Investigating mental rotation and screen arrangement using eye tracking

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Background: The ability to mentally rotate settings and constructions in space is part of the human cognitive ability and has been investigated for various shapes, constructions and different groups (Cooper, 1975). However, for deaf signers using visual sign languages as their native languages mental rotation has been described as an inherent part of their language system (Emmorey et al., 1998; Perniss, 2007; among others) and is, thus, used routinely in daily interactions. In this study, we examine to which extent effects of mental rotation can be observed using eye tracking and how mental rotation interacts with two-dimensional (2D) screen arrangements.

Methods: We recorded eye movements of 25 deaf early signers of German Sign Language (DGS) (*M* age = 35 years) in Exp. 1 and 17 deaf early signers (*M* age = 30 years) in Exp. 2 while they were presented with two pictures and a video stimulus. Each video stimulus consisted of a full sentence with the structure *referent-1* INDEX*-1 referent-2* INDEX*-2 agreement-verb* with the first referent always being placed on the right side of the signing space. The images displayed each one of the animate entities mentioned in the video. The position of the images was manipulated in relation to the placement of the referents in signing space. In the *aligned* condition, the position of the image matched the side of the referent in the signing space, thus, BOY as referent-1 is introduced on the right side in the signing space and the corresponding image is presented on the same side on the screen (Fig. 1a & c) and referent-2 is placed on the opposite side respectively. In contrast, in the *rotated* condition, the images are arranged following the mental rotation perception of the right side (Fig. 1b & d). The stimulus material was identical in Exp. 1 and 2 so that the experiments only differed in the spatial arrangement. In Exp.1, the video was presented at the bottom (Fig. 1a & b) while in Exp. 2 the video was presented at the top of the screen (Fig. 1c & d).

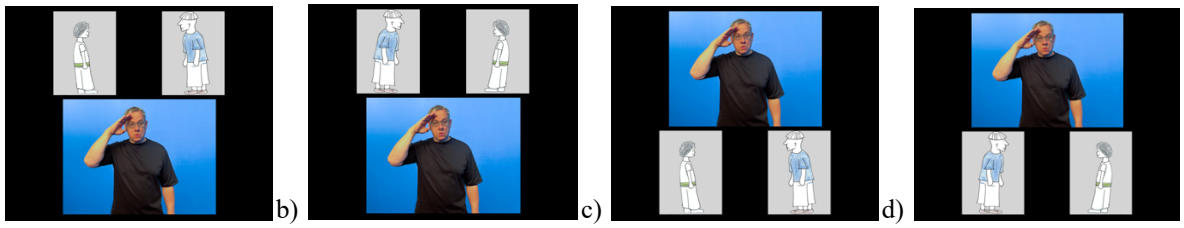
Data: Regarding the time course, we determined the visual search pattern for each experiment within each condition by comparing fixations to the images using a permutation-based analysis approach. For Exp. 1, adult DGS signers shift back and forth between the images and the linguistic stimuli presented in the video, but they do so irrespective of the presented condition. Thus, mental rotation seems not to be at play in the visual search pattern. However, in Exp. 2, participants' visual search patterns differ between conditions showing an effect of mental rotation. During the presentation of INDEX-1, i.e., when the first referent is expected to be fixated, they do so in both conditions but more in the aligned than in the rotated condition. Similarly, more looks to referent-2 are observed during the presentation of INDEX-2 in the aligned than in the rotated condition.

For two selected time windows, we computed mean log gaze probability ratios to examine overall fixations to the images across conditions. The first time window comprises all fixations during the presentation of INDEX-1 in the video and the second time window includes fixations during the presentation of INDEX-2. We fitted a linear-mixed effects regression with *condition*, *time window,* and their *interaction* as fixed effects and *participants* and *items* as random effects. For Exp. 1 (Fig. 2a), an effect of condition is detected only in the second time window with increased looks in the aligned condition (β = -.08; SE = .02; t = -3.78; p < .001). For Exp. 2 (Fig. 2b), we observed a main effect of time window (β = -.44; SE = .03; t = -14.57; p < .001), a main effect of condition (β = -.21; SE = .03; t = -7.21; p < .001) and an interaction of time window and condition (β = .43; SE = .04; t = 10.05; p = .004). Most importantly, there were more fixations (β = .27; SE = .02; t = 13.63; p < .001) in the aligned condition (M = .27, SD = .01) than in the rotated condition (M = .006, SD = .02).

Discussion: In general, signers follow and understand the signed video input and search as expected, i.e., looking at referent-1 or referent-2 when it is presented in the video

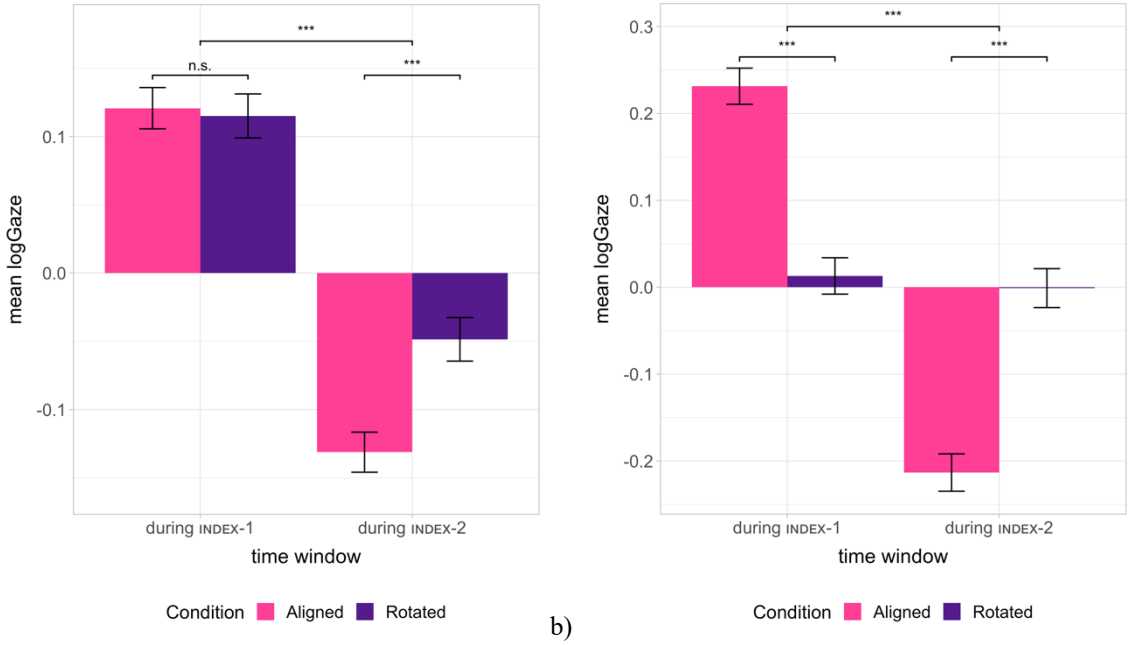
stimulus. In Exp. 1, signers initially allocate their attention to the first referent in both conditions. As the video stimulus unfolds, they have to re-check their perception of the display when the presentation of the images is rotated in relation to the content of the video. Therefore, the rotated condition seems to pose a certain challenge for processing. This effect becomes even more pronounced in Exp. 2 where the rotated condition seems to be particularly challenging because the pointing in the video contradicts the arrangement of the images and, thus, causes additional processing costs. For the aligned condition, the pointing and the image are placed on the same side of the screen, which does not require additional processing effort, showing that this setup allows for a deictic interpretation. The step-by-step process of mental rotation is not effortless and interpretations such as aligned 2D visualization may enhance processing. Thus, mental rotation does not seem to be a default process on a 2D screen and even harder in a topographic and deictic screen environment. Therefore, mental rotation and the screen arrangement, both impact the signers' processing, which needs to be considered methodologically when using eye tracking.

References: Cooper, L. A. (1975). Mental rotation of random two-dimensional shapes. *Cognitive Psychology*, *7*(1), 20–43. Emmorey, K., Klima, E., & Hickok, G. (1998). Mental rotation within linguistic and nonlinguistic domains in users of American Sign Language. Cognition, 68, 221–246. Perniss, P. (2007). Space and iconicity in German Sign Language (DGS). Max Planck Institute for Psycholinguistics, The Netherlands. PhD dissertation.



a) b) c) d)

Fig. 1. Example of the visual display where the referent-1 BOY is presented on the left side in the aligned condition (a & c) and on the right side in the rotated condition (b & d). The screen arrangement of Exp. 1 is presented in a and b and Exp. 2 is shown in c and d.



a) b)

Fig. 2. Mean logGaze transformations of fixations to referent-1 relative to referent-2 by condition (pink – aligned; purple – rotated) and for both time windows for a) Exp. 1 and b) Exp. 2.