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Electromyogram in Fine Motor Training Assessment: A Review

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Abstract: Fine motor skills are essential for daily activities, especially those requiring precision, such as grasping objects or writing. This review explores the role of electromyography (EMG), particularly surface EMG (sEMG), in assessing fine motor skills across various populations, including typically developing children, children with motor disabilities, young adults, and elders. These groups were selected due to their unique challenges and needs in motor skill development and rehabilitation. For instance, young children may require early intervention to address developmental delays, while individuals with motor disabilities, such as those with autism or cerebral palsy, benefit from tailored therapeutic approaches. The elderly population faces age-related motor decline, making EMG a valuable tool for maintaining or improving muscle function in this group. By capturing muscle activation patterns, EMG provides a comprehensive evaluation of muscle engagement during fine motor tasks. The paper also reviews the effectiveness of digital platforms and 3D-printed toys in fine motor training, demonstrating the potential of EMG as a tool for enhancing therapeutic interventions and refining motor assessments. Emerging technologies such as artificial intelligence and machine learning may further optimize EMG signal analysis, offering innovative solutions for both clinical and home-based motor skill training.

Keywords: Digital platform, EMG, Fine motor, Special need children

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1. INTRODUCTION

Fine motor skills are crucial for everyday life as they enable precise movements required for tasks such as writing, grasping objects, and performing self-care tasks. However, assessing these skills traditionally involves subjective methods, such as manual dexterity tests and visual observations, which fail to capture the detailed muscle activity underlying these tasks. This review addresses the gap in fine motor skill assessment methods by examining the application of electromyography (EMG), particularly surface EMG (sEMG), in evaluating muscle engagement during fine motor tasks. The objective of this paper is to review the current use of EMG across different populations—children, young adults, and elderly—and to explore the potential of emerging technologies like AI and machine learning to enhance the analysis of EMG signals. The scope of this review includes a discussion of the methodology used to select relevant studies, the comparative effectiveness of EMG in different populations, and the future directions for integrating advanced technologies into fine motor skill assessments.

These skills involve the use of small muscles in the hands, wrists, and fingers, allowing us to perform tasks like feeding ourselves, grasping objects, and buttoning clothes [1-3]. The development of fine motor skills begins early, starting from birth. It is important to track early childhood development milestones, as failure to meet them at specific ages can have various implications, such as weak finger and hand strength, delayed self-care abilities, low self-esteem when compared to peers, and poor visual-spatial integration and coordination [4-5]. Therefore, fostering fine motor skills from an early age is essential for children to perform self-care tasks independently.

Fine motor skills are vital for tasks requiring precise movements, such as gripping a pencil or tying shoelaces. These skills rely on the coordination of small muscle groups, and when impaired, they hinder an individual's ability to carry out daily activities. Assessing fine motor skills is important for designing effective interventions.

Traditionally, fine motor skills are measured through manual dexterity tests or visual observations, which may lack precision. These methods often fail to provide insights into underlying muscle activity or the coordination between different muscle groups during fine motor tasks [6]. Furthermore, such assessments are largely qualitative, relying on subjective observations that can vary between evaluators, leading to inconsistent results. For example, widely used tools like pegboard tests measure outcomes but do not analyze the dynamics of muscle engagement, limiting their utility in identifying specific motor deficits.

Activities like finger painting, touchscreen exercises, tearing paper, kneading dough, and block building are often used to help children develop fine motor skills. In addition, various occupational therapies aim to improve bilateral coordination, in-hand manipulation, and hand-eye coordination in children. However, there is insufficient data to prove that occupational therapy interventions lead to significant improvements in fine motor development

[6]. Traditional assessments may not provide enough insight into underlying muscle activity, which is where electromyography (EMG) offers a more comprehensive analysis [7]. EMG is an effective tool for evaluating muscle activity, enabling real-time assessment of muscle engagement during fine motor tasks.

This review was conducted by identifying and analyzing peer-reviewed studies focusing on the use of surface electromyography (sEMG) in fine motor skill assessment and training. Literature was sourced using academic databases such as PubMed, IEEE Xplore, and Google Scholar. The following keywords were used: surface EMG, fine motor skills, electromyography in training, children with special needs, AI in EMG analysis.

Studies published between 1996–2024 were included to ensure the relevance and recency of findings. The inclusion criteria focused on:

- Original research articles and reviews discussing sEMG in fine motor assessments.
- Comparative studies across diverse populations (e.g., children, adults, elderly).
- Interventions integrating technologies such as AI, digital platforms, or 3D-printed tools.
- Exclusion criteria omitted articles without full text or those focusing on gross motor assessments. This systematic approach ensured a comprehensive perspective on the topic.

2. ELECTROMYOGRAPHY (EMG)

Electromyography (EMG) is a technique used to measure the electrical activity generated by muscles during movement. Surface EMG (sEMG) is a non-invasive method where electrodes are placed on the skin to detect muscle signals. In fine motor assessments, sEMG captures subtle muscle contractions during tasks like gripping or pinching. This enables clinicians and researchers to observe the intensity and coordination of muscle movements in real-time.

There are two types of muscle contractions: isometric and isotonic. Isometric contractions occur without any change in muscle length, such as holding a bucket of water still for a period. During this time, the muscles in the hand maintain their length without movement. In contrast, isotonic contractions involve changes in muscle length, such as when the hand flexes or moves.

The smallest functional unit involved in controlling muscle contractions is called a motor unit (MU). Introduced by Liddell and Sherrington in 1925 [8], an MU consists of a single motor neuron, its axon, and the muscle fibers it innervates. The electrical signals from these fibers are picked up by surface electrodes during sEMG. Normal surface-based motor unit action potentials (SMUAPs) are typically biphasic or triphasic in shape, lasting between 3 and 15 milliseconds (ms), with amplitudes ranging from 100 to 300 microvolts (μV), and appearing in the frequency range of 6 to 30 Hertz (Hz). These characteristics are used as reference values in EMG studies to assess muscle function and diagnose neuromuscular disorders. Both the motor unit action potential (MUAP) magnitude and its firing frequency are key factors influencing the strength and density of the EMG signal. Figure 1 illustrates an EMG signal recorded during the isometric contraction of the first dorsal interosseous (FDI) muscle of the right hand, with force generated at 10% of the maximum voluntary contraction (MVC).

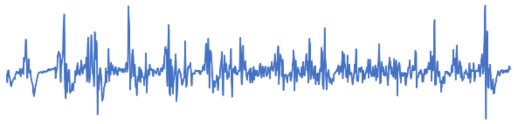

Figure 1. An example of EMG signal of FDI muscle

As voluntary muscle contraction strength increases, the same motor units (MUs) and additional ones are activated. The more MUs that are recruited, the more muscle fibers are stimulated and contracted. Another key factor in generating force is the firing frequency of the motor neuron, which stimulates its muscle fibers. In general, the firing rate of each MU increases with greater muscular effort. Figure 2 illustrates the two main mechanisms that influence the recorded EMG signal [7]. As shown, the EMG signal reflects muscle contraction due to the activation and contraction of several motor units. Muscles responsible for gross movements, which involve generating high force, contain hundreds of muscle fibers per motor unit. Gross movements typically involve larger muscle groups, such as those in the arms and legs. Examples include running, crawling, and lifting heavy objects, which require the coordinated effort of numerous motor units within these muscles to produce the necessary force for the task [9].

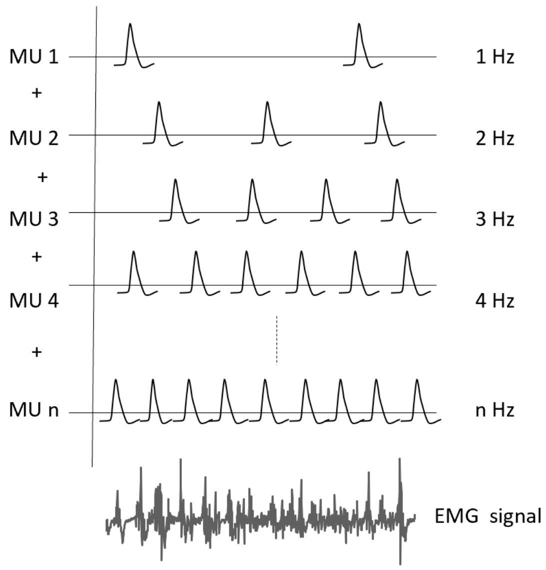

Figure 2. Generation of magnitude and density of EMG signal (Adapted from [7])

In contrast, muscles involved in precise, fine movements have fewer muscle fibers per motor unit. Fine movements depend on the smaller muscles found in the hands and fingers, which enable delicate and highly precise actions. Examples of fine motor skills include threading a needle, buttoning a shirt, and writing [10]. These tasks require fine control and dexterity, achieved through the precise coordination of motor units that contain fewer muscle fibers per unit.

Like other signals, an EMG signal can be analyzed using standard amplitude parameters, such as mean, peak, average, area, and even signal slope, in addition to its frequency components. However, because EMG signals are bipolar in nature, it is necessary to rectify them before further analysis. Rectification involves converting all negative values into positive ones, essentially taking the absolute value of each data point. Figure 3 illustrates the standard amplitude parameters based on the rectified EMG signal.

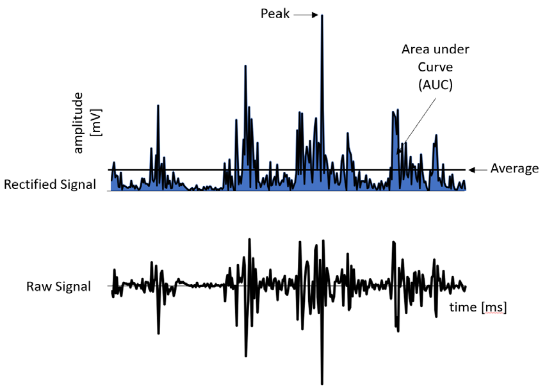

Figure 3. EMG standard amplitude parameters (peak, average, AUC) based on the rectified EMG signal

3. COMPARATIVE STUDIES ON DIFFERENT POPULATIONS

Recent studies have explored the use of EMG in assessing fine motor skills across various populations. The development of fine motor skills in children is a crucial foundation for their daily activities. However, some children struggle with fine motor skills due to poor hand coordination and low muscle tone. Children with Autism and Down syndrome are examples of those with motor skill disabilities, often facing challenges such as limited concentration, impulsive behavior, and slow task completion [11]. As a result, children with motor disabilities exhibit different muscle activation patterns compared to their typically developing peers.

One key study compared the muscle activation patterns of healthy children and children with motor disabilities, such as autism and Down syndrome, during fine motor activities [12]. The study found that children with motor disabilities exhibited distinct muscle activation patterns, highlighting the potential for using EMG as an early diagnostic tool for identifying motor impairments. These findings are significant because they demonstrate how EMG can provide valuable insights into the neuromuscular differences between typically developing children and those with special needs, guiding more targeted therapeutic interventions.

Brahim et al. (2017) [12] focused on enhancing fine motor skills in children with Autism and Down syndrome using tools incorporating light and sound to address concentration issues [13]. EMG data were collected from the flexor digitorum superficialis (FDS) muscle. The study compared conventional tools such as tearing manila cards and placing wooden blocks [14] with 3-D printed toys controlled by a microcontroller to activate a buzzer and LED strip. Figure 4 shows example of a special child with wooden blocks and 3-D printed toy.

Scientific studies have shown that art and music therapy significantly aid the learning process and emotional regulation [15][16]. Music therapy, in particular, positively impacts communication, maturity, and emotional development [15,16]. By incorporating art and music elements into educational activities, children's attention is captured, leading to repeated performance of tasks that train their muscles. This, in turn, helps develop self-help, communication, and cognitive skills, allowing children to self-feed, interact with peers, and solve problems [1].

(a) (b)

Figure 4. A special need child with (a) wooden block; (b) 3-D printed toy for fine motor training [12]

Back to Brahim et al. (2017) [12], the study found significant differences in muscle performance and engagement levels, suggesting that the developed tools effectively encouraged children to participate in activities. Conventional tools retained the attention of special needs children for less than four minutes, while the 3-D printed toys extended their focus up to five times longer. EMG analysis showed that the mean value of the EMG linear envelope increased over time for special needs children, while it remained constant or slightly decreased for typically developing children using the 3-D printed toys [12]. These findings were supported by subsequent research, which studied similar objectives with different participants, including both typically developing and special needs children [17,18]. The intervention showed promise in improving fine motor skills and muscle strength, highlighting the importance of engaging therapeutic methods for special needs children.

In another study, Rodi and Safri (2020) [19] explored the development and evaluation of a digital platform for fine motor skill training using 3-D printed toys and a digital platform-based system. Both systems used audio-visual rewards to keep children engaged. As noted in previous research, incorporating play in training helps retain children's interest. The concept of "pedagogical play," used in early 1900s kindergartens in Australia, remains relevant today [20,21]. Pedagogical play encourages focus through play, and as technology evolves, digital platforms like smartphones and tablets are becoming valuable tools for fine motor training [22]. Activities like gaming, drawing, and tracing on digital platforms help improve children's fine motor skills [23,24].

Rodi and Safri (2020) [19] compared two systems: a 3-D printed toy training system and a digital platform training system. The 3-D printed toy system involved placing small balls into holes, triggering music and lights as rewards, while the digital platform, developed with MIT App Inventor, offered three activities—tapping the ball, drawing, and tracing—designed to improve fine motor skills with auditory feedback. EMG signals from the FDS muscle were recorded, and the linear envelope method was used to study muscle activation. The study compared EMG responses from normal children and young adults during both training types, finding that while both systems engaged fine motor skills, in which children exhibited higher EMG responses on the digital platform. Figure 5 shows the electrode placement on the surface of the skin of FDS muscle, data acquisition unit, a child with 3-D printed toy and a digital platform for fine motor training.

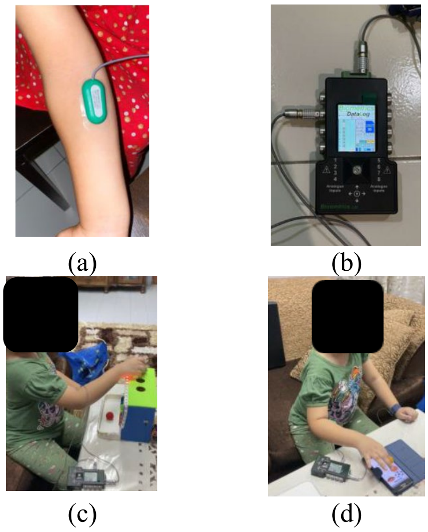

Figure 5. (a) Electrode placement on the FDS muscle; (b) DataLOG (MWX8) Biometrics Ltd EMG data acquisition unit; A child playing with (c) 3-D printed toy, and (d) with digital platform [19]

Based on the two studies, the following are highlighted:

- **Brahim et al. (2017) [12]**: The study demonstrated that 3D-printed toys significantly increased attention and engagement in children with special needs, as evidenced by higher muscle activity levels recorded by EMG compared to traditional tools. This highlights the effectiveness of integrating interactive technologies to enhance fine motor training for children with autism and Down syndrome.

- **Rodi and Safri (2020) [19]**: The comparison of digital platforms and 3D-printed toys showed that while both systems engaged fine motor skills, the digital platform led to greater EMG responses, suggesting its higher effectiveness in engaging muscle activity during fine motor tasks.

Improving fine motor skills is also important for the elderly, who require training to prevent skill degeneration with age. Aging can lead to reduced brain volume, cognitive decline, and diminished fine motor performance. A study found that both children and older adults have the lowest fine motor performance levels compared to other age groups but can improve with practice [25]. According to Neural Darwinism, neurons activated during fine motor training will survive, while less efficient, unused neurons will deteriorate. The principle of "use it or lose it" becomes increasingly important in older adults [26].

Chin (2024) [27] introduced a digital platform designed to enhance fine motor skills in children and older adults. The platform, developed with MIT App Inventor, includes three interactive tasks—"Tap the Picture," "Be a Painter," and "Trace the Line"—providing visual and auditory feedback. EMG analysis was used to evaluate muscle activity during task completion. Key findings included:

- Older participants showed higher muscle activity during simpler tasks, compensating for neuromuscular decline with age.

- Children exhibited lower muscle activity in more complex tasks, highlighting the need for further fine motor development.

- Tasks requiring greater precision, like "Trace the Line," demanded more muscle force across all participants.

Overall, the platform showed potential in supporting fine motor skill development in children and maintaining muscle function in older adults. These studies suggest that interactive digital platforms can be effective tools for fine motor interventions based on analysis of the EMG data.

These comparative studies demonstrate that EMG effectively distinguishes between groups, allowing for tailored interventions. In clinical settings, EMG is used for motor rehabilitation in patients recovering from strokes or with neuromuscular disorders such as cerebral palsy. By providing feedback on muscle activation, EMG helps guide therapeutic interventions. For children, EMG can identify abnormal muscle patterns early, enabling interventions to prevent future complications. For healthy individuals, EMG assesses typical motor function, providing a basis for comparison with populations that have motor impairments.

4. CHALLENGES AND LIMITATIONS

Conventional fine motor skill assessment methods, such as manual dexterity tests and observational techniques, are limited in their scope and precision. These methods focus on task completion rather than understanding the neuromuscular control involved in performing fine motor tasks. Additionally, they do not quantify muscle activation, making it challenging to design targeted interventions. EMG addresses these gaps by offering real-time data on muscle engagement and coordination, providing a more comprehensive understanding of motor function.

While EMG provides precise insights into muscle function, its use comes with certain challenges. Surface EMG signals can be influenced by external factors such as electrode placement, skin impedance, and motion artifacts. Additionally, ensuring comfort and cooperation during EMG usage in children, especially those with special needs, is a significant concern. For example, researchers in the case studies observed the following behaviours from special needs children:

- An autistic child frequently removed the surface electrode from her forearm and required assistance from a caregiver to help calm the child and proceed with the training system.
- A child with Down syndrome clapped her hands and laughed happily during the training. When lighting effects and music were played, the child exhibited a very positive response to the training.
- Many special needs children attempted to insert objects in incorrect places, such as sliding them up to the top or into the speaker hole of the 3-D printed toys.
- Several autistic children tried to peel off the RGB LED strip of the 3-D printed toy during the training.
- One child with Down syndrome paused activity until the music finished before inserting the ball into the correct hole.

The use of 3-D printed toy may alleviate some of these challenges while digital platform may reduce some of the disadvantages of the 3-D printed toy. However, this aspect requires further investigation and is highly influenced by individual behaviour.

While EMG provides precise insights into muscle function, its use comes with certain challenges. Surface EMG signals can be influenced by external factors such as electrode placement, skin impedance, and motion artifacts. Moreover, ensuring comfort and cooperation during EMG usage, particularly in special needs populations, is a significant concern. These challenges highlight the need for further technological advancements that could improve the accuracy and accessibility of EMG assessments. Addressing these limitations, through innovations like portable EMG devices and AI-driven analysis, will be essential to the continued evolution of fine motor skill assessments and their integration into both clinical and home-based settings.

5. FUTURE DIRECTIONS AND CONCLUSION

Emerging technologies, including artificial intelligence (AI) and machine learning (ML), have the potential to significantly enhance the use of EMG in fine motor skill assessments. AI-driven algorithms, such as neural networks and support vector machines, have been successfully used to classify EMG signals for movement detection and motor intention prediction [28-30]. These techniques enable automated feature extraction and real-time signal analysis, reducing reliance on manual data processing and increasing precision. For instance, studies show that ML models can identify subtle patterns in EMG data, enabling more personalized and adaptive motor skill interventions [28].

Integrating AI with EMG can facilitate predictive analysis, such as estimating motor fatigue or detecting early signs of neuromuscular disorders. These technologies also hold promise for the development of personalized training protocols tailored to individual needs. These innovations can automate signal analysis, making the process more user-friendly and precise. Additionally, portable and easy-to-use EMG devices could facilitate home-based assessments, allowing patients and therapists to monitor progress outside of clinical settings.

The use of EMG in fine motor skill training and assessment has shown great potential in research settings. By offering insights into muscle activity, EMG enhances the accuracy of motor assessments and improves the effectiveness of interventions. As technology advances, EMG is likely to play an increasingly vital role in fine motor skill development and rehabilitation.

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