CYCLIC MOVEMENT PRIMITIVES UNDERLYING TWO-HANDED ALTERNATING SIGNS IN SIGNED LANGUAGES

Oksana Tkachman *1, Gracellia Purnomo†1 and Bryan Gick ‡1, 2
[1] Department of Linguistics, University of British Columbia, Vancouver, British Columbia, Canada
[2] Haskins Laboratories, New Haven, Connecticut, USA

1 Introduction

In speech, biomechanical constraints shape phonetics-phonology. For example, English /r/ variants are selected based on minimizing biomechanical effort [1] and a single motor action in the tongue may govern multiple speech events to improve movement efficiency [2]. We propose that signed languages are similarly constrained by biomechanics. Specifically, the present paper considers the hypothesis that otherwise unexplained universal aspects of sign languages can be understood as resulting from a preference for repeated alternating arm movements triggered by vestigial locomotor CPGs developed in human ancestors for quadrupedal locomotion.

2 Background

Central pattern generators (CPGs) are networks of nerve cells located in the spinal cord often associated with control of repetitive or cyclic mostion, such as locomotion [3]. CPGs operate without any conscious effort, and do not require involvement of the brain: even dead bodies or bodies with the connection between the brain and the spine cut can walk if secured on a treadmill [4]. Although humans are bipedal, human hands still maintain vestigial traits of quadrupedalism, which surface in the coordination of arms and legs in walking, running and swimming [5]. CPGs in arms operate in ways similar to CPGs in legs [6]. In walking, swinging arms out of phase to legs helps to stabilize walking and is more energy-efficient [7]. Moreover, arm muscles activate during walking even when the arms are constrained [8, 9]. As such, we might well expect them to affect other manual activities using the forelimbs, such as the conventionalized manual movement systems used in natural sign languages of the deaf.

Signs in signed languages can be one- or two-handed. In two-handed signs, the non-dominant hand can be either passive (used as a place of articulation for the dominant hand) or active (where both hands have the same ("balanced") handshapes and move in a similar fashion) [10]. It is this last type of sign, "two-handed balanced" signs, that we consider in the present study. Importantly, in two-handed balanced signs, the hands can move either symmetrically/in-phase or alternatingly/anti-phase.

One might expect two-handed balanced signs to be rare, as moving two hands as opposed to one doubles the moving mass, thereby doubling the articulatory effort. This also requires the biggest reactive effort to stabilize the torso against the incidental movement induced by the moving hands [11]. And yet, such signs are quite frequent (in ASL such signs constitute about one third of the lexicon ([12], also see below). Balanced signs tend to resist change, either in phonological or historical processes, and are preferred in both first and second language acquisition [13, 14]. And some unbalanced signs become balanced over time [15, 16].

Two-handed balanced signs are not one unified group, and include signs with both symmetrical/in-phase and alternating/anti-phase movement. Evidence has accumulated for decades that balanced symmetrical signs and balanced alternating signs have different properties; e.g., some phonological processes (e.g., *weak drop*, where the non-dominant hand is dropped from the sign production) can be applied to signs with symmetrical but not with alternating movement [10, 17]. The same resistance to weak drop in alternating signs is found in first language acquisition of ASL [18]. And phonological processes that turn one-handed signs into two-handed signs (e.g., the Characteristic Adjective derivation in ASL) result in alternating signs, but not symmetrical signs [16].

If two-handed signs are influenced by locomotive CPGs, knowing that these govern repetitive movements, we can predict that in two-handed signs with both hands moving, the alternating movements will tend to be repeated and symmetrical, non-alternating movements to be single. We test this prediction with data from ASL and HKSL.

3 Method

We coded all signs from major dictionaries of two natural, unrelated sign languages of the deaf, American (ASL) [19] and Hong Kong Sign Language (HKSL) [20]. All signs were annotated for being one-handed (1h), two-handed unbalanced (2hb) and two-handed balanced (2hb). The latter were further annotated for movement pattern, single/repeated movement, plane of articulation (vertical, horizontal, etc.), iconicity (that is, their form resembles their meaning) (yes/no), and whether the sign was compound. Two types of signs were articulated on the horizontal plane and were coded as either symmetrical mirror movement (the two hands move away/toward each other on the horizontal plane), or symmetrical horizontal movement (the two hands move together synchronously leftwards/rightwards on the horizontal plane). These two groups of signs rely on different patterns from locomotion, and we do not discuss them here. The rest of the 2hb signs were coded as having symmetrical movement (the hands move in the same

*o.tkachman@alumni.ubc.ca
† gracellia.purnomo@gmail.com
‡ gick@mail.ubc.ca

direction at the same time), alternating movement (the hands move in the opposite directions), or none. The ASL dictionary [20] consisted of 4217 signs, of which 1407 (33%) were 2hb. Of the 2hb signs, 359 (25.5% of 2hb) were symmetrical and 217 (15.4% of 2hb) were alternating. The HKSL dictionary [20] had 1861 signs, of which 498 (27%) were 2hb. Of the 2hb signs, 83 (17% of 2hb) were symmetrical and 70 (14%) were alternating.

4 Results

For both languages, alternating signs showed a significantly greater tendency for repeated movement than symmetrical signs (Table 1 and Figure 1). Chi-squared tests indicate that, for both ASL and HKSL, the difference between single- versus repeated-movement signs proportions was significant (for ASL : χ^2 (1) = 131.5217, $p < 0.05$; for HKSL : χ^2 (1) = 11.2091, $p < 0.05$).

Table 1: The distribution of movement types in ASL and HKSL.

ASL	Single	Repeated	Iconic
Symmetrical	274, 76%	85, 24%	125, 35%
Alternating	60, 28%	157, 72%	73, 34%
HKSL	Single	Repeated	Iconic
Symmetrical	51, 61%	32, 39%	37, 44.5%
Alternating	24, 34%	46, 66%	20, 28.5%

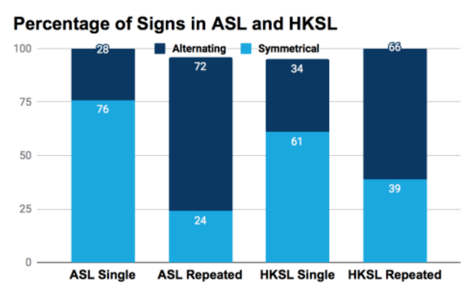

Figure 1: Proportions of signs with single and repeated movements in ASL and HKSL.

5 Discussion

This study shows that two-handed balanced signs, traditionally treated in sign-language linguistics as one group, have different movement tendencies depending on whether they are symmetric or alternating. In symmetric/in-phase signs, the hand movement tends to be single. In alternating/out-of-phase signs the movement tends to be repeated. A possible alternative explanation for these results could be iconicity. Previous studies showed that signs with inherent plural meaning favor two-handed forms [21]. In principle, iconicity can also favor movements that are single or repeated, but the proportion of iconic signs is comparable for both types of signs. We, therefore, explain our results with the view that two-handed signs are influenced by vestigial locomotor CPGs. As alternating bimanual movements are influenced by locomotor patterns, they favor repeated movements.

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