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Space, Movement and Articulation in a Newly Emergent Sign Language: Contributions for Neural and Sociocognitive Efficiency in Communication

Ana Maria Abreu[1,2], Ana Mineiro[1], Cláudia Ribeiro da Silva[3], & Alexandre Castro-Caldas[1]

1. *Universidade Católica Portuguesa, Institute of Health Sciences, Center for Interdisciplinary Reseach in Health (CIIS), Lisbon, Portugal*
2. *Faculdade de Ciências da Saúde e do Desporto, Universidade Europeia, Lisbon, Portugal*
3. *Superior de Saúde de Alcoitão, Alcoitão, Portugal*

Correspondent Author: Ana Maria Abreu, Ph.D

E-Mail Address: anamariablom@gmail.com; anelas@ucp.pt.

Abstract

Objective: Here we investigate the involvement of space, movement and nonmanual articulators throughout the evolution of a newborn sign language. We aimed to assess how the development of these constraints might lead to effortless movement and neural economy in social communication. **Methods:** We analyzed the gestures elicited from 100 sketch cards, produced by 100 deaf and hard of hearing individuals as they came together to develop a new sign language. **Results:** We found that throughout four two-year time phases, gestures reduced in number, motion amplitude and recruitment of nonmanual articulators. **Conclusions:** The evolution of a newborn sign language seems to follow the same phases of psychomotor development (experienced, manipulated and represented). Reduction of gesture number and changes in movement and space strategies seem to be linked to more efficient use of energy while enhancing cognition, allowing for the fruition of social communication enabled by sign language.

Keywords: Sign Language; Pantomime, Sign; Movement, Brain, Neural Efficiency.

Public Significance Statement: We show that the evolution of an emerging sign language seems to follow the same phases of psychomotor development (experienced, manipulated and represented), and reduction of gestures and changes in movement and space strategies seem to be linked to a more efficient use of energy while enhancing cognition. Insights on how sign languages emerge are critical for understanding and intervening in this area.

Introduction

Movement development, social communication and the brain

We tend to think of our first social encounters with the world as mediated by speech or gestures. However, even before the emergence of purposeful gestures or meaningful speech, movement plays a crucial role in the encounter between the developing being and the world, while setting the path for communicative development and language acquisition (Iverson, 2010). The acquisition of psychomotor skills is of paramount importance for the healthy development of the brain (e.g., Gabbard, 2009; Stevens-Smith, 2004). Indeed, our first encounters with the environment are expressed by our body in motion, reflecting the collective manifestation of our cognitive, affective and motor functions. Psychomotor development implies the development of three concurrent domains: i. motor skills that interact with constraints, task, organism and environment (e.g., Newell, 1984; 1986), ii: body awareness (Moore et al., 2007), and iii. awareness of the surrounding environment, highly mediated by movement experiences, as shown by systems interaction research (Rodríguez et al., 2013). These domains interact and mediate cognitive development (Roebers & Kauer, 2009). The acquisition of psychomotor skills in infancy is marked by corporeal experiences mediated by movement and perceptions, i.e., the perception-action system (Jiang & Rosengren, 2018). These psychomotor experiences imprint the cognitive and affective memories of the child. However, with time, psychomotor experiences evolve to separate action from feeling towards a more abstract knowledge (see, for example, Rivera-González et al., 2019). Thus, when learning a new concept such as “round”, the child first experiences roundness through corporeal involvement, e.g., by altering the shape of their own body to compose round shapes. Subsequently, the child starts to manipulate round shapes, e.g., by cutting a circle or playing with a ball. Finally, the child is able to represent roundness, e.g., by drawing, or even imagining, a round face. Throughout these phases, the “round” concept is first experienced, then, manipulated, and finally, represented, drifting from a dependency on movement to the integration of the ethereal abstract concept (e.g., Le Boulch, 1995). With concept abstraction, children are able to understand a world that has not been experienced and this is a precursor for the acquisition of norms and the development of sociocognitive skills. Since words can be viewed as social tools (Borghi, 2018) we expect an economization in movement expression in order to facilitate social interaction and communication.

Notably, the psychomotor theory of the human mind (Tan, 2007) rejects a duality between mind and brain and suggests a unified mind-brain-body theory, based on the shared feedback circuits between brain, mind and body. Consistently, earlier work (Gabbard, 1998) discusses the importance of movement experience in changing the brain (structure and function) and its cognitive implications. More recent work (Taylor et al., 2020) shows male and female differences in neurocognitive strategies underpinning abstract reasoning. Importantly, and independently of the strategies used by female and male participants, this research shows an association between neural efficiency and abstract reasoning. Just like expert athletes' mastery in movement is associated to neural efficiency, i.e., reduction of neural activity, leading to economy in brain function (Del Percio et al., 2009), it is possible that, with time, the symbolization and reduction of movement in space might lead to expertise in signing associated to neural efficiency and optimized competences for social communication. In a recent fMRI study with expert athletes, Zhang and collaborators (2019) show that expert athletes achieve superior performance in acquired motor skills, while showing reduced neural energy consumption. Since the motor theory of sign language considers that linguistic knowledge is mapped onto sensorimotor processes (Gibet et al., 2011), then, expert signers should also demonstrate neural efficiency when signing.

According to Inoue (2006), an embodied cognition approach to sign languages supports the interaction between sensory and motor functions with the environment, i.e. signing space. Since movement is crucial in sign languages, here we aim to investigate how movement evolves across the appropriation of an emergent sign language: Sao Tome and Principe Sign Language (LGSTP). In order to better comprehend movement and the development of the motor skills necessary for signing, we must first appreciate how space, movement and non-manual articulators are involved.

Notions of space, movement and non-manual articulators in sign languages

Sign languages are the natural languages of deaf communities. Signs of sign languages are established significant units which exist in the lexicon and grammar of a specific sign language. Like words, each sign has its own grammatical rules and can be classified in terms of phonology, morphology, semantics, pragmatics and syntax and can show dialectical variation (Moita et. al. 2018). Unlike oral languages, sign languages use hands and arms as major articulators. Early research on sign languages focused exclusively on hands, configurations, orientation and movement of hands and arms (Stokoe, 2005). More recently, the role of nonmanual articulators (head, torso, face and mouth) during signing has been investigated, and it has been recognized that signers use nonmanual articulators in systematic, rule-governed ways in which linguistic content can be conveyed (Baker & Padden, 1978; Boyes et al., 2002; Herrmann & Steinbach, 2013). Nonmanual actions are coordinated with movements of the hands during sign production. The head, mouth, trunk and legs are referred to be the nonmanual articulators in sign languages. In a young or newborn sign language, these nonmanual articulators play an important role (Dachkovsky et al., Stamp, 2018). Such nonmanual articulators reveal a whole-body commitment to communicate firstly with pantomimic gestures as argued by Mineiro and collaborators (2021) and then evolving to forfeiting larger movement as well as decreasing frequency in the use of nonmanual articulators.

Signed languages are perceived visually and produced by movements of the hands in space. As a result, signers have a rich spatial medium at their disposal to express both spatial and non-spatial information. Signing space is the term used for the three-dimensional space in front of the signer, extending from the waist to the forehead, where signs can be articulated. Several categorizations are used to define signing space, referring to different anatomical positions and relative locations of the human body, as described by healthcare professionals and biomedical engineers (e.g., Emmorey, 2001):

a) Medial and lateral: ***Medial*** refers to being toward the midline of the body or the median plane, which splits the body, head-to-toe, into two halves, the left and right. ***Lateral*** is the side of the body or part of the body that is away from the middle. Thus, arms are lateral to the torso while the torso is medial to the arms. And the medial side of the knee is the inside part or side nearest to the other knee, while the lateral side of the knee faces away from the center of the body and is farthest from the other knee.

b) Proximal and distal: These two terms are almost always used in reference to relative locations of parts on the limbs. ***Proximal*** refers to something closer to the torso while ***distal*** refers to parts and places away from the torso.

c) Superior and inferior: These two terms are used to refer the body's vertical axis. A body part higher than another or above it is said to be ***superior*** to it and conversely, the other body part is ***inferior*** to the former.

Movement is considered one of the major phonological parameters in sign phonology. All conventionalized signs have movement in them. Movement is conveyed, either by a path made by the dominant hand or both hands as they go from one location to another or by a change in handshape, orientation of hand or some combination of the two (Brentari, 2019; Wilbur & Shick, 1987). Movement typically identified in a sign can be characterized as being a major or minor movement. Major movement involves changing the position of the hand in signing space, involving the elbow or shoulder joint. This kind of movement can be straight or oblique (arched or in a circle). Although minor movement does not involve a change in the hands' location in space, it involves wrist and/or finger movements (Moita et al., 2018). Previous research stemming from this comprehensive social project has shown the existence of minor movement in the twist, rub, hook, or strum forms (Carmo et al., 2014). Some signs involve both major and minor movement simultaneously. Major and minor movements are relevant to the sign´s lexical interpretation. There is a third type of movement called transitional movement. This movement occurs when there is a need to move the hands from the place of articulation of one sign to the place of articulation of next sign. For the purpose of this paper, we will only be analyzing major and minor movements as our corpus is circumscribed to isolated signs and not signs in sentences.

Sao Tome and Principe Emergent Sign Language: from pantomime to early signs

Sign languages emerge from the interaction between deaf people and their willing interlocutors. While this fact is undisputed, the emergent sign languages studied by linguists unfold into two categories: "village sign languages" and "deaf community sign languages" depending if the language develops due to a shared geographic area or kinship between signers or if it is passed on to a cohort of students attending schools for the deaf, respectively (Sandler, 2005). Naturally, the emergency of village sign languages is more dynamic and flexible because it evolves from the need to communicate between deaf and hearing people in the community. Such flexibility also leads to within-community variations across generations, households and hearing signers (Vos & Nyst, 2018; Sandler et al., 2005). Deaf Community Sign Languages, on the other hand, develop when people from different geographical locations are gathered together for educational aims, as is the case of the modern example of Lengua de Senas de Nicaragua (NSL) wherein children living in remote places in Nicaragua were congregated in a school for the deaf (Senghas 1995; Kegl et al., & 1999). Critically, in NSL, schooling was meant to teach lip reading and Spanish and the systematization of signing was accomplished by the children's communication on buses and the school grounds, without foreign introduction of signs (Senghas & Coppola, 2001). We wonder if, despite being a village sign language, ABSL was contaminated by the introduction of foreign signs by experimenters (Erard, 2019). In São Tome and Principe, although there are approximately five thousand deaf and hard of hearing individuals, we would expect that such a large number of deaf individuals in a community (and the absence of deaf schooling) would lead to the emergence of a village sign language. However, these individuals are distributed across the region and lack means to group. We developed this project with the aim of helping these people come together, in order to allow the emergence of a novel language. Nevertheless, we desired to maintain the purity of the emergence of a new language and did not teach established signs but instigated their natural birth. In this sense, we grouped people together in ecological contexts (trips, conversation settings) but did so in a common pedagogical setting, in non-conformity with either type of sign languages.

Studies on emerging sign languages (e.g., Sandler, 2017; Senghas, 2001) provide evidence for how critical properties of the linguistic systems are created. In previous studies (Mineiro et al., 2021, Mineiro et al., 2017) we showed how gestures initially produced by participants lack systematicity and resemble pantomime, but come to develop fundamental language-like properties and lead to a gradual increase of regularity and systematic structure within linguistic rules for phonology, morphology and syntaxis (Mineiro et al., 2017). Our results showed in that within two years of contact, the deaf community of Sao Tome and Principe built a shared language. Previous research suggests that human communication may have begun in gesture (Corballis, 2002, 2009; Brown et al., 2019) and it is assumed by some investigators that sign languages begin life as gestural systems (Goldin-Meadow, 2003; Goldin-Meadow & Brentari, 2017; Janzen & Shaffer, 2002). Our previous study (Mineiro et al., 2021), aimed to investigate how quickly pantomimic communication turned into lexicalized and conventionalized signs of the emergent sign language of Sao tome and Principe. Here, we investigate the importance of movement development in affording an effective social communication.

Aims

We have argued, hitherto, that movement is paramount for communication, and there are few human conducts that that are not expressed by means of movement (e.g., Mojtahedi et al., 2017; Bassili, 1979). Indeed, motricity allows for nonverbal communication, that prevails throughout life (Iverson, 2010). However, it remains to be investigated, how the participation of movement evolves throughout the development of a new sign language. Here, we intend to investigate just that by analyzing the evolution of a newborn sign language. In recent years a newly emerging sign language in São Tomé and Príncipe was studied (Mineiro et al., 2021; Mineiro & Carmo, 2016; Mineiro et al., 2017). This research showed that the use of the hands, face, and body for language, gradually leads to the conventionalization and grammaticalization, systematicity, and complexity of linguistic form, distancing it from the first pantomime proposals of communication. Could we be dealing with a sort of Recapitulation Theory, whereby the establishment of a new sign language repeats the stages of psychomotor development, from experienced to represented levels? In the context of the establishment of a new sign language, might movement evolve from a more space-consuming, coarse and explosive communication to a more adapted economical use of abstract signs? In this study, we aim to answer these questions by investigating the use of space and movement conveyed by different gesture types across four time-phases in the establishment of a newly emergent sign language, as social communication becomes fluent.

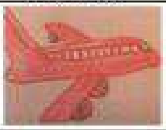
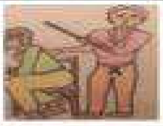
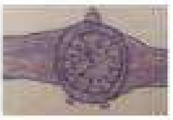
Methods

The project Sem Barreiras arose from the need, due to social and communication deprivation, to develop a language among deaf people at Sao Tome and Principe (Mineiro et al., 2021; Mineiro & Carmo, 2016; Mineiro et al., 2017). This project aimed at awakening a community, by congregating deeply isolated people, through common linguistic immersion, unfolding in the category of deaf community emerging sign languages (Sandler, 2005). This endeavor was implemented with all the ethical authorizations, between February 2013 and January 2015, during which 100 deaf people that had not previously known each other and without any previous language were brought together for linguistic immersion sessions in a common space in Sao Tome, every day and over time. The deaf participants were aged 4 to 25 years, 80% were female, and 20% were male. All of the participants enrolled in the program were severely or profoundly deaf. The deaf children (4-18 years old) from this sample (34%) were excluded from schools due to their deafness, and they were living in isolation as they were born in a rising tide of social deprivation and lack of communication. All families of the deaf participants signed the consent form allowing the children to be enrolled in the study. The sessions were all video-recorded, totaling about 400 videos with around 60 minutes each. The researcher elicited new signs through cards with drawings of simple objects (e.g. animals, everyday items). The cards were drawn by local artists (see examples in Table I) so that the participants might easily identify the cultural traits and so that the drawing itself would not hinder the recognition of the items presented. As the deaf researcher showed the cards, the participants produced pantomimic gestures which later, gradually, evolved to new conventionalized signs. As time went by, the task became more complex, and instead of simple objects, the researcher showed cards with drawings of more complex and abstract referents (concepts, emotions) as well as short stories reproduced in drawings that the participants could sign to each other.

For this paper, we focused on the first 100 sketch cards (examples in table I) presented to the participants over the 2-year project timeline. Here, we analyzed the video recordings registered during the implementation of the project, and we systematically observed how pantomimic gestures and signs for 100 of the original 280 sketch cards evolved across 4 phases, regarding (i) signing space, (ii) body movement and (iii) involvement of hands and other body articulators. This resulted in 100 analyzable signs and gestures, based on the highest frequency in the corpus at each time-phase. We considered four-time phases for analysis: Phase 1: February to July 2013; Phase 2: September 2013 to February 2014; Phase 3: March 2014 to July 2014; and Phase 5: September 2014 to February 2015. Since the implementation of this project, originally had a social aim, the procedures and registration of the videos were not research-oriented. As such, we could not, at times, identify the participants and/or the number of times each participant contributed to the signing bank. However, and considering the richness of this data, even though we were not able to make use of inferential measures, we were able to pool the gestures and use descriptive statistics to highlight the trends across time phases.

Table 1

Sketch card examples

Sketches	*Meaning*
	Airplane
	To beat
	Goat
	Snake
	Time
	Butterfly
	Fish
	Sadness

Results

Signing space

In order to report the evolution of movement in space, and given the descriptions used to characterize each gesture type, we assessed the number of i. medial and lateral gestures; ii. proximal and distal gestures; and iii. Superior and inferior gestures across the selected 100 sketch cards (please see Annex 1 for the complete list of sketches) and time phases. Figures 1, 2, and 3, map out these data.

Figure 1

Variation of the prevalance of medial and lateral gesturings across time phases

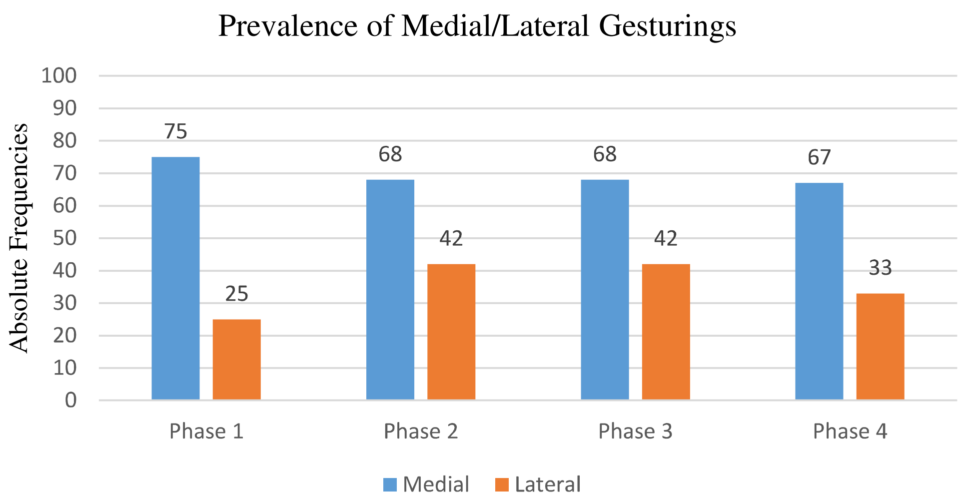


Figure 2

Variation of the prevalance of proximal and distal gesturings across time phases

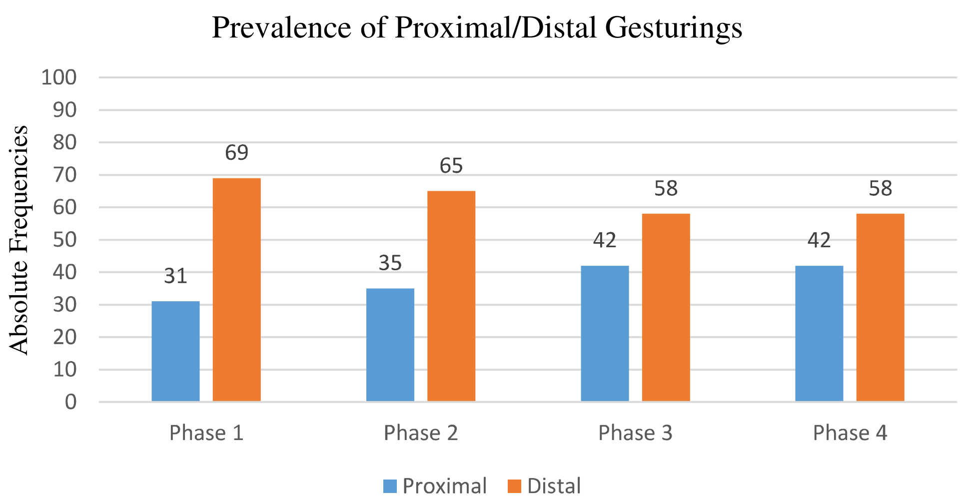
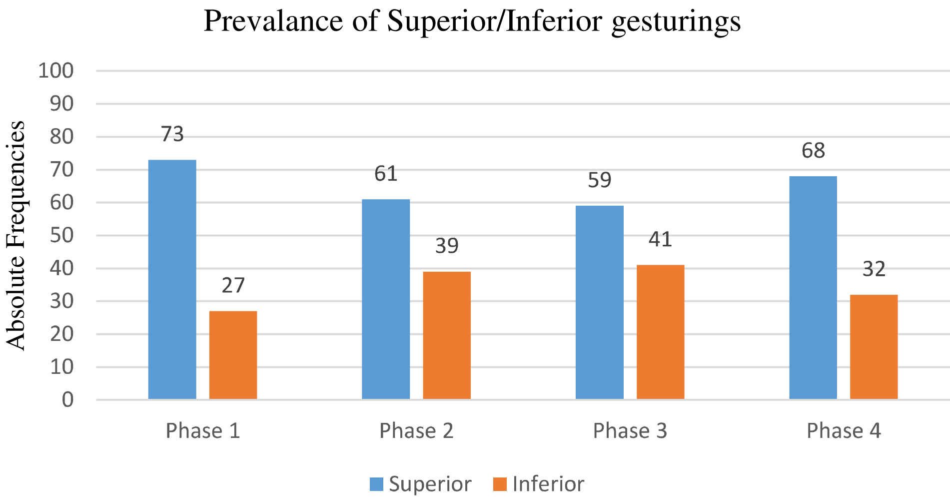


Figure 3

Variation of the prevalance of superior and inferior gesturings across time phases



The data shows an inverted U-shaped distribution across time for lateral gestures and an initial decrease in medial gestures that is stable over the remaining time phases. On the other hand, distal gestures slightly decrease while proximal gestures slightly increase. Both distal and proximal gesture frequency is unaltered from phase 3 onward. In what concerns superior and inferior gestures, we find an inverted U-shaped frequency distribution for the recruitment of inferior gestures and a U-shaped distribution for the frequency of superior gestures. After a reorganization period, i.e., in phase 4, participants seem to recruit a similar number of inferior and superior gestures as in phase 1. Medial/lateral ratio is difficult to interpret, and the main finding seems to pertain to a slight decrease in medial and a slight increase in lateral (with double the number of medial compared to lateral gestures by phase 4) pointing to the possibility that although medial is constantly more comfortable in signing, lateral gestures might, at times, play an important role in signing. Distal/proximal ratio shows that distal is consistently chosen to the detriment of proximal gesturing. However, this gap is shortened with time, with proximal gesturing acquiring an important place in communication. Finally, superior gestures are consistently chosen over inferior ones, which is consistent with greater familiarity and ease in using the upper body since the lower limbs are required to maintain balance.

Body Movement

Type of movement is very informative if we want to investigate an approximation to more abstract forms of communication with the appropriation of a new sign language. In figure 4 we present the evolution of the prevalence of different major movements throughout time phases and, in figure 5 we present the evolution of the prevalence of different minor movements throughout time phases.

Figure 4

Variation of the prevalance of major movements across time phases

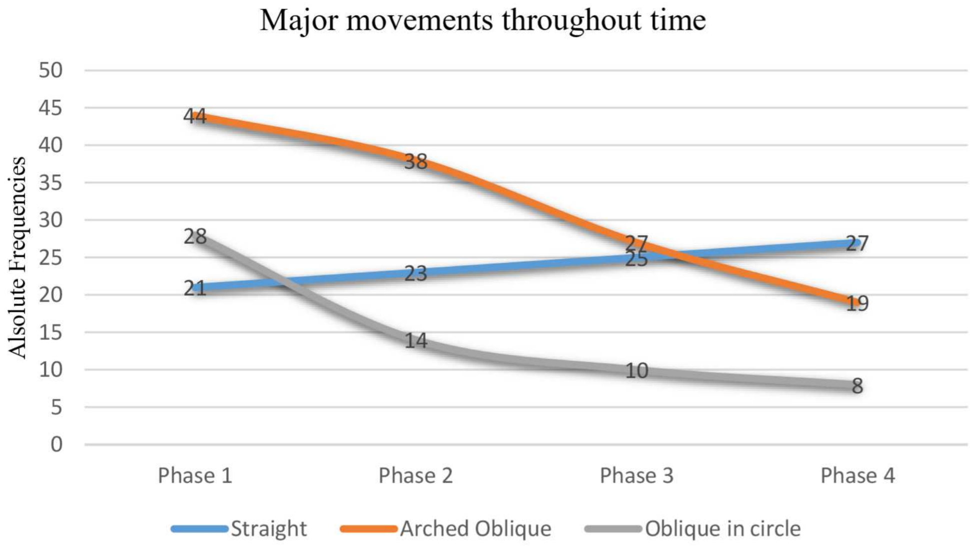
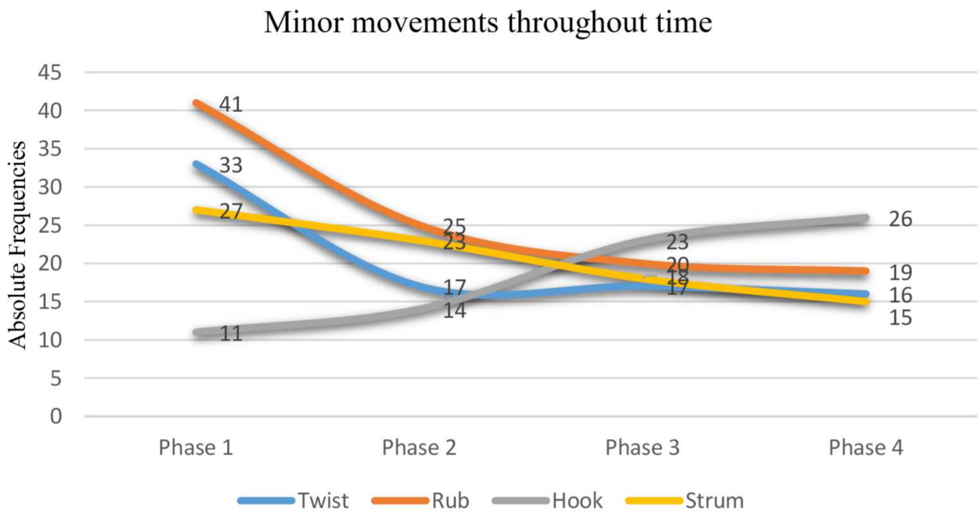


Figure 5

Variation of the prevalance of major movements across time phases



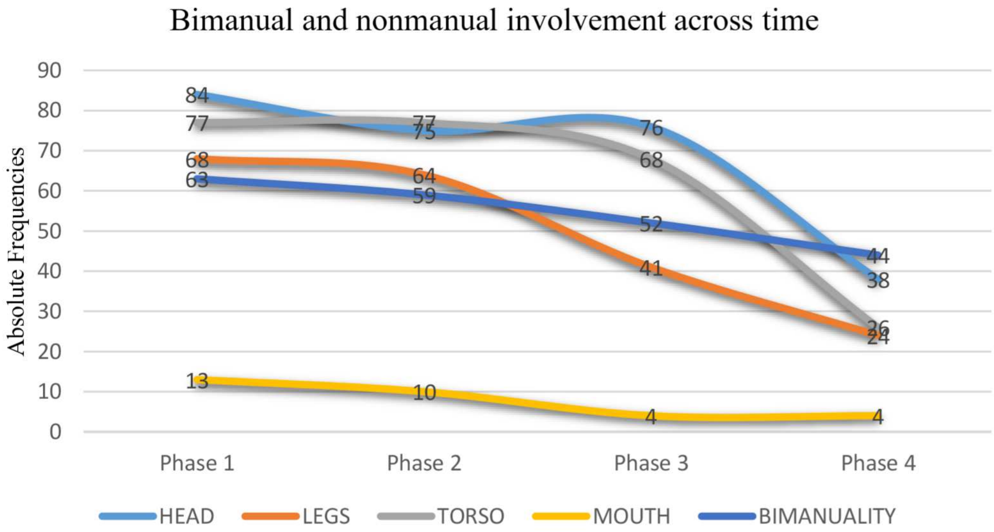
In what concerns major movements, the data presents a slight increase in straight movements, while presenting a substantial decrease in both oblique-type movements. Minor movements also decrease across time, with the exception of the hook-type movement that increases steadily across time phases. We cannot say that major movements transition to minor ones, showing economy and efficiency of space. However, it seems that gestures, in general, decrease, while enhancing those that might lead to a more efficient signing, such as straight major movements and hook minor movements. The decrease in gestures needed to represent the same sketches, in itself indicates a reduction in articulatory effort.

Involvement of other non-manual articulators

From our observations, it seems that the selected 100 sketches elicited pantomime gestures, in phases 1 and 2. However, in phases 3 and 4, there was a transition from the use of the whole body to the use of more conventionalized signs. Figure 6 represents this evolution by showcasing bimanual involvement and nonmanual involvement across the four-time phases.

Figure 6

Variation of the prevalance bimanual and nonmanual gestures across time phases



Bimanual gesturing decreases across time. However, steepest decreases are observed in nonmanuals such as legs, torso and head, indicating a transition from pantomime to sign. A slight decrease also occurs in the frequency of mouth use across time. Together, manual and nonmanual gestures decrease with time, indicating that gestures become more efficient and physically economical.

Discussion

Analyzing the development of a newborn sign language affords a promising vehicle for investigating language production and neuromotor constraints because the movements of the articulators in sign are directly visible. This window into movement cognition can show us the growth of linguistic complexity and symbolization when a new sign language is born. Here we focused on space and movement of signs and gestures and showed how, within two years of linguistic immersion, this newborn signing community decreased the use of whole-body expression and reduced the articulatory effort in the gestures and signs used amongst them. We also highlight how nonmanual articulators such as the torso, legs, and head, decreased across the four stages of observations and how gestures seemingly became easier to produce when they turned into conventionalized signs, reducing the involvement of nonmanual articulators. We had hypothesized that the evolution of movement in a newborn sign language might follow the developmental phases of psychomotor learning, leading to more economy in motion as well as in brain function as pantomime gives place to sign and symbolization. Previous research has shown that pantomime and signing differentially engage frontal and parietal cortices (Emmorey et al., 2011), showing partial segregation of the systems involved. However, neural efficiency seems to reflect an adaptation to specific task demands (Dunst et al., 2014). One such adaptation might be the movement reduction that occurs across time. Movement reduction has been associated with cognitive benefits as well as to saving physical energy (Warburton et al., 2013). Importantly, practice in a visuospatial task (for only three months) has shown increased cortical thickness, a sign of more grey matter and brain efficiency (Haier et al., 2009). The authors of this study suggest that alterations in brain structure would mean that the enlarged areas would not need to work as hard for task efficiency. We can find a striking parallel with expertise acquisition in signing, and we contend that the changes in movement, space usage and a number of gestures needed to communicate across time, are consistent with efficiency in neural processing and reduction of physical effort. In the future, we aim to investigate the brain alterations associated with expertise in signing.

Figure 7

Evolution of 'Airplane' gesturings (Figure provided by Rodrigo Rebello de Andrade)

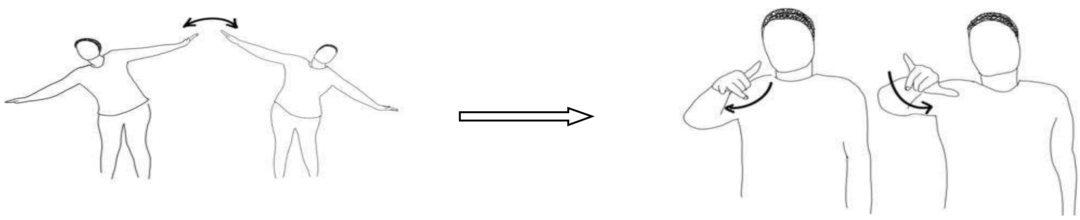


Figure 8

Evolution of 'Goat' gesturings (Figure provided by Rodrigo Rebello de Andrade)

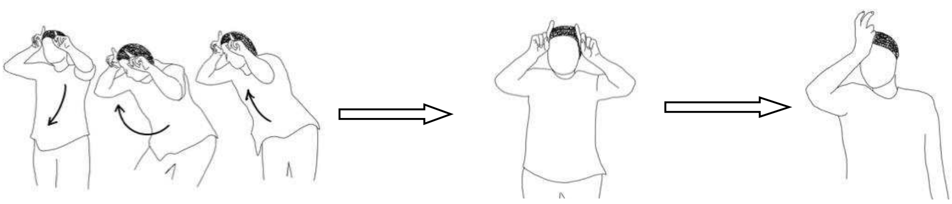
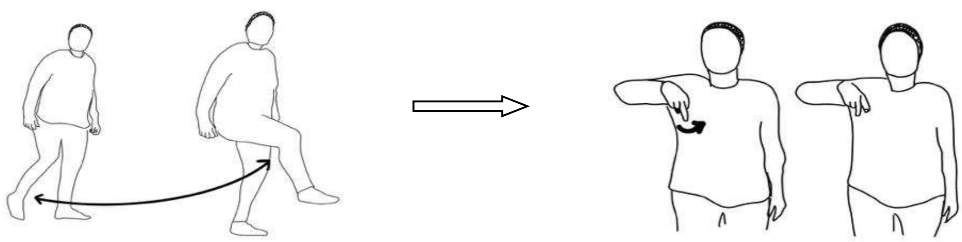


Figure 9

Evolution of 'soccer' gesturings (Figure provided by Rodrigo Rebello de Andrade)



In agreement with previous studies and reporting the growth of linguistic complexity in São Tomé and Principe Sign Language (Mineiro et al., 2021; Mineiro & Carmo, 2016; Mineiro et al., 2017), here we show that pantomimic gestures evolved into lexicalized and conventionalized signs, articulatory effortless, discarding a whole-body involvement and decreasing the amplitude of movement, progressive decrease in non-manual articulator and second-hand articulator use, as summarized in figures 7, 8 and 9. Hence, the evolution of a newborn sign language seems to follow the same phases of psychomotor development (experienced, manipulated and represented) and reduction of gestures and changes in movement and space strategies seem to be linked to a more efficient use of energy while enhancing cognition. Indeed, in her review, Calmels (2020) supports that brain functional and structural changes (leading to different cortical patterns) result from extensive motor training and that such extensive motor training can be found in all walks of life (e.g., musicians and athletes). Here we consider signing, not only an important form of communication, but also, a motor skill that can be learned through training. Since motor learning has been shown to implicate the motor cortex and execution of motor skills have been shown to depend on subcortical motor circuitry (Kawai et al., 2015), it is plausible that different strategies are used during acquisition and expertise phases. Moreover, concrete and abstract motor training lead to benefits that unfold differently across time. Abstract motor training unfolds online and offline (Levine at al., 2018), putatively bringing motor as well as cognitive benefits. Crucially, the participants in our study were able to learn a proper sign language only later in life. According to Corina and Gutierrez (2016) in cases of later learning of ASL, sign recognition is based on embodiment and makes use of internally simulated articulatory control signals, in contrast with native ASL signers. Importantly, Streeck (2015) describes embodied action as inherently cognitive and communicative, rejecting the idea that the body is an instrument of communication and supporting the notion of the always embodied materiality of the communicating body. Thus, the body needs but to learn to communicate efficiently, making use of the already embodied self. Here we bring new light into the development of a newborn sign language as we show how the evolution of movement might be linked to cognition and neural efficiency, facilitating human communication.

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Ethics Statement

All participants (or their parents while minors) provided informed consent to participate in this study. In the absence of an Ethics Committee at Sao Tome and Principe in 2013, the Ministry of Education Culture and Science were partners in the project and gave us an express consent for realizing the study and implementation of the project Sem Barreiras at Sao Tome and

Principe. Moreover, we had the Ethical approval from Catholic University of Portugal.

Conflicts of Interest

None of the authors have any conflicts of interest to disclose in relation to the current research

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Annex 1 – List of analyzed sketch cards

Sugar
Water
Banana
Cocoa
Coffee
Cajamanga
Sugar cane
Beer
Cuttlefish
Spaghetti
Milk
Butter
Eggs
Bread
Salt
Butterfly
Goat
Dog
Crab
Snake
Rooster
Cat
Monkey
Mosquito
Bird
Fish
Fly
Octopus
Pig
Mouse
Turtle
Cow
Ball
Chair
Bed
Home
Key
Cup
Knife
To open the door
To close the door
Fridge
Flashlight
To paint the house
Living room
Mobile Phone
TV
Scissors
Low
High
Heart
Standing
Arm
Fat
Skinny
Hands
Nose
Look / See
Eyes
Listener
Deaf
Joyful
Sad
To cry
Pencil sharpener
Eraser
Pencil
To read
Schoolbag
Friend
Baby
Married
Tree
Heat
Rain
Mom
Dad
Day

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