilities, aligns with the findings of Mahesan et al. (2024) who found that vestibular and proprioceptive processing were the predominantly affected sensory processing domains. Children with CP had problem in registration and therefore had a high threshold for environmental stimuli and respond passively. The pattern of sensory processing was similar across various CP subtypes.

Additionally, Pavao & Rocha (2017) found that children with CP have impairments in vestibular processing, visual processing, and multisensory processing. In addition to their motor impairment, children with cerebral CP are clumsy and their participation in physical therapies is affected by their sensory processing pattern, which was dominated by problems in registration or "bystander," suggesting that they have a high threshold for environmental stimuli and respond passively, possibly missing sensory inputs from their surroundings (Dunn & Daniels, 2002).

The significant differences between hemiplegic and TDC in the auditory processing section, vestibular processing and oral processing, comes in agreement with findings of Al-Heizan et al. (2015) who found that more than 50% of children in their study were in typical performance range in taste and smell sensitivity, movement sensitivity and auditory sensitivity.

A study by Erkek & Çekmece (2023) revealed that sensory-processing abilities among children having CP are associated with motor function, balance, together with bilateral upper-extremity utilization. There is a wide range of disorders affecting these skills, but problems with proprioception and vestibular sensory processing are prevalent. Children having CP are more likely to have sensory-modulation problems, especially those involving sensory sensitivity and registration. Sensory registration affects perception skills and sensitivity impacts activity participation. Raising awareness about sensory disorders can improve SP rehabilitation and positively impact treatment.

Considering postural stability; the significant differences in postural control parameters between children with hemiplegia and TDC come in line with the results of Abd Elaziz et al. (2024) who found that the mean values of all domains of Kids-BESTest for balance in hemiplegic children showed significant decrease compared to normal children. Children having CP may rely predominantly on feedback from their visual in addition to vestibular systems in balance-challenging circumstances, unlike individuals without CP. Children having CP may have trouble controlling their balance because of problems in at least one of the sensory systems listed above (Yu et al., 2020).

The significant decrease in postural stability tests' scores measured by HUMAC balance system among children having hemiplegic CP in comparison with TDC may be elucidated by the work of Zarkou et al. (2020) who found that children who have CP may have inadequate postural control and balance due to inefficient weight transfer along with deficient ankle strategies. Also, Kiefer et al. (2021) reported that balance is affected among children having CP due to spasticity, muscle weakness, limited range of joint movement, inadequate ankle and hip and stepping strategies and poor postural feedback reactions.

Kenis-Coskun et al. (2016) conducted a computerized assessment to compare the static and dynamic balance of a homogeneous group of hemiplegic CP children with TD children. They found significant differences between both groups in postural stability parameters which may be due to musculoskeletal asymmetry, and they added that these differences remain unaffected by age, gender, or spasticity but are typically consistent with the affected side.

Considering SVMC; Children with CP exhibit altered ankle and hip control synergies, with limb protraction/retraction contributing more than healthy controls, possibly due to poor ankle control. The augmentation of this contribution in the A-P plane is likely attributable to inadequate ankle control. Conversely, ankle inversion/eversion control contributes minimally to M-L sway within healthy individuals in addition to children having CP. Alterations in biofeedback inputs, particularly visual stimuli, may induce instability and elevate the risk of falls (Ferdjallah et al., 2002; Rojas et al., 2013).

The substantial differences among hemiplegic as well as TDC in SVMC, comes in agreement with findings of Lim (2015) who found that children having CP exhibit different muscle recruitment patterns and magnitudes, which can affect voluntary muscle recruitment and motor ability. Children having spastic CP engage unintended muscles during maximal voluntary contractions, particularly when the target muscles are more distal. In addition, there is an increase in SVMC impairment of the lower limb's distal joints, which means that these joints are less able to be moved independently.

The significant differences between hemiplegic and TD children in SVMC can be explained by the work of Fowler et al. (2009) who noted that children with cerebral palsy exhibit mirror movement, which is characterized by uncontrolled, paired motions at the joints opposite the affected one. Timing errors in muscle recruitment are the cause of this sign. Thus, synergies are a typical neurological symptom that arises from the inability to selectively recruit a muscle or group of muscles without incorrect antagonistic activation. There is a direct correlation between this sign and CST lesion together with SVMC loss.

Reports indicate that individuals with CP exhibit a 20–50% reduction in their ability to actively contract the plantar flexors and quadriceps, along with alterations in their muscle activation patterns, especially concerning distal agonists (Alves-Pinto et al., 2016). The enhancement in SVMC for proximal segments of the more affected LE may be attributed to anatomical connections, indicating that distal LE pathways are likely to be more susceptible than proximal LE tracts due to the somatotopic organization of the sensorimotor cortex (O'Brien et al., 2020).

A therapeutic environment is created in which the child learns rich sensory motor experience and improvement occurs in his ability to process and integrate visual, perceptual, proprioceptive and auditory sensory information. Because it aids in the simplification of the environment and leads to considerable behavioral efficiency advantages, this enables the individual to carry out every day functional activities and engage in meaningful occupations (Jovellar-Isiegas et al., 2020).

Better comprehension of sensory function and processing in children with CP is extremely important, since the sensory inputs are essential components of motor function, motor control and development. The main elements of sensory motor integration and conductive education should include: (1) task-oriented learning within highly structured programs; (2) facilitating and commenting on motor actions by rhythmic intending, for example, rhythmic speaking or singing; (3) integration of manual abilities into the context of activities of daily life (ADLs); and (4) child-oriented group settings to facilitate psychosocial learning to increase the level of participation (Blank et al., 2008).

Understanding how hemiplegic CP children process sensory information is crucial for understanding their functional performance, participation, and quality of life. Proprioceptive input difficulties contribute to poorer performance, while auditory, visual, and tactile information processing is associated with school participation. Psychological well-being is linked to sensory processing-related behavioral and social-emotional reactions. This study has clinical ramifications for families and professionals, demonstrating that knowledge of how UCP children interpret sensory data can help develop modifications for activities and environmental demands that encourage their involvement.

4.1. Limitations

This study was limited to one type of CP (children with hemiplegic CP aged from 6 to 10 years), a small sample size, which largely affects its generalizability, and being limited to caregivers who speak English well, which was challenging and time-consuming to find in a community where Arabic is the primary language.

5. CONCLUSIONS

The findings of this study showed that children with hemiplegic CP have greater impairments in sensory processing abilities and postural stability as well as selective voluntary motor control in comparison to TDC. These sensory motor impairments considered to be the main contributors to the functional limitations and hindering daily participations. These findings imply the importance of considering these clinical variables in designing rehabilitation program for clinical applications to enhance hemiplegic children their functional capabilities; movement performance; and to be active contributor in the community.

Future research should focus on different age groups and types of CP and evaluate different components of balance control. Further studies are recommended on a large sample of CP. Studying

the effect of gender on the sensory integrative function. Studying sensory integrative function during infancy, childhood, and adolescence is recommended.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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