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Development of AI-Based Measurement Techniques for Quantitative Behavioral Assessment in Clinical Observation Evaluations Based on Sensory Integration

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Sensory integration-based clinical observation refers to the process of integrating various sensory inputs to make observations. This integration is critical for children, as damage to the motor coordination system can lead to developmental coordination disorder, potentially causing delays in tasks like writing or language development. Clinical observations of this nature are qualitative, relying on therapists' visual confirmation and subject to their subjective judgments. To overcome the limitations of qualitative assessments, this study conducted a quantitative analysis. It involved capturing subjects' hands using a webcam and extracting joint coordinates from the resulting human model. The analysis aimed to generate quantitative metrics, such as the number of hand flips, angles, success rates, and the correlation coefficient between both hands. The results revealed that, in analyzing the RFR (Reaching, Flipping, and Returning) task of 21 subjects with normal hand function, the subjects averaged 14.6 (2.73) flips in a 15-second task, with success rates of approximately 95.5 % (6.43) for the left hand and 93.5 % (8.13) for the right hand. Therefore, the study confirmed the potential of integrating quantitative assessment methods to complement qualitative evaluation methods.

Keywords : qualitative assessment, quantitative assessment, sensory integration-based clinical observation

1. Introduction

In the field of occupational therapy, assessments based on sensory integration are conducted to evaluate the sensory processing abilities of children [1]. The development of sensory integration is fundamental for a child's posture and motor skills, achieved through the integration of sensory systems, and is primarily applied in children's therapy [2]. Sensory integration is thus essential for children; however, cases exist where developmental coordination disorder (DCD) emerges from damage to motor organization, as identified by the Dyspraxia Foundation [3]. Children with such developmental disorders may face challenges not only in simple tasks like language development and handwriting [4][5], but also in performing daily activities, socializing with peers, or engaging in other activities [6]. To address these challenges, sensory integration intervention is frequently utilized and has proven effective for children with DCD and various others experiencing sensory integration issues, including autism and intellectual disabilities [7]. Sensory integration intervention plays a significant role in child therapy, with diverse assessment methods employed to evaluate sensory integration skills. These methods include interviews, questionnaires, standardized tests, informal observations, and formal observations. Domestically, the most widely used assessment tools are the Sensory Profile, a questionnaire format for assessing sensory modulation, and clinical observations for evaluating children's motor skills based on sensory input [8].

Clinical observation assessment tools are primarily utilized to examine neurological signs, patterns, or characteristics of motor and sensory performance. These tools frequently evaluate the integration of functions on both sides of the body, muscle function, and reflex function [9]. Clinical observations can progressively reveal factors or performance abilities that either facilitate

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or impede the developing and evolving functions of children. For instance, reading abilities or attention can be significantly affected by oculomotor movements related to vestibular function, and these oculomotor control functions can be assessed through clinical evaluations [10]. However, clinical observation assessments face limitations because of the subjective judgment of the therapist, challenging the objective measurement of behavior [8]. These limitations underscore the necessity of ensuring objectivity in assessment tools by incorporating quantitative evaluation techniques.

Numerous studies have sought to enhance objectivity by combining quantitative assessments with qualitative evaluations. Among these, research focusing on the quantitative assessment of human motion in clinical observation assessments has frequently utilized sensors, wearables, and artificial intelligence (AI) methods.

In a study focused on the quantitative analysis of movement via modules and sensors, researchers evaluated shoulder joint movements using two inertial modules. Each module comprised a 32-bit microcontroller (MCU), a triaxial accelerometer, gyroscope, and magnetometer. To minimize errors in joint angle assessment, a quaternion-based complementary nonlinear filter was implemented [11]. Another investigation utilized motion sensors to assess lower limb functionality in Parkinson's disease patients. These sensors, attached to patients' lower limbs, facilitated leg agility tests. Data analysis techniques included support vector machines (SVM), decision trees, and linear regression, employing ten-fold cross-validation [12]. Despite their high accuracy, these methods have limitations due to the necessity of attaching sensors, which restrict movement and environmental adaptability, and are cost-intensive.

Another study investigating wearable technologies for quantitative motion analysis focused on walking assessment. Data were gathered using body-attached sensors and insole sensors in shoes, enabling the measurement of joint angles under various walking conditions [13]. Additionally, a study examined wrist stiffness in Parkinson's disease patients using a home-based wearable mechatronic device. This device, featuring one actuated joint and four passive revolute joints, facilitated the collection of wrist movement data in daily activities [14]. While these wearable technologies offer considerable accuracy, they are constrained by factors such as high cost and spatial limitations.

In a study focusing on quantitative measurement methods utilizing AI, the MediaPipe Hands Model was employed for hand detection, subsequently identifying changes in static postures through key points. This method demonstrated real-time recognition of hand points and hand-written gestures, achieving an average accuracy of 96.4 % [15]. Another study compared gender-based differences in vertical drop jumps using the VMocap system. This video-based VMocap system, in conjunction with convolutional networks, facilitated motion detection and the calculation of joint angles [16]. AI use presents a potential drawback of reduced accuracy compared to other quantitative evaluation methods. Nevertheless, it enables prediction of obscured movement parts by analyzing the front and rear sections. Additionally, the use of cost-effective cameras offers an affordable means of motion analysis without movement restrictions, as it is not physically attached to the body.

The aforementioned studies illustrate the application of diverse quantitative techniques in human motion assessment. These advancements confirm that engineering technology can effectively evaluate human movements. Consequently, integrating quantitative assessment techniques with clinical observation could enable the quantitative evaluation of aspects previously assessed qualitatively (subjectively) or challenging to measure. In this context, our study aimed to identify sensory integration-based clinical observation items suitable for technological application and to apply AI-based quantitative assessment techniques. This approach seeks to explore the potential for quantifying clinical observations. Moreover, we plan to employ the AI measurement program developed in this study to examine both children with developmental coordination disorders and typically developing children, investigating the characteristic and qualitative differences in their performance.

2. Materials and Methods

2.1. Participant Recruitment Methods

We conducted open recruitment within the local community and collaborated with developmental disability child centers, among others, to recruit participants. This effort resulted in the recruitment of 21 non-disabled children and 9 children with developmental disabilities (7 with autism spectrum disorder and 2 with intellectual disabilities) as participants (Table 1).

2.1.1. Subject

The Institutional Review Board for Human Research Ethics at Sangji University (1040782-220816-HR-11-104) granted approval for this study.

2.2. Experimental Setup and Environment

In this study, we conducted an experiment where

Table 1. Recruited subject information.

Gender (n)	Control group (n = 21)	Experimental group (n = 9)
Male	8	7
Female	13	2
Age (years)	8.8 ± 0.91	11.2 ± 2.0

selected tasks were given to child participants to perform, and their actions were recorded using a camera for subsequent analysis. A Logitech HD Stream Webcam (C920E(V-U0060)), an affordable camera, facilitated the recording. Participants wore different colors for their upper and lower garments to easily distinguish between the upper and lower body. Additionally, armless chairs were used to minimize errors. To ensure the participants' entire bodies were visible while seated, we positioned the camera approximately 175 cm away from the chair, with a height of 130 cm and an angle of about 45 degrees downward.

Figure 1 illustrates the entire development process of this study. After designing the experiment and setting up the camera, we recorded the participants performing two tasks. The recordings were then analyzed to extract quantitative values. These values included the coordinates of hand joints, upper body joints, and nose position, which were used to calculate the cross product vector of the hands or the distance between coordinates, representing angles or distances in the movements. The results were summarized in graphs and tables, presenting various quantitative values.

2.3. Selection of Task

2.3.1. Selection Process

For this study, various sensory integration-based performance items were chosen. The task selection process began with a literature review. The results of this review guided a panel of experts, comprising an engineering specialist and two Ph.D. holders in occupational therapy, to convene and finalize two tasks. Based on the literature review, two items were identified where occupational therapists faced measurement challenges in clinical observations: the "Finger-to-Nose" and "Postural Control" tasks. Additionally, items with a high perceived need for the application of AI measurement technology were ranked as follows: "Postural Control (on the ball)," "Eye Movement," "Prone Extension," and "Forearm Alternating Movements (Diadokokinesis)" [11]. An expert meeting, informed by these findings, considered the suitability of using AI technology to analyze movement. The experts agreed that activities involving the upper extremities would be more suitable for analysis. They also deemed the presence of repetitive movements crucial for validating movement measurement accuracy. These considerations led to the final selection of two tasks.

2.3.2. Selected Subjects

The tasks chosen, based on literature review and expert consultations, were the Rapid Forearm Rotation and the Finger-to-Nose Test. The Rapid Forearm Rotation requires flipping both hands simultaneously in the same direction, keeping the elbows close to the body. The Finger-to-Nose Test involves extending the arms sideways and alternately touching the nose with the index finger of each hand. These tasks are traditional neurological examination techniques used to assess cerebellar function and bilateral

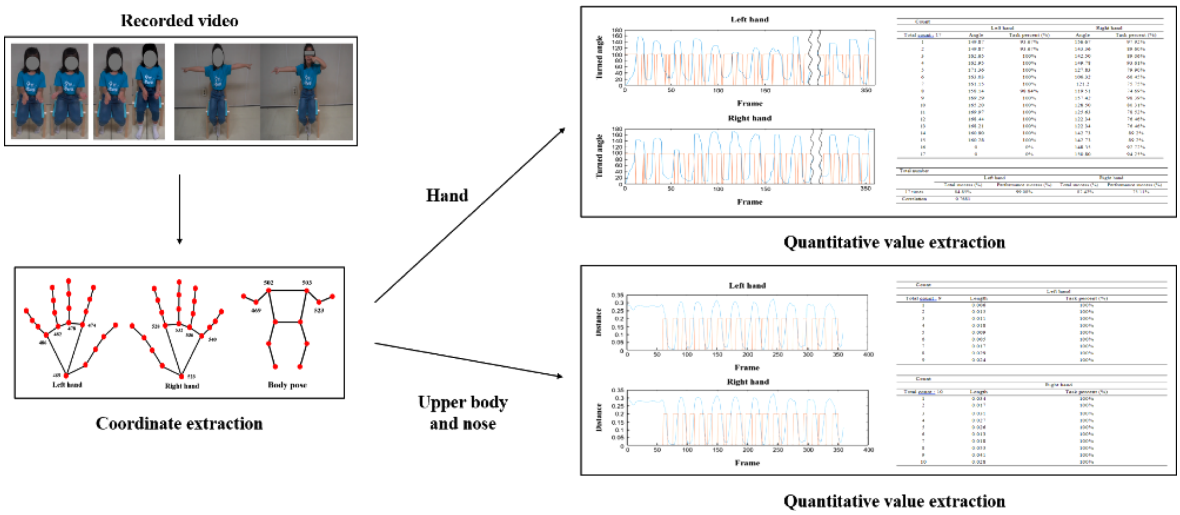

Fig. 1. (Color online) Total development process - Coordinates for the hand, upper body, and nose are extracted after recording the video. These coordinates are then used to evaluate the quantitative results of each movement.

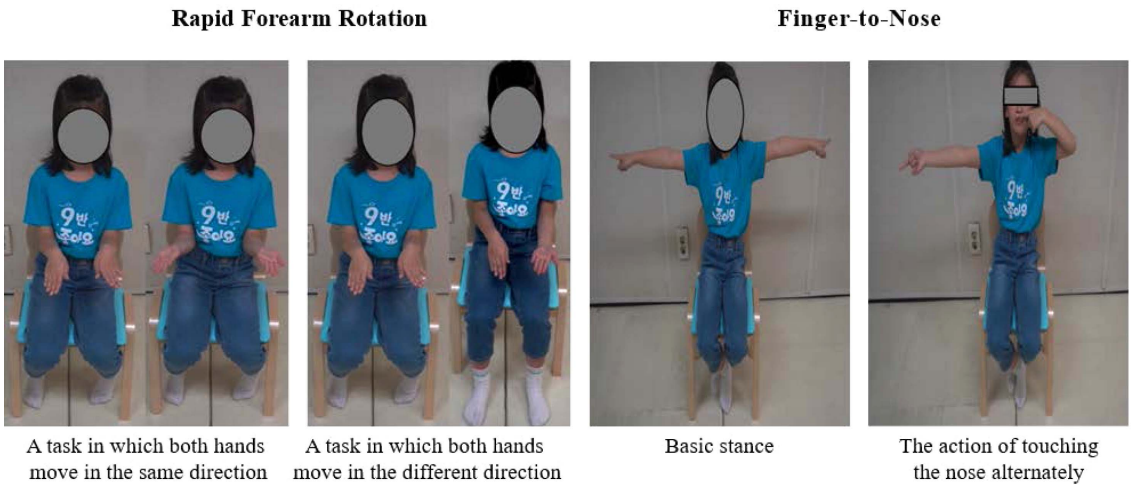

Fig. 2. (Color online) Rapid Forearm Rotation and Finger-to-Nose Test illustration.

coordination.

2.4. Rapid Forearm Rotation Analysis Method

2.4.1. Load Data

We recorded children's motions using a webcam at a frame rate of 24 frames per second. The lengths of the videos varied, with a minimum of 20 seconds and a maximum of 50 seconds. Given that the subjects were children, the occupational therapist occasionally intervened during the recordings to adjust their posture or prevent them from leaving their seats. To ensure data consistency and provide objective results, it was necessary to uniformly edit all the videos. Typically, a child's video could be segmented into 15-second intervals, as they often engage in activities independently for extended periods. However, the durations of independent activity were significantly shorter for children with disabilities. As a result, their videos were edited to various lengths according to their individual capabilities. Subsequently, we used MediaPipe's core technology to extract the coordinates of the human model. These coordinates were stored in a CSV file, with each coordinate comprising x, y, and z values. We identified a total of 543 keypoints, out of which we selected 10 coordinates related to the hand. Since the "Rapid Forearm Rotation" task involves flipping the hand, it is crucial to measure the rotation angle and accuracy during this movement. Thus, in this study, we focused on the x, y, and z values of the left-hand palm joint coordinates (469, 474, 478, 482, 486) and the right-hand palm joint coordinates (523, 528, 532, 536, 540) (Fig. 3).

2.4.2. Measurement Method

2.4.2.1. Cross Product Calculation and Direction of Rotation

In the Rapid Forearm Rotation Task, the cross product of the palm's coordinates was used to calculate the hand's rotation angle. This calculation involved dividing the palm's necessary coordinates into three sets of five points each, as shown in Fig. 4, and determining the cross product for each set. The average of these cross product values was then computed using Eq. (1), resulting in a

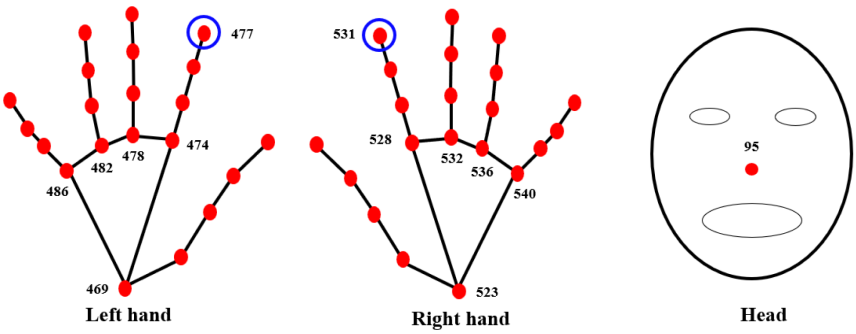

Fig. 3. (Color online) Palm joint coordinates for Rapid Forearm Rotation and nose coordinates for the Finger-to-Nose Test.

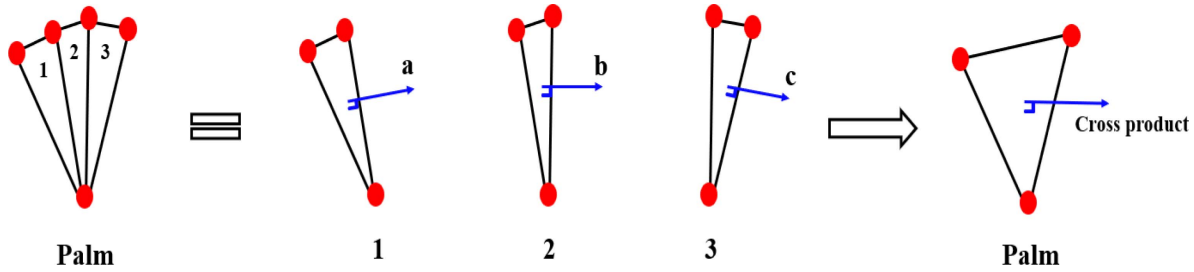

Fig. 4. (Color online) Process for calculating the average palm cross product angle - The palm is divided into three sections to calculate the average cross product values for each.

single cross product value, as depicted in Fig. 4. This value was stored as a vector. The next step was to calculate the rotation angle using the changing cross product values as the hand rotated. For this, the rotation angle was computed between two vectors: the current cross product represented as vector $C_1(x_1, y_1)$, and the subsequent cross product represented as vector $C_2(x_2, y_2)$. The angle between vectors C_1 and C_2 was calculated using Eq. (2).

$$Cross\ product\ mean = \frac{(a+b+c)}{3} \tag{1}$$

$$\theta = \operatorname{acos}\left(\frac{x^1y^2 - y^1x^2}{\sqrt{x_1^2+y_1^2}+\sqrt{x_2^2+y_2^2}}\right) \tag{2}$$

2.4.2.2. Finding the Timing for Flipping

During the visualization of rotation angles, if a child initially maintains their palm facing upward and motionless with an extended hand, the angle remains constant, yielding a straight line of consistent length. As the child rotates their hand clockwise, the angle incrementally increases from 0 degrees to a maximum of 180 degrees. This motion produces an upward-sloping straight line. Upon completing a full rotation, returning the palm facing position, the angle reverts to its initial value, forming a straight line. In the final stage, as the hand rotates counterclockwise, the angle decreases back from 180 degrees to 0 degrees, depicted by a downward-sloping straight line. During periods where the graph is either ascending or descending, the preceding and subsequent values differ, allowing us to identify these instances as the "flipping segments."

2.4.2.3. Count and Accuracy Calculation

In occupational therapy, the RFR task involves assessing hand rotation angles with reference to 160 degrees to ascertain motion accuracy. In this study, we adopted the same criterion to evaluate the accuracy of child participants' movements. A rotation angle of 160 degrees or more was deemed 100 % accurate. For angles less than 160 degrees, we utilized Eq. (2) to calculate the success probability based on the 160-degree benchmark. This method enabled us to determine not only if participants achieved the full 160 degrees but also the extent of their approximation to this angle, rather than simply classifying it as a failure for not reaching 160 degrees. We denoted the success probability as "success (%)" using Eq. (3), and the participants' rotation angle as the "cross product mean."

$$success(\%) = \frac{cross\ product\ mean}{160} \times 100 \tag{3}$$

2.4.2.4. Performance Success Rate Calculation

Beyond the success rate for individual tasks, we calculated the overall performance success rate using Eq. (4). The performance success rate represents the aggregate success rate of tasks executed by a participant. The term "total success" represents the cumulative success rates of all tasks undertaken by the participant. "Total number" reflects the total count of tasks completed by the participant. This approach facilitated the calculation of the participant's performance success rate based on the tasks they accomplished.

$$Performance\ success = \frac{total\ success\ 합}{total\ number} \tag{4}$$

2.5. Finger-to-Nose Test Analysis Method

2.5.1. Load Data

We filmed the current task under identical conditions to those used for the Rapid Forearm Rotation. Following the same procedure, we trimmed the video footage. Joint coordinates were extracted using the method described in Method 4.1. In the Finger-to-Nose Test movement, participants alternate touching their nose with the tip of their index finger. For this purpose, we used the coordinates of the tips of both index fingers (left: 477,

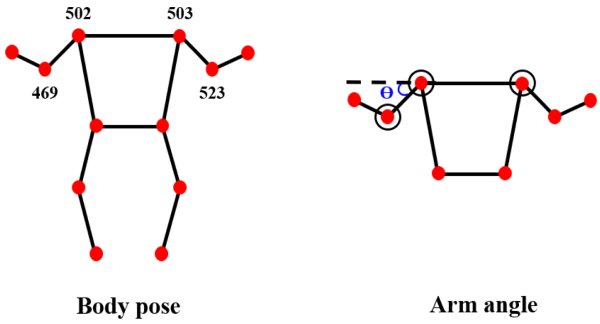

Fig. 5. (Color online) Body pose analysis - The left side shows four coordinates used, while the right side illustrates three coordinates, including both shoulders, to determine the arm's bent angle.

right: 531) and the nose tip (95) (Fig. 6). Furthermore, to confirm whether the child participant correctly performed the movement with their arms extended, we extracted the coordinates of both shoulder joints (left: 502, right: 503) and both elbow joints (left: 469, right: 523) (Fig. 5).

2.5.2. Measurement Method

2.5.2.1. Distance Between Finger and Nose Calculation

To assess whether the child participant successfully alternated touching their nose with the tip of the index finger, we utilized the coordinates of both index fingertips and the nose. We calculated the distance between each index fingertip and the nose. A distance of 0.2 or less was deemed a successful touch, while a distance greater than 0.2 indicated a failed touch. Eq. (5) was employed for calculating the distance, and Eq. (6) was used to compute the change in distance.

$$Distance = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2 + (x_3 - y_3)^2} \quad (5)$$

$$Difference = \left|\frac{\Delta\theta}{\Delta t}\right| \quad (6)$$

2.5.2.2. Find Touch Timing

In the Finger-to-Nose Test, which alternates between both hands, we established distinct criteria for determining successful touch for the left and right hands. To differentiate between the segments where the arm is in motion and those where the nose is being touched, we set an arbitrary threshold in the difference values. If the difference value remained below this threshold, we classified it as "arm in motion." Conversely, if the value surpassed the threshold, we concluded that the participant had "touched the nose."

2.5.2.3. Accuracy Judgment of Motion

Participants frequently exhibit a decrease in concentration during the movement, often leading to their arms drooping or bending. To evaluate the accuracy of these movements, we utilized the coordinates of both shoulder and elbow joints, as shown in Fig. 5. For assessing the right hand's accuracy, we used the coordinates of the right arm along with both shoulder joints. We calculated the angle formed by the vector from the right shoulder to the left shoulder and the vector from the right shoulder to the right elbow. We then measured how much this angle deviated from 180 degrees. An angle closer to 180 degrees indicates a fully extended arm, which we categorized as a perfect movement. Similarly, for the left hand's accuracy, we used the vector from the left shoulder to the right shoulder and the vector from the left shoulder to the left elbow. If, during the task, the angle between the participant's shoulders reduced to 150 degrees or less, we deemed the task's accuracy as compromised.

3. Results

3.1. Rapid Forearm Rotation

3.1.1. Cross Product Calculation and Rotation Angle

Figure 6 illustrates the x-axis as the frame length when the video is trimmed to 15 seconds, and the y-axis shows the child participant's rotation angle in degrees, ranging from 0 to 180. Considering that the participant is a child, and certain scenes might include deviations from the recording location or therapist assistance, we trimmed all videos to 15 seconds to focus on the segments independently performed by the child. The blue graph depicts the child participant's rotation angle. Initially, the child's hand is stationary, with the palm facing upwards, starting the

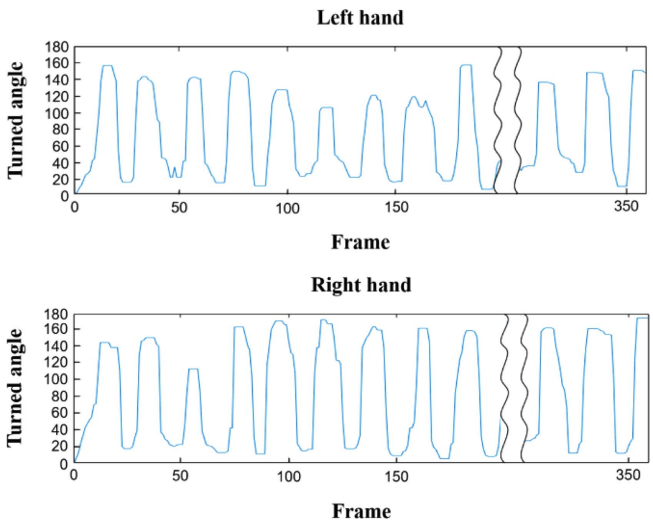

Fig. 6. (Color online) Graph depicting the rotation angle using cross product calculation.

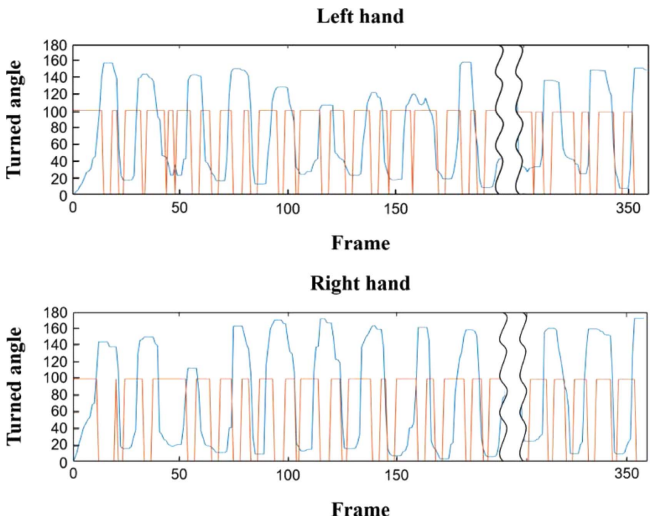

Fig. 7. (Color online) Graph visualizing flipping intervals - Rotation angle (blue line) and flipping segments (orange line).

angle at 0 degrees. As the palm flips, the angle increases, reaching a peak of 180 degrees when the palm is fully flipped. Upon returning the palm to its initial position, the angle decreases. Thus, when the palm is upwards, as in the beginning, it registers 0 degrees, and it measures up to 180 degrees when rotated to face downwards. This approach enables a quantitative assessment of the extent of the child's palm flipping.

3.1.2. Finding the Timing for Flipping

In Fig. 7, the x-axis represents the frame length when videos are segmented into 15-second intervals, and the y-axis shows the rotation angle in degrees (0 to 180) executed by the child subject. The graph features a blue line representing the rotation angle determined through cross products, and an orange curve indicating the hand rotation of the child subject.

3.1.3. Count and Accuracy Calculation

In Fig. 8, the orange column graph depicts instances of the subject rotating their hand, leading us to identify the sections where it increases and then decreases as "in the midst of rotation." Consequently, in Fig. 8, the first of the four orange graphs signifies "clockwise rotation," while the second graph indicates "counterclockwise rotation." The rationale for grouping the first and second graphs together in Fig. 8 is identical. Considering these two points collectively, the motion reverts to its initial state post hand flipping, hence we classified this as "flipped once." The peak value between these two points is identified as the angle rotated by the child subject, termed as the "rotation angle." In occupational therapy, hand

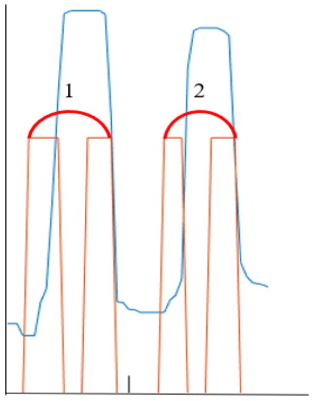

Fig. 8. (Color online) Timing of flipping in the orange graph - One full rotation is considered to occur between two points.

movement accuracy is evaluated using a reference rotation angle of 160° in the RFR task. The success rate of the rotation angle was calculated based on this standard and denoted as "Task percent." The subjects completed a total of 17 tasks in 15 seconds, with the left hand remaining inactive, thus registering an angle of 0 degrees. Task execution involved only the right hand, from which the angles were derived (Table 2).

Table 2. Number of movements, rotation angles, and success rate for a single child participant.

Count				
	Left hand		Right hand	
Total count: 17	Angle	Task percent (%)	Angle	Task percent (%)
1	149.87	93.67%	156.67	97.92%
2	149.87	93.67%	143.36	89.60%
3	162.65	100%	142.50	89.06%
4	162.95	100%	149.78	93.61%
5	171.36	100%	127.83	79.90%
6	163.03	100%	106.32	66.45%
7	161.15	100%	121.2	75.75%
8	158.14	98.84%	119.51	74.69%
9	169.29	100%	157.42	98.39%
10	165.20	100%	128.50	80.31%
11	169.97	100%	125.63	78.52%
12	168.44	100%	122.34	76.46%
13	168.21	100%	122.34	76.46%
14	160.90	100%	142.73	89.2%
15	160.28	100%	142.73	89.2%
16	0	0%	148.35	92.72%
17	0	0%	150.80	94.25%

Table 3. Total number, performance success, task success, correlation.

Total number				
	Left hand		Right hand	
	Total success (%)	Performance success (%)	Total success (%)	Performance success (%)
17 times	84.85%	99.08%	87.42%	75.11%
Correlation	0.7681			

3.1.4. Performance Success Rate Calculation

Table 3 presents quantitative data of participant performance for RFR. The term "total number" denotes the total tasks undertaken by the participant, in this instance amounting to 17 tasks. "Total success" refers to the success rate per task, defining 100 % success as instances where the rotational angle of the movement surpasses 160°, and 0 % when it fails to reach this angle. "Performance success" indicates the task-specific success rate, categorizing 100 % success as occasions where the rotational movement angle exceeds 160° and calculating the success rate accordingly when the angle falls short of this threshold. "Correlation" describes a value range between -1 and 1, which indicates the degree of synchronicity between the left and right hand movements. A value nearing -1 or 1 suggests a similarity in hand movements, while a value close to 0 suggests dissimilarity.

3.2. Finger-to-Nose Test

3.2.1. Calculating the Distance Between the Fingers and Nose

In Fig. 9, the x-axis represents the length of frames when the captured video is cut into 15-second segments, and the y-axis represents the relative distance between the participant's nose and hands during alternating movements. The blue graph illustrates the distance between the hands and nose for a single child participant. Initially, with the participant's arms extended, the graph exhibits a relatively stable value. As the participant moves their hand toward their nose, this value steadily decreases. The moment the fingertips and nose tip make contact, the distance registers as 0. Subsequently, as the hand withdraws, the value on the blue graph increases.

3.2.2. Find Touch Timing

Figure 10 illustrates the x-axis as the length of frames when the captured video is segmented into 15-second intervals, and the y-axis as the distance between the subject's nose and hands during alternating movements. The blue graph depicts the distance between the hands and nose for a single child participant, whereas the orange graph shows the segments when the arms are in motion. In occupational therapy, standard values for the Finger-to-Nose Test have not been established. Therefore, an arbitrary threshold of 0.2 was set. Distances greater than 0.2 between the fingertip and nose were interpreted as no

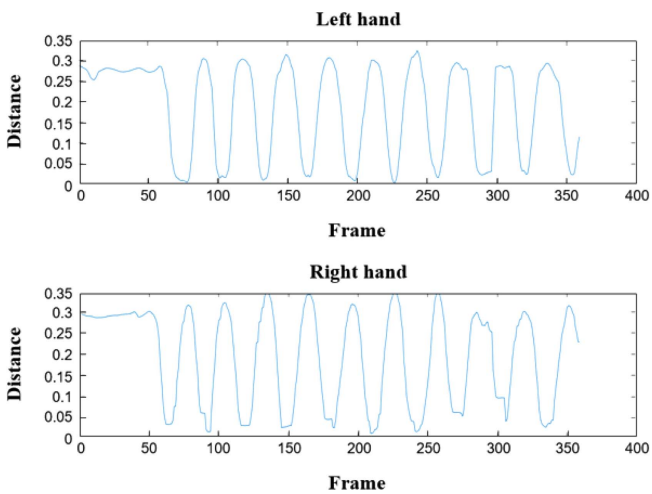

Fig. 9. (Color online) Graph showing the distance between the hand and the nose.

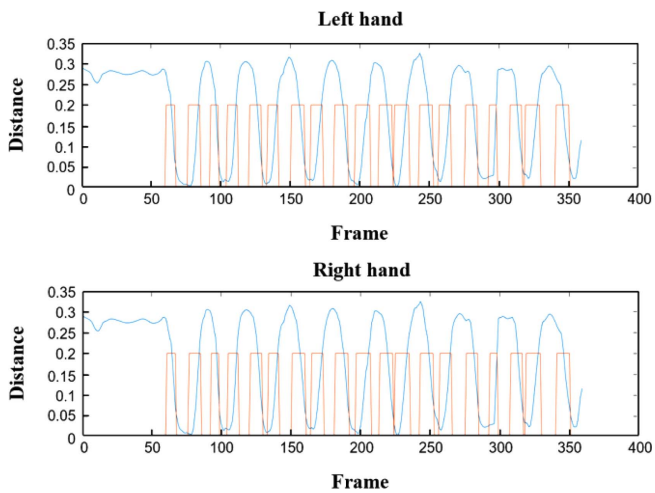

Fig. 10. (Color online) Graph depicting points of contact - Distance between nose and hand (blue) and flipping segments (orange).

Table 4. Distance between the fingertip of the index finger and the nose.

	Left hand		Right hand	
Count	Length	Task percent (%)	Length	Task percent (%)
1	0.006	100%	0.034	100%
2	0.015	100%	0.017	100%
3	0.011	100%	0.031	100%
4	0.018	100%	0.027	100%
5	0.009	100%	0.026	100%
6	0.005	100%	0.013	100%
7	0.017	100%	0.018	100%
8	0.029	100%	0.053	100%
9	0.024	100%	0.041	100%
10	0	0%	0.028	100%

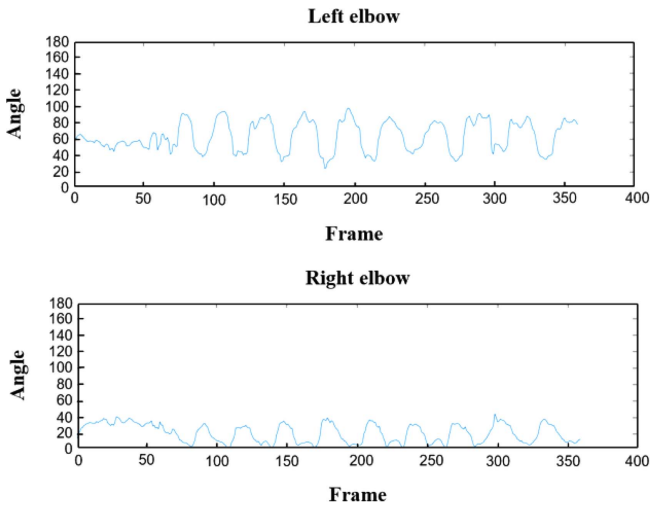

Fig. 11. (Color online) Graph indicating the extent of elbow extension away from the body.

touch, whereas distances of 0.2 or less were considered a touch.

3.2.3. Summary and Accuracy Assessment

To quantify the number of movements by the participant, we analyzed the intervals on the orange graph in Fig. 10, identifying moments when the fingertip touched the nose and then retracted. In addition to calculating the success rates for each task, we compiled the "Performance success," indicating the overall task completion rate by the participant, and the "Total success," reflecting the cumulative success rates of all tasks performed by the participant, as presented in Table 5. Fig. 11 displays the x-axis as the length of frames in 15-second segments from the video, and the y-axis as the angle showing the extent of elbow extension from the body while the participant alternated hand movements.

3.3. Comparison of Performance Outcomes Between Typically Developing Children and Children with Disabilities

Table 6 presents the results of the Rapid Forearm Rotation Task and the Finger-to-Nose Test, comparing typically developing children with children with disabilities. For children with disabilities, instances where evaluation was not feasible were recorded as 0. The data revealed that typically developing children completed the Rapid Forearm Rotation Task, on average, 14 times within 15 seconds, in contrast to children with disabilities, who managed it only 3 times. Typically developing children also exhibited marginally superior performance in the Finger-to-Nose Test compared to the Rapid Forearm Rotation Task. In contrast, children with disabilities demonstrated consistently lower success rates in all tasks. In the Finger-to-Nose Test, typically developing children

Table 5. Task organization.

Left hand		Right hand	
Total success (%)	Performance success (%)	Total success (%)	Performance success (%)
100%	100%	100%	100%

Table 6. Comparison between typically developing children and children with disabilities groups.

	Rapid Forearm Rotation (same direction)		Rapid Forearm Rotation (different direction)		Finger-to-Nose Test	
	Normal	Disabled	Normal	Disabled	Normal	Disabled
Count	14.6(2.73)	3.5(6.2)	14.2(2.04)	2.5(5.7)	5.8(1.6)	0.4(1)
Left success	95.5(6.43)	29.9(45.3)	95.0(6.34)	21.5(42.7)	100(0)	22.2(44)
Right success	93.5(8.13)	32.7(49.1)	93.1(6.57)	19.2(38.2)	100(0)	22.2(44)

achieved a 100 % success rate, averaging 5 successful attempts, whereas children with disabilities encountered difficulties in completing the task.

4. Discussion

In the Rapid Forearm Rotation (RFR) task employed in this study, participants flip both hands and then return them to their original position. This task is designed to assess a child's coordination ability through cerebellar integration function. To determine the accuracy of the RFR, we extracted the average coordinates of the palms from the skeleton model. These coordinates enabled us to calculate the extent of forearm rotation performed by the participants in the RFR task. The RFR task involves a dorsal rotation angle of the hand that can vary from 0 degrees to a maximum of 180 degrees. A rotation close to 180 degrees is considered a perfect flip. For our study, we established a success criterion of 160 degrees or higher. Tables 2 and 3 present various metrics. "Count" refers to the number of times the participant executed the task, while "Total number" shows the cumulative count. "Total success" is defined as a successful flip when the angle is 160° or above, and a failure when below this threshold, reflecting the success rate of these actions. "Performance success" indicates that each attempt is deemed 100 % successful if the rotational angle surpasses 160°; if not, the success rate is evaluated against the 160° benchmark. The term "Correlation" denotes the synchronicity of movement between both hands. "Total success" allows for an assessment of whether the task was accomplished, and "performance success" provides a quantitative measure of success for each attempt. The frequency or probability of success offers insight into the child's performance levels. A "Correlation" value nearing 1 or -1 indicates simultaneous movement of both hands, which is indicative of the child's ability to coordinate movements concurrently. This assessment method enabled us to evaluate the child's simultaneous coordination skills.

The Finger-to-Nose Test (FNT) involves the participant touching the tip of their nose alternately with the index finger while the arm is fully extended. Task success was assessed based on whether the distance between the fingertip and the nose tip was 0.2 or less. An increased distance between the nose and fingertip indicated an extended arm, while a decreased distance suggested the nose and fingertip were closer. In Tables 4 and 5, "Count" refers to the number of times the task was performed by the participant. "Length" denotes the distance between the fingertip of the index finger and the nose tip upon contact. "Task percent" is calculated on a 0.2 threshold, considering each count as 100 % successful if the length is 0.2 or less, and calculating the success rate based on the 0.2 threshold for greater lengths. "Total success" represents the success rate per count, with lengths of 0.2 or less deemed successful, and greater lengths considered failures, thus presenting the success rate for successful cases only. "Performance success" indicates the overall success rate across all Task percents.

In this study, we explored the cooperative-centered executive abilities of children with disabilities and their typically developing peers. Similar research has been conducted to quantify drawing abilities in children with learning disabilities and their typically developing counterparts. These studies involved attaching a marker to a pen to track drawing trajectories, employing parameters such as drawing angles and side lengths in the analysis. These parameters were chosen for their ability to characterize drawing accuracy and specific geometric features. By comparing these parameters between the two groups, distinctions were identified.

In this study, we similarly sought to quantitatively assess children's performance through two tasks commonly used in clinical settings. Nonetheless, our study faced several limitations. Specifically, participants with developmental disabilities showed lower task performance than typically developing children. This discrepancy introduced noise during the data extraction process and significantly affected AI recognition rates. Consequently, the human model was not accurately implemented, leading to issues such as disappearing or misplaced coordinates. Additionally, situations arose where participants deviated from the intended location during filming or required therapists' assistance due to limited task performance capability.

Therefore, these limitations made analyzing data from children with developmental disabilities nearly impossible. To address these challenges, adopting multi-camera setups and developing models focused on measuring only the upper body, rather than the entire human model, are essential. It is anticipated that with these two technologies, data acquisition from children with developmental disabilities will be feasible. In addition to children with developmental disabilities, typically developing children encountered challenges such as lower task performance and significant noise in the data, rendering it unusable, or issues with coordinate extraction. Nonetheless, it is posited that these issues can be mitigated through the use of multi-camera setups or upper body models. Furthermore, comparing the quantitative values with occupational therapists' perspectives to confirm their reliability is crucial.

5. Conclusion

In this study, we developed a program based on sensory integration to explore the feasibility of quantifying clinical evaluation through the application of AI to specific clinical observation items, namely the Rapid Forearm Rotation and Finger-to-Nose Test. Our objective was to discern the behavioral performance characteristics and qualitative differences between children with developmental disabilities and their typically developing peers using this program. We focused on two tasks from the clinical observation items: the Rapid Forearm Rotation and Finger-to-Nose tasks. By employing the coordinates of a human model, we successfully calculated angles and distances for each task. This approach also enabled us to assess overall success rates and task-specific accuracy by setting benchmarks. Our findings reveal that the program can effectively quantify children's tasks. While acknowledging certain limitations, future research is expected to further refine these methods, paving the way for more effective implementation of clinical assessment programs.

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