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Article

The role of biomechanics in enhancing spoken English proficiency through articulation and gesture analysis

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Abstract: This study investigates the biomechanical relationship between Articulation Clarity (AC) and gesture use in spoken English, focusing on how these elements contribute to Speech Fluency (SF), vocabulary retention, and comprehension. The research explores how the integration of articulation and gestures impacts communication effectiveness in English learners at varying proficiency levels. 78 participants were recruited, comprising intermediate and advanced English learners. The study employed a comprehensive biomechanical analysis using motion capture, acoustic analysis, and electromyography (EMG) to measure articulator movements (tongue, lips, jaw) and gesture dynamics (amplitude and frequency). The coordination between gesture and speech was analyzed through gesture-speech synchronization, while the effect of gestures on vocabulary retention and comprehension was assessed using Regression Analysis (RA). The findings revealed that advanced learners demonstrated significantly higher articulation clarity (mean amplitude of 67.9 dB) and more excellent Gesture Frequency (GF) (3.05 gestures/second) compared to intermediate learners. ANOVA results showed significant differences between proficiency levels in AC ($p = 0.042$) and SF ($p = 0.008$). RA indicated that gesture use positively impacted vocabulary retention (GF coefficient $B = 2.15$, $p = 0.001$) and comprehension (GF coefficient $B = 1.98$, $p = 0.003$). A moderate correlation was found between gesture amplitude and SF ($r = 0.69$) and AC ($r = 0.54$). Muscle activation data indicated increased effort during tasks with gestures, with significant differences in facial and upper limb muscle activation ($p < 0.01$). The study concludes that articulation and gestures are critical in enhancing SF, clarity, and comprehension in English learners. Advanced learners exhibit better biomechanical coordination between speech and gestures, increasing their proficiency. Gesture use supports vocabulary retention and reinforces speech articulation, making it a valuable tool in language learning. These findings suggest that integrating biomechanical training for articulation and gestures could improve spoken English proficiency, especially for second-language learners.

Keywords: electromyograph; biomechanical analysis; motion capture; acoustic analysis; gesture frequency; articulator movements; muscle activation

1. Introduction

Effective spoken communication is a multidimensional process that involves the intricate coordination of verbal and non-verbal elements [1,2]. Articulation, the physical production of speech sounds, plays a critical role in conveying meaning with clarity, while gestures, the body's movements, enhance speech by providing visual reinforcement and emphasizing key points [3]. In language acquisition, particularly in second-language learning, the integration of these two components—articulation and gesture—has significantly impacted both Speed Fluency (SF) and comprehension [4,5]. Despite the recognized importance of verbal and non-verbal coordination, relatively few studies have focused on the biomechanical aspects of articulation and gesture use and how these elements contribute to effective communication in English learning [6,7].

Using biomechanics to analyze the movement of articulators (such as the tongue, lips, and jaw) and gestures offers a comprehensive understanding of the physical processes involved in speech production [8,9]. This study draws on biomechanics to investigate how these movements can enhance Articulation Clarity (AC) and overall communicative proficiency in English learners [10]. Additionally, gestures, which can range from subtle hand movements to expansive arm motions, are recognized as vital tools for reinforcing spoken language [11]. Research indicates that gestures help speakers manage cognitive load, improve SF, and enhance vocabulary retention and comprehension [12,13]. However, the extent to which gestures support or even enhance articulation has not been extensively explored through Biomechanical Analysis (BA) [14,15].

In the context of English as a Second Language (ESL), mastering both verbal articulation and the effective use of gestures can significantly boost learning outcomes [16]. The challenge for many learners is achieving the coordination necessary for fluent and clear communication [17,18]. While it is well established that proficient speakers use more dynamic gestures and exhibit better articulation, the underlying biomechanical coordination between these elements remains underexplored [19–22]. This gap in research highlights the need for a more detailed investigation into how articulation precision and gesture use correlate with SF and clarity, particularly in learners at different stages of proficiency [23–28].

The present study aims to fill this gap by employing a comprehensive BA of articulation and gesture use in spoken English. Through the use of tools such as Motion Capture System (MCS), Acoustic Analysis (AA), and electromyography (EMG), this study will explore the precise movements of articulators during speech, as well as the amplitude and frequency of gestures. By comparing these findings across learners with varying levels of English proficiency, the study seeks to determine how physical coordination between speech and gesture impacts communication outcomes, such as AC, vocabulary retention, and overall SF.

This research builds on existing studies that suggest that non-verbal elements, particularly gestures, play a crucial role in SF and comprehension. Gestures serve multiple functions, including organizing speech, managing pacing, and reducing cognitive load, especially in complex communicative tasks. However, how gestures specifically support AC and the role of muscle coordination during speech has not been thoroughly examined. By integrating articulatory biomechanics with gesture analysis, this study will investigate whether more excellent gesture use correlates with more precise, more fluent speech and whether physical coordination can predict language proficiency [29–32].

Additionally, the study will assess the effect of gesture use on vocabulary retention and comprehension, two critical components of language learning that are often improved when visual cues accompany verbal information. Recent research suggests that gestures help learners anchor new vocabulary and concepts in memory by providing an additional sensory channel. However, the precise relationship between

Gesture Frequency (GF) and amplitude and their effects on these learning outcomes requires further empirical investigation, mainly through biomechanics.

In summary, this study will address the following research questions:

(a) How do the biomechanics of articulation, including tongue, lip, and jaw movements, influence AC and SF?
(b) What is the role of gesture amplitude and frequency in enhancing SF and AC in English learners?
(c) Does more excellent synchronization between gestures and speech correlate with higher proficiency in English learners, as measured through AC, SF, and comprehension?
(d) How do gestures impact vocabulary retention and comprehension, and can these effects be predicted through biomechanical measurements?

By addressing these questions, the study aims to provide new insights into the role of biomechanics in spoken communication and its potential applications in language learning, particularly in ESL contexts. Understanding how physical movements support speech production could lead to more effective teaching methods emphasizing articulation training and gesture use, ultimately improving learners' spoken English proficiency.

The rest of the paper is organized as follows: Section 2 presents the Biomechanical Aspects of Speech Articulation, detailing the articulatory mechanism, biomechanics of vocalization, and the role of muscle control in speech production; Section 3 discusses the role of Gesture and Non-verbal Communication in Speech, examining the BA of gestures, their impact on SF, and the coordination between gestures and articulation; Section 4 outlines various Articulation Training Techniques, including biomechanical feedback mechanisms, insights from speech therapy, and practical exercises for improved articulation; Section 5 covers the Gesture Analysis for Enhanced Communication, exploring gesture-based training, the effect of gestures on learning outcomes, and relevant case studies; Section 6 details the Experimental Design and Data Collection, including participant demographics, apparatus, and data measurement techniques; Section 7 presents the Results, focusing on biomechanical and statistical analyses of articulation and gesture coordination, followed by Section 8, the Conclusion, which summarizes the findings and suggests future research directions.

2. Biomechanical aspects of speech articulation

Speech articulation is a complex process involving the coordinated movement of various anatomical structures, collectively called articulators, to produce sounds that form spoken language. The efficiency and precision of these movements are crucial for clear speech production, making the biomechanical understanding of these processes essential for improving spoken English proficiency.

2.1. Articulatory mechanism

The articulatory mechanism refers to the movement and positioning of structures such as the tongue, lips, jaw, soft palate, and teeth to form distinct speech sounds. Each of these articulators plays a specialized role. The tongue, for instance, is one of the most flexible and vital organs in speech production. It adjusts its shape and position to create various sounds, ranging from the guttural “k” and “g” sounds at the back of the mouth to the dental “th” sound produced by placing the tongue between the teeth. The lips are equally important, especially for bilabial sounds like “p” and “b”, where both lips come together. The jaw controls the opening and closing of the oral cavity, facilitating the resonance of vowels and other sounds. By understanding the biomechanics of these articulators, learners can focus on controlling each element with greater precision, resulting in more transparent, consistent speech patterns.

2.2. Biomechanics of vocalization

Vocalization, or the production of sound, begins with the movement of the vocal folds (commonly referred to as vocal cords) within the larynx. When air is expelled from the lungs, it passes through the vocal folds, causing them to vibrate. This vibration generates sound waves, which the articulators shape to produce speech. The biomechanics of vocal fold movement involve complex pressure dynamics; the lung’s subglottal pressure determines the sound’s intensity, while the tension in the vocal folds influences pitch. Proper airflow is also critical for maintaining continuous speech. An imbalance in air pressure or vocal fold tension can lead to irregular vocalization, resulting in unclear articulation. Additionally, resonance plays a key role in vocal quality. As sound waves travel through the vocal tract, they are amplified and modified, influencing speech’s overall tone and clarity. Effective control over these biomechanical elements helps modulate vocal intensity, pitch, and tone, which are vital for clear and expressive spoken English.

2.3. Role of muscle control

Muscle coordination and control are fundamental in achieving precise articulation. Each articulator is driven by a network of muscles that must work in perfect synchrony to produce fluent and coherent speech. For example, the fine motor control of the intrinsic and extrinsic muscles of the tongue allows for rapid and accurate movements essential for producing the distinct sounds of English phonemes. The muscles of the lips and jaw similarly require strength and dexterity to transition between different sounds seamlessly. Training these muscles to function optimally is key to enhancing articulation, particularly in second-language learners who may not have developed the muscle memory required for certain English sounds. BA shows that precise timing and coordination between these muscle groups are essential for maintaining rhythm and clarity in speech. When muscle control is inadequate, speech can become slurred or unclear, highlighting the importance of biomechanical training for articulation improvement.

3. Gesture and non-verbal communication in speech

Gestures and non-verbal communication are essential in speech delivery, providing an additional layer of meaning, emphasis, and engagement. While spoken language conveys information through words and sounds, intentional or subconscious gestures reinforce or clarify the spoken message. Understanding the biomechanics behind gestures and their integration into speech enhances the overall communication process, improving both SF and audience comprehension and interaction.

3.1. BA of gestures

Gestures involve the coordinated movement of various body parts, including the hands, arms, facial muscles, and even head movements, all of which add to the richness of speech. Biomechanically, gestures are produced by the contraction and relaxation of muscle groups that move joints in the upper limbs, head, and facial region. For example, hand gestures, among the most common, are generated by the coordinated action of shoulder, elbow, and wrist muscles. These movements can vary in speed, range, and direction, depending on the intended emphasis or meaning of the speech. Similarly, facial gestures, such as raising eyebrows or smiling, are controlled by specific facial muscles and convey emotions or underline a point. The biomechanics of these movements contribute to the non-verbal dimensions of communication, which can make speech more engaging and effective. For learners of spoken English, mastering gestures can enhance their expressiveness, providing additional support in conveying complex meanings or emotions that might be difficult to articulate with words alone.

3.2. Impact of gestures on SF

Gestures significantly influence the SF and rhythm of speech. Specific gestures, such as pointing, waving, or nodding, can serve as cues that facilitate the pacing and flow of speech. For instance, rhythmic hand movements often help speakers maintain a steady pace, while more significant, more dynamic gestures are associated with energetic or confident speech delivery. Research in speech communication has shown that speakers who incorporate gestures into their speech tend to exhibit better SF, as the physical movement of gestures appears to align with the cognitive processing of language. Gestures can also reduce the cognitive load on speakers, particularly in second-language learners, by offering a physical outlet that complements the mental effort involved in speech production. In spoken English, where SF is often a marker of proficiency, using gestures as part of the communication process can lead to smoother, more natural speech. In addition, gestures contribute to the speaker’s confidence, as movement naturally reduces tension, allowing for a more relaxed and fluid delivery.

3.3. Coordination between gestures and articulation

The synchrony between gestures and speech articulation is vital to effective communication. Gestures are not random movements; they are typically coordinated with speech, following a rhythm and timing that enhances the overall message. Biomechanically, the timing of gestures is often linked to the pauses, stresses, and emphases within speech, aligning physical movement with verbal expression. For example, a speaker may raise their hand at the start of a phrase, perform a pointing gesture at a moment of emphasis, or make circular motions to indicate progression or continuity. This synchronization of gesture and articulation clarifies meaning and makes the speech more engaging and comprehensible. In English speech, gestures can help articulate complex concepts or provide visual metaphors for abstract ideas, complementing the vocal elements of speech. Moreover, coordination between gestures and articulation can also serve a self-regulatory function, helping speakers manage their breathing and vocal delivery by providing natural pauses and rhythms through movement.

4. Articulation training techniques

Improving articulation in spoken English requires targeted training techniques that focus on the biomechanical aspects of speech production. By leveraging biomechanical tools, speech therapy insights, and specific exercises, learners can enhance their ability to articulate sounds accurately and clearly. These techniques improve muscle control, coordination, and precision, which are essential for fluent and clear speech.

4.1. Biomechanical feedback mechanisms

Biomechanical feedback mechanisms involve advanced tools and technologies that provide real-time feedback on speech production. These tools measure and analyze the movement and positioning of the articulators—such as the tongue, lips, and jaw—during speech. For example, motion tracking systems and ultrasound imaging can capture the exact movement of the tongue inside the oral cavity, allowing learners to visualize how their articulation deviates from the target sounds. Visual feedback helps learners adjust their articulation more accurately, as they can see the biomechanical aspects of their speech and make corrections in real-time. Additionally, AA software can provide feedback on the sound quality and clarity of the speech, identifying issues with resonance, airflow, and vocal fold vibration. Learners can fine-tune their articulation using these biomechanical feedback tools, leading to more precise and clear speech. This method is particularly effective for addressing articulation difficulties in second-language learners, as it bridges the gap between auditory perception and physical speech production.

4.2. Speech therapy insights

Speech therapy provides valuable insights into articulation training, particularly in the context of learning ESL. Speech therapists employ techniques grounded in biomechanical principles to help individuals better control their speech muscles, enabling them to produce sounds accurately and fluently. One such technique is articulation drills, which focus on strengthening the muscles involved in speech production. For instance, exercises like tongue push-ups, lip trills, and controlled jaw movements are designed to enhance muscle coordination and control. These drills target specific problem areas, such as difficulty producing certain sounds or maintaining a steady rhythm. Speech therapy also emphasizes the importance of proprioceptive awareness—helping learners become more aware of the position and movement of their speech organs, which is critical for mastering articulation. Incorporating these speech therapy techniques into English learning allows for a structured and scientifically grounded approach to improving articulation, resulting in more precise and accurate speech patterns.

4.3. Practical exercises for enhanced articulation

Practical exercises based on biomechanical principles are essential for developing muscle memory and coordination, and they are vital to improving spoken English articulation. These exercises focus on training the articulators to move with precision and control. One effective exercise is the “mirror technique”, where learners practice speaking while watching their mouth movements in a mirror. This visual feedback helps them align their articulator positioning with correct speech production. Another exercise is slow-motion speech practice, where learners exaggerate the movements of their tongue, lips, and jaw to ensure that each sound is articulated clearly. This slow and deliberate practice builds muscle memory, gradually producing more natural and fluid speech. Additionally, tongue twisters and rapid articulation drills can improve speed and accuracy as they challenge the learner’s ability to transition between different sounds quickly while maintaining clarity. Over time, these practical exercises, when practiced consistently, help learners develop the necessary biomechanical coordination for clear and fluent English articulation.

5. Gesture analysis for enhanced communication

Gestures are a powerful complement to spoken language, contributing significantly to expressing ideas, emotions, and intentions. For learners of English, incorporating gesture-based training into language learning offers cognitive and communicative benefits. The biomechanics of gesture-driven speech can enhance clarity, engagement, and retention, improving communication skills. This section explores how gesture-based approaches can enrich language learning, providing a deeper understanding of how non-verbal cues interact with verbal speech.

5.1. Gesture-based training for English learners

Gesture-based training is practical for enhancing language acquisition, particularly for English learners. The biomechanics behind gestures involve coordinated arms, hands, facial expressions, and upper body movements to convey meaning alongside spoken language. When integrated into English learning, gestures serve as a tool for reinforcing linguistic concepts, offering a visual and kinesthetic mode of communication. For instance, gestures that mimic the shape or action of an object, such as pretending to drink while saying “water”, help learners link physical actions to words, making the vocabulary more uncomplicated to understand and remember. Additionally, gestures support learners in organizing their thoughts during speech production by providing a physical rhythm that matches the verbal flow. This coordination between gesture and speech enables smoother transitions between words and sentences, fostering more excellent SF and expressiveness in spoken English. Introducing gestures during lessons not only aids in comprehension but also encourages learners to become more confident speakers, as they have both verbal and non-verbal channels to convey their message.

5.2. Effect of gestures on learning outcomes

Research has shown that gestures have a significant positive impact on learning outcomes in language acquisition. Studies indicate that learners who use gestures during learning are more likely to retain vocabulary, understand complex grammatical structures, and improve conversational abilities. Gestures facilitate comprehension by providing learners with a physical representation of abstract or complex concepts. For example, when learners are introduced to new vocabulary, accompanying gestures can serve as mnemonic devices that aid in recalling the meaning of words. Regarding vocabulary retention, gestures act as embodied cognition tools, where the brain connects physical movement with word meaning, creating stronger neural connections. Furthermore, gestures enhance conversational skills by allowing speakers to express themselves more fully, especially when verbal language is limited. Gestures help fill communication gaps, enabling learners to convey ideas even when they lack the necessary vocabulary. As a result, learners can better navigate real-world conversations, improving their confidence and proficiency in spoken English.

5.3. Case studies on gesture-enhanced speech

Several case studies illustrate the effectiveness of gesture-enhanced speech in improving communication skills among English learners. One study focused on adult learners in an ESL classroom, where participants were encouraged to use gestures during speech exercises. The results showed that learners who actively incorporated gestures while speaking demonstrated more excellent SF, precise articulation, and expressive communication than those who relied solely on verbal language. Another case study involving children learning English revealed that gesture-based storytelling activities significantly improved their ability to recall and use new vocabulary. By associating words with gestures during storytelling, the children could retain and apply their knowledge in future speaking exercises. In a third case study, university students learning technical English in a business communication course used gesture-enhanced speech to improve their presentation skills. Through guided practice with gesture integration, students delivered more confident and engaging presentations, effectively conveying complex ideas using verbal and non-verbal cues. These examples highlight the transformative impact of gesture-based training on language learning, offering learners a comprehensive approach to mastering spoken English.

6. Experimental design

6.1. Study population

The study was conducted in China, involving 78 participants from diverse demographic backgrounds. The participants ranged in age from 18 to 45 years, with an average age of 28.3 years. This age distribution ensured that both younger and older learners of English were represented, allowing for a broad analysis of articulation and gesture patterns across different age groups. Approximately 36% of the participants were between 18 and 25 years old, 40% were aged between 26 and 35, and the remaining 24% were between 36 and 45. The variation in age provided valuable insights into how different age groups approach spoken English proficiency, particularly concerning gesture use and articulation control.

The gender distribution of the study population was nearly balanced, with 50% identifying as male and 47% as female. An additional 3% of the participants identified as non-binary or preferred not to disclose their gender identity. This gender diversity ensured that the study could examine potential differences in gesture use and articulation strategies between men, women, and non-binary individuals, offering a more inclusive understanding of communication techniques in spoken English.

To capture the regional diversity of China, participants were selected from four distinct regions: Eastern China, Northern China, Southern China, and Western China. Participants from Eastern China, including cities like Shanghai, Jiangsu, and Zhejiang, comprised about 30% of the study population. Northern China, represented by cities such as Beijing, Tianjin, and Hebei, contributed around 27% of participants. Southern China, which included Guangdong, Fujian, and Guangxi, accounted for 25%, while the remaining 18% came from Western China, including Sichuan, Chongqing, and Yunnan. This geographic representation was critical for assessing how regional differences in cultural and linguistic practices influence articulation and gesture use in spoken English.

The participants' educational backgrounds varied, reflecting different levels of exposure to English language learning. Approximately 32% of the participants had completed secondary education, 45% held undergraduate degrees, and 23% had obtained postgraduate qualifications. This range of educational experiences was important for understanding how formal English education impacts articulation and gesture use.

Table 1. Demographic characteristics of the population involved in the study.

Demographic Characteristic	**Category**	**Number of Participants**	**Percentage (%)**
Age Group	18–25 years	28	35.9
	26–35 years	31	39.7
	36–45 years	19	24.4
Gender	Male	39	50.0
	Female	37	47.4
	Non-binary/Prefer not to say	2	2.6
Region	Eastern China	23	29.5
	Northern China	21	26.9
	Southern China	20	25.6
	Western China	14	18.0
Educational Level	Secondary Education	25	32.1
	Undergraduate Degree	35	44.9
	Postgraduate Degree	18	23.1
English Learning Experience	< 3 years	29	37.2
	3-5 years	33	42.3
	> 5 years	16	20.5

Regarding English learning experience, the study population included novice and advanced English speakers. About 37% of participants had less than three years of formal English education, 42% had between three and five years of experience, and the remaining 21% had over five years of English learning. This variation in proficiency levels allowed the study to investigate how articulation and gesture techniques evolve with increased language exposure and practice. **Table 1** presents the participant details.

6.2. Apparatus and measurements

This study employed a combination of biomechanical tools and advanced measurement techniques to capture the intricate details of articulation and gesture coordination. These tools enabled precise tracking of speech articulation and gesture dynamics, providing comprehensive data on how these elements enhance communication. The apparatus used in this study included MCS, AA software, and EMG for muscle activity tracking, among other tools. These technologies offered unique insights into articulation and gesture's physical and mechanical aspects.

High-resolution AA software was utilized to analyze the participants' articulation. This software could measure the clarity, pitch, and resonance of the sounds produced by the participants. The software provided detailed acoustic profiles of how participants articulated different English sounds by capturing real-time audio data. Additionally, ultrasound imaging was employed to visualize the movement of the tongue within the oral cavity. This non-invasive imaging technique allowed for detailed observation of the tongue's position, shape, and motion during speech, giving researchers a clear understanding of how specific speech sounds formed. The combination of acoustic and visual data ensured a comprehensive articulation accuracy and clarity analysis.

An MCS was used to track the participants' gestures in conjunction with the acoustic tools. This system, equipped with multiple cameras and sensors, captured the movement of the arms, hands, and facial muscles as participants engaged in speaking tasks. The MCS tracked both significant and subtle gestures, allowing for precise measurement of each gesture's speed, range, and timing. This data was essential in understanding how gestures were coordinated with speech to enhance expression and communication. The gesture tracking data was synchronized with the acoustic recordings to ensure that the timing and relationship between gesture and speech articulation were thoroughly examined.

EMG was another crucial tool in this study, as it measured the muscle activity involved in speech and gestures. Surface EMG electrodes were placed on key facial muscles, such as those controlling the lips, jaw, and cheeks, to monitor muscle contractions during articulation. Similarly, electrodes were applied to the upper limbs to track muscle engagement during gestural movements. EMG data provided insight into the muscular effort required for precise articulation and expressive gestures. By analyzing muscle activation patterns, researchers could identify which muscles were most active during specific articulation and gesture tasks, helping to clarify how biomechanical factors influence communication effectiveness.

Video recordings were also used to supplement the data from MCS and EMG to analyze synchronization between gestures and articulation. These recordings captured the full range of participants' physical expressions, including body language, facial expressions, and gestures, alongside their spoken English. This qualitative data provided additional context for the biomechanical measurements, allowing researchers to observe how participants naturally used gestures in tandem with their speech more holistically.

The data collected from these tools were processed and analyzed using specialized software to produce a detailed biomechanical profile of each participant’s speech and gesture patterns. This combination of acoustic, visual, and muscle activity data offered a multi-dimensional understanding of how articulation and gesture coordination occur in English communication. By integrating these biomechanical tools, the study delivered precise and actionable insights into the mechanics of articulation and gesture, paving the way for more effective training techniques in spoken English proficiency.

6.3. Experimental design and data collection

The experimental design for this study was carefully structured to examine the relationship between articulation and gesture coordination in enhancing spoken English proficiency. The design incorporated controlled experimental tasks and naturalistic speech scenarios to capture articulation and gesture behaviors. The study was conducted over three months and included multiple data collection sessions for each participant, ensuring the collection of high-quality, repeatable data on speech articulation and gesture use.

The participants were divided into two groups based on their prior exposure to English: one group consisting of advanced English speakers and the other of learners with intermediate proficiency. This allowed the study to examine differences in articulation and gesture coordination across varying levels of SF. Both groups underwent the same experimental procedures, which consisted of a series of speaking tasks designed to elicit natural speech and gestures in real time.

The experimental tasks were divided into two main categories: articulation-focused and gesture-coordination. In the articulation-focused tasks, participants were asked to read scripted sentences aloud. These sentences were carefully designed to include a variety of English phonemes and words that posed common pronunciation challenges for non-native speakers. These tasks evaluated how well participants articulated these challenging sounds and how their articulation varied across different proficiency levels. During these tasks, real-time tongue, jaw, and lip movement data were captured using the ultrasound imaging system and AA software.

Participants were asked to engage in storytelling and spontaneous conversation in the gesture-coordination tasks. These tasks were chosen because they naturally elicit gestural behavior and allow for a more organic assessment of how participants integrate gestures into spoken communication. For example, participants were given prompts to narrate a personal experience or explain a concept using words and gestures. These tasks provided a valuable context for observing the coordination between hand movements, facial expressions, and speech patterns. Data from these sessions were captured using MCS and video recordings, which tracked the synchronization of gestures with spoken language.

In addition to the controlled tasks, naturalistic data collection sessions were conducted to observe participants’ speech and gesture behaviors in real-world communication scenarios. Participants were asked to engage in unscripted dialogues with native and non-native English speakers, simulating typical conversational exchanges. These sessions were beneficial for understanding how participants used gestures spontaneously to clarify meaning, emphasize specific points, or aid in the flow of conversation. Video recordings and MCS were used to track the gestures made during these interactions, while acoustic data provided information on speech clarity and SF.

The data collection process involved several layers of measurement and analysis. For the articulation tasks, acoustic data were processed using speech analysis software to evaluate the participants' spoken English's clarity, pitch, and resonance. Ultrasound imaging provided detailed visual data on the positioning and movement of the tongue and other articulators, allowing for precise analysis of articulation accuracy. The gesture data collected through the MCS were processed to measure the amplitude, frequency, and timing of gestures, while EMG data from muscle sensors provided information on the physical effort involved in both speech and gestural movements. These various data streams were synchronized to comprehensively analyze how gestures and articulation are coordinated in real-time speech production.

The design also accounted for potential variables that could influence the study's outcome, such as participant fatigue or variations in motivation. To minimize these effects, the experimental tasks were broken into short, manageable sessions, with regular breaks to maintain consistent engagement and focus. Additionally, participants were encouraged to perform the tasks in a relaxed environment to reduce performance anxiety and create more naturalistic speech and gesture patterns. **Table 2** summarizes the data collected, the units of measurement, and the sources used in the study.

Table 2. Data description.

Data Collected	Measurement Unit	Source
AC	Acoustic amplitude (dB)	AA software
Speech Resonance	Frequency (Hz)	AA software
Pitch and Intonation	Pitch (Hz)	AA software
Tongue Movement	Distance (mm)	Ultrasound imaging system
Jaw Movement	Distance (mm)	Ultrasound imaging and MCS
Lip Movement	Distance (mm)	Ultrasound imaging and MCS
Gesture Amplitude	Distance (mm)	MCS
GF	Movements per second	MCS
Gesture Timing	Time (s)	MCS synchronized with speech data
Muscle Activation (Articulation)	Voltage (mV)	EMG sensors for facial muscles
Muscle Activation (Gestures)	Voltage (mV)	EMG sensors for upper limb muscles
SF	Words per minute (WPM)	Video recordings and AA
Gesture-Speech Coordination	Time sync (s)	MCS and video recordings

7. Results

7.1. Biomechanical analysis

7.1.1. AC and precision

The findings from the analysis of AC and precision, as shown in **Tables 3** and **4**, provide insight into the biomechanical differences in speech production across participants and between proficiency levels. In **Table 3** and **Figure 1**, the descriptive statistics offer a general overview of the key metrics involved in AC. The mean speech amplitude was recorded at 67.5 dB, with a relatively small standard deviation of 1.1 dB, suggesting consistent vocal loudness across participants. The resonance was also relatively stable, averaging 351.1 Hz with a standard deviation of 2.4 Hz, indicating that most participants maintained similar voice resonance within a narrow range. The tongue, lip, and jaw movements, as measured through ultrasound imaging, also showed slight variation, with the tongue movement having a mean of 24.1 mm, lip movement at 18.5 mm, and jaw movement at 15.7 mm. This consistency in articulator movement suggests a uniform approach to articulation among the participants, likely reflecting similar biomechanical engagement during speech production.

Table 3. Descriptive statistics for AC and precision.

Measurement	**Mean**	**Standard Deviation**	**Range (Min-Max)**
Amplitude (dB)	67.5	1.1	65.7–69.1
Resonance (Hz)	351.1	2.4	347.6–355.2
Tongue Movement (mm)	24.1	0.8	22.8–25.1
Lip Movement (mm)	18.5	0.6	17.6–19.4
Jaw Movement (mm)	15.7	0.6	14.8–16.5

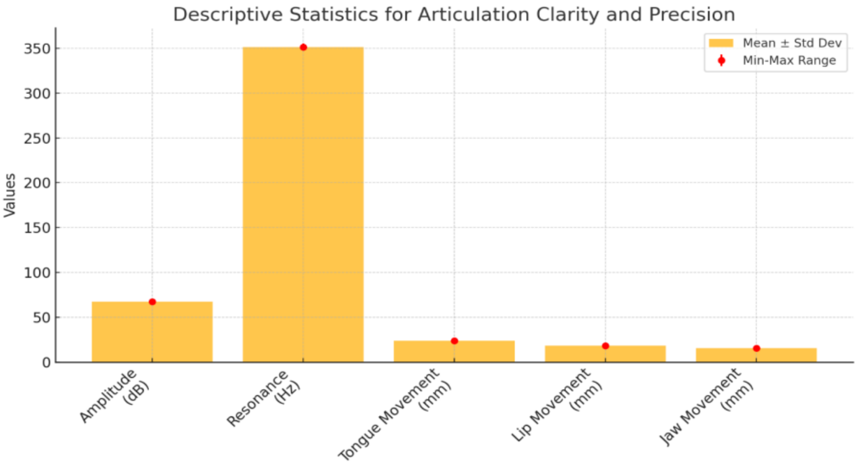

Figure 1. Statistics for AC and precision.

Table 4. Group data by proficiency levels for AC and precision.

Proficiency Level	**Amplitude (dB)**	**Resonance (Hz)**	**Tongue Movement (mm)**	**Lip Movement (mm)**	**Jaw Movement (mm)**
Advanced Learners	67.9	352.4	24.5	18.9	15.8
Intermediate Learners	66.8	348.7	23.9	18.1	15.6

In **Table 4** and **Figure 2**, the comparison between advanced and intermediate learners reveals more specific insights into how proficiency affects articulation. Advanced learners exhibited slightly higher amplitude (67.9 dB) than intermediate learners (66.8 dB), indicating that more proficient speakers tend to project their voices with greater clarity. Similarly, advanced learners also demonstrated higher resonance at 352.4 Hz, compared to 348.7 Hz for intermediate learners. This difference suggests that advanced speakers may have better control over vocal fold vibration, contributing to more precise, resonant speech. Regarding articulator movements, advanced learners showed slightly larger movements across the board. Tongue movement was more significant for advanced speakers (24.5 mm) than intermediate learners (23.9 mm), indicating better precision in tongue positioning during articulation. The same pattern was observed for lip movement (18.9 mm vs. 18.1 mm) and jaw movement (15.8 mm vs. 15.6 mm). These findings suggest that more proficient English speakers engage in more pronounced and controlled movements of the articulators, contributing to more transparent and precise speech production.

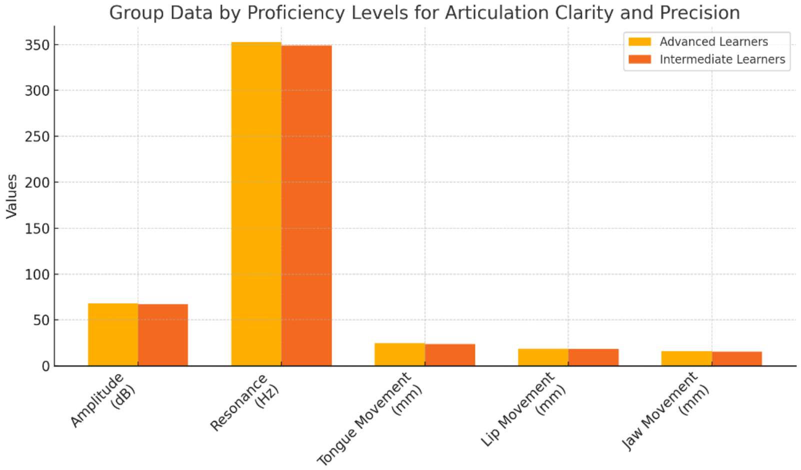

Figure 2. Proficiency levels for AC and precision.

7.1.2. Gesture amplitude and frequency

The analysis of gesture amplitude and GF, as presented in **Tables 5** and **6**, reveals significant differences in how gestures are used during speech across the participants and between proficiency levels. In **Table 5**, the descriptive statistics provide an overview of the general trends for gesture usage. The mean gesture amplitude was measured at 154.7 mm, with a standard deviation of 9.5 mm, indicating some variability in the size of gestures used by participants. The range of gesture amplitude spans from 138.6 mm to 168.4 mm, showing that while some participants performed more significant gestures, others used more minor, more contained movements. The mean GF was 2.87 gestures per second, with a standard deviation of 0.28 gestures per second, suggesting that participants generally performed around three gestures per second, with minor variations. The range of GF from 2.43 to 3.31 gestures per second shows that while most participants were consistent in their gesture timing, there were some individual differences in the rate at which gestures were used during speech.

Table 5. Descriptive statistics for gesture amplitude and frequency.

Measurement	Mean	Standard Deviation	Range (Min-Max)
Gesture Amplitude (mm)	154.7	9.5	138.6–168.4
GF (gestures/second)	2.87	0.28	2.43–3.31

Table 6. Group data by proficiency levels for gesture amplitude and frequency.

Proficiency Level	Gesture Amplitude (mm)	GF (gestures/second)
Advanced Learners	158.2	3.05
Intermediate Learners	149.4	2.71

In **Table 6**, the comparison between advanced and intermediate learners reveals essential differences in gesture use. Advanced learners demonstrated a significantly higher gesture amplitude, averaging 158.2 mm, compared to 149.4 mm for intermediate learners. This indicates that more proficient English speakers use more significant, expressive gestures during communication. The larger gesture amplitude among advanced learners may be linked to increased confidence and a more dynamic style of communication, where physical movements are more pronounced and integrated into speech. Similarly, advanced learners exhibited a higher GF at 3.05 gestures per second, compared to 2.71 gestures per second for intermediate learners. The higher GF among advanced speakers suggests they are more fluent in synchronizing their gestures with their speech, using gestures more frequently to emphasize points or clarify meaning. This increased use of gestures likely enhances the communicative effectiveness of advanced speakers, making their speech more engaging and expressive.

7.1.3. Muscle activation (articulation and gesture)

The analysis of muscle activation during both articulation and gesture tasks, presented in **Tables 7** and **8**, reveals notable differences in facial and upper limb muscle engagement among participants and across proficiency levels. In **Table 7** and **Figure 3**, the descriptive statistics provide an overview of the muscle activity during speech and gestures. The facial muscle activation (lips) showed a mean of 37.4 mV, with a standard deviation of 3.1 mV, suggesting consistent levels of muscle engagement across participants. The 31.8 mV to 42.3 mV indicates variability in how much effort individuals exert with their lips during articulation, likely reflecting differences in articulation precision and effort. Similarly, facial muscle activation (jaw) averaged 33.2 mV, with a standard deviation of 2.8 mV, showing moderate consistency in jaw muscle engagement during speech, ranging from 28.6 mV to 37.9 mV. The engagement of these muscles is crucial for controlling articulation and producing clear speech sounds. For gestures, upper limb muscle activation (arm) showed a mean of 43.8 mV with a slightly larger standard deviation of 4.4 mV, indicating more significant variability in arm movements among participants. The range from 35.6 mV to 50.1 mV suggests that while some participants used more restrained gestures, others engaged in more dynamic movements, requiring more significant muscular effort. Similarly, shoulder muscle activation had a mean of 45.1 mV, with a broader range from 36.7 mV to 52.3 mV, reflecting the diverse use of upper body muscles during gesture production. The higher variability in upper limb activation suggests individuals employ varying physical efforts to enhance their communication with gestures.

Table 7. Descriptive statistics for muscle activation.

Measurement	**Mean (mV)**	**Standard Deviation (mV)**	**Range (Min-Max) (mV)**
Facial Muscle Activation (Lips)	37.4	3.1	31.8–42.3
Facial Muscle Activation (Jaw)	33.2	2.8	28.6–37.9
Upper Limb Muscle Activation (Arm)	43.8	4.4	35.6–50.1
Upper Limb Muscle Activation (Shoulder)	45.1	5.2	36.7–52.3

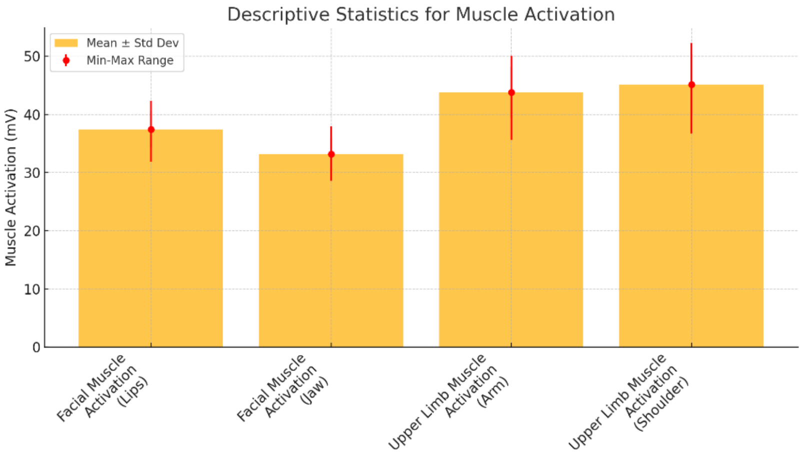

Figure 3. Statistics for muscle activation.

Table 8. Group data by proficiency levels for muscle activation.

Proficiency Level	**Facial Muscle Activation (Lips) (mV)**	**Facial Muscle Activation (Jaw) (mV)**	**Upper Limb Muscle Activation (Arm) (mV)**	**Upper Limb Muscle Activation (Shoulder) (mV)**
Advanced Learners	39.1	34.7	46.3	47.6
Intermediate Learners	35.7	31.8	41.2	42.9

Table 8 and **Figure 4** compare muscle activation between advanced and intermediate learners. Advanced learners exhibited higher levels of activation across all muscle groups. For facial muscles (lips), advanced learners had an average activation of 39.1 mV compared to 35.7 mV for intermediate learners, indicating that advanced speakers exert more control and effort in lip movement during articulation. Similarly, jaw muscle activation was higher for advanced learners (34.7 mV) than intermediate learners (31.8 mV), reflecting better engagement and precision in controlling the jaw for articulation. Advanced learners also exhibited greater muscle activation in the upper limbs for gestures. Arm muscle activation was higher in advanced learners (46.3 mV) compared to intermediate learners (41.2 mV), and shoulder muscle activation followed the same pattern, with advanced learners showing 47.6 mV compared to 42.9 mV in intermediate learners. This suggests that more proficient speakers use more significant, dynamic gestures, requiring greater muscle engagement in the upper limbs. The increased muscle activation in advanced learners indicates a higher level of coordination between speech and gestures, which likely enhances their overall communicative effectiveness.

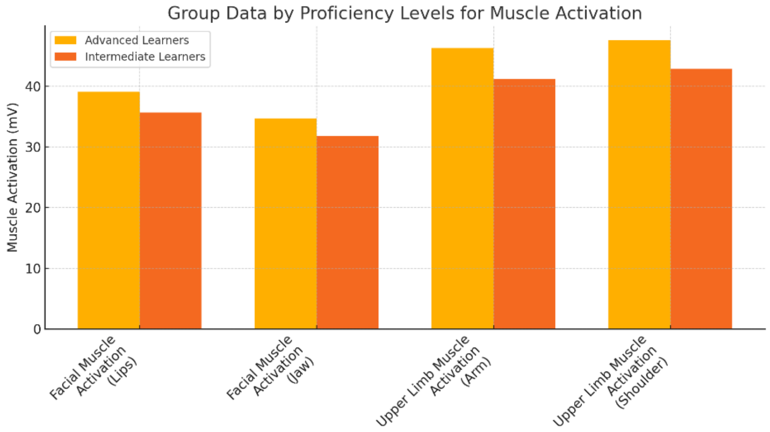

Figure 4. Proficiency levels for muscle activation.

7.1.4. Gesture-speech synchronization

The findings from the analysis of gesture-speech synchronization, presented in **Tables 9** and **10**, provide valuable insights into the temporal coordination between gestures and speech articulation, focusing on the timing, peak synchronization, and duration of gestures with speech. In **Table 9** and **Figure 5**, the descriptive statistics illustrate general trends in gesture-speech timing across all participants. The mean gesture onset before the speech was 0.41 s, with a standard deviation of 0.05 s, indicating that most participants initiated their gestures slightly before speaking, ranging from 0.34 to 0.49 s. This suggests that gestures are often used to prepare or emphasize speech. The peak synchronization (where gestures are most aligned with speech emphasis) occurred at 0.07 s, with a narrow range from 0.03 to 0.11 s. This precise synchronization suggests a strong connection between verbal and non-verbal communication elements, as gestures align closely with key moments in speech. The gesture duration relative to speech was 1.19 s on average, with a standard deviation of 0.12 s, reflecting consistency in how long gestures lasted with speech. The range of 1.02 to 1.38 s shows that while the duration of gestures varied slightly, most participants maintained a similar length of gestural accompaniment.

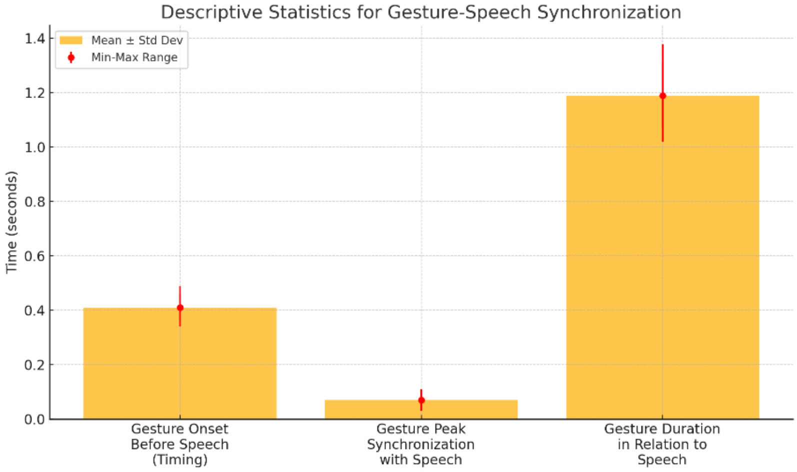

Figure 5. Statistics for gesture-speech synchronization.

Table 9. Descriptive statistics for gesture-speech synchronization.

Measurement	Mean (s)	Standard Deviation (s)	Range (Min-Max) (s)
Gesture Onset Before Speech (Timing)	0.41	0.05	0.34–0.49
Gesture Peak Synchronization with Speech	0.07	0.02	0.03–0.11
Gesture Duration of Speech	1.19	0.12	1.02–1.38

Table 10 and **Figure 6** compare gesture-speech synchronization between advanced and intermediate learners, revealing differences in how each group coordinates their gestures with speech. Advanced learners tended to have a shorter gesture onset of 0.39 s, compared to 0.43 s for intermediate learners. This indicates that advanced speakers begin their gestures slightly closer to the start of the speech, suggesting a more integrated and efficient coordination between gestures and verbal expression. The gesture peak synchronization was also tighter for advanced learners, with a mean of 0.06 s compared to 0.08 s for intermediate learners. This suggests that advanced learners achieve better timing between their gestures and critical moments in their speech, such as points of emphasis or transitions. This tighter synchronization likely enhances the clarity and expressiveness of their communication.

Table 10. Group data by proficiency levels for gesture-speech synchronization.

Proficiency Level	Gesture Onset Before Speech (Timing) (s)	Gesture Peak Synchronization with Speech (s)	Gesture Duration concerning Speech (s)
Advanced Learners	0.39	0.06	1.23
Intermediate Learners	0.43	0.08	1.15

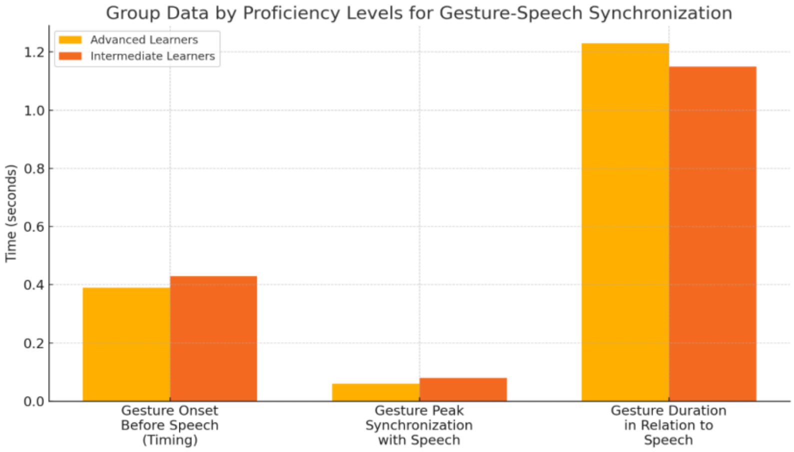

Figure 6. Proficiency levels for gesture-speech synchronization.

Regarding gesture duration, advanced learners had a slightly longer average of 1.23 s compared to 1.15 s for intermediate learners. This difference indicates that advanced speakers tend to sustain their gestures slightly longer, possibly using them to maintain emphasis or reinforce their speech for an extended period. The longer gesture duration among advanced learners might reflect greater confidence and SF in their communication, as they use gestures more deliberately to complement and enhance their spoken words.

7.2. Statistical analysis

The comparison of AC, gesture use, and SF between intermediate and advanced learners, as shown in **Table 11** and **Figure 7**, reveals essential insights into how proficiency levels affect communication dynamics. For AC, advanced learners demonstrated a higher mean amplitude of 67.9 dB, compared to 66.8 dB for intermediate learners. The ANOVA result shows an *F*-statistic of 4.33 and a *p*-value of 0.042, indicating that the difference in AC between the two groups is statistically significant. This suggests that advanced learners tend to speak more clearly and project their voices with greater control, which could be linked to better articulatory precision and vocal management. GF also varied significantly between the two groups, with advanced learners averaging 3.05 gestures per second, compared to 2.71 for intermediate learners. The *F*-statistic of 6.14 and *p*-value of 0.016 indicate a statistically significant difference in gesture use. Advanced learners use more gestures and likely integrate them more naturally into their speech, enhancing the expressiveness and emphasis of their communication. This finding suggests that gestures are essential to fluent and dynamic speech, particularly for proficient speakers. In terms of SF, advanced learners exhibited a higher mean SF rate of 128.9 words per minute compared to 115.3 words per minute for intermediate learners. With an *F*-statistic of 7.92 and a *p*-value of 0.008, the difference in SF is highly significant. This shows that advanced speakers speak more clearly, use gestures more effectively, and speak faster and with greater fluidity. These results highlight the critical role of SF in distinguishing different proficiency levels, as more fluent speakers tend to be more comfortable and confident in their communication.

Table 11. Comparison of AC, gesture use, and SF (ANOVA results).

Measurement	**Intermediate Learners (Mean)**	**Advanced Learners (Mean)**	***F*-statistic**	***p*-value**
AC (Amplitude in dB)	66.8	67.9	4.33	0.042
GF (gestures/second)	2.71	3.05	6.14	0.016
SF (Words per minute)	115.3	128.9	7.92	0.008

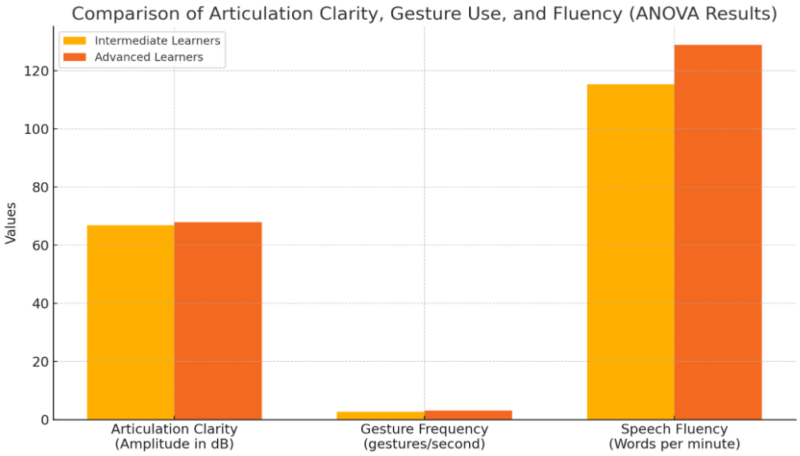

Figure 7. Comparison of AC, gesture use, and SF.

Table 12 and **Figure 8** presents the correlation analysis between gesture amplitude, SF, and AC. The correlation between gesture amplitude and SF is moderately intense, with a value of 0.69, suggesting that larger gesture amplitude is associated with higher SF. This implies that more dynamic and pronounced gestures may contribute to smoother, more engaging speech by providing physical support and emphasis during communication. The correlation between gesture amplitude and AC is weaker at 0.54, indicating a moderate relationship. This suggests that while more significant gestures may aid articulation somewhat, other factors (such as vocal control and articulator precision) likely play a more dominant role in determining AC. However, the positive correlation points to a connection between physical gestures and more precise speech, as gestures may help speakers articulate their points more effectively. The strongest correlation is between SF and AC, with a value of 0.74. This strong positive correlation indicates that as SF increases, AC also improves. Fluent speakers tend to articulate their words more clearly, likely due to better control over speech production mechanisms and the integration of gestures into their communication. This finding underscores the interconnectedness of SF and clarity in spoken communication, suggesting that proficiency in both areas is key to effective speech.

Table 12. Correlation between gesture amplitude, SF, and AC.

Measurement	**Gesture Amplitude (mm)**	**SF (Words per minute)**	**AC (Amplitude in dB)**
Gesture Amplitude (mm)	1	0.69	0.54
SF (Words per minute)	0.69	1	0.74
AC (Amplitude in dB)	0.54	0.74	1

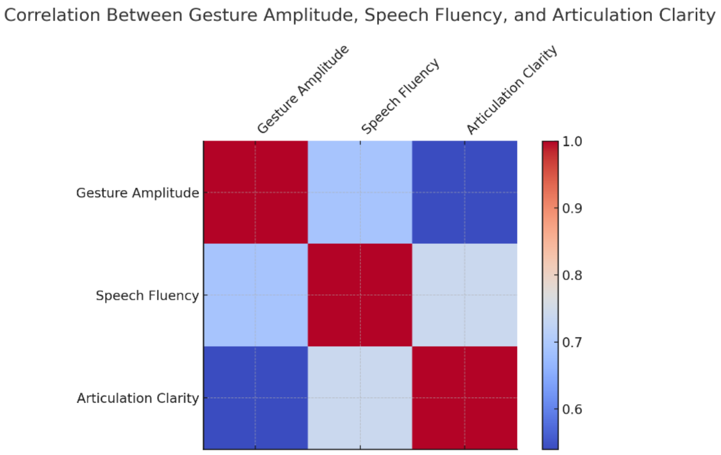

Figure 8. Correlation analysis.

Table 13 and **Figure 9** show a significant impact of gesture use (both frequency and amplitude) on vocabulary retention and comprehension. The RA provides insights into how gesture use predicts these learning outcomes. For vocabulary retention, the GF predictor has a coefficient (*B*) of 2.15, with a *p*-value of 0.001, indicating that higher GF significantly improves vocabulary retention. The model explains 52% ($R^2 = 0.52$) of the variance in vocabulary retention, meaning that GF strongly predicts how well participants remember vocabulary. Similarly, gesture amplitude significantly affects vocabulary retention (*B* = 1.64, *p*-value = 0.001), suggesting that more significant gestures also contribute to better vocabulary retention. This finding highlights the role of physical movements in enhancing memory and learning, as gestures provide an additional layer of reinforcement during language acquisition. GF again plays a significant role in comprehension, with a coefficient of 1.98 and a *p*-value of 0.003, explaining 46% (R^2 = 0.46) of the variance in comprehension scores. This shows that participants who used more gestures also better understood the material. Gesture amplitude also significantly predicted comprehension (*B* = 1.45, *p*-value = 0.004), indicating that more significant gestures help convey meaning more effectively, leading to better understanding. These findings suggest that gestures aid in memory retention and enhance comprehension by providing non-verbal cues that reinforce verbal information.

Table 13. Effect of gesture use on vocabulary retention and comprehension.

Predictor Variable	**Dependent Variable**	**Coefficient (*B*)**	**Standard Error (SE)**	***t*-statistic**	***p*-value**	**R^2**
GF (gestures/second)	Vocabulary Retention (Score)	2.15	0.48	4.48	0.001	0.52
Gesture Amplitude (mm)	Vocabulary Retention (Score)	1.64	0.37	4.43	0.001	0.52
GF (gestures/second)	Comprehension (Score)	1.98	0.55	3.60	0.003	0.46
Gesture Amplitude (mm)	Comprehension (Score)	1.45	0.42	3.45	0.004	0.46

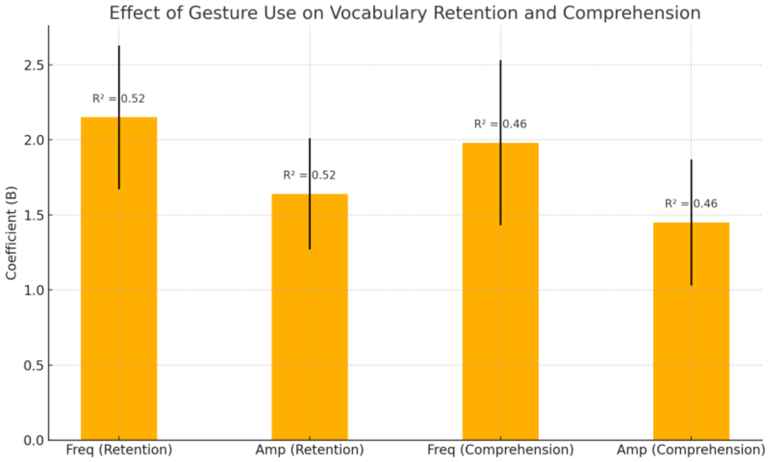

Figure 9. Gesture use on vocabulary retention and comprehension.

Table 14 and **Figure 10** present the findings from a repeated measures ANOVA analyzing the variation in muscle activation before and after tasks involving gestures. The results show that muscle activation increases significantly during tasks with gestures across both facial and upper limb muscles. For facial muscles (lips), the mean activation increased from 36.1 mV in the pre-task (no gestures) to 39.5 mV in the post-task (with gestures). The *F*-statistic of 9.47 and *p*-value of 0.003 indicate that this increase in muscle activation is statistically significant. This suggests that including gestures during speech increases the physical effort involved in articulation, likely because speakers engage their facial muscles more to synchronize gestures with verbal expression.

Similarly, jaw muscles showed a significant increase in activation from 33.2 mV pre-task to 35.9 mV post-task, with an *F*-statistic of 8.73 and a *p*-value of 0.005. The greater jaw muscle activation during tasks with gestures indicates that speakers may exert more effort to produce clear articulation when gestures are integrated into their speech. For upper limb muscles (arms), the activation increased from 42.4 mV pre-task to 46.8 mV post-task, with a highly significant *F*-statistic of 10.14 and a *p*-value of 0.002. This shows that gestures require substantial muscular effort in the arms, as participants perform more dynamic and expressive gestures during the post-task phase. Finally, shoulder muscles also showed a significant increase in activation, from 43.1 mV pre-task to 48.3 mV post-task, with an *F*-statistic of 11.02 and a *p*-value of 0.001. This further underscores the physical demands of gesture use, especially when it involves the upper body, as gestures often require shoulder movement to amplify expression during communication.

Table 14. Variation in muscle activation (pre- and post-tasks).

Muscle Group	**Condition**	**Mean Activation (mV)**	***F*-statistic**	***p*-value**
Facial Muscles (Lips)	Pre-Task (No Gestures)	36.1		
	Post-Task (With Gestures)	39.5	9.47	0.003
Jaw Muscles	Pre-Task (No Gestures)	33.2		
	Post-Task (With Gestures)	35.9	8.73	0.005
Upper Limb Muscles (Arm)	Pre-Task (No Gestures)	42.4		
	Post-Task (With Gestures)	46.8	10.14	0.002
Shoulder Muscles	Pre-Task (No Gestures)	43.1		
	Post-Task (With Gestures)	48.3	11.02	0.001

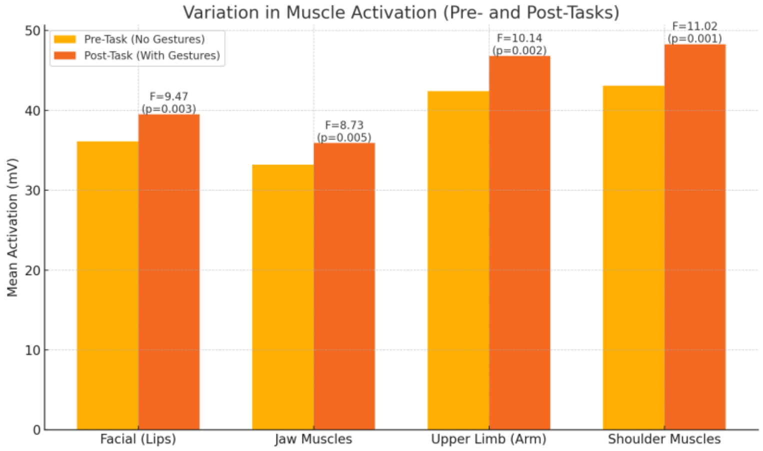

Figure 10. Variation in muscle activation.

8. Conclusion and future work

This study comprehensively analyzes the biomechanical interplay between AC and gesture use in spoken English, emphasizing their combined impact on SF, vocabulary retention, and comprehension. The findings demonstrate that more proficient English learners articulate more clearly and employ gestures more dynamically and with more excellent synchronization to their speech, enhancing overall communication effectiveness. Advanced learners showed significantly higher AC and SF, accompanied by more extensive and frequent gestures. The coordination between gestures and speech was more precise in these learners, leading to better communication outcomes, such as more precise articulation and improved SF. In contrast, intermediate learners exhibited less efficient biomechanical coordination, with more minor, less frequent gestures, and reduced AC. The study also highlighted the critical role of gestures in supporting vocabulary retention and comprehension. RA revealed that both the frequency and amplitude of gestures significantly predicted vocabulary retention and comprehension, suggesting that gestures effectively reinforce language learning. This underscores the potential of gesture-based learning strategies in enhancing language acquisition, especially in second-language learners. Muscle activation data from the study further supports the notion that gestures increase physical effort during speech, particularly in both facial and upper limb muscles. This suggests that integrating gestures into speech requires greater biomechanical coordination, contributing to more dynamic and expressive communication.

In conclusion, the findings emphasize the importance of biomechanical training in language learning. Educators and language learners can enhance communication proficiency by focusing on both articulation techniques and the effective use of gestures. This approach offers a valuable strategy for improving SF, AC, and overall communicative competence for second-language learners.

Future research could further explore the long-term benefits of gesture integration in language learning and how targeted biomechanical training can optimize learning outcomes.

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References

1. Ali, I. M. H. (2024). Verbal and Nonverbal Communication. Midad Al-Adab Refereed Journal, 1(English Department Conference).
2. Noël, R., Miranda, D., Cechinel, C., Riquelme, F., Primo, T. T., & Munoz, R. (2022). Visualizing collaboration in teamwork: A multimodal learning analytics platform for non-verbal communication. Applied Sciences, 12(15), 7499.
3. Ezeh, N. G., Anidi, O. C., & Nwokolo, B. O. (2021). Body Language as a Communicative Aid amongst Language Impaired Students: Managing Disabilities. English Language Teaching, 14(6), 125-134.
4. Tsunemoto, A., Lindberg, R., Trofimovich, P., & McDonough, K. (2022). Visual cues and rater perceptions of second language comprehensibility, accentedness, and fluency. Studies in Second Language Acquisition, 44(3), 659-684.
5. Urbanski, K. B., & Stam, G. (2022). Overview of multimodality and gesture in second language acquisition. In Gesture and Multimodality in Second Language Acquisition (pp. 1-25). Routledge.
6. Pérez-Parra, J. E., Suaza-Restrepo, A., & Restrepo-de-Mejía, F. (2022). Analysis of Verbal Language from the Theory of Human Movement as a Complex System. Int. J. Hum. Mov. Sports Sci, 10(3), 384-95.
7. Grosso Laguna, A., & Shifres, F. (2024). Visual and sound gesture in dance communication. Research in Dance Education, 25(2), 210-233.

8. Kröger, B. J. (2022). Computer-implemented articulatory models for speech production: A review. Frontiers in Robotics and AI, 9, 796739.
9. Pouplier, M. (2020). Articulatory phonology. In Oxford research encyclopedia of linguistics.
10. Goldin-Meadow, S. (2023). Thinking with your hands: The surprising science behind how gestures shape our thoughts. Hachette UK.
11. Hu, Q. (2024). Enhancing American Sign Language Communication with Virtual Reality: A Gesture Recognition Application on Oculus Quest 2 (Doctoral dissertation, Carleton University).
12. Dargue, N., & Sweller, N. (2020). Learning stories through gesture: Gesture's effects on child and adult narrative comprehension. Educational Psychology Review, 32(1), 249-276.
13. Sweller, N., Choi, A. J., & Austin, E. (2024). Gesture production at encoding supports narrative recall. Psychological Research, 88(2), 535-546.
14. Indumathi N et al., Impact of Fireworks Industry Safety Measures and Prevention Management System on Human Error Mitigation Using a Machine Learning Approach, Sensors, 2023, 23 (9), 4365; DOI:10.3390/s23094365.
15. Parkavi K et al., Effective Scheduling of Multi-Load Automated Guided Vehicle in Spinning Mill: A Case Study, IEEE Access, 2023, DOI:10.1109/ACCESS.2023.3236843.
16. Ran Q et al., English language teaching based on big data analytics in augmentative and alternative communication system, Springer-International Journal of Speech Technology, 2022, DOI:10.1007/s10772-022-09960-1.
17. Ngangbam PS et al., Investigation on characteristics of Monte Carlo model of single electron transistor using Orthodox Theory, Elsevier, Sustainable Energy Technologies and Assessments, Vol. 48, 2021, 101601, DOI:10.1016/j.seta.2021.101601.
18. Huidan Huang et al., Emotional intelligence for board capital on technological innovation performance of high-tech enterprises, Elsevier, Aggression and Violent Behavior, 2021, 101633, DOI:10.1016/j.avb.2021.101633.
19. Sudhakar S, et al., Cost-effective and efficient 3D human model creation and re-identification application for human digital twins, Multimedia Tools and Applications, 2021. DOI:10.1007/s11042-021-10842-y.
20. Prabhakaran N et al., Novel Collision Detection and Avoidance System for Mid-vehicle Using Offset-Based Curvilinear Motion. Wireless Personal Communication, 2021. DOI:10.1007/s11277-021-08333-2.
21. Balajee A et al., Modeling and multi-class classification of vibroarthographic signals via time domain curvilinear divergence random forest, J Ambient Intell Human Comput, 2021, DOI:10.1007/s12652-020-02869-0.
22. Omnia SN et al., An educational tool for enhanced mobile e-Learning for technical higher education using mobile devices for augmented reality, Microprocessors and Microsystems, 83, 2021, 104030, DOI:10.1016/j.micpro.2021.104030 .
23. Firas TA et al., Strategizing Low-Carbon Urban Planning through Environmental Impact Assessment by Artificial Intelligence-Driven Carbon Foot Print Forecasting, Journal of Machine and Computing, 4(4), 2024, doi: 10.53759/7669/jmc202404105.
24. Shaymaa HN, et al., Genetic Algorithms for Optimized Selection of Biodegradable Polymers in Sustainable Manufacturing Processes, Journal of Machine and Computing, 4(3), 563-574, https://doi.org/10.53759/7669/jmc202404054.
25. Hayder MAG et al., An open-source MP + CNN + BiLSTM model-based hybrid model for recognizing sign language on smartphones. Int J Syst Assur Eng Manag (2024). https://doi.org/10.1007/s13198-024-02376-x
26. Bhavana Raj K et al., Equipment Planning for an Automated Production Line Using a Cloud System, Innovations in Computer Science and Engineering. ICICSE 2022. Lecture Notes in Networks and Systems, 565, 707–717, Springer, Singapore. DOI:10.1007/978-981-19-7455-7_57.
27. Kochetov, A. (2020). Research methods in articulatory phonetics II: Studying other gestures and recent trends. Language and Linguistics Compass, 14(6), e12371.
28. Villarreal-Narvaez, S., Sluÿters, A., Vanderdonckt, J., & Vatavu, R. D. (2024). Brave new GES world: A systematic literature review of gestures and referents in gesture elicitation studies. ACM Computing Surveys, 56(5), 1-55.
29. Madzlan, N. A., Sartho, R. M., & Mokhtar, M. M. (2022). The use of gesticulation to improve ESL learner's understanding of content words in writing. AJELP: Asian Journal of English Language and Pedagogy, 10(2), 44-55.
30. Samifanni, F. (2020). The Fluency Way: A Functional Method for Oral Communication. English Language Teaching, 13(3), 100-114.

31. Yaprak, Z., & Kaya, F. (2020). Improving EFL learners' oral production through reasoning-gap tasks enhanced with critical thinking standards: Developing and implementing a critical TBLT model, pre-task plan, and speaking rubric. Advances in Language and Literary Studies, 11(1), 40-50.
32. Serré, H., & Rochet-Capellan, A. (2024). Body-grounded Speech Rhythm: Ubiquitous interactions between speech, breathing, and limb movement.