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Examining the contribution of motor movement and language dominance to increased left lateralization during sign generation in native signers

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ABSTRACT

The neural systems supporting speech and sign processing are very similar, although not identical. In a previous fTCD study of hearing native signers (Gutierrez-Sigut, Daws, et al., 2015) we found stronger left lateralization for sign than speech. Given that this increased lateralization could not be explained by hand movement alone, the contribution of motor movement versus 'linguistic' processes to the strength of hemispheric lateralization during sign production remains unclear. Here we directly contrast lateralization strength of covert versus overt signing during phonological and semantic fluency tasks. To address the possibility that hearing native signers' elevated lateralization indices (LIs) were due to performing a task in their less dominant language, here we test deaf native signers, whose dominant language is British Sign Language (BSL). Signers were more strongly left lateralized for overt than covert sign generation. However, the strength of lateralization was not correlated with the amount of time producing movements of the right hand. Comparisons with previous data from hearing native English speakers suggest stronger laterality indices for sign than speech in both covert and overt tasks. This increased left lateralization may be driven by specific properties of sign production such as the increased use of self-monitoring mechanisms or the nature of phonological encoding of signs.

1. Introduction

In a recent study of hemispheric lateralization of language production in hearing native signers we showed stronger left lateralization for British Sign Language (BSL) than for speech during overt sign and word generation tasks (Gutierrez-Sigut, Daws, et al., 2015). Sign production requires predominantly asymmetrical movements of the arms and hands (Battison, 1978), yet strength of lateralization during sign production did not show a robust correlation with amount of time producing movements of the right hand. In addition, hearing native signers showed much stronger lateralization during BSL production than hearing non-signers who performed a non-sign repetition task. Together these findings suggest that the stronger left lateralization found during sign production in native signers could not wholly be explained by movement of the right hand and may also be due to specific sign processing factors.

Unlike phonological encoding of words, which requires the selection and arrangement in time of a series of phonemes, phonological encoding of signs requires the selection of a particular handshape in a specific body location and a movement (see e.g. Stokoe, 1960). Furthermore, while the speaker can directly hear her own utterances, the signer has only partial perceptual feedback of her own signing. Even when she can see her hands moving in space, her point of view is different to that during sign perception. This raises the likelihood that in order to keep track of the position and precise movements of the hands, overt sign production relies more on proprioceptive and somatosensory feedback than speech. These factors have been linked with increased left parietal activation found in previous neuroimaging studies (Corina, San Jose-Robertson, Guillemin, High, & Braun, 2003; Emmorey, McCullough, Mehta, & Grabowski, 2014; Emmorey, Mehta, & Grabowski, 2007). It is also possible however that the stronger

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lateralization is due to two other factors, not wholly addressed in our previous study: the precise role of motor movement, and the language dominance status of the hearing signers.

In our previous study of sign and speech production, we assessed the contribution of motor movement to strength of lateralization by examining correlations with the amount of hand movement (Gutierrez-Sigut, Daws, et al., 2015). Using this correlational approach, we showed no influence of amount of motor movement on strength of lateralization indices (LIs) when participants performed a BSL semantic fluency task. A moderate correlation was found for the BSL phonological fluency task, which we suggested could relate to the motoric prompting strategy used by participants when presented with a phonological target (handshape). Participants tended to maintain the target handshape, moving it to different locations in an attempt to activate lexical signs (Gutierrez-Sigut, Daws, et al., 2015; Marshall, Rowley, & Atkinson, 2014). However, we did not experimentally manipulate the amount of overt motor movement required.

In the current study we test the hypothesis that strength of lateralization increases with overt motor movement by directly comparing laterality indices across covert and overt sign generation tasks. These data are then compared to previously reported data from hearing native speakers of English who did not know BSL (Gutierrez-Sigut, Payne, & MacSweeney, 2015) and from hearing bimodal bilinguals (native users of BSL and English; Gutierrez-Sigut, Daws, et al., 2015) performing the same covert and overt tasks in English. Crucially, we contrast sign and speech LIs during *covert* language production, when no overt motor movement is required during the recording period. A finding of stronger lateralization for BSL than English generation in the covert tasks, would suggest that explicit motor movement does not make a major contribution to the strength of lateralization observed during overt sign production. The direct comparison of covert and overt tasks also allows assessment of the impact of continuous body movements on the quality of the TCD signal. Finding a similar number of unusable trials due to artefacts in both tasks would contribute to the development of strong experimental paradigms to assess the factors influencing lateralization during online language production.

Another possible explanation for the previously observed elevated LIs during sign compared to speech production (Gutierrez-Sigut, Daws, et al., 2015) is the language dominance of the participants tested. Participants in our previous study were hearing native signers. Although these individuals have deaf parents and have learned BSL from birth, their main means of communication and dominant language is English, reflecting the dominant language of the majority community, (see Emmorey, Giezen, & Gollan, 2015). It is possible that they found the tasks more challenging than deaf native signers (Emmorey, Petrich, & Gollan, 2013; Emmorey et al., 2015). Certain aspects of task difficulty can influence the strength of lateralization as measured with fTCD (Payne, Gutierrez-Sigut, Subik, Woll, & MacSweeney, 2015). This raises the possibility that the elevated LIs were due to generating lexical items in their less dominant language, which makes the task more challenging. Additionally, phonological fluency has been shown to be more challenging for signers than semantic fluency (see Marshall et al., 2014 for a discussion). Here we examine the strength of lateralization during BSL phonological and semantic fluency tasks and its relationship with behavioural measures in a group of deaf native signers, whose dominant language is BSL. We predicted similar levels of lateralization between phonological and semantic signed tasks although the phonological overt condition was expected to be less productive (see Gutierrez-Sigut, Daws, et al., 2015; Marshall et al., 2014). Furthermore, elevated LIs for deaf native signers producing signs than for native English speakers producing speech, during both the semantic and phonological fluency tasks, would support the idea that the stronger left lateralization shown for hearing native signers producing BSL is not due to the difficulty of performing a task in a less dominant language.

2. Methods

2.1. Design

A 2 (*production type*: covert vs. overt) $\times$ 2 (*task:* phonological vs. semantic) design was used, resulting in four conditions: phonological-covert, phonological-overt, semantic-covert and semantic-overt. In the English phonological task,[2] a series of letters are displayed and participants are asked to generate words beginning with this letter. In contrast, in our BSL phonological task participants are asked to generate signs containing a particular handshape (a major phonological parameter of signs). Here we use the term phonological fluency to refer to the analogous tasks in both languages for clarity and comparability with previous results. The semantic task proceeds in the same way, but here the cue is a semantic category.

These four conditions were presented in separate blocks, the order of which was counterbalanced across participants. Data from the deaf participants, who completed the tasks in BSL, were compared to two previously published datasets. One from hearing non-signers (Gutierrez-Sigut, Payne, et al., 2015) and one from hearing native signers (Gutierrez-Sigut, Daws, et al., 2015) who performed the same tasks in English.

2.2. Participants

Sixteen deaf native signers of BSL (9 female) were recruited from a volunteer database. The mean age of participants was 26 (*SD* = 5.9 range 16.9–36). All participants were profoundly deaf from birth and learnted BSL as their first language from their deaf parents. No participants reported a history of neurological disorders or language related problems. Participants were all right handed as assessed by the abridged version of the Edinburgh Handedness Inventory (Oldfield, 1971). Since all participants were signers, handedness for sign production was also assessed. Participants were asked to produce nine signs (all of which are produced in BSL with the dominant hand alone in BSL), to count to 20 (the dominant hand is always used) and to fingerspell three items (the dominant hand is clearly evident from fingerspelling production; see Sharma, 2013).

Due to insonation difficulties it was not possible to find the TCD signal in one participant. Of the 15 remaining participants (8 female; mean age 26.4, *SD* = 6.1, range 16.9–36), it was not possible to acquire a reliable TCD signal in one or more of the four conditions in four participants: one had poor data for both covert conditions (see Fig. 2 panel a: orange diamond), one for the semantic covert (see Fig. 2 panel a: green dash), one for the phonological overt (see Fig. 2 panel a: red square) and one for the semantic overt (see Fig. 2 panel a: blue triangle). Eleven participants had good quality data for all four conditions. Participants without TCD data in all four conditions were not included on the repeated measures ANOVAs. However, data from these participants in conditions where they had good signal were included in the correlational analyses with behavioural measures.[3]

In a previously published fTCD study we tested 22 hearing non-signing participants (8 female) on English versions of the four experimental conditions tested here in BSL (Gutierrez-Sigut,

[2] The phonological fluency task is often referred to in the fTCD literature as "Word Generation".

[3] The exclusion of participants with incomplete datasets from the correlational analyses did not alter the pattern of results.