Fine Motor Training Using Conventional Tools, 3D-Printed Toys and Digital Platform

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Abstract
Early childhood muscle development is vital, especially for activities like pinch and grip, which require fine motor skills and eye coordination. Children with autism and Down syndrome often struggle with these activities, leading to rehabilitation programs using conventional tools. However, special needs children's limited attention span poses a challenge for trainers. This research aimed to address this issue by developing a training tool capturing and sustaining special needs children's attention, and analyzing their muscle activity with surface electromyography (sEMG). A comparison was made between conventional tools and 3D-printed toys with integrated audio and visual stimuli, extending to normal children and young adults using 3D-printed toys and a digital platform. sEMG signals from the flexor digitorum superficial muscle were recorded during fine motor training sessions. The findings revealed that the attention span of special needs children increased between 44% and 250% when using 3D-printed toys compared to conventional tools. Simultaneously, sEMG temporal analysis indicated lower mean amplitude for special needs children compared to their typically developed counterparts. Regarding the digital platform, it was observed that the muscle activity of typically developed children resembled that of those using 3D-printed toys when compared to young adults. In conclusion, the use of 3D-printed toys and digital platforms may offer additional advantages for fine motor skill training in children.

Keywords: sEMG, Fine Motor, Special Need Children

1. Introduction

Fine motor skills are essential in everyday life since they aid a person's movement. Fine motor skills allow us to make precise movements using small muscles in our hands, wrists, and fingers to perform tasks such as feeding ourselves, grasping objects, buttoning clothes, etc. [1]. The stage of the development of fine motor skills starts early at birth. It is important to refer to the milestones of early childhood development because if the typical milestones are not achieved at a specific age, there might be several possible implications, such as poor development of finger and hand strength, delayed self-care skills, low self-esteem when work is being compared to peers, and poor visual-spatial integration and visual-motor coordination [2]. Therefore, the development of fine motor skills from an early age is really important for children to perform self-care tasks.

However, some children face challenges with fine motor skills due to a lack of coordination in their hands and low muscle tone. Examples of such children include those with autism and Down syndrome. These motor skill disabilities often manifest in various issues, such as limited concentration, behavioral problems, and a delay in completing tasks [3].

This paper introduces the design of a fine motor intervention tool crafted to engage children, encouraging them to willingly participate in repeated fine motor activities. The primary objective is to aid in the improvement of their fine motor skills and enhance muscle strength. Furthermore, the study focuses on recording surface electromyography (sEMG). The aim is to investigate the distinctions in flexor muscle activity during fine motor activities between two groups of children: those who are typically developing and those with motor skills disabilities. The research is expanded to include a comparative analysis between typical children and young adults utilizing the digital platform tool.

2. Fine Motor Training Device

Fine motor skill acquisition involves the manipulation of hands and fingers, encompassing fundamental movements such as picking up and transferring objects [4]. In a study, children were engaged in creative manipulation of objects like paper, scissors, and glue to promote imaginative expression, fostering these skills [5].

The intervention activities also included finger painting, exploring resistive materials like play clay for small object discovery, and using magnetic wands to pick up metal objects. These activities aimed to expose children to small object manipulation, enhancing sensory experiences to improve tool use, grasp strength, and individual functional abilities [6].

However, these activities lacked a music element, despite scientific studies emphasizing the significant role of art and music therapy in efficient learning processes and emotional self-regulation [7]. Music therapy has shown positive effects on communication skills, maturity, and emotional development in children [7,8]. Scientific evidence supports the integration of music and art elements into educational activities, expediting skill development, sustaining children's interest, and training their muscles. Moreover, it contributes to the development of self-help, communication, and cognitive skills, enabling children to engage in activities like self-feeding, playing with peers, and problem-solving [4].

Table 1 presents the fine motor training tools used in the study. Conventional tools included tearing manila cards and placing wooden blocks in wooden pegs. In addition, three types of 3D-printed toys were used. Type A was initially employed but faced challenges such as low-quality sound from the buzzer, a lack of visual rhythm from the analog RGB LED strip, and poor 3D printing design as noted by special needs children training practitioners. Consequently, Type A was replaced by Type B, where some hardware components were upgraded, and the device's outlook became more decorative based on received feedback. However, after usage, Type B was further replaced by Type C due to the observation that special needs children tended to tear off the decoration of the 3D printed toy body during training. Additionally, the music storage in the WTD020-SD module in Type B was replaced with a sound program embedded in the microcontroller for Type C.

3. Participants and Training Protocol

The study included four autistic children (aged 4-8 years old), four children with Down syndrome (aged 4-8 years old), ten typically developing children (aged 4-8 years old), and four young adults (aged 18-25 years old).

Autistic and Down syndrome participants were recruited from Sekolah Kerencatan Akal Johor Bahru. The intervention tools for these groups encompassed activities such as playing with playdough, tearing manila cards, placing wooden blocks in wooden pegs, drawing, and matching interlocking puzzles. Specifically chosen for research purposes were tearing manila cards and placing wooden blocks in wooden pegs.

Table 1: Devices For Fine Motor Training

Type	Component
Conventional Tools	Manila Cards (Tearing) Wooden peg (Placing Wooden Block)
3D-Printed Toy (Type A)	3D Printing + others Analog RGB LED Strip HC-SR04 Ultrasonic Sensor Buzzer Arduino Uno R3 Microcontroller 12 V Power Supply
3D-Printed Toy (Type B)	3D Printing WS2812B Addressable RGB LED Strip Infrared (IR) Sensor LM386 Audio Amplifier Module 8Ω, 0.5W speaker WTD020-SD module Arduino UNO Microcontroller 5V DC Supply
3D-Printed Toy (Type C)	3D Printing WS2812B Addressable RGB LED Strip Infrared (IR) Sensor LM386 Audio Amplifier Module 8Ω, 0.5W speaker Arduino UNO Microcontroller 5V DC Supply & Power Bank
Digital Platform	Using MIT App Inventor - Tap the Ball Module - Drawing Module - Tracing Module

In the realm of 3D-printed toys, the emphasis was on in-hand manipulation, utilizing a small ball as the training object to encourage participants to grasp and manipulate it. The use of a small object was justified by its ability to captivate children's attention, facilitating the strengthening of fine motor muscles.

Furthermore, the incorporation of light and music elements aimed to make fine motor activities engaging and enjoyable, encouraging repeated participation.

The tool's functionality involved inserting a small ball into one of the holes, activating light and music. The holes corresponded to different musical tones, and an ultrasonic/IR sensor served as a distance sensor with a measurement range of approximately 2-4 cm. Light and music activation were achieved through an Analog LED RGB strip/WS2812B addressable RGB LED strip and a buzzer/speaker, respectively. An Arduino Uno board functioned as the controller, with the three components connected to it.

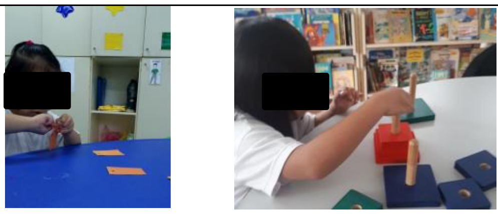
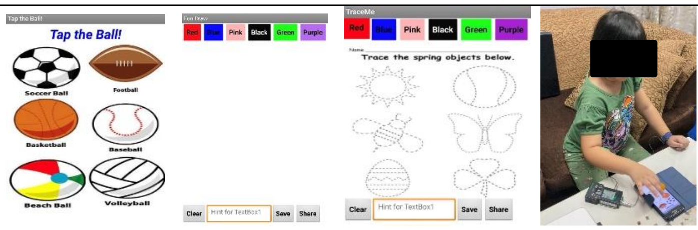
Simultaneously, the digital platform utilized MIT App Inventor, a block-based coding program for building applications (apps). Three levels of activities were created on this app. The first, "Tap the Ball", required children to drop a small ball onto various virtual balls appearing on smartphones or tablets. Sound or music played as a reward. The next level involved drawing and the final level was tracing, representing the highest level of fine motor skills training. Progress for drawing and tracing activities could be saved for evaluation and monitoring purposes. All of these tools are illustrated in Table 2.

4. sEMG Data Acquisition and Processing

The activities of the flexor digitorum superficialis muscle [9] were recorded using either the DataLOG (MWX8) by Biometrics Ltd, connected via Bluetooth to the personal computer (PC), or an isolation amplifier, ISO-Z, and BMA-400 bioamplifier. Both devices are capable of collecting the sEMG signal, which can be transferred and displayed in real-time on a PC. Figure 1 illustrates an example of sEMG electrode placement and the data acquisition unit using DataLOG equipment.

Table 2: Training Session

Device Type	Related Pictures
Conventional Tools	 
3D-Printed Toy (Type A)	
3D-Printed Toy (Type B)	

Device Type	Related Pictures
Conventional Tools	
3D-Printed Toy (Type C)	
Digital Platform	

		
(a) sEMG Electrode Placement	(b) DataLOG Equipment	(c) Real-time sEMG Data Acquisition

Figure 1: sEMG Electrode Placement and Acquisition

The surface EMG electrode is positioned on the flexor digitorum superficialis of the test subject's dominant hand, while the reference electrode is attached to the wrist. To enhance the sEMG signal by reducing skin impedance, an alcohol swab is used to clean the skin near the flexor digitorum superficialis muscle. Following electrode placement, children are instructed to train with the developed devices. The task continues for as long as the children can maintain focus during a session.

Once sEMG signals were recorded, the time frame of sEMG data to be analyzed was identified. One method used to eliminate muscle fatigue, if present, was to divide the sEMG signal into three parts: the early, middle, and late stages, with each stage lasting 30 seconds. Before feature extraction, the sEMG signal underwent filtering to remove unwanted noise or artifacts. A band-pass filter with a low cut-off frequency of 5 Hz and a high cut-off frequency of 500 Hz was employed to capture sEMG characteristics.

In this study, some of the features analyzed in the time domain included peak amplitude, mean absolute value, and normalized amplitude. Typically, these parameters were obtained after filtering the raw sEMG signal to remove unwanted signals. Following filtration, the sEMG signal was rectified before extracting parameters such as amplitude. One method for rectifying the sEMG was by applying a linear envelope [10]. Linear Envelope is an application that provides visual feedback on muscle activation. This method usually consists of full-wave rectification (making all values positive), followed by integration to smoothen the peaks. Three methods were used in computing the linear envelope: a 6-Hz low-pass filter, moving average, and root mean square (RMS) smoothing to optimize peak smoothening. Once the sEMG signal was rectified and smoothed, parameters such as mean amplitude were extracted for further analysis. Figure 2 (a) presents an example of raw sEMG signals during fine motor training, and Figure 2 (b) displays the sEMG signal after the application of the linear envelope.

5. Results and Discussion

Table 3 summarizes the attention span of special needs children for various device types. Throughout the data collection phase, the children were allowed to train at their own free will without interference, avoiding any attempts to force or enforce longer training durations while using the fine motor training. This was done to prevent any skewing of data during collection.

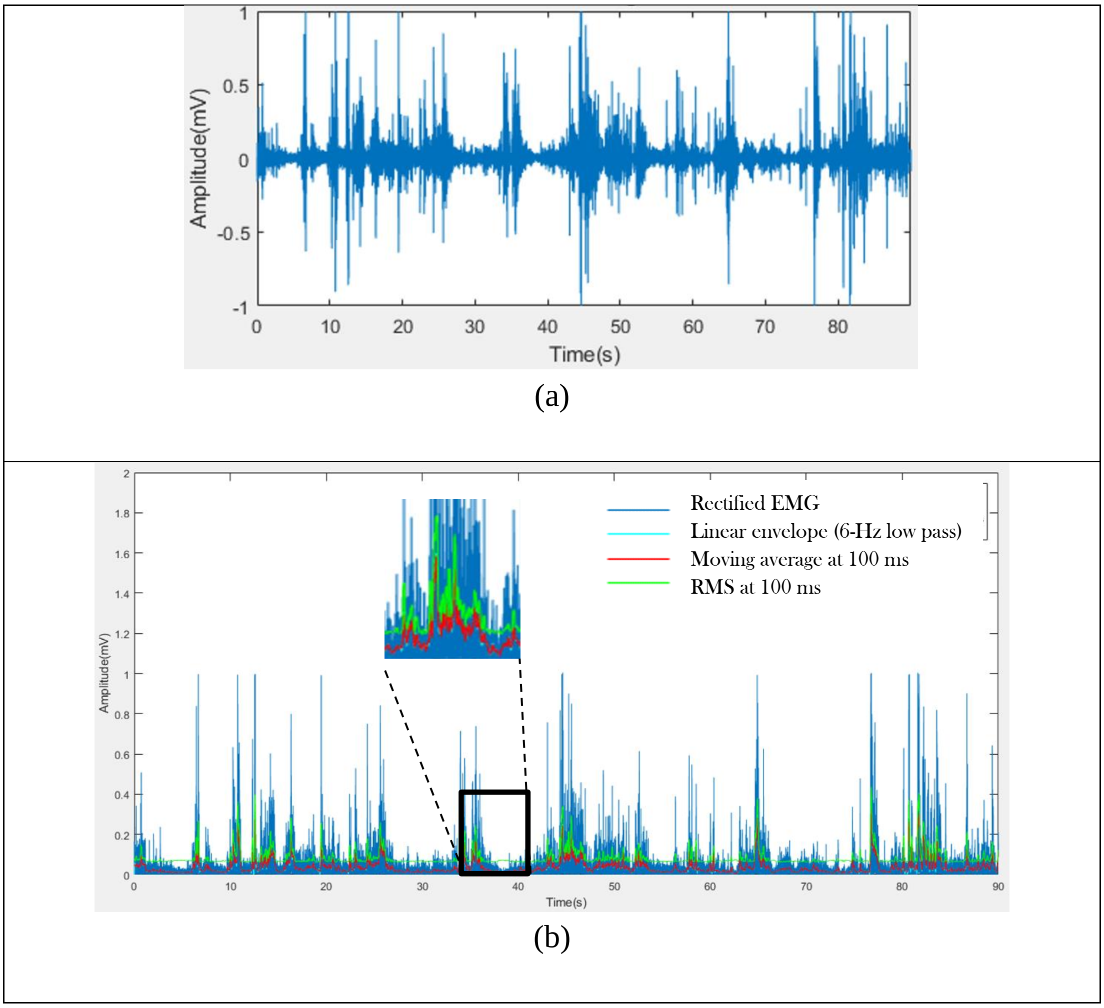


Figure 2 (a) Raw sEMG Signal; (b) Linear Envelope on 90 seconds of sEMG

Some observations during training with conventional tools and 3D-Printed Toys are listed below:

(a) While collecting data from the conventional training method, the autistic child, A3, consistently walked away from the wooden peg and chose a storybook from the rack next to him to read. Autistic child, A2, would wander from the training area to explore other items in the room. Additionally, Down's syndrome child, DS3, began by playing with another toy before starting to train with the wooden peg.

(b) Due to Autistic child, A2, constantly removing the surface electrode from the forearm, assistance from the caregiver at the school was requested to help calm the child down and train with the system.

(c) During training with the system, Down's syndrome child, DS3, clapped hands and laughed happily while training. When lighting effects and music were played, she showed a very positive attitude towards the training. However, for three other special needs children, A2, A3, and DS2, they attempted to insert the object into incorrect places, such as sliding it up to the top or into the speaker hole. Both autistic children, A2 and A3, tried to peel off the RGB LED from the strip. Down's syndrome child, DS2, paused the play until the music finished before inserting the ball into the hole.

Overall, the findings revealed that the attention span of special needs children increased between 44% and 250% when using 3D-printed toys compared to conventional tools.

Table3: Participant Attention Span During Training

Type	Attention Span
Conventional Tools	Manila Cards (Tearing) Autistic Child, A1: 55 seconds Down Syndrome Child, DS1: 3 min. 45 seconds Wooden peg (Placing Wooden Block) Autistic Child, A2: 2 min. Autistic Child, A3: 1 min. 30 seconds Down Syndrome Child, DS2: 4 min. Down Syndrome Child, DS3: 16 min.
3D-Printed Toy (Type A)	Autistic Child, A1: 10 min. Down Syndrome Child, DS1: 5 min.
3D-Printed Toy (Type B)	Autistic Child, A4: 7 min. Down Syndrome Child, DS4: 13 min. Typically Developing Child, N1: 4 min. Typically Developing Child, N2: 25 min.
3D-Printed Toy (Type C)	Autistic Child, A2: 3 min. 42 seconds Autistic Child, A3: 4 min. Down Syndrome Child, DS2: 8 min. 30 seconds Down Syndrome Child, DS3: 24 min. Typically Developing Child, N3: 8 min. 30 seconds

In the analysis of sEMG signals, the following findings are noted:

(a) The moving average method yields values that are nearly identical to those obtained through the 6 Hz linear envelope method.

(b) Muscle activity in typically developed children shows minimal fluctuations between the early, middle, and late segments of the training session compared to special needs children. However, almost all subjects, including typically developed children, exhibited lower amplitudes at the end of the training session compared to earlier segments when analyzed using the 6 Hz linear envelope and RMS smoothing methods.

(c) Typically developed children demonstrated higher rectified sEMG amplitudes compared to children with special needs.

(d) Regarding the digital platform, it was observed that the muscle activity of typically developed children resembled that of those using 3D-printed toys when compared to young adults.

6. Conclusion

Based on the results, special needs children engage in longer training sessions using the developed fine motor training device (3D-Printed Toys) compared to conventional tools. A prolonged training session is beneficial for enhancing fine motor skills among special needs children. Therefore, a device with a reward system proves more effective in promoting concentration, motivation, and enjoyment in fine motor tasks. The sEMG analysis indicates that muscle activity in typically developed children shows minimal fluctuations between the early, middle, and late segments of the training session compared to special needs children. However, a decrease in normalized sEMG amplitudes was observed in all children during the late training segment compared to the early one.

Regarding the comparison between 3D-Printed Toys and digital platforms, further study is necessary to compare special needs children with their typically developed counterparts.

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