# Flexibility in Adopting Relative Frames of Reference in Dorsal and Lateral Settings

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Abstract

The relative frame of reference (FoR) is used to describe spatial relations between two objects from an observer's perspective. Standard, *frontal* referencing situations with objects located in the observer's visual field afford three well-established variants: translation, reflection, and rotation. Here, we focus on references in non-standard situations with objects located at the back or at the side of an observer (*dorsal* and *lateral*, respectively). We scrutinise the *consistency assumption*, which was introduced to infer the covert strategy used in dorsal tasks from an ambiguous overt response: that, when confronted with a non-standard situation, people adopt a strategy consistent with how they construct the relative FoR in frontal situations. Lateral tasks enable us to disentangle the ambiguous response. The results of a study in Norway and Germany support the consistency assumption in part: Nearly all participants with a preference for translation in frontal tasks applied translation in lateral tasks, and some participants with a preference for reflection in frontal tasks turned towards the objects before applying reflection in lateral tasks. Most other participants with a preference for reflection in frontal tasks, however, switched to translation in lateral tasks. The latter may be due to a specific affordance of the lateral arrangements, which invite translation as the easier strategy compared to the alternative derived from reflection. Our findings indicate that people do not apply their preferred variant of the relative FoR to all kinds of situations, but rather flexibly adapt their strategy when it is more convenient to do so.

*Keywords:* Spatial cognition; frames of reference (FoR); variants of the relative FoR; frontal, dorsal, and lateral references; perspective taking

# Introduction

Questions about the spatial location of objects are frequent accompaniments to daily life. You may ask, for example, the shop assistant where to find the beans, "on the rack in front of me or on the one behind me?" Or, when helping to tidy your child's room: "Where should the ball go, on the shelf to my left or to my right?" Answers to such questions require the application of a frame of reference (FoR) that specifies the orientation of the relevant dimensions, here: *front-back* and *left-right*. The most basic FoR providing a coordinate system suitable to localize the objects in the examples above is the *direct* FoR (Danziger, 2010; see Figure 1A[i]). It is anchored in one's body and builds on its front-back and left-right axes. As such, the FoR provides spatial orientation to the dimensional prepositions "in front of", "behind", "to the left of", and "to the right of", which is necessary to comprehend the above questions and to come up with a reasonable answer: "The beans are on the rack behind you" and "The ball goes on the shelf to your left". Technically speaking, adopting the direct FoR results in a binary relation between the figure object F (here: rack or shelf) and the ground entity G (here: you).

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In ternary relations, the figure F is not to be localized directly in reference to oneself (the referencing person), but in reference to another entity, which then serves as the ground entity G (Figure 1B). When having turned to the rack previously at your back, you may start wondering: "Are the beans to the left or to the right of the peas?" Or, when placing the ball on the shelf: "Should it go in front of or behind the box?" To establish such a ternary FoR, the (direct) FoR is transferred onto the intended reference point G (here: the peas or the box),

which then allows one to refer F to G from the viewpoint of the observer O: “The beans are to the right of the peas” and “The ball should go behind the box”. In Levinson’s (2003) nomenclature, the direct FoR is a specific instance of the *intrinsic* FoR (Figure 1A[ii]), whereas each FoR including an observer O distinct from G is a *relative* FoR because the description of the spatial relation changes with O’s viewpoint relative to the objects F and G (when you place the ball “behind the box” from your point of view, it may be “to the left of the box” from your child’s point of view, if your child is looking at it from a different angle). In this paper, we focus on how flexible people are in using the relative FoR in different kinds of spatial settings. Specifically, we aim to assess whether they transfer preferences for a specific variant of referencing from standard to non-standard situations. This is of interest not only in its own right, but critical for theoretical claims according to which reference strategies are adopted in a consistent manner across domains and spill over, for instance, into spatial representations of time (Boroditsky, 2000; Clark, 1973) or number (Dehaene, Bossini, & Giraux, 1993; Fias & Fischer, 2005).

Previous research on spatial FoRs has indicated variation in the use of the relative FoR along several lines. First, there is variation across languages and cultures with regard to whether a relative FoR is adopted at all and, if so, whether it is preferred over the other two basic FoRs: the *absolute* FoR derived from a superordinate field like the cardinal directions, and the *intrinsic* FoR derived from an intrinsically oriented ground object like a person or a car (Bohnemeyer & O’Meara, 2012; Levinson, 2003; Majid, Bowerman, Kita, Haun, & Levinson, 2004; Senft, 1997). For example, speakers of several Australian languages lacking dimensional prepositions for the intrinsic and relative FoR make exclusive use of the absolute FoR (Levinson, 2003; Majid et al., 2004). By contrast, speakers of European languages prefer the relative or intrinsic FoR over the absolute FoR, specifically in small-scale settings (Majid et al., 2004; Mishra, Sing, & Dasen, 2009). Similarly, the degree to which people adopt the

intrinsic FoR compared to the relative FoR varies cross-linguistically (Beller & Bender, 2017; Beller, Singmann, Hüther, & Bender, 2015; Majid et al., 2004) and depends on experiential and contextual factors (Bohnemeyer, 2011; Carlson-Radvansky & Radvansky, 1996; Carroll, 1997; Grabowski & Miller, 2000; Hill, 1978; Hüther, Müller, & Spada, 2016; Levelt, 1984; Surtees, Noordzij, & Apperly, 2012).

Second, how the relative FoR is constructed also varies. For standard referencing situations in which figure and ground are located in the visual field of an observer, Levinson (2003) suggested three variants of the relative FoR that emerge from different construction principles: translation, reflection, and rotation. In the case of *translation*, the FoR originally anchored in the observer O is simply shifted into the ground object G without changing the orientation of the axes, so that FRONT of the derived FoR is aligned with O's looking direction. Hence, the area beyond G is defined as FRONT, and LEFT and RIGHT correspond to O's LEFT and RIGHT (Figure 1B[i]). In the case of *reflection*, the FoR originally anchored in O is mirrored in G. As in a mirror image, FRONT and BACK of the derived FoR are swapped (but not its LEFT and RIGHT), with FRONT now pointing towards O. Hence, the area between O and G is defined as FRONT, while LEFT and RIGHT still correspond to O's LEFT and RIGHT (Figure 1B[ii]). In the case of *rotation*, finally, the FoR originally anchored in O is rotated in G, so that FRONT of the derived FoR is again pointing towards O. Therefore, the area between O and G is defined as FRONT, while LEFT and RIGHT are swapped compared to O's LEFT and RIGHT (Figure 1B[iii]). A survey across seven languages revealed diverging preferences for translation or reflection, whereas rotation occurs only rarely (Beller et al. 2015; Beller & Bender, 2017) The proportion of reflection was highest among German participants (88%) and lowest among Tongan participants (8%), and reversed for translation (6% vs. 58%). These results indicate cross-cultural variation in the use of the different variants of the relative FoR, but also inter-individual differences within each sample.

A third line of variation in the use of the relative FoR emerges when we turn from standard referencing situations with F and G being in the observer's visual field (i.e., *frontal* settings) to a non-standard, *dorsal* setting in which F and G are located *behind* the observer (Beller et al., 2015). Here, what varies is whether people directly apply a variant of the relative FoR (presumably the one they prefer in standard, frontal situations), or whether they mentally turn the observer (i.e., the depicted person or themselves) towards the setting—thereby converting the non-standard, dorsal situation into a standard, frontal situation—before applying a FoR (*turn-strategy*; Grabowski, 1999; Grabowski & Miller, 2000, footnote 5; Grabowski & Weiß, 1996; and see Beller et al., 2015). Irrespective of the method used to provide the participants with access to spatial information in the observer's back, only few participants chose to mentally turn before referencing (Beller & Bender, 2017; Beller, Bohlen, Hüther, & Bender, 2016; Beller et al., 2015; Fischer, 2016). Most participants either applied the *translation strategy* directly, that is, without a previous mental turn, by shifting the FoR backward into G (as illustrated in Figure 2A), or they generalized the reflection strategy to a kind of *inward-directed* FoR. In doing so, they considered the area between O and G as "in front of" G and the area beyond G as "behind" G, while "left" and "right" corresponded to O's LEFT and RIGHT (Figure 2B).

---------- Insert Figure 2 about here ----------

The three types of variability described here differ in what they reveal about theoretical assumptions on FoR selection. While variability in usage of basic FoRs (absolute, intrinsic, or relative) mainly arises from different options to anchor the coordinate system (i.e., in a superordinate field, the ground object, or the observer), and hence is a matter of *perspective-taking*, variability in usage of relative FoR variants (translation, reflection, or rotation) arises

from different options to transfer the direct FoR from the observer to another ground object, and hence is a matter of *construction*. Which perspective one takes partly depends on cultural and linguistic conventions, but also on demand characteristics of task and situation (e.g., if the ground object lacks orientation, the intrinsic FoR cannot be applied). When it comes to the relative variants, factors influencing the selection are basically unknown. Even the question of whether people do select one anew every time need arises, rather than following stable habits has not been asked, let alone answered. Given the cognitive effort involved in constructing a ternary FoR, it seems plausible to assume that people follow existing preferences for a specific variant (*consistency assumption*), but this assumption has not been tested empirically. Non-standard referencing situations have the potential to scrutinize whether the assumption holds. Similar FoR patterns across standard and non-standard situations would support the consistency assumption and speak for habitualized referencing, whereas variability in FoR patterns would suggest that people construct FoRs depending on situational characteristics.

To distinguish between the two options, being able to disentangle direct *translation* (Figure 2A) and *inward-directed* reflection (Figure 2B) is essential. For logical reasons, however, these two covert strategies generate the same overt response in dorsal tasks[1]. In our previous papers, which basically aimed at exploring people's referencing strategies in dorsal settings, we therefore used the *consistency assumption* to disambiguate responses. Specifically, we reasoned that participants adopt a strategy in dorsal settings that is at least consistent with, if not derived from, how they construct the relative FoR in frontal settings, and infered that those with a frontal preference for translation adopted backward translation, and those with a frontal preference for reflection adopted inward-directed reflection (Beller et

[1] Actually, a third strategy also generates the same response: turn-rotation (i.e., first turn O towards the objects and then apply rotation). However, this strategy is not very likely for two reasons: First, the rotation variant of the relative FoR is very rare even in standard, frontal situations (Beller et al., 2015; Beller & Bender, 2017), and second, its application in dorsal situations should be further discouraged by the cost of two mental rotations involved.

al., 2016; Beller & Bender, 2017). Yet, even though the consistency assumption is plausible from a theoretical point of view, it remains inconclusive without independent tests of its validity.

In the present paper, we therefore attempt to directly assess the *consistency assumption* by including a non-standard referencing situation for which translation and inward-directed reflection do produce *different* overt responses: lateral settings, that is, settings in which the objects are located *at one side* of the observer O. While the translation strategy can be applied to a lateral setting in exactly the same way as to a frontal and dorsal setting—by shifting the FoR originally anchored in O sideward into G (Figure 2C)—the construction of the inward-directed FoR is similar only for frontal and dorsal settings. Specifically, considering the area between O and G as "in front of" G allows one to take LEFT and RIGHT from O's LEFT and RIGHT in frontal and dorsal settings only. By contrast, in the lateral setting, LEFT and RIGHT have to be assigned according to the newly constructed FRONT, which necessitates a rotation of the left-right dimension (Figure 2D).

In a nutshell, the main goal of this paper is to investigate whether people's spatial references generalize from standard to non-standard situations in line with the consistency assumption. If this assumption holds, people who prefer *translation* in frontal settings should also adopt translation in dorsal and lateral settings, and people who prefer *reflection* in frontal settings should also adopt (inward-directed) reflection in dorsal and lateral settings. Importantly, the front-back axis of the derived FoR is aligned to O's front-back axis in dorsal, but not lateral situations, which will allow us to disentangle translation and inward-directed reflection in lateral situations. Furthermore, while consistency is easy to preserve for translation regardless of where the objects are located, consistency is more difficult to preserve for reflection because it requires a rotation of the left-right axis that is not necessary in frontal and dorsal settings.

# Experiment

In the following experiment, we investigated different strategies of applying a relative FoR to non-standard, dorsal and lateral settings as compared to the standard, frontal setting. The main question we seek to answer is whether participants follow the consistency assumption by using a FoR variant in non-standard settings that is consistent with the variant preferred in the standard setting. Particularly interesting in this regard are participants with a frontal preference for reflection, as consistency is more difficult for them to preserve compared to participants with a preference for translation. We therefore focus on speakers of German and Norwegian, who, according to a previous survey (Beller & Bender, 2017), are those with the highest proportion of the reflection variant in frontal settings (88% and 72%, respectively). The proportion of speakers adopting translation (6% and 22%, respectively) would serve as a reference for comparison. If the consistency assumption is true, all users of frontal translation should adopt translation also in lateral settings, and all users of frontal reflection should adopt inward-directed reflection in lateral settings. If speakers deviate from this pattern, the consistency assumption would have to be qualified or discarded. As items, we used drawings of small-scale, static situations with two objects, F and G, and an observer O whose perspective had to be taken. To check whether participants do take the observer's perspective, we implemented all items with two perspectives. To scrutinize the extent to which participants' referencing behaviour follows the consistency assumption, we presented frontal, dorsal, and lateral items within-subject.

## *Method*

*Materials*. A total of 28 items were used. Each item depicted a spatial configuration with three entities—a black square (G), a white circle (F), and an observer (O)—from a bird's eye

view. The items varied with respect to two aspects: the gaze direction of O in relation to the direction of the participant's gaze, and the location of F and G in relation to O. For half of the items, O's gaze direction was identical with the participant's gaze direction (*aligned-gaze condition*); for the other half, it was rotated 90° counterclockwise (*rotated-gaze condition*). For each of the two gaze conditions, we constructed four items with F and G being in O's visual field (*frontal item set*), four items with F and G being behind O (*dorsal item set*), and six items with at least one object being at one side of O (*lateral item set*), amounting to six item sets overall; see Figure 3 for a selection of example items, and Appendix A for the complete sets of items. Each item required participants to describe (from the perspective of the depicted observer) how F is related to G by marking one of eight response options:

The white circle is located …

| | |
|---|---|
| □ in front of | □ in front and to the left of |
| □ behind | □ in front and to the right of |
| □ to the left of | □ behind and to the left of |
| □ to the right of | □ behind and to the right of |

… the black square.

All materials were prepared in Norwegian and German by the bilingual authors and were cross-checked by native speakers.

---------- Insert Figure 3 about here ----------

*Design and procedure*. The Norwegian part of the study was carried out at the University of Bergen (Norway) and the German part at the University of Freiburg (Germany).

Participants worked on the task individually. Written informed consent was obtained, and demographic characteristics were collected.

The study was implemented as a paper-and-pencil questionnaire. The six item sets were presented within-subjects in two blocks. To control for possible order effects, half of the participants started with the three item sets of the aligned-gaze condition in the first block followed by the three item sets of the rotated-gaze condition in the second block. For the other half of participants, block assignment was reversed. Within each block, six orders of items were implemented. The items of each set (frontal, dorsal, and lateral) were presented in a row, implementing three orders: (i) frontal items first, then lateral and dorsal ones; (ii) dorsal items first, then frontal and lateral ones; (iii) lateral items first, then dorsal and frontal ones. For each set, the individual items were arranged in a "standard" sequence (from 1 to N, as indicated in Appendix A) or in the reversed sequence (from N to 1). Participants were assigned randomly to, but distributed equally across, the two orders of blocks and, within each block, to one of the six orders of items. They were instructed to work on all items in the given order. The time needed to complete each of the two blocks was measured (in minutes and seconds).

Finally, participants were asked which strategies they had used to adopt the perspective of the depicted observer (when it differed from their own), and whether they regarded certain types of items as more difficult than others. The strategy question used a task from the rotated-gaze condition as example and provided four response options as multiple choice: (a) turning the questionnaire physically or (b) mentally, or (c) turning oneself physically or (d) mentally. An open response option was provided for describing any other strategy participants may have used instead or as well. Three questions assessed subjective item difficulties. Each repeated two example tasks (A and B) and provided three options: (a) task A was more difficult than task B, (b) task B was more difficult than task A, or (c) tasks A and B were equally difficult.

The first question required participants to compare an item with rotated gaze (A) to an item with aligned gaze (B); the second to compare a frontal item (A) to a dorsal item (B); and the third to compare a frontal item (A) to a lateral item (B).

*Participants*. The Norwegian sample consisted of 42 native speakers of Norwegian (24 female, 18 male; age: $M$ = 22.0 years, $SD$ = 2.1, *range* 19-28 years). Most of them were students from the University of Bergen studying different subjects; some were non-students. The German sample consisted of 42 native speakers of German (34 female, 7 male, one participant did not indicate his/her gender; age: $M$ = 22.6 years, $SD$ = 4.4, *range* 19-42 years). Most of them were students from the University of Freiburg studying different subjects; some were non-students. Participation was voluntary. Participants were compensated with a voucher worth 65 Norwegian kroner (in Norway) or with 5 EURO (in Germany).

*Results*

On average, participants took 6:17 minutes to complete the two blocks of referencing items from the main part of the study. An analysis of variance with two within-subject factors *block* (first vs. second) and *gaze condition* (aligned vs. rotated), and one between-subjects factor *country* (Norway vs. Germany) indicated two main effects: *block* and *country*. Generally, participants needed significantly more time to complete the first block of items (230.9 s) than to complete the second block (146.0 s); $F(1,80) = 163.268$, $p < .001$, $\eta^2 = .671$; which is consistent with an increasing familiarization with the task. In addition, there was a small difference between countries: The Norwegian participants needed slightly longer to complete a block (201.5 s on average per block) than did the German participants (175.4 s); $F(1,80) = 4.069$, $p = .047$, $\eta^2 = .048$. Interestingly, gaze condition (aligned vs. rotated) did not make any difference; for all effects that included gaze condition: $F(1,80) < 1.094$, $p > .298$, $\eta^2 < .014$.

*Coding of FoRs.* All FoRs were determined from the point of view of the depicted observer. For *frontal* items, we distinguished between Levinson's (2003) three variants of the relative FoR: translation, reflection, and rotation (see Figure 1B). For the *dorsal* items, we distinguished—according to the "turn-strategy" (Grabowski & Miller, 2000) and in line with previous studies (e.g. Beller et al., 2015, 2016)—between turn-translation, turn-reflection, and turn-rotation. As explained in the introduction, turn-rotation is logically equivalent to translation and to inward-directed reflection (cf. Beller et al., 2015, Figure 7; and see footnote 1). Therefore, the corresponding response option also covers responses from participants adopting one of these two FoRs. In the *lateral* case, turn-rotation is logically equivalent to inward-directed reflection, but not to translation, and our lateral items were designed such that translation would produce a response distinct from the three turn-variants. This allowed us to distinguish between translation, turn-translation, turn-reflection, and turn-rotation (also covering responses from participants adopting inward-directed reflection). Finally, responses that were not covered by any of these FoRs were classified as "unexplained" responses.

The referencing data were analyzed in three steps. First, we inspected the extent to which participants' responses could not be explained by the FoRs under scrutiny in the different item sets (frontal, dorsal, and lateral); then, we looked at how consistently participants responded in terms of FoRs within each set; and finally, we determined which FoR (if any) each participant preferred in each set.

*(1) Unexplained responses*. First, we checked the different item sets for differences in the mean number of responses that were *not* covered by any of the FoRs under scrutiny. Across the two countries and all items, this number of "unexplained" responses was fairly low ($M$ = 9.0%; see Table 1). An analysis of variance of the proportion of unexplained responses with two within-subject factors *item set* (frontal vs. dorsal vs. lateral) and *gaze condition* (aligned vs. rotated), and three between-subjects factors *country* (Norway vs. Germany), *order of item*

*sets in Block 1* (frontal first vs. dorsal first vs. lateral first) and *order of item sets in Block 2* (frontal first vs. dorsal first vs. lateral first), indicated only one significant effect: a main effect of *order of item sets in Block 1*; $F(2,66) = 4.379$; $p = .016$; $\eta^2 = .117$; for all other effects: $p > .166$; $\eta^2 < .075$. The proportion of unexplained responses was significantly higher when participants had started the questionnaire with a frontal item set ($M = 17.1\%$; $N = 31$; $p < .010$; Bonferroni-corrected) than when they had started with a dorsal item set ($M = 5.6\%$; $N = 26$) or a lateral item set ($M = 3.0\%$; $N = 27$). Importantly, the analysis indicated no significant differences between the three item sets (*frontal*: 6.8%; *dorsal*: 9.5%; *lateral*: 10.6%; $F(1.76,116.40$ [Greenhouse-Geisser-corrected degrees of freedom]$) = 1.234$; $p = .292$; $\eta^2 = .018$), no significant differences between the two gaze conditions (*aligned*: 9.0%; *rotated*: 9.0%; $F(1,66) < 1$), and no significant differences between the two countries (*Norway*: 8.1%; *Germany*: 9.9%; $F(1,66) < 1$), suggesting that neither the non-standard, dorsal and lateral referencing situations, nor the mental rotation involved in the rotated-gaze condition, influenced the coverage of responses by the FoRs under scrutiny in the two countries alike.

*Table 1*. Frequency (in %; $N = 42$) of responses that were not covered by any of the FoRs under scrutiny.

| | *Item set* | | | | | |
|---|---|---|---|---|---|---|
| | Frontal *Country* | | Dorsal *Country* | | Lateral *Country* | |
| Gaze condition | Norway | Germany | Norway | Germany | Norway | Germany |
| Aligned | 4.8 | 5.4 | 7.1 | 13.1 | 10.7 | 13.1 |
| Rotated by 90° | 8.9 | 8.3 | 7.1 | 10.7 | 9.9 | 8.7 |

*(2) Individual consistency within sets*. Next, we determined whether an individual participant adopted one FoR consistently and, if so, which one. To this end, we counted for

each participant how often each FoR could be coded in each of the six item sets (frontal aligned/rotated, dorsal aligned/rotated, and lateral aligned/rotated). For example, if reflection could be coded on three items and translation on one item, consistency would be 75% for reflection and 25% for translation. We then used the *maximum* of these values as an estimate of a participant's consistency in FoR adoption across the items of the respective set (75% in the example). Mean consistency values are displayed in Table 2.

*Table 2.* Individual consistency in FoR adoption (in % of items).

| | *Item set* | | | | | |
|---|---|---|---|---|---|---|
| | Frontal (4 items) *Country* | | Dorsal (4 items) *Country* | | Lateral (6 items) *Country* | |
| Gaze condition | Norway | Germany | Norway | Germany | Norway | Germany |
| Aligned | 91.7 | 91.1 | 89.9 | 85.7 | 84.9 | 75.8 |
| Rotated by 90° | 88.1 | 87.5 | 88.7 | 86.9 | 81.7 | 80.2 |

Across the two countries and all items, FoRs were adopted with a mean consistency of 86.0%. An analysis of variance of the consistency values with the same within-subject and between-subjects factors as before indicated two significant effects: a main effect of *item set*; $F(2,132) = 4.110$; $p = .019$; $\eta^2 = .059$; and a main effect of *order of item sets in Block 1*; $F(2,66) = 4.738$; $p = .012$; $\eta^2 = .126$; for all other effects: $p > .122$; $\eta^2 < .102$. Consistency values were higher for the frontal item sets ($M = 89.6\%$) and the dorsal item sets ($M = 87.8\%$) than for the lateral item sets ($M = 80.7\%$). And, complementary to the number of unexplained responses, consistency values were significantly lower across all items when participants had started the questionnaire with a frontal item set ($M = 77.3\%$; $N = 31$; $p < .003$; Bonferroni-corrected) than when they had started with a dorsal item set ($M = 90.4\%$; $N = 26$) or a lateral item set ($M = 91.8\%$; $N = 27$). Again, the analysis indicated no significant differences between

the two gaze conditions (*aligned*: 86.5%; *rotated*: 85.5%; $F(1,66) < 1$), and no significant differences between the two countries (*Norway*: 87.5%; *Germany*: 84.5%; $F(1,66) < 1$), suggesting that the mental rotation involved in the rotated-gaze condition did not influence the consistency of responses in terms of FoRs adoption in the two countries alike.

*(3) FoR preference*. Finally, we identified each participant's preferred FoR as the one that was coded (a) more often than all others and (b) in at least three out of the four items of each frontal and dorsal set, or in at least four out of the six items of each lateral set, respectively (i.e., with a consistency of ≥ 66.7%). Participants' preferred FoRs are presented in Table 3.

*Table 3*. Preferred FoR (in %; $N = 42$).

| | *Country* | | | |
|---|---|---|---|---|
| | Norway | | Germany | |
| | *Gaze condition* | | *Gaze condition* | |
| FoR | Aligned | Rotated by 90° | Aligned | Rotated by 90° |
| *(A) Frontal items: FoR adopted in at least 3 out of the 4 items* | | | | |
| Translation | **66.7** | **64.3** | 28.6 | 35.7 |
| Reflection | 21.4 | 21.4 | **57.1** | **47.6** |
| Rotation | 0.0 | 2.4 | 2.4 | 4.8 |
| No preference | 11.9 | 11.9 | 11.9 | 11.9 |
| *(B) Dorsal items: FoR adopted in at least 3 out of the 4 items* | | | | |
| Turn-translation | 0.0 | 2.4 | 2.4 | 2.4 |
| Turn-reflection | 4.8 | 9.5 | 7.1 | 9.5 |
| Turn-rotation/ translation/inward | **85.7** | **76.2** | **73.8** | **71.4** |
| No preference | 9.5 | 11.9 | 16.7 | 16.7 |
| *(C) Lateral items: FoR adopted in at least 4 out of the 6 items* | | | | |
| Translation | **78.6** | **73.8** | **57.1** | **69.0** |
| Turn-translation | 0.0 | 2.4 | 2.4 | 0.0 |
| Turn-reflection | 7.1 | 7.1 | 16.7 | 11.9 |
| Turn-rotation/inward | 0.0 | 2.4 | 4.8 | 2.4 |
| No preference | 14.3 | 14.3 | 19.0 | 16.7 |

*Note*. Modal response printed in **bold** face.

*Statistical analyses*. Due to different variants and numbers of FoRs (cf. the section on FoR coding), the frontal, dorsal, and lateral data were analyzed separately. In each case, we performed a log-linear analysis (Kennedy, 1992) on the distribution of participants' FoR preferences, in which we included three factors: the two main factors of interest, *country* (Norway vs. Germany) and *gaze condition* (aligned vs. rotated), and the control factor *order of item sets in Block 1* (frontal first vs. dorsal first vs. lateral first) that proved to be significant in the analyses of unexplained responses and consistency values. As *gaze condition* is considered as a between-subjects factor in this analysis, the total *N* equals twice the total number of participants (i.e., $N_2 = 2 \times 84 = 168$). The analyses were performed in two steps: model selection and model comparisons. *Model selection* generally aims at identifying the combination of factors that is sufficient to explain the data without losing the fit between model and data. Fit values were determined according to the $G^2$ statistics (criterion: $p \geq .100$). We started model selection with the model that includes all factors and their interactions and explains the data with a perfect fit ($G^2 = 0$; $df = 0$; $p = 1$). More parsimonious models were then selected in a systematic, hypothesis-driven manner, which is described in detail in Appendix B. After model selection, we performed *model comparisons* with the aim of determining main effects and interactions as in an analysis of variance. Model comparisons are performed by comparing two models that differ in a particular candidate factor and thus allow one to test whether the candidate factor makes a significant difference (in our case: according to the $G^2$ statistics, criterion: $p < .050$). Finally, particular hypotheses such as the hypothesis on perspective taking were substantiated in follow-up analyses.

*(3A) Frontal item sets*. According to previous data from Norway and Germany (Beller & Bender, 2017), we expected a general preference for reflection. However, this overall preference should be more pronounced among German participants than among Norwegian participants, leading to a main effect of *country*. In addition, if participants adopted different

strategies for generating a FoR in standard versus non-standard settings, an effect of the control variable *order of item sets in Block 1* might emerge, which would indicate that FoR preferences depended on whether participants started with a frontal, dorsal, or lateral item set. Finally, assuming that participants do not change their FoR preference when adopting the perspective of the depicted observer (aligned vs. rotated), we did not expect a difference in FoR preference between the two gaze conditions. Model selection indeed revealed the model with the two main effects of *country* and *order of item sets in Block 1* as the most parsimonious model showing sufficient fit ($G^2 = 14.802$; $df = 24$; $p = .926$). Model comparisons indicated the expected main effect of *country* ($G^2 = 22.493$; $df = 3$; $p < .001$) and a significant main effect of *order of item sets* ($G^2 = 31.116$; $df = 6$; $p < .001$), but no interaction of these two factors ($G^2 = 8.866$; $df = 6$; $p = .181$). As hypothesized, the factor *gaze condition* together with all of its interactions did not prove to have any significance for explaining the data (summed effect: $G^2 = 5.936$; $df = 18$; $p = .996$).

Overall, translation and reflection prevailed across the two frontal item sets, covering 85.7% of the preferences ($N_2 = 168$), whereas rotation was only rarely adopted consistently (2.4%; see Table 3 [A]). However, in the Norwegian sample, the majority of participants preferred translation (65.5% on average across the two gaze conditions; $N_2 = 84$) and only a smaller proportion preferred reflection (21.4%). In the German sample, the pattern was reversed: The majority of participants preferred reflection (52.4%; $N_2 = 84$) and a smaller proportion preferred translation (32.1%). Across countries, starting with a frontal item set resulted in a lower proportion of participants with a preference for translation and a higher proportion with no clear preference (*trans*: 30.6%; *ref*: 37.1%; *no pref*: 25.8%; $N_2 = 62$) as compared to starting with a dorsal item set (*trans*: 59.6%; *ref*: 36.5%; *no pref*: 3.8%; $N_2 = 52$) or a lateral item set (*trans*: 59.3%; *ref*: 37.0%; *no pref*: 3.7%; $N_2 = 54$). The proportion of participants adopting reflection was almost unaffected by item order.

The log-linear analysis did not indicate differences between the two frontal gaze conditions, suggesting that the FoR each participant preferred was independent of the perspective to be taken. While this analysis is based on group data only, the within-subject design allowed us to check this on an individual basis. To this end, we cross-tabulated participants' preferred FoR in the aligned-gaze condition and the rotated-gaze condition, summed over the two countries. Of the 84 participants, 65 (77.4%) exhibited the same preference in the two gaze conditions: 37 participants (44.0%) preferred translation, 27 (32.1%) reflection, and one (1.2%) rotation. Six participants (7.1%) changed their preferred FoR from one gaze condition to the other, while the remaining 13 participants (15.5%) exhibited no preference for any of the three FoRs under scrutiny in at least one of the two gaze conditions. A non-significant marginal homogeneity test for paired tasks supported the assumption that the preference distributions of the two gaze conditions were nearly identical; std. MH statistic < .001, $p > 0.999$. We thus have no reason to assume that participants preferred different FoRs in the two gaze conditions.

For coding of the FoRs, we assumed that participants adopted O's point of view, as required by the instruction, and determined the FoRs from this perspective. However, for the frontal aligned-gaze condition, there is a second, confounded possibility: that participants simply relied on their own perspective on the situation, which is identical to O's perspective, and thus produced the same responses. For the frontal rotated-gaze condition, adopting one's own perspective instead of O's perspective should result in different responses. Having coded FoRs according to O's perspective, the above finding that most participants preferred the same FoR in the aligned-gaze condition as in the rotated-gaze condition is therefore a clear indication of perspective taking. As a cross-check, we may look at the match in participants' FoR preferences between the two gaze conditions, this time coding the FoRs according to the perspective of the participants (*direct FoR*). If participants do take O's perspective, this

comparison should result in a mismatch between the two gaze conditions. This is exactly what we found when cross-tabulating participants' preferred FoRs in the aligned-gaze condition (in which the participant's and O's perspective are identical) and those in the rotated-gaze condition (with FoRs now determined from the participant's perspective): Of the 84 participants, only one (1.2%) would then exhibit the same preference in the two gaze conditions; 81 (96.4%) would exhibit no preference for any of the three FoRs under scrutiny in at least one of the two gaze conditions; and two (2.4%) would change their preferred FoR from one gaze condition to the other. A new marginal homogeneity test indicated that the preference distributions of the two gaze conditions differed; std. MH statistic = 7.752, $p <$ .001. This cross-check suggests that participants did not take their own perspective in the rotated-gaze condition, but adopted the observer's point of view, as required by the instruction.

This conclusion is in line with the result from the strategy question, which asked participants post-hoc to indicate how they had taken the observer's perspective in the rotated-gaze condition. Of the 84 participants, 81 (96.4%) used at least one of the four strategies. Testing (for each strategy separately) the number of participants who adopted the respective strategy or not, revealed no significant differences between countries ($p > .104$; Fisher's exact test, two-sided). Aggregated across the two countries, the majority of participants (56 out of 84; 66.7%) stated to have turned themselves mentally, 17 (20.2%) stated to have turned themselves physically, 15 (17.9%) stated to have turned the questionnaire mentally, and nine (10.7%) stated to have turned it physically. Overall, participants preferred mental over physical rotation, and a rotation of one's own perspective over a rotation of the questionnaire. Finally, we asked participants for the relative difficulty of the items of the rotated-gaze and aligned-gaze condition. The difficulty rating revealed no differences between the two countries ($\chi^2 = 0.306$; $N = 84$; $df = 2$; $p = .858$). Aggregated across the two countries, items of

the rotated-gaze condition were more often regarded as more difficult than items of the aligned-gaze condition (*more difficult:* 49; *less difficult:* 7; $\chi^2 = 31.500$; $N = 56$; $df = 1$; $p < .001$).

*(3B) Dorsal item sets.* Based on previous work (Beller & Bender, 2017), we expected a general preference for the ambiguous response option turn-rotation/translation/inward for the two countries alike, because this option subsumes responses from participants with a preference for translation and from participants with a preference for inward-directed reflection. As for the frontal item set, we did not expect a difference between the two gaze conditions, but expected that we may find an effect of the control variable *order of item sets in Block 1*. Model selection indeed revealed the one-factor model *order of item sets in Block 1* as the most parsimonious model showing sufficient fit ($G^2 = 20.018$; $df = 27$; $p = .830$). Model comparisons again indicated a significant main effect of this factor ($G^2 = 32.481$; $df = 6$; $p < .001$), but, as expected, no main effect of *country* ($G^2 = 1.822$; $df = 3$; $p = .610$), and no interaction between the two factors ($G^2 = 7.140$; $df = 6$; $p = .308$). As hypothesized, the factor *gaze condition* together with all of its interactions did not prove to have any significance for explaining the data (summed effect: $G^2 = 11.056$; $df = 18$; $p = .892$).

In line with the expectations, the majority of participants (76.8%; $N_2 = 168$) preferred the ambiguous option consistently across the two dorsal item sets in the two countries alike, whereas turn-translation (1.8%) and turn-reflection (7.7%) were only rarely adopted consistently (see Table 3[B]). The order effect showed a similar pattern as for the frontal item sets. Starting with a frontal item set resulted in a lower proportion of participants with a preference for the ambiguous response option and a higher proportion of participants with no clear preference (*turn-rot/trans/inw*: 56.5%; *turn-ref*: 8.1%; *no pref*: 30.6%; $N_2 = 62$) as compared to starting with a dorsal item set (*turn-rot/trans/inw*: 86.5%; *turn-ref*: 9.6%; *no pref*: 3.8%; $N_2 = 52$) or a lateral item set (*turn-rot/trans/inw*: 90.7%; *turn-ref*: 5.6%; *no pref*:

3.7%; $N_2$ = 54). The proportion of participants adopting turn-reflection was almost unaffected by item order.

In order to check, on an individual basis, whether or not participants preferred the same FoR in each of the two dorsal gaze conditions, we cross-tabulated participants' preferred FoR in the aligned-gaze condition and the rotated-gaze condition, summed over the two countries. Of the 84 participants, 62 (73.8%) exhibited the same preference in the two gaze conditions: 58 participants (69.0%) preferred the option turn-rotation/translation/inward, three (3.6%) preferred turn-reflection, and one (1.2%) turn-translation. Six participants (7.1%) changed their preferred FoR from one gaze condition to the other, while the remaining 16 participants (19.0%) exhibited no preference for any of the three FoRs under scrutiny in at least one of the two gaze conditions. A non-significant marginal homogeneity test (std. MH statistic = .624, $p$ = .533) provides no reason to assume that participants preferred different FoRs in the two gaze conditions. Again, this result also supports the assumption that participants adopted the observer's point of view and described the position of F in relation to G from this perspective.

The implementation of the two object locations *frontal* and *dorsal* as a within-subject factor allowed us to relate each participant's preference in the dorsal item sets to the participant's preference in the frontal item sets and thereby to infer, based on the consistency assumption, the strategy that might have generated the dorsal response. To this end, we cross-tabulated participants' preferred FoR for frontal and dorsal tasks, summed over the two countries. The results are reported in Table 4. Of the 129 preference pairs in which the ambiguous response option turn-rotation/translation/inward was chosen on dorsal items, 77 (59.7%) were indicative of the translation strategy also in the dorsal case (consistent with a preference for translation in the frontal case), 42 (32.6%) were indicative of the inward strategy (consistent with a preference for reflection in the frontal case), and only one (1.0%) was indicative of the turn-rotation strategy (consistent with a preference for rotation in the

frontal case). Generally, the turn-strategy—that is, turn the observer towards the objects and then adopt the same FoR as on frontal items—was used rarely. Only 13 (7.7%) preference pairs were indicative of this strategy (grey cells), and most of these participants adopted turn-reflection consistent with their frontal preference for reflection.

*Table 4*. Preferred FoR among dorsal items depending on the preferred FoR among frontal items.

| | *Frontal preference* | | | | |
|---|---|---|---|---|---|
| *Dorsal preference* | Translation | Reflection | Rotation | No preference | Σ |
| Turn-translation | $0^{C}$ | 0 | 3 | 0 | 3 |
| Turn-reflection | 0 | $12^{C}$ | 0 | 1 | 13 |
| Turn-rot/trans/inw | $77^{trans, C}$ | $42^{inw, C}$ | $1^{C}$ | 9 | 129 |
| No preference | 5 | 8 | 0 | 10 | 23 |
| Σ | 82 | 62 | 4 | 20 | 168 |

*Note*. Data are summed over the two gaze conditions and the two countries. Grey cells: Responses in dorsal tasks according to the turn-strategy; rot: rotation, trans: translation, inw: inward-directed.
[C] Preferences that are in line with the consistency assumption.

Finally, comparing dorsal and frontal items, we asked participants for the relative difficulty of the dorsal and frontal items. The difficulty rating revealed no differences between the two countries ($\chi^2 = 0.260$; $N = 84$; $df = 2$; $p = .878$). Aggregated across the countries, dorsal items were more often regarded as more difficult than frontal items (*more difficult:* 52; *less difficult:* 7; $\chi^2 = 34.322$; $N = 59$; $df = 1$; $p < .001$).

*(3C) Lateral item sets*. For participants with a preference for translation, nothing should change across item sets; they can apply translation on lateral items in the same way as on frontal and dorsal items. But what about participants with a preference for reflection? Will they follow the consistency assumption and adopt inward-directed reflection even though it is

more difficult to construct in lateral settings than in dorsal settings? In that case, we would expect an effect of *country* similar to that from the frontal item sets: a dominance of translation over inward-directed reflection in the Norwegian sample and the reverse pattern in the German sample (cf. Table 3[A]). As for the other item sets, we expected that we may find an effect of the control variable *order of item sets in Block 1*, but did not expect a difference in FoR preference between the two gaze conditions. Yet, model selection revealed the null-logit model without any of the three factors as the most parsimonious model showing sufficient fit ($G^2 = 46.373$; $df = 44$; $p = .375$). Different from what we would expect according to the consistency assumption, the analysis did not indicate a main effect of *country* ($G^2 = 4.455$; $df = 4$; $p = .348$). If at all, the analysis suggested, again, a main effect of *order of item sets* ($G^2 = 24.863$; $df = 8$; $p = .002$), but no interaction between the two factors ($G^2 = 6.961$; $df = 8$; $p = .541$). As hypothesized, the factor *gaze condition* together with all of its interactions did not prove to have any significance for explaining the data (summed effect: $G^2 = 10.163$; $df = 24$; $p = .994$).

As indicated in Table 3(C), the majority of participants (69.6%; $N_2 = 168$) preferred translation consistently across the two lateral item sets in the two countries alike, whereas turn-translation (1.2%), turn-reflection (10.7%), and the option turn-rotation/inward (2.4%) were less often adopted consistently. The order effect produced a similar pattern to that for the frontal item sets: Starting with a frontal item set resulted in a lower proportion of participants with a preference for translation and a higher proportion with no clear preference (*trans*: 50.0%; *turn-ref*: 17.7%; *no pref*: 22.6%; $N_2 = 62$) as compared to starting with a dorsal item set (*trans*: 78.8%; *turn-ref*: 7.7%; *no pref*: 13.5%; $N_2 = 52$) or a lateral item set (*trans*: 83.3%; *turn-ref*: 5.6%; *no pref*: 11.1%; $N_2 = 54$). This time, the proportion of participants adopting turn-reflection was also affected by item order.

In order to check, on an individual basis, whether or not participants preferred the same FoR in each of the two lateral gaze conditions (determined from the observer's point of view), we cross-tabulated participants' preferred FoR in the aligned-gaze condition and the rotated-gaze condition, summed over the two countries. Of the 84 participants, 59 (70.2%) exhibited the same preference in the two gaze conditions: 52 participants (61.9%) preferred translation, six (7.1%) turn-reflection, one (1.2%) the option turn-rotation/inward, and none preferred turn-translation. Three participants (3.6%) changed their preferred FoR from one gaze condition to the other, while the remaining 22 participants (26.2%) exhibited no preference for any of the four FoRs under scrutiny in at least one of the two gaze conditions. A non-significant marginal homogeneity test (std. MH statistic = .457, $p$ = .648) provides no reason to assume that participants preferred different FoRs in the two gaze conditions. This result again supports the assumption that participants adopted O's point of view and described the position of F in relation to G from this perspective.

The implementation of the two object locations *frontal* and *lateral* as a within-subject factor allowed us to relate each participant's preference in the lateral item sets to the participant's preference in the frontal item sets and thereby to infer the strategy that might have generated the lateral response. To this end, we cross-tabulated participants' preferred FoR for frontal and lateral tasks (summed over the two countries). The results are reported in Table 5. They reveal a marked difference between participants preferring translation in frontal settings and those preferring reflection. Nearly all participants with a preference for forward translation in frontal settings preferred sideward translation in lateral settings (95.1% of the $N_2$ = 82 preference pairs), in accordance with the consistency assumption. Participants with a preference for reflection in frontal settings did not show such a uniform pattern. Only three (4.8% of the $N_2$ = 62 preference pairs) were indicative of inward-directed reflection in the lateral case. While substantial proportions of participants either adopted the turn-reflection

strategy (22.6%) or exhibited no clear preference (27.4%), the majority (43.5%) adopted the sideward translation variant, thereby *changing* their preference, which is at odds with the consistency assumption (Figure 5). As for the dorsal data, the turn-strategy was generally rarely used. Of the total of 168 preference pairs, only 15 (8.9%) were indicative of this strategy (grey cells in Table 5).

---------- Insert Figure 5 here ----------

Finally, we had asked participants for the relative difficulty of the lateral and frontal items. Difficulty ratings revealed no differences between the two countries ($\chi^2 = 3.067$; $N = 84$; $df = 2$; $p = .216$). Aggregated across the two countries, lateral items were more often regarded as more difficult than frontal items (*more difficult:* 42; *less difficult:* 7; $\chi^2 = 25.000$; $N = 49$; $df = 1$; $p < .001$).

*Table 5*. Preferred FoR among lateral items depending on the preferred FoR among frontal items.

| | *Frontal preference* | | | | |
|---|---|---|---|---|---|
| *Lateral preference* | Translation | Reflection | Rotation | No preference | Σ |
| Translation | 78[C] | 27 | 2 | 10 | 117 |
| Turn-translation | 1[C] | 1 | 0 | 0 | 2 |
| Turn-reflection | 0 | 14[C] | 2 | 2 | 18 |
| Turn-rot/inw | 0 | 3[inw, C] | 0[C] | 1 | 4 |
| No preference | 3 | 17 | 0 | 7 | 27 |
| Σ | 82 | 62 | 4 | 20 | 168 |

*Note*. Data are summed over the two gaze conditions and the two countries. Grey cells: Responses in lateral tasks according to the turn-strategy; rot: rotation, trans: translation, inw: inward-directed.
[C] Preferences that are in line with the consistency assumption.

# Discussion

In this study, we focused on how flexible people are in using the relative FoR in different kinds of spatial settings. Specifically, we aimed to assess whether people's preferences for a specific variant of referencing generalize from standard to non-standard situations in line with the *consistency assumption*. If the consistency assumption holds, people with a preference for translation in frontal settings should adopt translation also in dorsal and lateral settings, and those with a preference for reflection in frontal settings should adopt inward-directed reflection also in dorsal and lateral settings. Alternatively, people might switch from a preference for reflection in frontal settings to other strategies in lateral settings because consistency is more difficult to preserve for reflection (than for translation) as it requires an additional rotation of the left-right axis. To test these hypotheses, we assessed FoR preferences in frontal, dorsal, and lateral settings, and we compared two perspectives (aligned vs. rotated gaze).

Overall, the results indicated that participants adopted the requested perspective without noticeable impairment to cognitive processing; had strong preferences for a particular FoR within item sets; and exhibited similar FoR preferences in frontal and dorsal situations as in previous studies, but changed these preferences at least partly in lateral situations. In the following, we give a brief summary of each of these findings, before discussing open questions arising from them.

The participants did take the perspective of the depicted observer (with aligned or rotated gaze) as required by the instruction. Subjectively, many participants regarded items with rotated gaze as more difficult compared to items with aligned gaze, but this difference was not reflected in the time on task, the number of unexplained responses, the consistency of FoR adoption, or the FoR preference within different item sets (generally, we observed fairly low

rates of unexplained responses, indicating that the FoRs considered here were sufficient to cover most responses). The large majority of our participants chose to turn themselves (physically or mentally) rather than the questionnaire to take the rotated perspective, and the ease with which they engaged in referencing from this perspective is in line with research revealing that people perceive viewer rotation to be easier than array rotation (Lambrey, Doeller, Berthoz, & Burgess, 2012; Wang & Simons, 1999).

Participants responded highly consistently within item sets by adopting their preferred FoR on most items of the respective set, suggesting that many participants decided on the first item of a set which FoR to adopt and then applied this FoR to the whole set of similar items (cf. Beller et al., 2016).

Regarding FoR preferences, our *frontal* data replicated previous findings (Beller & Bender, 2017) insofar as most participants adopted either translation or reflection, with a higher rate of translation in the Norwegian than the German sample. in the Norwegian sample, however, the overall preference flipped from a majority preferring reflection in our 2017 study, to a majority preferring translation in the current study; and the overall preference for reflection in the German sample was less pronounced in the current study than it was in all of our previous studies (Beller et al., 2015, 2016; Beller & Bender, 2017). These differences in preferences may be due to accidental variation or due to the specific mindset participants happened to have prior to the experiment (e.g., having moved to the lab is likely to prime translation), and are in line with the general observation that people flexibly switch FoRs depending on demand characteristics of task and situation.

As expected, the *dorsal* data replicated the high rate of participants who chose the ambiguous turn-rotation/translation/inward option in the two countries. In line with the consistency assumption, this might reflect a preference for backward translation and for inward-directed reflection when applied to dorsal items. In contrast, the *lateral* data supported

the consistency assumption only partially, namely (a) for those participants with a preference for translation in frontal settings who were found to adopt turn-translation and sideward translation in the lateral settings, and (b) for those participants with a preference for (inward-directed) reflection in frontal settings who were found to adopt turn-reflection or inward-directed reflection in the lateral settings. However, most participants with a preference for (inward-directed) reflection in frontal settings adopted sideward translation in lateral settings, which is at odds with the consistency assumption.

Taken together, these findings leave us with at least three questions to be discussed in the remainder of this section: What can be inferred from the lateral results for the consistency assumption? Why do so many people switch from frontal reflection to lateral translation? And what does this reveal about referencing more generally? For a discussion of possible reasons for the order effects, see Appendix C.

*The lateral results and the consistency assumption*

The consistency assumption is one answer to the theoretical question of whether people transfer preferences for a specific variant of referencing from standard to non-standard situations. It was introduced in order to infer from an ambiguous *overt* response option in dorsal tasks which *covert* strategy participants might have used to solve these tasks: the translation strategy, the inward-directed strategy, or the turn-rotation strategy (Beller et al., 2015, 2016). We argued that people would prefer a strategy that is at least consistent with (or derived from) how they construct the relative FoR in frontal situations; and on the basis of participants' preference for translation and (inward-directed) reflection in frontal tasks, we inferred translation and inward-directed reflection to be the most likely strategies for making dorsal references. But data from dorsal tasks remain empirically inconclusive. We therefore designed lateral tasks so as to allow us to disentangle translation from the other two strategies.

While the empirical results are straightforward, they only partly support the consistency assumption: Nearly all participants with a preference for translation in frontal tasks consistently used translation also in lateral tasks. Participants with a preference for (inward-directed) reflection, however, did not respond in such a homogeneous way. While a few of them indeed adopted inward-directed reflection in lateral tasks, and some adopted turn-reflection (both in line with the consistency assumption), most switched to translation in the lateral tasks—contrary to the consistency assumption.

As described in the introduction, applying inward-directed reflection to a lateral task is different from applying this FoR to a dorsal task. Whereas the two cases are identical in that the front-back axis is chosen so as to point towards the observer, which implicates relatively few cognitive costs, the two cases differ in how the left-right axis is construed: by a direct mapping from O's left-right in a dorsal task (see Figure 2B), yet by a cognitively more demanding rotation of the left-right axis in a lateral task (Figure 2D). The assumption that participants may simply have tried to avoid this rotation is supported by the observation that most of them did not adopt the rotation variant of the relative FoR in frontal tasks (cf. Table 3[A]), and that they evaluated tasks involving rotation of the perspective as more difficult (despite the ease with which they adopted the rotated observer's perspective).

*Sideward translation as an eye-catching alternative*

In a lateral task, the ground object G is located at one side of the observer O. This arrangement suggests dividing the space around O along the left-right axis into two areas: a "frontal" area extending from this axis in the gaze direction of O, and a "dorsal" area extending from this axis in the opposite direction, as illustrated in Figure 4. Having defined space in this way, sideward translation of the FoR originally anchored in O along the left-right axis O–G suggests itself as an easy operation.

---------- Insert Figure 4 about here ----------

The availability of this alternative strategy may explain the high proportion of sideward translation among participants with a preference for reflection in frontal settings.

*Implications of the flexibility in FoR use*

Research on spatial referencing has demonstrated that the relative FoR is used with a substantial amount of variation: variation with regard to whether a relative FoR is adopted at all and, if so, whether it is preferred over the other FoRs; variation with regard to how the relative FoR is constructed (i.e., by translation, reflection, or rotation); and variation with regard to whether the principles for constructing a relative FoR are preserved when moving from standard to non-standard referencing situations. Apparently, people do not apply their preferred variant of the relative FoR to all kinds of situations, but rather flexibly adapt their strategy when doing so is more convenient.

Importantly, much of this variation occurs not only across populations (languages and cultures), but also within populations, and not only between individuals, but also within individuals. If one assumes that referencing is an inherently communicative activity, both a preference for the relative FoR and the flexibility in using it must be puzzling. Other than the binary FoRs, different variants of the relative FoR produce different accounts of spatial relations. Not knowing on which principles a speaker's FoR is based renders it a priori impossible for the hearer to know whether the ball is "in front of" or "behind" the box (Wu & Keysar, 2007). To avoid misunderstandings, additional explanations and deictic gestures seem to be indispensable. In so doing, however, they render the referencing expression redundant, which raises the possibility that one key purpose of such expressions might be encoding for representation and memorization rather than communication.

The degree of flexibility in choosing a relative FoR in space also has implications for other domains. As stated in the introduction, some theories claim that referencing preferences are generalized from space to more abstract domains. For instance, representations of time or number are supposed to unfold along similar axes, in line with cultural conventions for spatial representations (e.g., Boroditsky & Gaby, 2010; Shaki, Fischer, & Petrusic, 2009). In light of how flexible people actually are in adopting their FoRs depending on task and context (including the construction of specific variants of this FoR according to diverging principles), generalizations to other domains should be take with more caution (cf., Bender & Beller, 2014; Bender, Rothe-Wulf, & Beller, 2018).

*Conclusion*

The current study scrutinised the consistency assumption, according to which people in non-standard, dorsal and lateral referencing situations adopt a strategy that is consistent with (or derived from) how they construct the relative FoR in standard, frontal situations. We found the assumption to be violated for those participants with a preference for reflection in frontal settings, who prevalently switched to translation in lateral settings. This implies that these participants adopted a FoR based on a different construction principle in non-standard situations. The finding demonstrates within-subject variation with regard to which variant of the relative FoR people adopt in static, small-scale referencing tasks, most likely due to specific affordances of the lateral tasks that invite sideward translation. Generally, people with a preference for reflection in frontal situations need to be more flexible in FoR construction, since the reflection principle does not neatly apply to non-standard, dorsal and lateral situations, whereas the translation principle can always be applied in the same way, independently of where the objects are located around a person. For two reasons, however, the consistency assumption does not need to be abandoned completely. First, the violation of the

assumption in lateral settings does not necessarily generalize to dorsal settings; after all, constructing the consistent inward-directed FoR is less difficult in dorsal than lateral settings. And second, even in lateral tasks, the majority of participants responded in line with the consistency assumption, namely all those with a preference for translation in frontal tasks, who adopted turn-translation and sideward translation, and those with a preference for reflection who adopted turn-reflection or inward-directed reflection.

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Figure Captions

*Figure 1.* (A) FoRs for binary relations: (i) the *direct* FoR (Danziger, 2010) as a specific case of (ii) the intrinsic FoR. (B) Three variants of the relative FoR for ternary relations (Levinson, 2003; adapted from Beller et al., 2015, Figure 2). FRONT in a coordinate system is indicated by the tip of the arrow; F = figure object, G = ground object, O = observer's viewpoint, L/R = left/right.

*Figure 2.* Variants of the relative FoR for dorsal settings (A and B) and lateral settings (C and D). FRONT in a coordinate system is indicated by the tip of the arrow; F = figure object, G = ground object, O = observer's viewpoint, L/R = left/right.

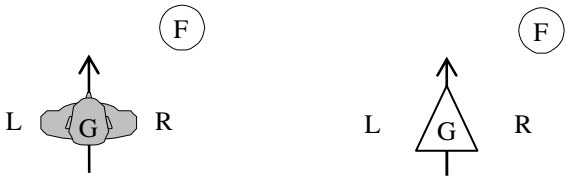
*Figure 3.* Example items from each of the six item sets.

*Figure 4.* Dividing the space along the left-right axis O–G defines a frontal area and a dorsal area and suggests a sideward translation of the observer's direct FoR.

*Figure 5.* FoR selection in lateral settings among participants with a frontal preference for translation (n=82) and reflection (n=62), respectively (C indicating consistency in preferences).

Figure 1

**(A) FoRs for binary relations**



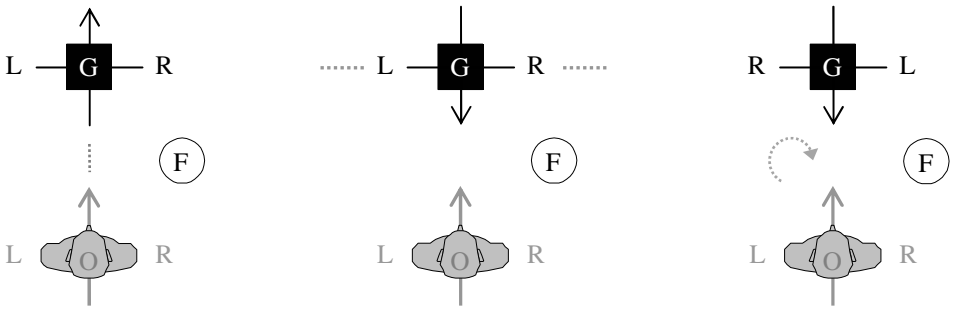

*(i) Direct FoR*

The ball is *in front and to the right of* me.

*(ii) Intrinsic FoR*

The ball is *in front and to the right of* the arrow.

**(B) FoRs for ternary relations**




*(i) Translation*

The ball is *behind and to the right of* the box.

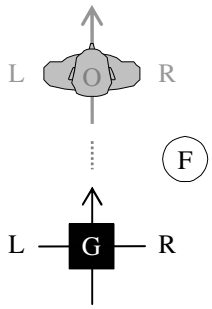
*(ii) Reflection*

The ball is *in front and to the right of* the box.

*(iii) Rotation*

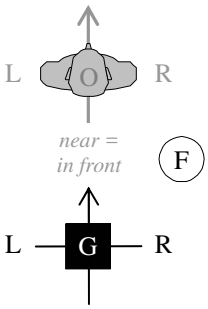
The ball is *in front and to the left of* the box.

Figure 2




*(A) Translation*

The ball is *in front and to the right of* the box.

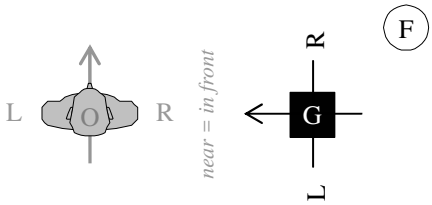



*(B) Inward-directed*

The ball is *in front and to the right of* the box.


*(C) Translation*

The ball is *in front and to the right of* the box.




*(D) Inward-directed*

The ball is *behind and to the right of* the box.

Figure 3

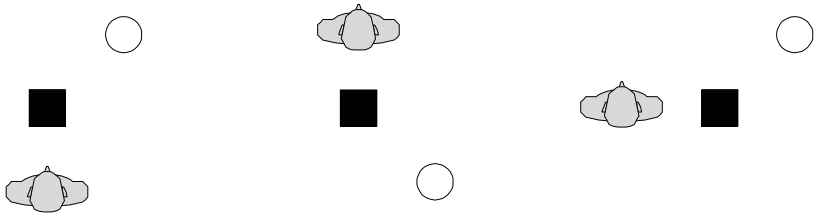
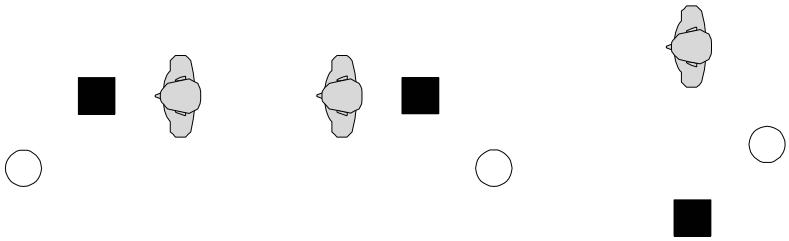
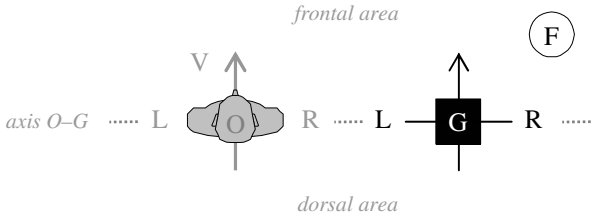
| Gaze of observer in relation to participant | *Location of the objects in relation to the observer* | | |
|---|---|---|---|
| | Frontal | Dorsal | Lateral |
| Aligned |  | | |
| Rotated 90° counter-clockwise |  | | |

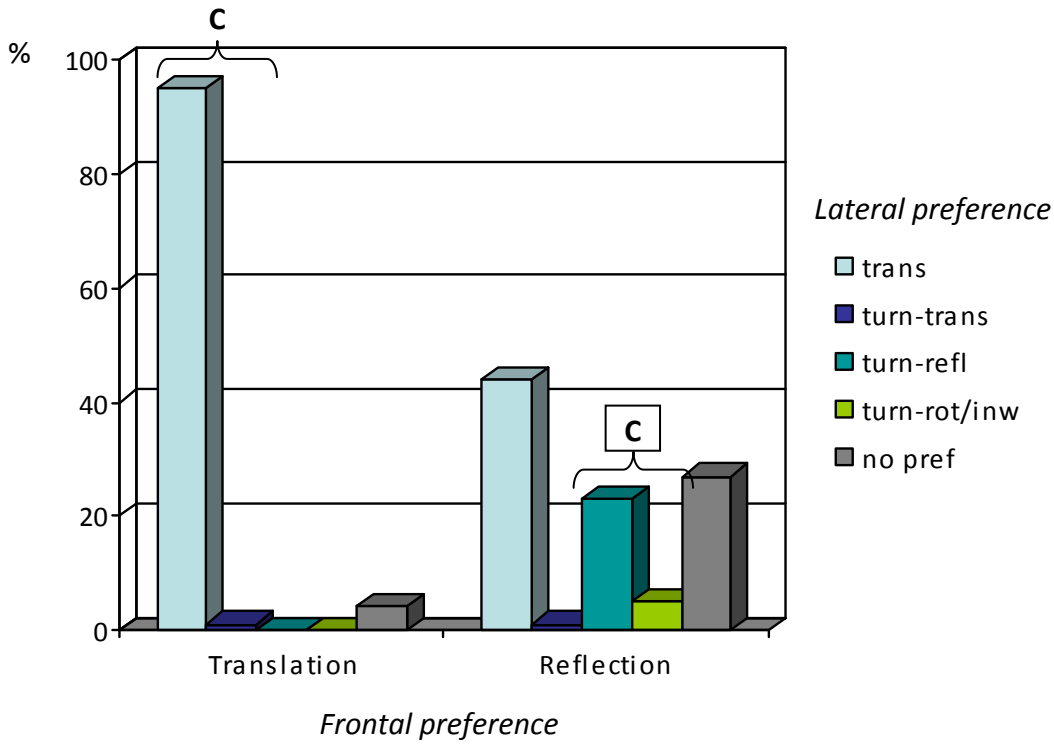
Figure 4




*Translation*

The ball is *in front and to the right of* the box.

Figure 5

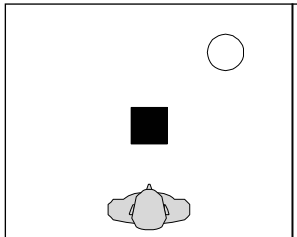

C
%
100
80
60
40
20
0
C
Translation
Reflection
Frontal preference
Lateral preference
trans
turn-trans
turn-refl
turn-rot/inw
no pref

Appendix A

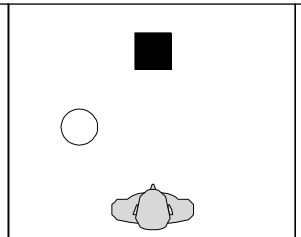
In the following, the spatial configurations of all items are displayed. In each case, the task required participants to take the perspective of a depicted observer and to describe (from this perspective) how the white circle is related to the black square by marking one of eight response options.

**(A) Gaze of observer in relation to Ego: aligned**

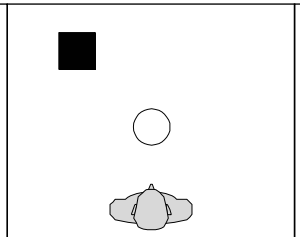
*Frontal items*



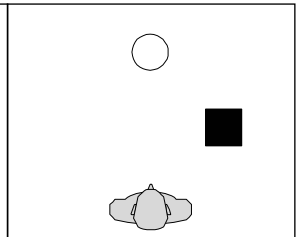
*f_00_1*



*f_00_2*



*f_00_3*



*f_00_4*

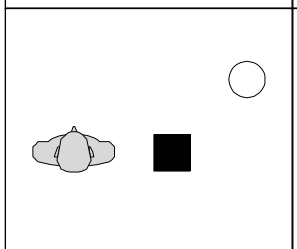
*Response format*

The white circle is located …

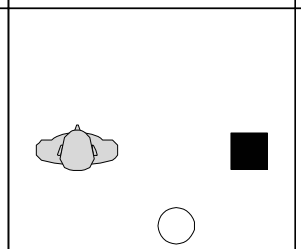
□ in front of
□ behind
□ to the left of
□ to the right of
□ in front and to the left of
□ in front and to the right of
□ behind and to the left of
□ behind and to the right of

… the square.

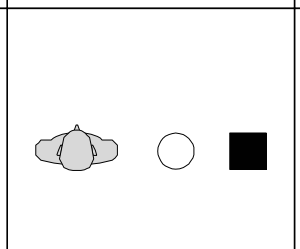
*Lateral items*



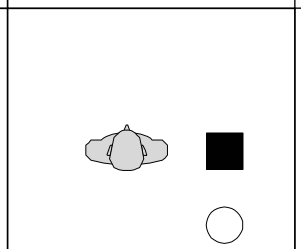
*l_00_1*



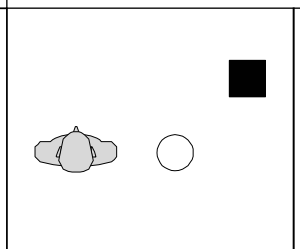
*l_00_2*



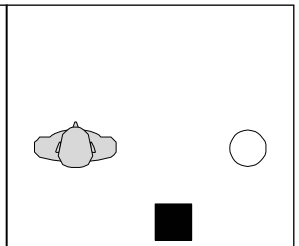
*l_00_3*



*l_00_4*

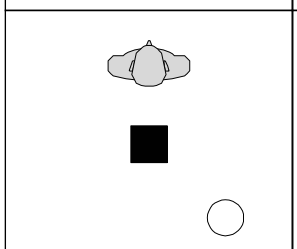


*l_00_5*

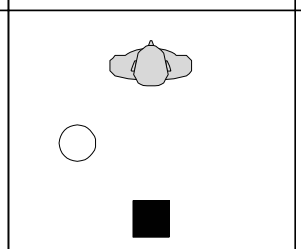


*l_00_6*

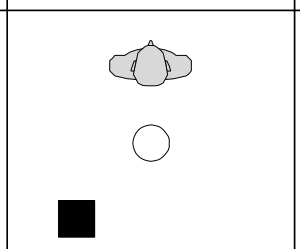
*Dorsal items*



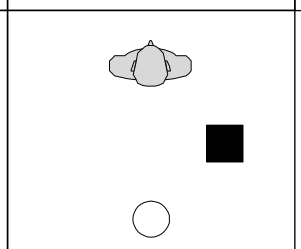
*d_00_1*



*d_00_2*



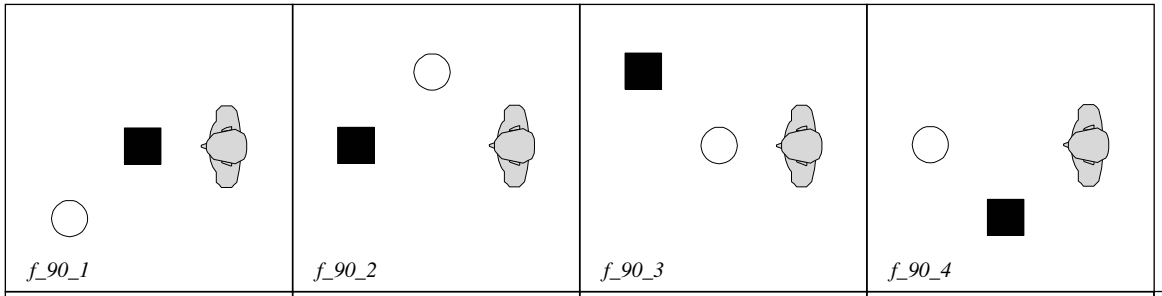
*d_00_3*



*d_00_4*

**(B) Gaze of observer in relation to Ego: rotated 90° counterclockwise**

*Frontal items*



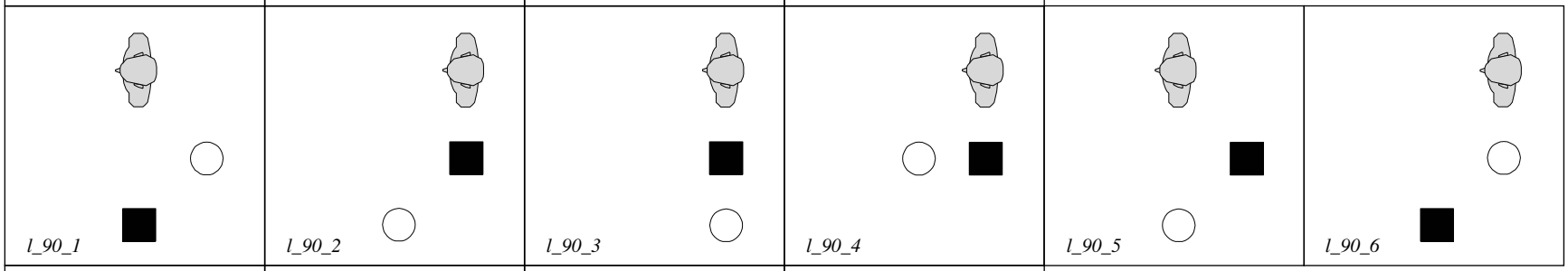

*Response format*

The white circle is located …

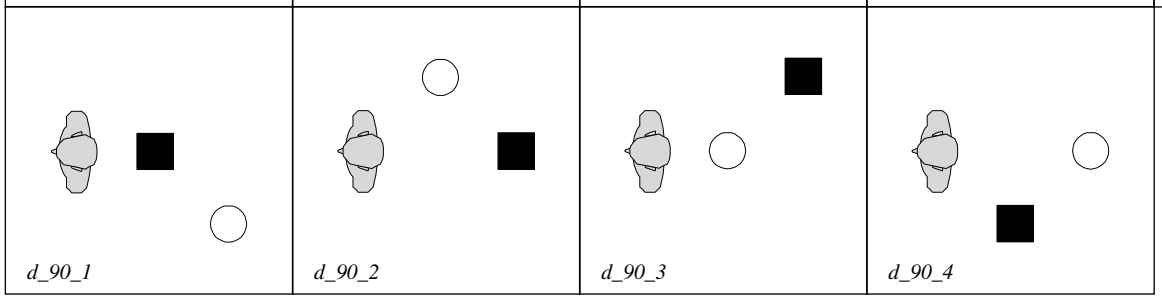
□ in front of
□ behind
□ to the left of
□ to the right of
□ in front and to the left of
□ in front and to the right of
□ behind and to the left of
□ behind and to the right of

… the square.

*Lateral items*




*Dorsal items*



Appendix B

In order to analyse the distribution of participants' FoR preferences, we performed three log-linear analyses (Kennedy, 1992), one each for the frontal, the dorsal, and the lateral data. The analyses included the two main factors of interest, *country* (Norway vs. Germany) and *gaze condition* (aligned vs. rotated), and the control factor *order of item sets in Block 1* (frontal first vs. dorsal first vs. lateral first) that proved to be significant in the analyses of the unexplained responses and the consistency values described in the main text. *Gaze condition* is considered as between-subjects factor; therefore, the total *N* of the analyses (168) equals twice the total number of participants (84).

*Model selection strategy*: Model selection generally aims at identifying the most parsimonious combination of factors that is sufficient to explain the data without losing the fit between model and data. In our case, model fit was determined based on the $G^2$ statistics, with $p \geq .100$ indicating sufficient fit. We started model selection with the *saturated* model. This model includes all factors and their interactions, and therefore, by definition, explains the data with a perfect fit ($G^2 = 0$; $df = 0$; $p = 1$). More parsimonious models were then selected in the following, hypothesis-driven manner. First, we excluded the factor *gaze condition* (and all its interactions with the other factors) based on the hypothesis that participants do take the perspective of the depicted observer (aligned vs. rotated) and adopt the same FoR from each of the two perspectives. In each of the three analyses, the resulting interaction model *country* × *order of item sets in Block 1* had sufficient fit ($p \geq .892$), indicating that the factor *gaze condition* was not necessary to explain the data. Next, we excluded the interaction *country* × *order of item sets in Block 1* based on the fact that such an interaction was not significant in the analyses of the unexplained responses and the consistency values. In each of the three analyses, the resulting model with two main effects, *country* and *order of item sets in Block 1*, had sufficient fit ($p \geq .793$). Then, we tested whether or not the main effects of *country* and

*order of item sets in Block 1* could be excluded from the model in order to check whether or not any of these factors are necessary to explain the data. We hypothesized a main effect of *country* not for the dorsal item set, but for the frontal set based on the results of a previous study (Beller & Bender, 2017) and also for the lateral set based on the consistency assumption. A main effect of *order of item sets in Block 1* was suggested by the analyses of the unexplained responses and the consistency values. If the exclusion of one of these factors resulted in a loss of fit between model and data, the corresponding factor remained in the model, otherwise not. If none of the factors under scrutiny were necessary, then model selection ended with the *null-logit* model, which is by definition the most parsimonious model.

# Appendix C

Included as a control variable, the *order of item sets in Block 1* had consistent and systematic effects on participants' references in all three types of analyses: for unexplained responses, consistency values, and FoR preferences. Participants starting the questionnaire with a frontal item set had higher proportions of unexplained responses, lower consistency values, and more often no clear FoR preference across all item sets. Some possible reasons can be inferred by inspecting the data from the questionnaire's first block of items (see Table C1; and for similar patterns in the second block of items, Table C2).

One reason could be that this subsample of participants happened—by coincidence—to give more heterogeneous responses in general. Some support for this assumption can be found by inspecting the very first item set participants had worked on, which represents responses unaffected by order effects. In their first item set, participants who started with a frontal set already exhibited a higher proportion of unexplained responses (13.7%), lower consistency values (82.3%), and more often no clear FoR preference (25.8%) as compared to those participants who started the questionnaire with a dorsal item set (*unexplained*: 7.7%; *consistency*: 90.4%; *no pref*: 7.7%) or a lateral item set (*unexplained*: 4.9%; *consistency*: 84.6%; *no pref*: 11.1%) as indicated in Table C1, first sets.

Another reason could be that participants starting with a standard (frontal) referencing situation and the reflection strategy are required to adapt their strategy to the subsequent non-standard (dorsal and lateral) situations—and might struggle with this adaptation. This assumption is reflected in two observations: First, participants who started with the frontal item set exhibited a relatively high preference for reflection (41.9%) as compared to translation (25.8%) in their frontal item set. And second, the proportion of unexplained responses increased from the first, frontal set to the second, lateral set (*first set*: 13.7%; *second set*: 22.0%), while this was not the case for participants who started with the dorsal item set

(*first, dorsal set*: 7.7%; *second, frontal set*: 3.8%) or for participants who started with the lateral item set (*first, lateral set*: 4.9%; *second, dorsal set*: 0.0%; see Table C1).

*Table C1*. Unexplained responses, individual consistency, and preferred FoR in the different item sets (frontal, lateral, and dorsal) of the first block of items, depending on the order of the item sets in this block. The data are aggregated over the two gaze conditions (aligned and rotated) and the two countries (Norway and Germany).

| | *Order of item sets in Block 1* | | |
|---|---|---|---|
| | Frontal, lateral, dorsal ($N$ = 31) | Lateral, dorsal, frontal ($N$ = 27) | Dorsal, frontal, lateral ($N$ = 26) |
| *Frontal item sets* | ***Set 1*** | *Set 3* | *Set 2* |
| Unexplained responses (%) | **13.7** | 3.7 | 3.8 |
| Individual consistency (%) | 82.3 | 95.4 | 90.4 |
| *Preferred FoR (% [N])* | | | |
| Translation | 25.8 (8) | 63.0 (17) | 61.5 (16) |
| Reflection | 41.9 (13) | 33.3 (9) | 34.6 (9) |
| Rotation | 6.5 (2) | 0.0 (0) | 0.0 (0) |
| No preference | 25.8 (8) | 3.7 (1) | 3.8 (1) |
| *Lateral item sets* | *Set 2* | ***Set 1*** | *Set 3* |
| Unexplained responses (%) | **22.0** | 4.9 | 10.3 |
| Individual consistency (%) | 67.7 | 84.6 | 84.0 |
| *Preferred FoR (% [N])* | | | |
| Translation | 45.2 (14) | 85.2 (23) | 76.9 (20) |
| Turn-translation | 0.0 (0) | 0.0 (0) | 0.0 (0) |
| Turn-reflection | 12.9 (4) | 3.7 (1) | 3.8 (1) |
| Turn-rotation/inward | 9.7 (3) | 0.0 (0) | 0.0 (0) |
| No preference | 32.3 (10) | 11.1 (3) | 19.2 (5) |
| *Dorsal item sets* | *Set 3* | *Set 2* | ***Set 1*** |
| Unexplained responses (%) | **21.0** | 0.0 | 7.7 |
| Individual consistency (%) | 75.8 | 95.4 | 90.4 |
| *Preferred FoR (% [N])* | | | |
| Turn-translation | 6.5 (2) | 0.0 (0) | 0.0 (0) |
| Turn-reflection | 9.7 (3) | 3.7 (1) | 3.8 (1) |
| Turn-rotation/translation/inward | 51.6 (16) | 92.6 (25) | 88.5 (23) |
| No preference | 32.3 (10) | 3.7 (1) | 7.7 (2) |

By contrast, participants starting with a non-standard, dorsal situation may have had more difficulties in producing a reference strategy in the first place, but fewer difficulties in keeping it. Whatever strategy they came up with in their first item set could simply have been re-used for a subsequent frontal item set (Beller et al., 2016). The pre-activated dorsal FoR typically has the orientation of a translational FoR—irrespective of the mental strategy that led to this FoR—leading to an increase of translation in subsequent frontal situations. There is also some support for such a priming effect. While the group of participants starting with a frontal item set exhibited a clear preference for reflection over translation in frontal tasks (*refl*: 41.9%; *trans*: 25.8%), the reverse holds for the group starting with a dorsal item set (*refl*: 34.6%; *trans*: 61.5%) and for the group starting with a lateral item set (*refl*: 33.3%; *trans*: 63.0%): a preference for translation over reflection for a frontal item set subsequent to a dorsal item set (see Table C1). Such a priming effect can also explain the generally high preference for translation in frontal situations: The majority of participants had worked on dorsal items prior to the frontal ones (priming possible), whereas only a minority started directly with the frontal items (no priming possible).

*Table C2.* Unexplained responses, individual consistency, and preferred FoR in the different item sets (frontal, lateral, and dorsal) of the second block of items, depending on the order of the item sets in the first block. Please note that the frontal, lateral, and dorsal sets do not correspond to the fourth, fifth, and sixth item set of the questionnaire due to the grouping of the data according to the order in Block 1 (a different grouping is shown in Table C3). The data are aggregated over the two gaze conditions (aligned and rotated) and the two countries (Norway and Germany).

| | Order of item sets in Block 1 | | |
|---|---|---|---|
| | Frontal, lateral, dorsal ($N$ = 31) | Lateral, dorsal, frontal ($N$ = 27) | Dorsal, frontal, lateral ($N$ = 26) |
| *Frontal item sets* | | | |
| Unexplained responses (%) | 12.9 | 1.9 | 2.9 |
| Individual consistency (%) | 82.3 | 95.4 | 94.2 |
| *Preferred FoR (% [N])* | | | |
| Translation | 35.5 (11) | 55.6 (15) | 57.7 (15) |
| Reflection | 32.3 (10) | 40.7 (11) | 38.5 (10) |
| Rotation | 6.5 (2) | 0.0 (0) | 0.0 (0) |
| No preference | 25.8 (8) | 3.7 (1) | 3.8 (1) |
| *Lateral item sets* | | | |
| Unexplained responses (%) | 11.8 | 4.9 | 7.7 |
| Individual consistency (%) | 79.0 | 84.6 | 86.5 |
| *Preferred FoR (% [N])* | | | |
| Translation | 54.8 (17) | 81.5 (22) | 80.8 (21) |
| Turn-translation | 6.5 (2) | 0.0 (0) | 0.0 (0) |
| Turn-reflection | 22.6 (7) | 7.4 (2) | 11.5 (3) |
| Turn-rotation/inward | 3.2 (1) | 0.0 (0) | 0.0 (0) |
| No preference | 12.9 (4) | 11.1 (3) | 7.7 (2) |
| *Dorsal item sets* | | | |
| Unexplained responses (%) | 21.0 | 2.8 | 1.0 |
| Individual consistency (%) | 76.6 | 95.4 | 97.1 |
| *Preferred FoR (% [N])* | | | |
| Turn-translation | 3.2 (1) | 0.0 (0) | 0.0 (0) |
| Turn-reflection | 6.5 (2) | 7.4 (2) | 15.4 (4) |
| Turn-rotation/translation/inward | 61.3 (19) | 88.9 (24) | 84.6 (22) |
| No preference | 29.0 (9) | 3.7 (1) | 0.0 (0) |

*Table C3*. Unexplained responses, individual consistency, and preferred FoR in the different item sets (frontal, lateral, and dorsal) of the second block of items, depending on the order of the item sets in this block. Different from Table C2, the frontal, lateral, and dorsal sets correspond to the fourth, fifth, and sixth set of the questionnaire as indicated in the table. The data are aggregated over the two gaze conditions (aligned and rotated) and the two countries (Norway and Germany).

| | *Order of item sets in Block 2* | | |
|---|---|---|---|
| | Frontal, lateral, dorsal ($N$ = 25) | Lateral, dorsal, frontal ($N$ = 29) | Dorsal, frontal, lateral ($N$ = 30) |
| *Frontal item sets* | *Set 4* | *Set 6* | *Set 5* |
| Unexplained responses (%) | 5.0 | 5.2 | 8.3 |
| Individual consistency (%) | 92.0 | 90.5 | 88.3 |
| *Preferred FoR (% [N])* | | | |
| Translation | 40.0 (10) | 51.7 (15) | 53.3 (16) |
| Reflection | 48.0 (12) | 37.9 (11) | 26.7 (8) |
| Rotation | 4.0 (1) | 0.0 (0) | 3.3 (1) |
| No preference | 8.0 (2) | 10.3 (3) | 16.7 (5) |
| *Lateral item sets* | *Set 5* | *Set 4* | *Set 6* |
| Unexplained responses (%) | 11.3 | 6.3 | 7.8 |
| Individual consistency (%) | 78.0 | 85.1 | 85.6 |
| *Preferred FoR (% [N])* | | | |
| Translation | 60.0 (15) | 79.3 (23) | 73.3 (22) |
| Turn-translation | 0.0 (0) | 3.4 (1) | 3.3 (1) |
| Turn-reflection | 24.0 (6) | 6.9 (2) | 13.3 (4) |
| Turn-rotation/inward | 4.0 (1) | 0.0 (0) | 0.0 (0) |
| No preference | 12.0 (3) | 10.3 (3) | 10.0 (3) |
| *Dorsal item sets* | *Set 6* | *Set 5* | *Set 4* |
| Unexplained responses (%) | 12.0 | 3.4 | 11.7 |
| Individual consistency (%) | 85.0 | 94.8 | 86.7 |
| *Preferred FoR (% [N])* | | | |
| Turn-translation | 4.0 (1) | 0.0 (0) | 0.0 (0) |
| Turn-reflection | 16.0 (4) | 10.3 (3) | 3.3 (1) |
| Turn-rotation/translation/inward | 64.0 (16) | 86.2 (25) | 80.0 (24) |
| No preference | 16.0 (4) | 3.4 (1) | 16.7 (5) |