Sign Language Handshapes, Similarly to Speech Sounds, Exploit Biomechanical Endpoints

Oksana Tkachman[1*], Shannon Hsu[1†], Maria Samarskaya[1‡], Cindy Zhao[1], Bryan Gick[1, 2‡‡]**
[1]Department of Linguistics, University of British Columbia, Vancouver, Canada
[2]Haskins Laboratories, New Haven, Connecticut, USA

1 Introduction

Speech motor control approaches have argued that the dimensionality problem can be handled by exploiting endpoints, a type of biomechanical quantal region [1, 2], where a stable output can be obtained regardless of the starting position or variable muscle activation of the articulators [3]. Endpoints involve a contact between two articulators or an active articulator and a passive articulator. One advantage endpoints offer is in preventing overshoot. In spoken languages, endpoints are maximally exploited in plosive sounds, the most frequent type of consonants occurring in all known spoken languages [4]. In signed languages, endpoints are exploited in signs where two hands make contact with each other, or where a hand(s) makes contact with the signer's body [5]. For example, in signs produced with body contact, variable arm muscle activation does not lead to variable place of articulation [6]. In this study, we extend research on sign-language endpoints by investigating handshape-internal endpoints, which is a state of a finger/joint where it is maximally extended or flexed, or where the fingers and/or thumb make a contact with each other and/or the palm. We annotated handshape inventories from three genetically distinct sign languages (Icelandic Sign Language, Turkish Sign Language, and Taiwan Sign Language) to determine the extent to which phonemic handshapes in the inventory exploit handshape-internal endpoints. These results support the view that the biomechanical quantal regions previously observed for speech are general to communicative control systems.

2 Methods

2.1 Data

Phonemic handshape inventories from three genetically unrelated sign languages have been chosen for annotation and analysis: Icelandic Sign Language (ISL) [7], Turkish Sign Language (TID) [8], and Taiwan Sign language (TSL) [9]. The ISL inventory consisted of 33 handshapes, the TID inventory of 32 handshapes, and the TSL inventory of 60 handshapes.

2.2 Annotation and analysis

The handshape inventories have been annotated following a modified version of the Sign Language Phonetic Annotation (SLPA) system proposed by Johnson and Liddell [10, 11]. SLPA is probably the most phonetically comprehensive sign annotation system proposed to date; each handshape requires 23-34 symbols of annotation. It focuses on four subcomponents of the handshape: (1) the configuration of the four fingers, including extension/flexion of each joint and abduction/adduction of adjoint fingers; (2) the presence and manner of a contact between the thumb and finger(s); (3) the thumb configuration, including extension/flexion of each joint and abduction/adduction/opposition to the palm; and (4) extension to the forearm (for cases where a forearm forms a part of the sign). In this project, we focus exclusively on handshape-internal endpoints, and therefore no annotation for the handshape extension (4) has been included.

In addition, following Tkachman et al. [12], we use fewer labels for degrees of flexion. SLPA uses six labels for indicating different degrees of flexion for each finger joint: fully extended *E* (0°), partially extended *e* (+30° for proximal joints, +10° for distal joints), partially flexed *f* (+60° for proximal joints, +20° for distal joints), fully flexed *F* (+90° to 100° for proximal joints, +45° to 80° for distal joints), and two degrees of hyperextension, *h* and *H*, where the joint extension goes beyond *E*. Some of these distinctions have been argued to be impossible to distinguish, especially in distal joints. Following [12], we do not differentiate between *h* and *H* (that is, all hyperextension cases are treated the same). Similarly, we adopt *I* (intermediate) instead of *e* and *f*, for all cases of partial extension/flexion of the joints. Thus, we only use 4 labels for join flexion: *E, I, F,* and *H*.

Each inventory was annotated by two coders. In cases of disagreement between coders, a third coder made the judgment as to which annotation to use. The number of endpoints was calculated for each handshape individually. There are three types of handshape-internal endpoints: one pertaining to joints (when a finger/thumb joint is either maximally extended/hyperextended or maximally flexed), one pertaining to contact (contact between fingers, contact between finger(s) and the thumb, and contact between fingers/thumb and the palm of the hand), and one pertaining to maximum abduction (when the fingers and/or thumb are maximally abducted from each other). Thus, a single handshape can have up to 14 joint endpoints (3 for each finger and 2 for thumb), up to 9 contact endpoints (3 between fingers, 1 between the thumb and fingers/palm, and 4 between fingers and the palm), and up to 5 abduction endpoints (4 for fingers and 1 for thumb). Accounting for the fact that a handshape cannot have a maximum amount of adduction and abduction endpoints simultaneously, the maximum number of endpoints per handshape therefore is 23 for handshapes with all fingers abducted (14 joint endpoints + 4 contact with the palm endpoints + 5

* o.tkachman@alumni.ubc.ca
† chsu02@student.ubc.ca
‡ samarsky98@gmail.com
** cindyzhao325@gmail.com
‡‡ bryan.gick@ubc.ca

abduction endpoints, but excluding 4 adduction endpoints) or 22 for handshapes with all fingers adducted (because there are only 4 adduction endpoints). Note that it is possible for a handshape not to have any endpoints (e.g., in a relaxed hand all joints are intermediate, and fingers and the thumb are neither adducted nor fully abducted). Thus, each handshape was assigned an endpoint number between 0 and 23, based on its annotation.

3 Results

The ISL handshape inventory has an average of 17.15 endpoints per handshape (range 9-23); the TID inventory has an average of 17.125 endpoints per handshape (range 2-22); and the TSL inventory has an average of 15.88 endpoints per handshape (range 4-22).

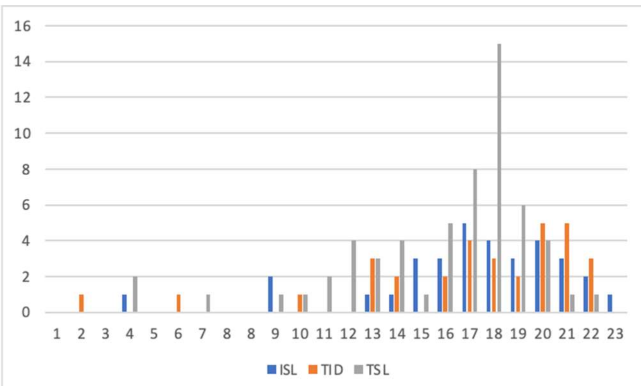

Figure 1: The distribution of endpoint values across handshape inventories (ISL: Icelandic Sign Language; TID: Turkish Sign Language; TSL: Taiwan Sign Language).

Results indicate that all three sign languages heavily exploit handshape-internal endpoints in their handshape inventories. Those handshapes with fewer endpoints do occur, most handshapes in all three sign languages exploit multiple endpoints of various types (see Figure 1).

4 Discussion

Human hands allow for an incredible intricacy; each hand has about 25-30 degrees of freedom [13, 14]. However, sign languages do not exploit the whole range of possible handshapes; only a limited number of phonemic handshapes get conventionalized. Phonemic handshapes have been argued to maximally distinctive/perceptually salient; however, articulatory factors undoubtedly also play a role in shaping handshape inventories. In this preliminary study, we explored the possibility that phonemic handshapes in sign languages exploit biomechanical endpoints, which at least for spoken languages have been argued to be a type of quantal region [1, 2]. Even though this is just a preliminary study, the fact that three unrelated sign languages heavily exploit endpoints just like spoken languages do suggest that biomechanical quantal regions are general to communicative control systems. Theories of speech motor control need to incorporate evidence from both spoken and signed languages to fully account for cross-modal tendencies exploited by articulatory systems of natural human languages.

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