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Object's symmetry alters spatial perspective-taking processes

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Abstract Spatial perspective-taking (SPT) refers to one's ability to identify or understand the location of a target relative to another viewpoint, which could be specified by a human-like agent or a reference object (e.g., a chair). Previous studies have shown that SPT is characterized by different processes depending on whether one is required to make a left/right or front/behind judgment. An object's shape, however, may also account for the different processes, as previous studies typically used reference objects that were left–right symmetrical and front–back asymmetrical (e.g., human figures, dolls, or chairs), thus confounding effects of judgment direction and effects of objects' shape. To address this issue, we manipulated objects' shape (symmetrical or asymmetrical about front–back or left–right) independently of judgment direction (i.e., left/right or front/behind) and compared participants' efficacy of such judgments. Our results showed that egocentric transformations were used more frequently for judgments orthogonal to the object's symmetry plane than for judgments orthogonal to the object's asymmetry plane, whereas the inverse was true for mental scanning. Notably, these tendencies were observed regardless of whether the judgment was about left/right or front/behind. Nonetheless, egocentric transformations were found to be more difficult to apply to the front/behind judgments than to the left/right judgments. We also found that this difficulty was alleviated by rich imagination. Furthermore, we found that participants tended to erroneously perceive a front–back symmetrical human-like object as facing them, even when it was actually facing away from them (facing bias). This in turn forced the participants to conduct unnecessary egocentric transformations. Overall, our findings demonstrated that objects' symmetry dramatically influenced SPT processes.

Keywords: Spatial perspective-taking, Egocentric transformation, Mental scanning, Autistic spectrum, Social cognition

1. Introduction

As social beings, humans are sometimes required to imagine what others see, infer what others think, and empathize as well as compete with others. Hence, an ability to place oneself in another person's position (i.e., perspective-taking) is an important human capability. Understanding the spatial location of a target from another person's viewpoint is a form of perspective-taking (e.g., you can ask a friend to pass you a glass on his/her left side, although the glass is not on your left side) called "spatial" perspective-taking (SPT). The present study reported five experiments conducted to increase the existing knowledge of the cognitive mechanisms of SPT.

To comprehend the cognitive mechanisms underlying SPT, it is pertinent to discuss a similar kind of perspective-taking called "visual" perspective-taking (VPT), which includes the awareness of a target's visibility or invisibility to another person (called level-1 VPT) and the understanding of how a target appears to another person (called level-2 VPT; e.g., Flavell, Everett, Croft, & Flavell, 1981; Flavell, Green, & Flavell, 1986). Analogically, SPT has also been categorized into front/behind judgments (called level-1 SPT) and left/right judgments (called level-2 SPT; Surtees, Apperly, & Samson, 2013a). Much of the cognitive literature pertaining to visuospatial perspective-taking does not differentiate between SPT and VPT (e.g., Kessler & Rutherford, 2010; Michelon & Zacks, 2006). However, Surtees et al. (2013a, 2013b) have demonstrated that different processes are involved in level-1 and level-2 perspective-taking, at least in terms of the adopted mental spatial transformation, independent of whether the judgments are visual or spatial. Thus, although the present study focuses primarily on SPT, we present a review of the literature pertaining to both VPT and SPT in the section that follows. Exploring the cognitive mechanisms of SPT may be helpful to understand the cognitive properties of VPT.

The present study investigates the manner in which SPT processes are modulated by the shapes of objects whose perspective participants are to take. As indicated by Surtees, Noordzij, and Apperly (2012), people can conduct SPT not only for humans but also for non-human objects, such as a chair or a doll, as long as the objects have their own intrinsic reference frame. For example, since a chair has its own front–back and top–bottom axes characterized by its shape and function (e.g., a backrest and legs), one can describe the position of an object near the chair by using spatial terms such as “in front of the chair” or “on the left side of the chair.”

1.1. Different processes of level-1 and level-2 perspective-taking

In their seminal study, Michelon and Zacks (2006) presented participants with photographs of a square table on which objects (one of them was a target) and occluders were placed. The participants were required to adopt the perspective of a reference object (a doll or an asterisk) inside a given photograph. Then, they were asked to perform a visibility judgment task (level-1) as well as a left/right judgment task (level-2). Michelon and Zacks manipulated (1) the angular disparity between the participants’ and reference objects’ positions and (2) the distance between a reference object and a target for both of these tasks. The results of the experiment revealed a clear distinction between the level-1 and level-2 tasks. The response times (RT) for the level-2 task increased monotonically with larger angular disparities. It has been believed that the angle effect observed in the level-2 task reflects the cost of egocentric transformations (i.e., the mental rotation of one’s own body toward an object’s position). On the other hand, the level-1 task demonstrated no such systematic angle effect. Instead, it showed a distance effect where the RTs were shorter when a target was placed closer to a reference object. This discovery was replicated by Surtees et al. (2013a), who compared the RTs of front/behind judgments (level-1) and left/right judgments (level-2).

Michelon and Zacks (2006) suggested that the result of visibility judgments evidences that people trace avatar’s line of sight during the level-1 task. According to Michelon and Zacks

(2006), tracing the line of sight constitutes a form of mental scanning (Kosslyn, Ball, & Reiser, 1978). In other words, for the level-1 task, participants initially assign a “mental marker” on an avatar’s position. Subsequently, they imagine moving the mental marker to the target position. The processing time for this mental scanning is known to be proportional to the distance traveled by the mental marker (Kosslyn et al., 1978). This estimation is consistent with the distance effect observed in the visibility judgment task (Michelon & Zacks, 2006; Surtees et al., 2013a) and the front/behind judgment task (Surtees et al., 2013a). The term “line of sight” cannot be applied to inanimate objects such as chairs. Hence, in this paper, the more general term “mental scanning” is employed for inanimate objects.

In sum, previous studies have suggested that SPT (as well as VPT) is characterized by two distinct processes. Egocentric transformations have been shown to be elicited by left/right judgments (level-2) and are typified by a steep RT slope as a function of angles. In contrast, mental scanning has been proven to be produced by front/behind judgments (level-1) and characterized by an almost flat RT slope as a function of angles and by the distance effect.

1.2. Potential effects of an object’s symmetry on SPT processes

Earlier investigations on SPT and VPT have employed a wide range of reference objects, including human figures, dolls, chairs, cameras, arrows, and symbols. Nonetheless, most, if not all, of the studies, have used objects that were left–right symmetrical and front–back asymmetrical. For example, human figures and dolls had faces, chairs had backrests, and cameras had a lens on their front side. Even though the object Michelin and Zacks (2006) utilized in their Experiment 3 was a point-symmetrical asterisk, it was embedded in photographs of a table. Thus, participants could easily recognize the part of the asterisk that was close to the table as the figure’s “front” side.

Given their wide usage of left–right symmetrical objects, the previous studies could not distinguish between the following two theoretical possibilities: (1) a participant’s selection of

one of the two different SPT processes depends on the direction of the judgment in relation to the object's intrinsic reference frame (left/right or front/behind); or (2) the choice of the SPT process relies on the judgments' direction relative to the plane of symmetry (i.e., left/right judgments are always orthogonal to the object's symmetrical plane, whereas front/behind judgments are always along the object's symmetrical plane). More specifically, the front-back asymmetry of a typical object always served as a useful cue in determining the front or back aspect, whereas the left-right symmetry of a typical object did not serve as a direct cue in ascertaining the left or right side. As a result, participants could not establish the left or right side of a left-right symmetrical object without first determining the object's front and back. This two-tier processing may affect an individual's selection of SPT processes (i.e., egocentric transformation or mental scanning). On the other hand, whether the judgment is about the left-right or front-behind direction may have no impact on the choice because the two-tier processing is also required for a front-back symmetrical and left-right asymmetrical object (i.e., first identifying left or right, then identifying front or behind).

Overall, at least two factors can ascertain whether the egocentric transformation or mental scanning process is elicited during SPT. First, as claimed by previous studies (Kessler & Rutherford, 2010; Michelon & Zacks, 2006; Surtees et al., 2013a), whether judgments are made with regard to left/right or front/behind would be a major determinant of SPT processes if functional and developmental differences in the concepts of "left and right" and "front and behind" led to the different processes. Second, whether judgments are orthogonal to or along the object's plane of symmetry or asymmetry (either sagittal or coronal plane) would

Figure 1. Illustrative examples of symmetrical and asymmetrical judgments.

significantly clarify SPT processes if the physical form of an object and a person's knowledge of it affect the SPT processes (e.g., "a certain side of the object is always its front"). To theorize about the processes involved in SPT, it should be verified which factor is more crucial in establishing the SPT processes.

To ensure brevity, judgments orthogonal to the object's symmetry plane (i.e., left/right judgments for left-right symmetrical objects or front/behind judgments for front-back symmetrical objects) shall be denoted from this point onwards as "symmetrical judgments." Likewise, judgments orthogonal to the object's asymmetry plane (i.e., left/right judgments for left-right asymmetrical objects or front/behind judgments for front-back asymmetrical objects) shall be referred to as "asymmetrical judgments." Figure 1 presents illustrative examples of symmetrical and asymmetrical judgments.

1.3. The mediating role of autistic spectrum traits

We also investigated in an exploratory manner the mediating role of autistic spectrum traits in SPT performance. In previous studies, SPT and VPT were found to be associated with social abilities (Erle & Topolinski, 2015; Hamilton, Brindley, & Frith, 2009; Kessler & Wang, 2012; Shelton, Clements-Stephens, Lam, Pak, & Murray, 2012). In particular, it has been shown that stronger autistic spectrum traits, measured using the Autism-Spectrum Quotient (AQ)

questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), predict lesser use of embodied strategy for a level-2 SPT task (Kessler & Wang, 2012) and lower performance on a level-2 VPT task involving a human-like object (Shelton et al., 2012). Therefore, the present study also measured individual AQ scores to evaluate the potential effects of autistic traits on the performance on SPT tasks involving various reference objects. AQ comprises five subscales: social skills, attention switching, local details, communication, and imagination. Since we did not have a robust prediction with regard to the mediating role of AQ in our tasks, we analyzed the correlations of the mean RTs of each SPT task with a score provided for each of the five AQ subscales in an exploratory manner.

1.4. Purposes of the present study

This investigation primarily aims to investigate the effects of (1) a reference object's shape (symmetry or asymmetry about sagittal or coronal plane) and (2) the direction of judgments (left/right or front/behind) on SPT processes. To this end, we systematically varied the symmetry/asymmetry of objects across Experiments 1–5 and compared performance pertaining to left/right and front/behind judgment tasks in each experiment. It should be noted at this juncture that it is impossible to test objects that are symmetrical in relation to both sagittal and coronal planes, as they do not have directional cues other than the top-bottom. Therefore, there are only three possible combinations of left–right and front–back symmetry/asymmetry, and Experiments 1–5 covered all three arrangements (see [Table 1](#)).

Table 1. Symmetry of Objects in Experiments 1–5

Object axis	Experiment				
	1	2	3	4	5
Front–back	A	A	S	S	A
Left–right	S	A	A	A	S

Note: S = symmetrical; A = asymmetrical.

A number of studies have demonstrated that factors such as the human-likeness or animacy

of reference objects modulates the processing of SPT (e.g., Kessler & Thomson, 2010; Shelton et al., 2012; Surtees et al., 2012; Tarampi, Heydari, & Hegarty, 2016; Yu & Zacks, 2010). However, the animacy of objects was discovered to be irrelevant to the elicited process (i.e., egocentric transformation versus mental scanning; Michelon & Zacks, 2006). The present study employed inanimate reference objects to draw conclusions that could be widely applied to generic objects, and not merely to specific deductions about human-like figures (Experiment 3 is the exception; please review the introduction to Experiment 3).

Following the extant studies, we varied the angular disparities between the perspectives of the participants and the reference objects. The RT data and introspective reports were used as major indexes of the elicited processes. Specifically, steeper RT slopes as a function of angles were regarded to evidence the use of egocentric transformations, whereas flatter RT slopes as a function of angles were considered to prove the use of mental scanning. Error data were also analyzed as an auxiliary measure to corroborate the findings and to obtain further information.

To ensure a rigorous comparison of the left/right and front/behind judgments, we refined the paradigms utilized by previous studies in two ways. First, the same stimuli were used for both the left/right and front/behind judgment tasks. Two of the three previous studies comparing level-1 and level-2 SPT (Kessler & Rutherford, 2010; Surtees et al., 2013a) employed different stimuli for the level-1 and the level-2 tasks. The third study, conducted by Michelon and Zacks (2006), used the same pool of stimuli for the level-1 and the level-2 tasks. Some of the stimuli were, however, presented only for the level-1 task. Since the use of different stimuli for the two types of tasks may have affected the task performance, the present study used the same stimuli for both the left/right and the front/behind judgment tasks.

Second, we adjusted the alignment of response keys according to the direction of the judgments. All previous experiments used response keys placed on the participants' left and right. Only one exception, Kessler and Rutherford's (2010) Experiment 2, employed a voice

key. This fixed key alignment regardless of the tasks may have caused interference effects on left/right judgments (e.g., May & Wendt, 2013). In the 180° condition, for example, a target's left/right position from the participants' viewpoint is a reversal of the position of a to-be-pressed left/right key, whereas a target's near/far position from participants' own viewpoint is not conflicted with the position of a to-be-pressed left/right key. To avoid the influence of such key alignment effects, the present experiments utilized response keys that were aligned with the direction of judgments (i.e., left- and right-positioned keys for left/right judgments and far- and near-positioned keys for front/behind judgments). Using a typical object (a chair) in Experiment 1, we examined whether previous findings could be replicated despite the application of the above refinements.

As has been detailed in the previous section, the secondary aim of this study is to assess the mediating role of autistic spectrum traits in level-1 and level-2 SPT. To this end, we administered the AQ questionnaire and analyzed the correlations between SPT performance and AQ subscores in an exploratory manner.

2. Experiment 1

In essence, Experiment 1 was a replication of previous studies that compared level-1 and level-2 SPT (Kessler & Rutherford, 2010; Surtees et al., 2013a; Michelon & Zacks, 2006). Nonetheless, it also had two novel points: (1) the same stimuli were used for left/right and front/behind tasks; and (2) response keys were aligned with the judgment direction (i.e., left and right keys for left/right judgments and far and near keys for front/behind judgments).

2.1. Method

2.1.1. *Participants*

Six women and six men (mean age = 22.3 years, ranging from 19 to 26) with normal or corrected-to-normal vision participated in Experiment 1.³ Participants were not informed of the study's purpose. They were given pre-paid cards for purchasing books for their participation. All experiments reported in this article were approved by the ethics board of the School of Human Sciences of Osaka University.

The number of participants was determined in advance for the following two reasons. First, a multiple of four was needed for counterbalancing the two factors (Gender and Task Order). Second, the angle effect observed in an SPT task is a robust phenomenon, and its detection would not require a large sample size. Indeed, this sample size of 12 would give us more than .99 power to detect the angle effect at the .05 significance level according to a post-hoc power analysis for data obtained in a similar SPT experiment we conducted before (Experiment 4 in Muto, Matsushita, & Morikawa, 2018). For these reasons, we adopted the same number of participants for all experiments.

2.1.2. *Stimuli and apparatus*

Experimental stimuli were created using Blender 2.77 (Blender Foundation, Amsterdam), a 3D graphics software. The stimuli were created with a resolution of $1,920 \times 1,200$ pixels. Each stimulus showed a room with a red chair (the reference object) surrounded by a square-shaped array of four pillars (Figure 2). The chair was completely left-right symmetrical, but front-back asymmetrical, as it had a backrest. One of the four pillars was blue, whereas the other pillars were white. We used images with a chair oriented away from the viewer as stimuli for the 0° condition. The other stimuli were created by rotating the whole array, including the chair of the 0° images in the ground plane ($\pm 45^\circ$, $\pm 90^\circ$, $\pm 135^\circ$, and 180°). Thus, we created a total of 32

³ Thirty-six participants (18 women and 18 men) were randomly assigned to Experiments 1, 2, or 3.

images (4 positions of a blue pillar $\times$ 8 rotational angles).

All stimuli were displayed on a 24.1-in-wide LCD monitor (NEC MultiSync LCD-PA241W; resolution of $1,920 \times 1,200$ pixels). The viewing distance was approximately 60 cm. A numeric keypad was placed in front of the participants. The keypad was placed in its normal direction (i.e., the “4,” “6,” “8,” and “2” keys were located at the left, right, far, and near positions respectively from the participants’ perspective).

2.1.3. Procedure

The experiment was conducted individually in a laboratory and took about 37 min on average to complete. Each trial began with the display of a white fixation cross at the center of a black screen. The cross was displayed for one second. This was followed by a room stimulus. Participants’ task was to indicate the location of a target (a blue pillar) from the chair’s perspective as accurately and quickly as possible. In the front/behind judgment task, participants had to judge whether the target was in front of or behind the chair⁴. They were required to press the “8” key if the target was in front of the chair and the “2” if it was behind the chair. It must be noted that the left/right direction was ignored in this task. Similarly, in the left/right judgment task, participants had to judge whether the target was to the chair’s left or right by pressing the “4” or “6” key while ignoring the front/behind direction. In addition, participants were required to press the “4” and “2” keys with their left index finger and the “6” and “8” keys with their right index finger. During trials, participants kept their fingers on the relevant keys to ensure quick response. The next trial began immediately after a key response was made.

⁴ All experiments were conducted in Japanese. The original instruction used in Experiment 1 was “椅子の位置から見た時に、青い柱が前後 [左右] どちらにあるかを判断してください。” , which means “Please judge whether a blue pillar is located in front or behind [left or right] when seen from a chair’s position.”

All participants performed the left/right judgment task and the front/behind judgment task in a counterbalanced order. Each task consisted of 320 trials, which were divided into four blocks. Each block contained 80 trials of 5 angles $\times$ 2 rotational directions (i.e., clockwise or counterclockwise, which was identical for 0° and 180°) $\times$ 4 target positions $\times$ 2 repetitions. Trials within a block were presented in random order. This design enabled us to set an equal number of total trials (64) for each of the five angle conditions for both the left/right and front/behind judgment tasks. Participants were given the opportunity to take a break before starting each block by their key response. Participants also performed 40 practice trials (randomly selected from experimental trials) before each task. A “Miss!” message was displayed on the monitor for one second whenever participants made an error during the practice trials. No feedback was given for the experimental trials.

After completing both tasks, participants completed a strategy questionnaire where they were asked to estimate how often they used an egocentric transformation and a mental scanning strategy during each task. The questionnaire consisted of two sets of two questions (a set for each task). The first, “In what percentage of trials did you use imagery to rotate your own body?”

Figure 2. Examples of stimuli used in Experiment 1.

(e.g., When you made a left/right [front/behind] judgment by imagining you sitting on the red chair),” was related to an egocentric transformation strategy. The second, “In what percentage of trials did you make judgments based on the configuration of parts of the chair? (e.g., When you made a left/right [front/behind] judgment based on the distance or positional relationship between the backrest of the chair and the target),” was related to a mental scanning strategy. Participants answered these two questions in this order within each set. The order of each set was the same as the task order of each participant. For each question, participants indicated their answers by drawing a vertical line at an appropriate position on a 100-mm horizontal analog scale. The left endpoint, the central point, and the right endpoint of the scale were labeled “0%,” “50%,” and “100%,” respectively. The length between the left endpoint (0%) and a line drawn by the participant was measured in millimeters and was treated as the frequency of using a given strategy (1 mm = 1%). Upon answering the strategy questionnaire, participants were required to complete 50 items of the Japanese version of the AQ questionnaire (Wakabayashi, Tojo, Baron-Cohen, & Wheelwright, 2014).

2.2. Results and discussion

Individual mean RTs and error rates were calculated for each of the ten conditions that consisted of the combination of tasks (left/right or front/behind) and angles (0°, 45°, 90°, 135°, and 180°). Before calculating mean RTs, we excluded data from (1) incorrect trials (2.49%), (2) trials for which RT was shorter than 200 ms (0.01%), and (3) trials for which RT was longer than 1,647 ms (i.e., three standard deviations above the mean RT, 1.74%). [Figure 3](#) shows the average RTs, and [Figure 4](#) shows the average error rates.

For RT data, a 2×5 repeated measures ANOVA,⁵ with Task and Angle as factors, revealed significant main effects of both Task, $F(1, 11) = 37.18$, $\eta_p^2 = .772$, $p < .001$, and Angle, $F(2.05, 22.50) = 53.32$, $\eta_p^2 = .829$, $p < .001$. The interaction between Task and Angle was also found to be significant, $F(3.77, 41.43) = 17.59$, $\eta_p^2 = .615$, $p < .001$. Post-hoc t-tests revealed that front/behind judgments were faster than left/right judgments at all angles (at 0° , $t(11) = 2.86$, $d = 0.46$, $p = .016$, $\alpha = .050$; at 45° , $t(11) = 3.33$, $d = 0.39$, $p = .007$, $\alpha = .030$; at 90° , $t(11) = 3.29$, $d = 0.58$, $p = .007$, $\alpha = .040$; at 135° , $t(11) = 6.35$, $d = 1.12$, $p < .001$, $\alpha = .020$; at 180° , $t(11) = 7.49$, $d = 1.45$, $p < .001$, $\alpha = .010$). To further characterize the interaction between Task and Angle, we estimated RT slopes as a function of Angle for each Task condition and each participant (Figure 5). Both tasks showed positive mean RT slopes significantly greater than

Figure 3. Means and standard errors of response times in Experiments 1–5

Figure 4. Means and standard errors of error rates in Experiments 1–5.

⁵ For the repeated-measures ANOVAs conducted in this article, we reported degrees of freedom and p values corrected by Chi-Muller's ϵ (Chi, Gribbin, Lamers, Gregory, & Muller, 2012) to guard against violations of sphericity. For multiple comparisons after ANOVAs, we reported raw p values with significance levels (α) corrected by Holm's (1979) sequentially rejective Bonferroni procedure to keep the overall significance levels of .05.

zero (1.01 ms/deg for the left/right task, $t(11) = 7.48$, $p < .001$; 0.30 ms/deg for the front/behind task, $t(11) = 8.07$, $p < .001$). More importantly, the RT slope of the left/right task was steeper than that of the front/behind task, $t(11) = 5.71$, $d = 2.08$, $p < .001$. The steeper RT slope

Figure 5. Means and standard errors of RT slopes as a function of angle in Experiments 1–5.

of the left/right task may reflect the cost of egocentric transformations, whereas the flatter RT slope of the front/behind task may be due to mental scanning processes, which are less affected by objects' orientation.

For error data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed a significant main effect of Angle, $F(3.30, 36.31) = 4.49$, $\eta_p^2 = .290$, $p = .007$. A main effect of Task, $F(1, 11) = 0.02$, $\eta_p^2 = .002$, $p = .889$, and the interaction between Task and Angle, $F(2.47, 27.17) = 0.70$, $\eta_p^2 = .060$, $p = .536$, were not significant.

The results of the strategy questionnaire (Figure 6) revealed that the egocentric

Table 2. Correlation coefficients between mean response times for spatial perspective-taking tasks and Autism-Spectrum Quotient (AQ) scores

Experiment and task		AQ Scores				
		Social Skill	Attention Switching	Local Details	Communication	Imagination
Exp. 1 (N = 12)	F/B	-.345	-.356	.160	-.464	-.369
	L/R	-.206	-.350	.243	-.332	-.341
Exp. 2 (N = 12)	F/B	.385	.307	.012	.232	.319
	L/R	.256	.134	.315	.237	.047
Exp. 3 (N = 12)	F/B	.193	.358	-.163	-.086	.658*
	L/R	-.145	.099	-.304	.006	.636*
Exp. 4 (N = 12)	F/B	.410	.415	-.519	.577*	.711**
	L/R	.210	.245	-.538	.248	.363
Exp. 5 (N = 12)	F/B	-.156	.003	.081	.130	-.279
	L/R	-.416	-.404	-.160	-.131	-.200

Note: F/B = front/behind judgment task; L/R = left/right judgment task. * $p < .05$; ** $p < .01$.

Figure 6. Means and standard errors of rated frequency at which participants adopted the egocentric transformation strategy (left panel) and the mental scanning strategy (right panel) in Experiments 1–5.

transformation strategy was more frequently employed for the left/right task than for the front/behind task, $t(11) = 8.84$, $d = 3.20$, $p < .001$. In contrast, the mental scanning strategy was more frequently employed for the front/behind task than for the left/right task, $t(11) = 7.75$, $d = 2.82$, $p < .001$. None of the five AQ subscale scores predicted mean RTs for the left/right or front/behind task ($ps > .128$; see [Table 2](#)).

In sum, the results of Experiment 1 indicate that the left/right judgment elicits egocentric transformations, whereas the front/behind judgment elicits mental scanning. This finding is consistent with the findings presented by previous studies investigating differences in the processes of level-1 and level-2 SPT (Kessler & Rutherford, 2010; Surtees et al., 2013a; Michelon & Zacks, 2006). Unlike previous studies, however, the present experiment showed a slightly, but reliably, positive RT slope even for the front/behind judgment. This might be explained at least partially by the spatial incompatibility between a key alignment (e.g., the “front” key was far from participants) and a target position in high angle conditions (e.g., a “front” target was near participants). Another explanation is that one occasionally employs an egocentric transformation strategy even for the front/behind judgment. Consistent with this explanation is the fact that participants reported using the egocentric transformation strategy in about 11% of the trials (on average) for the front/behind judgment. It is worth noting that these

two explanations are not mutually exclusive (e.g., our key alignment could elicit a few egocentric transformations). Nonetheless, Experiment 1 succeeded in replicating the core findings of previous studies, even when the same stimuli were used for the left/right and front/behind tasks. Thus, in the following experiments, we adopt the same paradigm, except for the objects' shape.

3. Experiment 2

We conducted Experiment 2 to mainly examine whether participants apply the mental scanning strategy or egocentric transformation strategy to the left/right judgment when an object is left–right asymmetrical. To this end, in Experiment 2, we used an object that was asymmetrical in terms of its left–right and front–back directions. If mental scanning is mainly elicited for asymmetrical judgments, then the angle effect for the left/right judgment would be weakened in Experiment 2 compared to Experiment 1 (i.e., the RT slope would be flatter).

3.1. Method

3.1.1. Participants

Six women and six men (mean age = 22.0 years, ranging from 18 to 28) with normal or corrected-to-normal vision participated in Experiment 2. As was the case with Experiment 1, participants were not informed of the study's purpose. They were given pre-paid cards for purchasing books for their participation. None of the participants had taken part in the previous experiment.

3.1.2. Stimuli, apparatus, and procedure

Stimuli, apparatus, and procedure were the same as those of Experiment 1, except for a reference object. In this second experiment, we added a black armrest to the right side of the

chair used in Experiment 1 (Figure 7). Thus, the chair was asymmetrical in terms of its left/right and front/back directions. At the beginning of the experiment, participants were informed that chairs displayed during the experiment would always have a black armrest on their right side. On average, the experiment lasted for about 37 min.

3.2. Results and discussion

As was the case with Experiment 1, we excluded data from incorrect trials (2.80%) and trials for which RT was longer than 1,271 ms (i.e., three standard deviations above the mean RT, 1.65%) for RT analyses. None of the trials had an RT shorter than 200 ms. Figure 3 shows the average RTs, whereas Figure 4 shows the average error rates.

For RT data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed a significant main effect of Angle, $F(1.69, 18.62) = 23.09$, $\eta_p^2 = .677$, $p < .001$. However, the analysis did not reveal a significant main effect of Task, $F(1, 11) = 0.52$, $\eta_p^2 = .045$, $p = .486$. Although the interaction between Task and Angle was significant, $F(2.89, 31.75) = 6.13$, $\eta_p^2 = .358$, $p = .002$, post-hoc t-tests revealed no significant difference in mean RT between left/right and front/behind tasks for any angles ($ps > .026$, $\alpha = .010$). The RT slope of the left/right task was steeper than that of the front/behind task (see Figure 5), $t(11) = 3.39$, $d = 0.90$, $p = .006$, although both tasks showed positive RT slopes significantly greater than zero (0.53 ms/deg for the left/right task, $t(11) = 5.79$, $p < .001$; 0.27 ms/deg for the front/behind task, $t(11)$

Figure 7. Examples of stimuli used in Experiment 2.

= 3.59, $p = .004$). To examine whether the introduction of the object's left-right asymmetry (i.e., the addition of an armrest) reduced the difference in the RT slopes between the left/right and front/behind tasks, we compared RT slopes obtained from Experiments 1 and 2. A 2×2 mixed design ANOVA, with Experiment (1 or 2) and Task (left/right or front/behind) as factors, revealed a significant interaction between Experiment and Task, $F(1, 22) = 9.37$, $\eta_p^2 = .299$, $p = .006$. Post-hoc t-tests revealed that the addition of the armrest (in Experiment 2) did not reduce the RT slope for the front/behind judgment, $t(16.01) = 0.33$, $d = 0.14$, $p = .744$, $\alpha = .050$; however, compared to Experiment 1, it did reduce the RT slope for the left/right judgment, $t(19.39) = 2.92$, $d = 1.19$, $p = .009$, $\alpha = .025$. This suggests that egocentric transformations are suppressed when a reference object is left-right asymmetrical versus left-right symmetrical.

For error data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed significant main effect of Angle, $F(1.93, 21.18) = 7.95$, $\eta_p^2 = .420$, $p = .003$. A main effect of Task, $F(1, 11) = 1.53$, $\eta_p^2 = .122$, $p = .242$, and the interaction between Task and Angle, $F(4, 44) = 1.45$, $\eta_p^2 = .117$, $p = .234$, were not significant.

The results of the strategy questionnaire (Figure 6) showed no detectable strategy difference between the left/right and front/behind tasks (for the egocentric transformation strategy, $t(11) = 1.49$, $d = 0.51$, $p = .164$; for the mental scanning strategy, $t(11) = 1.80$, $d = 0.63$, $p = .100$). On average, the mental scanning strategy was employed in more than half of the trials, regardless of whether the judgment direction was left/right or front/behind. On the other hand, the egocentric transformation strategy was employed in less than half of the trials. None of the scores for the five AQ subscales predicted mean RTs for the left/right nor front/behind task ($ps > .217$; see Table 2).

In sum, the results of Experiment 2 indicate that people prefer mental scanning to egocentric transformations even for left/right judgments, especially when a reference object is left-right asymmetrical. Nonetheless, egocentric transformations may still be performed, even if only

rarely, as evidenced by the steeper RT slope for the left/right than front/behind judgment. It is noteworthy that the introspective report showed that the egocentric transformation strategy was employed in nearly half of the trials (44% on average) even for the front/behind judgment. For the front/behind judgment, our participants could use asymmetrical cues of both the left–right and front–behind axes of the reference object. This may allow them to execute egocentric transformations by matching their right arm to the chair’s right armrest. It remains unclear, however, whether people can apply egocentric transformations to front/back judgments when a reference object is front–back symmetrical and left–right asymmetrical. Therefore, Experiments 3 and 4 aim to address this question.

4. Experiment 3

As previous studies only employed reference objects that were front/back asymmetrical and left/right symmetrical, they could not distinguish the nature of front/back judgments from the nature of asymmetrical judgments, or the nature of left/right judgments from the nature of symmetrical judgments. To overcome such limitations, Experiment 3 made front/back judgments across the symmetry plane and left/right judgments across the asymmetry plane. For this purpose, Experiment 3 used a human-like object, which was front–back symmetrical, but left–right asymmetrical, because identifying its intrinsic reference frame is easy (e.g., Amorim, Isableu, & Jarraya, 2006; Marr & Nishihara, 1978; Sayeki, 1981). If egocentric transformations are elicited by symmetrical judgments, then the RT slope for the front/behind judgment in Experiment 3 would be steeper compared to Experiments 1 and 2. In addition, the left/right judgment in Experiment 3, which was across the object’s asymmetry plane, would yield an almost flat RT slope, as was the case with Experiment 2, because of the frequent use of mental scanning.

4.1. Method

4.1.1. Participants

Six women and six men (mean age = 22.0 years, ranging from 19 to 27) with normal or corrected-to-normal vision participated in Experiment 3. As was the case with the first two experiments, participants were not informed of the study's purpose. They were also given pre-paid cards for purchasing books for their participation. None of the participants had taken part in previous experiments.

4.1.2. Stimuli, apparatus, and procedure

Stimuli, apparatus, and procedure were the same as those of Experiments 1 and 2, except for a reference object. For Experiment 3, we used an abstract human-like figure as a reference object (Figure 8; see also Figure 1). The figure was of the same color as the chair used in Experiment 2 (i.e., the figure was colored red except for its right armrest, which was black in color). The figure was made completely front-back symmetrical, in that it wore no clothes, had no feet, and its head was a simple sphere without any facial features (e.g., eyes, hair, or surface information). In contrast, the figure was left-right asymmetrical, in that its black right arm was raised, whereas its red left arm was placed down. At the beginning of the experiment,

Figure 8. Examples of stimuli used in Experiment 3.

participants were informed that whenever a red human-like figure was displayed during the experiment, it would always raise its black right hand. The experiment took about 41 min to complete on average.

4.2. Results and discussion

For this experiment, too, we excluded data from incorrect trials (4.00%) and trials for which RT was longer than 2,701 ms (three standard deviations above the mean RT, 1.68%) for RT analyses. None of the trials had RTs shorter than 200 ms. [Figure 3](#) shows the average RTs, whereas [Figure 4](#) shows the average error rates.

For RT data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed significant main effects of Task, $F(1, 11) = 86.41$, $\eta_p^2 = .887$, $p < .001$, and Angle, $F(2.75, 30.23) = 4.82$, $\eta_p^2 = .305$, $p = .009$. The interaction between Task and Angle was not significant, $F(2.73, 30.07) = 1.55$, $\eta_p^2 = .123$, $p = .224$. These results showed that the RT for the front/behind task was, on average, 511 ms slower than the RT for the left/right task, regardless of the angles. However, the RT slopes of the left/right and front/behind task were numerically equivalent and statistically indistinguishable (see [Figure 5](#)), $t(11) = 0.04$, $d = 0.02$, $p = .968$. The RT slope of the left/right task was significantly greater than zero (0.30 ms/deg), $t(11) = 2.99$, $p = .012$, whereas the RT slope of the front/behind task was indifferent from zero (0.29 ms/deg), $t(11) = 0.99$, $p = .343$; this discrepancy can be attributed to a larger individual variation in RT slopes for the front/behind task than the left/right task (see error bars in [Figure 5](#)). In addition, the RT difference between the left/right and front/behind judgments was much larger in Experiment 3 (511 ms on average) than in Experiment 1 (93 ms on average), $F(1, 22) = 24.43$, $\eta_p^2 = .526$, $p < .001$ ⁶. For asymmetrical judgments where the mental scanning strategy was supposedly dominant, the front/behind judgment in Experiment 1 was as fast as the left/right judgment in

⁶ This difference was confirmed by a significant interaction of a 2×2 mixed design ANOVA, with Experiment (1 or 3) and Symmetry (symmetrical or asymmetrical judgment) as factors

Experiment 3, $t(16.57) = 1.94$, $d = 0.79$, $p = .070$, $\alpha = .050$. However, for symmetrical judgments where the egocentric transformation strategy was supposedly dominant, the left/right judgment in Experiment 1 was faster than the front/behind judgment in Experiment 3 (symmetrical judgment), $t(17.53) = 6.26$, $d = 2.56$, $p < .001$, $\alpha = .025$.

For error data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed significant main effects of Task, $F(1, 11) = 24.12$, $\eta_p^2 = .687$, $p < .001$, and Angle, $F(2.68, 29.43) = 4.24$, $\eta_p^2 = .278$, $p = .016$. The interaction between Task and Angle was also found to be significant, $F(3.14, 34.56) = 10.73$, $\eta_p^2 = .494$, $p < .001$. Post-hoc t-tests revealed that front/behind judgments were more error-prone than left/right judgments at 0° , $t(11) = 5.47$, $d = 2.15$, $p < .001$, $\alpha = .010$, and 45° , $t(11) = 3.01$, $d = 1.10$, $p = .012$, $\alpha = .020$, but not at 90° or at other larger angles (at 90° , $t(11) = 0.00$, $d = 0.00$, $p = 1.00$, $\alpha = .030$; at 135° , $t(11) = 0.11$, $d = 0.04$, $p = .913$, $\alpha = .030$; at 180° , $t(11) = 0.00$, $d = 0.00$, $p = 1.00$, $\alpha = .030$). To further characterize the interaction between Task and Angle, we estimated and analyzed error slopes as a function of angles for each task and each participant. Although the left/right task showed an error slope numerically positive but indistinguishable from zero ($0.00010\%/deg$), $t(11) = 1.83$, $p = .094$, the front/behind task showed a significantly negative error slope smaller than zero ($-0.00045\%/deg$), $t(11) = 4.33$, $p = .001$.

The results of the questionnaire (Figure 6) revealed that the egocentric transformation strategy was more frequently employed for the front/behind task than for the left/right task, $t(11) = 12.14$, $d = 4.94$, $p < .001$. In contrast, the mental scanning strategy was more frequently employed for the left/right task than for the front/behind task, $t(11) = 11.47$, $d = 4.47$, $p < .001$.

The results of the AQ questionnaire showed that participants with higher scores on the imagination subscale (i.e., poorer imagination) showed longer mean RTs for both the left/right, $r = .636$, $t(10) = 2.60$, $p = .026$, and front/behind task, $r = .658$, $t(10) = 2.76$, $p = .020$. These details are presented in Figure 9. No other scores were correlated with mean RTs for either the

left/right or front/behind task ($ps > .252$; see Table 2). These results suggest that, when a reference object is front–back symmetrical and left–right asymmetrical, people with better imagination can perform SPT more easily. Given that we conducted correlational analyses in an exploratory manner, however, we cannot draw strong conclusions from this result alone. Given that one participant (Case 3-03 shown in Figure 9) exhibited extremely slow RTs and a high imagination score, we cannot rule out the possibility that his case could lead to overestimation of the correlation coefficients as an outlier. To ensure the association between SPT performance and autistic traits, this finding should be replicated in another sample. Experiment 4 aims to address this concern.

In sum, RTs for the left/right and front/behind task were less affected by angles and resulted in the almost flat slopes. This might indicate that mental scanning was elicited by both the left/right and front/behind judgments. However, this conclusion may be premature for the following two reasons. First, the rather long RT for the front/behind judgment in Experiment 3 may reflect a cognitive effort that cannot be explained by the mental scanning cost alone.

Figure 9. Relationships of imagination scores of Autism-Spectrum Quotient to mean response times for the font/behind (left panel) and left/right judgments (right panel) in Experiments 3 and 4. Higher imagination scores represent poorer imagination. The point indicated by a broken-line circle is a suspected outlier (Case 3-03).

Second, participants' introspective report on their choice of strategy showed that the egocentric transformation strategy was more favored for the front/behind. These contradicting and unexpected results may be explained by considering the results of error data. The front/behind task induced many errors, especially at less than 90°. These errors, in turn, resulted in a monotonic decreasing function of angles. This difficulty at low angles (reflected by the error data) may delay RTs at lower angles, thereby making the RT function apparently flat. In other words, by removing errors at low angles, a RT function might exhibit a monotonic increase with angles, which is typical of egocentric transformations.

The observation of the monotonically decreasing errors with increasing angle is noteworthy, as this is clearly contrary to the typical results of increasing errors. A possible explanation is that participants may have perceived the human-like object as facing them even when the object was actually facing away from them. This facing bias might tempt participants to accidentally take the perspective of the (illusorily) facing human at less than 90°, resulting in many errors and slow RTs. The large individual variation in RT slopes for the front/behind task could also be explained by assuming that participants susceptible and unsusceptible to the facing bias exhibited negative and positive RT slopes, respectively, which resulted in the mean RT slope as shallow as that of the left/right task. Consistent with this speculation, one participant informally reported this facing bias after the experiment. If this account is true, eliminating the human-likeness of a reference object would reduce the facing bias and restore a steeper RT slope, which is evidence of the egocentric transformation. This prediction is tested in Experiment 4.

5. Experiment 4

The results of Experiment 3 showed that participants may have erroneously perceived an object that was actually facing away from them as facing them, especially when the object is

human-like and its front–back direction is rather ambiguous. To examine this possibility, we reduced the object’s human-likeness for Experiment 4. If the results of Experiment 3 can be explained in terms of the facing bias, then removing an object’s human-likeness should reduce errors at low angles and restore a steeper RT slope in the front/behind task.

Experiment 3 also showed that rich imagination was associated with quicker responses for an SPT task in which a reference object was front–back symmetrical and left–right asymmetrical. The second purpose of Experiment 4 is to examine whether this relationship can be replicated in a new sample.

5.1. Method

5.1.1. Participants

Six women and six men (mean age = 21.5 years, ranging from 19 to 27) with normal or corrected-to-normal vision participated in Experiment 4.⁷ As was the case with earlier experiments, participants were not informed of the study’s purpose. In addition, participants were given pre-paid cards for purchasing books for their participation. None of the participants had taken part in the previous experiments.

5.1.2. Stimuli, apparatus, and procedure

Stimuli, apparatus, and procedure were the same as those of Experiments 1–3, except for a reference object. Experiment 4 used an abstract object, which was created by removing the left arm and the head from the figure used in Experiment 3 (Figure 10). Accordingly, the object was front–back symmetrical and left–right asymmetrical, as in Experiment 3, but the object was not human-like. At the beginning of the experiment, participants were informed that they would see

⁷ Twenty-four participants (12 women and 12 men) were randomly assigned to either Experiment 4 or 5.

Figure 10. Examples of stimuli used in Experiment 4.

an object with its own direction and that the black part of the object would always appear on its right side. Notably, the experimenter did not use any bodily analogy (e.g., “the object raises its right *hand*”). On average, the experiment took about 40 min to complete.

5.2. Results and discussion

As with previous experiments, we excluded data from incorrect trials (4.04%) and trials for which RT was longer than 2,359 ms (three standard deviations above the mean RT, 1.55%) for RT analyses. None of the trials had RTs shorter than 200 ms. [Figure 3](#) shows the average RTs, whereas [Figure 4](#) show the average error rates.

For RT data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed a significant main effect of Task, $F(1, 11) = 63.57$, $\eta_p^2 = .853$, $p < .001$, indicating that the RT for the front/behind task was, on average, 392 ms slower than the RT for the left/right tasks. A significant main effect of Angle ($F(1.69, 18.54) = 16.42$, $\eta_p^2 = .599$, $p < .001$) and a significant interaction between Task and Angle, $F(2.16, 23.75) = 5.80$, $\eta_p^2 = .345$, $p = .008$, were also confirmed. Post-hoc t-tests revealed that left/right judgments were faster than front/behind judgments at all angles (at 0° , $t(11) = 6.17$, $d = 1.85$, $p < .001$, $\alpha = .050$; at 45° , $t(11) = 6.98$, $d = 1.90$, $p < .001$, $\alpha = .040$; at 90° , $t(11) = 7.91$, $d = 2.15$, $p < .001$, $\alpha = .010$; at 135° , $t(11) = 7.45$, $d = 2.08$, $p < .001$, $\alpha = .020$; at 180° , $t(11) = 7.12$, $d = 2.07$, $p < .001$, $\alpha = .030$). The

interaction between Task and Angle could be attributed to the steeper RT slope of the front/behind task than to the RT slope of the left/right task (see [Figure 5](#)), $t(11) = 2.79$, $d = 1.04$, $p = .017$. The RT slopes of the left/right and front/behind tasks were significantly greater than zero (0.33 ms/deg for the left/right task, $t(11) = 3.29$, $p = .007$; 1.19 ms/deg for the front/behind task, $t(11) = 3.66$, $p = .004$).

For error data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed a significant main effect of Task, $F(1, 11) = 7.08$, $\eta_p^2 = .392$, $p = .022$. It did not, however, reveal a main effect of Angle, $F(2.72, 29.95) = 1.56$, $\eta_p^2 = .124$, $p = .221$, and interaction between Task and Angle, $F(1.70, 18.70) = 1.27$, $\eta_p^2 = .104$, $p = .298$. These results showed that the error rate for the front/behind task was, on average, 2.08% more than the error rate for the left/right task regardless of the angles. Unlike Experiment 3, the error slopes of the left/right and front/behind task were indistinguishable from zero (0.00001%/deg for the left/right task, $t(11) = 0.24$, $p = .815$; -0.00004%/deg for the front/behind task, $t(11) = 0.41$, $p = .689$), which indicated the absence of facing bias. The difference in the error slopes between the left/right and front/behind tasks were also not significant, $t(11) = 0.61$, $d = 0.19$, $p = .554$.

The results of the strategy questionnaire ([Figure 6](#)) revealed that the egocentric transformation strategy was more frequently employed for the front/behind task than for the left/right task, $t(11) = 7.13$, $d = 2.47$, $p < .001$. In contrast, the mental scanning strategy was more frequently employed for the left/right task than for the front/behind task, $t(11) = 14.44$, $d = 5.45$, $p < .001$.

As shown in [Figure 9](#), the results of the AQ questionnaire revealed that participants with higher scores on the imagination subscale (i.e., poorer imagination) had longer mean RTs for the front/behind task, $r = .711$, $t(10) = 3.20$, $p = .009$. Although higher scores on the communication subscale (i.e., lower communication skill) were also found to be associated with longer mean RTs for the front/behind task, $r = .577$, $t(10) = 2.24$, $p = .049$, this correlation may

be due to the positive correlation between imagination and communication scores, $r = .664$, $t(10) = 2.81$, $p = .019$. The mean RT for the front/behind task had a marginally significant correlation with the imagination score, even when controlling for the communication score, partial $r = .537$, $t(9) = 1.91$, $p = .089$. However, the mean RT was not significantly correlated with the communication score when controlling for the imagination score, partial $r = .200$, $t(9) = 0.61$, $p = .555$. Unlike in Experiment 3 and as shown in [Figure 9](#), the mean RT for the left/right task was not predicted by the imagination score, $r = .363$, $t(10) = 1.23$, $p = .246$. No other scores were correlated with the mean RTs for the left/right or front/behind task ($ps > .071$; see [Table 2](#)).

To confirm the replicability of the observed correlations and the effect of an outlier, we conducted correlation analyses for mixed data of Experiments 3 and 4 (see [Figure 9](#)). The imagination score significantly predicted the mean RTs for both the left/right, $r = .546$, $t(22) = 3.06$, $p = .006$, and front/behind tasks, $r = .680$, $t(22) = 4.35$, $p < .001$. When removing data from Case 3-03 suspected as an outlier, the imagination score was still a good predictor of the mean RT for the front/behind task, $r = .607$, $t(21) = 3.50$, $p = .002$, but was no longer correlated with the mean RT for the left/right task, $r = .245$, $t(22) = 1.16$, $p = .259$. Therefore, at least the positive correlation between the imagination score and the mean RT for the front/behind judgment was shown to be replicable. This association suggests that rich imagination alleviates the difficulties involved in applying egocentric transformations to front/behind judgments for an object with front–back symmetry.

6. Experiment 5

Experiments 3 and 4 demonstrated that front/behind judgments for an object with front–back symmetry required more time than left/right judgments for an object with left–right symmetry

(Experiment 1), even if egocentric transformations are used in both cases. This suggests that people tend to find it more difficult to apply egocentric transformations to front/behind judgments than to left/right judgments. However, since the objects used in Experiments 3 and 4 were less familiar than the object used Experiment 1 (i.e., a chair), we cannot rule out the possibility that the novelty of the objects made it difficult for the participants to conduct egocentric transformations in Experiments 3 and 4. It is also unclear whether the relationship between rich imagination and high performance on SPT, which was especially found in Experiments 3 and 4, could be attributed to the novelty of the objects or the application of egocentric transformations to front/behind judgments for front–back symmetrical objects. To examine the presence or absence of this novelty effect, we used the object for Experiment 4 in Experiment 5 as well. However, in Experiment 5, the black portion of the object was labeled as the front unlike Experiment 4 where the black portion was labeled as the right. In other words, the object used in Experiment 5 was left–right symmetrical and front–back asymmetrical, much like the object used in Experiment 1. Nonetheless, the object used in Experiment 5 was as novel as the object used in Experiment 4.

6.1. Method

6.1.1. Participants

Six women and six men (mean age = 21.5 years, ranging from 19 to 23) with normal or corrected-to-normal vision participated in Experiment 5. As with the previous experiments, participants were not informed of the study's purpose. In addition, participants were given pre-paid cards for purchasing books for their participation. None of the participants had taken part in the previous experiments.

6.1.2. Stimuli, apparatus, and procedure

For Experiment 5, we used the stimuli, apparatus, and procedure employed in Experiment 4.

However, we instructed participants about the intrinsic reference frame of the abstract object in a different way from Experiment 4. That is, the reference object for Experiment 5 was the same one used in Experiment 4 (Figure 11). In Experiment 5, the black portion of the abstract object was labeled as its front side, whereas it was labeled as the right in Experiment 4. Accordingly, the object was left–right symmetrical, but front–back asymmetrical, as was the case in Experiment 1. At the beginning of the experiment, participants were informed that the object that would be displayed during the experiment would have its own direction and that its black portion would always be its front side. As in Experiment 4, the experimenter did not use any bodily analogy (e.g., “the object was an animal with a black neck”). On average, the experiment took about 37 min to complete.

6.2. Results and discussion

As we had done with the previous experiments, we excluded data from incorrect trials (3.50%) and trials for which RT was longer than 1,220 ms (three standard deviations above the mean RT, 1.90%) for RT analyses. None of the trials had RTs shorter than 200 ms. Figure 3 shows the average RTs, whereas Figure 4 shows the average error rates.

For RT data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed significant main effects of both Task, $F(1, 11) = 16.05$, $\eta_p^2 = .593$, $p = .002$, and Angle, $F(2.39, 26.25) = 75.61$, $\eta_p^2 = .873$, $p < .001$. The interaction between Task and Angle was also found to

Figure 11. Examples of stimuli used in Experiment 5.

be significant, $F(2.13, 23.41) = 27.90$, $\eta_p^2 = .717$, $p < .001$. Post-hoc t-tests revealed that front/behind judgments were faster than left/right judgments at an angle of 90° and higher (at 90° , $t(11) = 2.86$, $d = 0.64$, $p = .015$, $\alpha = .030$; at 135° , $t(11) = 4.02$, $d = 1.27$, $p = .002$, $\alpha = .020$; at 180° , $t(11) = 5.73$, $d = 1.64$, $p < .001$, $\alpha = .010$), but not at 0° ($t(11) = 2.32$, $d = 0.45$, $p = .040$, $\alpha = .040$) and 45° ($t(11) = 1.12$, $d = 0.22$, $p = .287$, $\alpha = .040$). Both tasks showed positive RT slopes significantly greater than zero (1.13 ms/deg for the left/right task, $t(11) = 9.70$, $p < .001$; 0.43 ms/deg for the front/behind task, $t(11) = 12.07$, $p < .001$). More importantly, the RT slope of the left/right task was steeper than that of the front/behind task (see [Figure 5](#)), $t(11) = 6.13$, $d = 2.34$, $p < .001$.

Although left/right judgments for the left–right symmetrical object had slightly longer RTs (68 ms on average) than front/behind judgments for the front–back asymmetrical object, the difference in RT was smaller compared to the difference observed in Experiment 4. Notably, in Experiment 4, front/behind judgments for the front–back symmetrical object had longer RT (391 ms on average) than left/right judgments for the left–right symmetrical object. This contrast was statistically confirmed: a 2×2 mixed design ANOVA, with Experiment (4 or 5) and Symmetry (symmetrical or asymmetrical judgment) as factors, revealed a significant interaction between Experiment and Symmetry, $F(1, 22) = 27.82$, $\eta_p^2 = .558$, $p < .001$. Post-hoc t-tests revealed that the symmetrical judgment in Experiment 5 (left/right judgment) was faster than the symmetrical judgment in Experiment 4 (front/behind judgment), $t(13.15) = 5.88$, $d = 2.40$, $p < .001$, $\alpha = .025$. In addition, rather unexpectedly, the asymmetrical judgment in Experiment 5 (front/behind judgment) was also faster than the asymmetrical judgment in Experiment 4 (left/right judgment), $t(16.68) = 2.54$, $d = 1.04$, $p = .002$, $\alpha = .050$.

For error data, a 2×5 repeated measures ANOVA, with Task and Angle as factors, revealed a significant main effect of Angle, $F(1.69, 18.56) = 10.01$, $\eta_p^2 = .476$, $p = .002$. A main effect of Task, $F(1, 11) < 0.01$, $\eta_p^2 < .001$, $p = .968$, and the interaction between Task and Angle,

$F(1.48, 16.25) = 1.23, \eta_p^2 = .101, p = .304$, were not significant.

The results of the strategy questionnaire (Figure 6) revealed that the egocentric transformation strategy was more frequently employed for the left/right task than for the front/behind task, $t(11) = 3.81, d = 1.31, p = .003$. In contrast, the mental scanning strategy was more frequently employed for the front/behind task than for the left/right task, $t(11) = 4.36, d = 1.61, p = .001$. None of the scores of the five AQ subscales predicted mean RTs for the left/right or front/behind task ($ps > .178$; see Table 2).

In sum, the results of Experiment 5 were very similar to results of Experiment 1. The participants preferentially performed egocentric transformations for left/right judgments and mental scanning for the front/behind judgments. Although the same stimuli were used in Experiments 4 and 5, the number of difficulties involved in applying the egocentric transformations strategy to the front/behind task for Experiment 4 was lesser than the number of difficulties involved in applying the strategy to the left/right judgment for Experiment 5. Thus, the much slower RTs for symmetrical versus asymmetrical judgments in Experiments 3 and 4 could be attributed not to the novelty of objects used in Experiments 3 and 4 (or the familiarity of the object in Experiment 1) but to more difficulty applying egocentric transformations to the front/behind than left/right judgment. Moreover, mental scanning was performed more quickly for the front/behind task of Experiment 5 than for left/right task of Experiment 4. This suggests that people can use mental scanning more efficiently for front/behind versus left/right judgments.

7. General discussion

7.1. Effects of objects' symmetry on SPT processes

The main finding of this study is that objects' symmetry determines SPT processes, whereas

the direction of judgments does not. Our results for both RT slopes and introspective reports revealed that egocentric transformation was elicited for symmetrical judgments (i.e., left/right judgments for left–right symmetrical objects or front/behind judgments for front–back symmetrical objects), whereas mental scanning was elicited for asymmetrical judgments (i.e., front/behind judgments for front–back asymmetrical objects or left/right judgments for left–right asymmetrical objects). This finding challenges previous explanations suggesting that the direction of the judgment (left/right or front/behind) determines the SPT processes (Kessler & Rutherford, 2010; Surtees et al., 2013a; Michelon & Zacks, 2006). In addition, we have also found that mental scanning was performed even for left/right judgments (Experiments 2, 3, and 4). Similarly, we found that egocentric transformation was performed even for front/behind judgments (Experiments 3 and 4). These observations also contradict the notion that any kind of left/right judgment task requires egocentric reference (Voyer, Jansen, & Kaltner, 2016).

We can hypothesize the following descriptive model about the two distinctive processes that are elicited in an SPT task. When participants notice that a given reference object has a consistent asymmetry plane (e.g., a face always indicates its front side), they can use the asymmetrical cue as primary reference to judge the orientation of the object. If the cued direction (e.g., the front–back direction indicated by the face) is the same as the to-be-judged direction, then participants can directly and immediately judge whether or not a target object is close to the cued side by performing mental scanning. On the other hand, if the to-be-judged direction is orthogonal to the objects' symmetry plane (e.g., left/right judgments for a typical left–right symmetrical human), there is no direct cue for the judgment. In this case, participants should mentally rotate their own body so that its corresponding axis aligns with the asymmetrical direction of the object (e.g., orienting their own front–back axis to objects' asymmetrical front–back axis). This egocentric transformation allows participants to utilize their own body axis to judge the target position relative to the reference object, even when no

direct cue is available. This model is supported by our finding that, compared to symmetrical judgments, RTs were consistently shorter for asymmetrical judgments (Experiments 1, 3, 4, and 5). Moreover, Experiment 2 showed that providing a direct left–right cue (Experiment 2) reduces RT for left/right judgments compared to Experiment 1, in which no direct left–right cue was available.

Nonetheless, whether the judgment is about left/right or front/behind still seems important for the SPT processes. A comparison of Experiments 4 and 5 showed that egocentric transformation could be more easily applied to left/right judgments than front/behind judgments, whereas mental scanning could be more easily performed for front/behind judgments than left/right judgments. These results suggest that each of the two SPT processes has been originally tuned to a specific direction of judgments. In other words, egocentric transformation may be optimized specifically for left/right judgments, whereas mental scanning may be optimized specifically for front/behind judgments. This tuning seems to reflect the fact that animals, including humans, are typically left–right symmetrical and front–back asymmetrical. Given this, it is worth noting that people can apply the two processes (i.e., egocentric transformation and mental scanning) rather flexibly to even the untuned and unnatural direction by paying an additional cognitive cost.

As for the flexibility of the processes, the present study suggests at least one possible mediator to assist the novel application of the egocentric transformation to front/behind judgments. We showed that participants with richer imagination, measured using the AQ questionnaire, could apply egocentric transformations to front/behind judgments in Experiments 3 and 4 more quickly than those with poorer imagination. Imagination may allow people to apply knowledge about the human body to atypical objects (i.e., left–right asymmetrical and front–back symmetrical objects like ones used in Experiments 3 and 4) by anthropomorphizing the objects. This assumption is consistent with the findings presented by

Shelton et al. (2012): the authors showed that higher social skills, measured by AQ (the sum of communication and social skill scores), predicted better performance on a SPT task when a human-like, faceless figure was used as a reference object, but not when a reference object was a triangle-shaped object or a camera. Shelton et al. also suggested that people with higher social skills could take advantage of various objects, such as the human-like, faceless figure, better than people with lower social skills. However, the AQ subscore correlated with performance in the present study (i.e., imagination score) was different from the subscore reported by previous studies (the sum of communication and social skill scores). This inconsistency may be attributed to a difference in tasks or potential intercorrelations across AQ subscales. Future studies should attempt to unveil the mediating role of AQ traits or other factors in the specific context of perspective-taking. It is equally important to acknowledge that there might be undiscovered mediating factors that make the application of mental scanning to left/right judgments easier.

Regarding the difficulty with front/behind judgments for front–back symmetrical objects, introspective reports obtained from the participants contradicted an alternative account that the participants in Experiments 3 and 4 imagined front/behind judgments as left/right judgments. According to this account, for example, participants may have regarded the black portion of front–back symmetrical objects as the front rather than the right, executed the egocentric transformation in the same manner as in left/right judgments for left–right symmetrical objects (like Experiments 1 and 5), and then rephrased “left” and “right” into “front” and “behind,” respectively. However, the majority of the participants in Experiments 3 and 4 spontaneously reported mentally matching their right arm or shoulder to the object’s black portion, and none reported performing such a rephrasing strategy. As the rephrasing strategy should be intentional and needs conscious effort, the absence of introspective reports of rephrasing ruled out this account.

What caused the difficulty in applying egocentric transformations to front/behind judgments

for front–back symmetrical objects? Given that the RT slope for symmetrical judgments in Experiment 4 was not steeper than those of Experiments 1 and 5 (see Figure 6), we can consider that the employment of egocentric transformations was delayed, but once employed, the egocentric transformation per se proceeded at a normal speed. For example, the participants may have found it more difficult to use an asymmetrical cue to identify the left–right than front–back direction of an object and thus the employment of an egocentric transformation may have been delayed. A richer imagination may help to identify the left–right direction of a front–back symmetrical object or to employ the execution of an egocentric transformation in some way.

Unlike previous studies (Kessler & Rutherford, 2010; Surtees et al., 2013a; Michelon & Zacks, 2006), our results exhibited weak but statistically significant positive RT slopes in all conditions in which mental scanning was preferred to egocentric transformation. A possible explanation for this is that the slightly positive RT slopes were due to the spatial incompatibility between our key alignment and required responses in high angle conditions in which a target position seen from participants' viewpoint was opposite to a correct key position (e.g., the left key for a right target or the near key for a far target). This explanation suggests that the typically steeper RT slopes observed in left/right judgment tasks were at least partially caused by the spatial incompatibility, as well as the cost of egocentric transformation (e.g., May & Wendt, 2013). Another (but not mutually exclusive) explanation is that, even in conditions in which mental scanning can be performed, people could occasionally attempt to use egocentric transformation. This explanation is supported by a steeper RT slope for the left/right than front/behind judgments for the object with both left–right and front–back asymmetry in Experiment 2, together with participants' introspective report of the relatively frequent use of the egocentric transformation strategy. Nonetheless, as shown in Figure 5, RT slopes in mental scanning conditions (0.36 ms/deg on average) were much shallower than those in egocentric transformation conditions (1.11 ms/deg on average; for this calculation, we excluded data from

the front/behind task in Experiment 3, which seems to be contaminated by facing bias). This clear distinction of RT slopes, which is consistent with the reported strategies, indicates the existence of dominant processes (i.e., egocentric transformation versus mental scanning), which depend on an object's symmetry.

As the present study did not manipulate the distance between a reference object and a target unlike previous experiments (Michelon & Zacks, 2006; Surtees et al., 2013a), we could not obtain direct behavioral evidence for mental scanning. Nonetheless, we consistently reported shallower RT slopes in the asymmetrical judgment conditions in comparison to the symmetrical judgment conditions where the egocentric transformation was predominantly adopted. This finding, at least, guarantees the use of a strategy other than egocentric transformation for asymmetrical judgments. Moreover, by administering the strategy questionnaire, we obtained new subjective evidence for mental scanning in asymmetrical judgments and for egocentric transformation in symmetrical judgments. Thus, the present findings can be considered comparable to previous evidence for distinct processes between level-1 and level-2 SPT.

7.2. Implications for the level-1 and level-2 processes of SPT and VPT

Flavell et al. originally proposed the distinction between level-1 and level-2 VPT (Flavell et al., 1981; Flavell et al., 1986). Typically, level-1 VPT develops faster (e.g., Flavell et al., 1981), and requires less cognitive resources (Surtees, Samson, & Apperly, 2016) than level-2 VPT. Moreover, non-human animals such as primates and dogs are also capable of level-1 VPT (e.g., Bräuer, Call, & Tomasello, 2005; Maginnity & Grace, 2014; Tomasello, Carpenter, Call, Behne, & Moll, 2005). There is no evidence, however, to suggest that non-human animals are capable of level-2 VPT. As for SPT, it has also been observed that children use spatial terms such as “in front” and “behind” earlier than they can grasp words such as “left” and “right” (e.g., Bialystok & Codd, 1987; Harris, 1972; Harris, & Strommen, 1972; Kuczaj & Maratsos, 1975).

Additionally, adults find it more difficult to ascertain whether an object is located to their left or right, than to determine whether an object is located in front of or behind them (Franklin & Tversky, 1990). These findings imply developmental and evolutionary differences between level-1 and level-2 perspective-taking.

Previous studies have demonstrated that the two levels of perspective-taking are characterized by distinctive cognitive processes, especially among adult humans. The angle effect observed in level-2 SPT and VPT has been considered to reflect the cost of egocentric transformations. Specifically, this process is subserved by the motor simulation of whole-body movement. To support this notion, Kessler and Thomson (2010) manipulated the body orientation of participants in a clockwise or a counterclockwise direction during the performance of a left/right judgment task (level-2 SPT). Their results clearly proved that level-2 SPT performance improved when the orientation of participants was congruent with the direction of the imagined movement and that the functioning deteriorated when the orientation was incongruent with the targeted motion. (see also Surtees et al., 2013b, for a replication). Similarly, Muto et al. (2018) manipulated a responding limb (i.e., putting left/right foot or left/right hand forward) and demonstrated that actions congruent with the imagined movement facilitated level-2 SPT more than incongruent actions. These findings suggest that the level-2 SPT is “embodied” in the form of whole-body motor simulation. Notably, this embodiment effect was not observed in a visibility judgment task (level-1 VPT; Kessler & Rutherford, 2010). Thus, level-1 perspective-taking may be embodied in a manner that is different from the level-2 perspective-taking or it may not be embodied at all.

The current findings carry implications for the dissimilarities in developmental/evolutionary trajectories and the distinctions in the processes embodied for level-1 and level-2 SPT. In most situations, people interact with front–back asymmetrical social agents (i.e., having faces) from a young age. Therefore, level-1 SPT is naturally better suited for asymmetrical judgments

(Figure 1) and level-2 SPT is apt for symmetrical judgments. Using unnatural situations (i.e., level-1 SPT for symmetrical judgments and level-2 SPT for symmetrical judgments), the experiments presented in this paper demonstrated that people can apply egocentric transformations (commonly used for level-2 VPT and SPT) to level-1 SPT tasks, probably in an embodied way, and that they can employ mental scanning (commonly used for level-1 VPT and SPT) to level-2 SPT tasks, probably in a non-embodied (or differently embodied) way. When and how this flexibility develops still remains to be studied so that a more intensive understanding of the cognitive malleability of spatial thinking may be obtained. Also, by manipulating the body orientation (e.g., Kessler & Thomson, 2010) or response methods (e.g., Muto et al., 2018) of participants, future experiments should be able to confirm whether the process underlying the front/behind decision (level-1 SPT) for a front–back symmetrical object is actually identical to the process elicited for level-2 SPT for a natural left–right symmetrical object.

As already mentioned, VPT and SPT show similar cognitive processes in terms of the spatial transformation that is adopted (i.e., mental scanning or egocentric transformations; Surtees et al., 2013a, 2013b). However, this similarity does not mean that all the processes are shared by VPT and SPT. By definition, VPT involves imagining another person’s visual experience, whereas SPT pertains to knowing only the positional relationship between a reference object and a target object. Given this clear distinction, the common aspects of VPT and SPT processes remain unclear. The requirement of asymmetrical information may account for a similarity between VPT and SPT, at least in level-1 processes. To understand what another person is seeing, one must know the direction of the person’s gaze by identifying his/her front side as characterized by front–back asymmetry (e.g., Clark, 1973). It is noteworthy that unlike level-1 SPT, level-1 VPT may sometimes require a person to take the individual’s physical or mental state into account (e.g., discerning whether the person’s eyes are closed, or being aware of the

direction the person's eyes are oriented independently of the head). More elaborate and sensitive experimental procedures are needed to grasp such potential distinctions between VPT and SPT.

7.3. Facing bias for a human-like object with front–back symmetry

Another important finding of this study was obtained by comparing Experiments 3 and 4. The human-like object with front–back symmetry in Experiment 3 led to unexpected and novel results: the front/behind judgments yielded a flat RT slope (see Figure 3) in spite of the frequent subjective use of egocentric transformations. It also yielded decreasing errors with increasing angles (see Figure 4), contrary to the typical pattern. We postulated the existence of a facing bias or the tendency to erroneously perceive a front–back ambiguous, human-like figure as facing the viewer, even when the figure was actually facing away from the viewer (i.e., at less than 90°). To support this notion, we eliminated the object's human-like features (Experiment 4), which in turn recovered the positive RT slope and reduced errors at less than 90°. The facing bias at lower angles may occur automatically and tempt participants to perform an unnecessary egocentric transformation, which in turn may lead to high error rates. Participants had to overcome or suppress this automatic process by investing additional cognitive resources to respond correctly, which resulted in delayed RTs at lower angles and the apparently flat RT slope.

A similar phenomenon has been reported in studies on biological motion. Vanrie, Dekeyser, and Verfaillie (2004) presented their participants with ambiguous point-light walkers, which could be interpreted as walking either toward or away from the viewer. The participants showed a strong tendency to interpret the point-light walker as walking toward them, rather than away from them. The present study demonstrated that the facing bias was caused not only by the moving stimuli (i.e., point-light walkers) but also by a still image of a human-like object with

front–back ambiguity. We experience a similar bias in our daily lives: when viewing pictograms representing upright human figures, such as toilette pictograms. In this situation, people seem to interpret the visible side of such pictograms as its front rather than its back side. Given that it remains unclear whether these kinds of facing bias share a common mechanism, future studies should aim to directly compare these phenomena.

The facing bias may have an evolutionary advantage. Because the direction in which a person gazes is an important social cue, people should be sensitive to the others' gaze to ensure effective communication, to understand others' intentions, or to avoid potential enemies. In other words, we have to decide whether to approach or avoid a person who is actively looking at us. Consistent with this notion, previous studies have shown that others' gaze enhances arousal, captures attention, and evokes the social brain network (for reviews, Becchio, Bertone, & Castiello, 2008; Hamilton, 2016; Senju & Johnson, 2009). To be on the safer side, it is rational and adaptive to assume that another person whose orientation is ambiguous is facing toward us. The consequences of erroneously perceiving a person facing us as facing away from us are more serious than the cost of erroneously perceiving a person facing away from us as facing us. Admittedly, this explanation is rather similar to the well-known phenomenon of negativity bias (for a review, Rozin & Royzman, 2001). To validate this adaptive account, it is necessary to collect more instances of facing bias.

This finding about the facing bias also has implications for the automaticity of SPT. Previous studies demonstrated that people sometimes spontaneously or automatically adopt another person's perspective, even when they are not required to do so (Freundlieb, Kovács, & Sebanz, 2016; Qureshi, Apperly, & Samson, 2010; Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010; Surtees et al., 2012; Surtees, Samson, & Apperly, 2016; Tversky & Hard, 2009). For example, Samson et al. (2010) provided evidence for automatic level-1 VPT. In their task, participants were presented a scene depicting a room with a human agent and disks on the wall.

Although participants' task was to judge the number of disks visible from *their own* perspective, and not *the other's* perspective (i.e., task-irrelevant), their performance was impaired when they could not see the same number of disks as the agent could (e.g., participants saw three disks but an agent could see only one disk).

Such “altercentric intrusions” were not observed in level-2 VPT, but in level-1 VPT tasks (Surtees et al., 2016). These intrusions also occurred when a high cognitive load was imposed during a level-1 VPT task (Qureshi et al., 2010). These findings suggested the automatic calculation of what another person is seeing (Qureshi et al., 2010). Similarly, facing bias, as it occurred in Experiment 3, might evoke the automatic calculation of the perspective of a human-like object who appears to be facing the participants. This may induce the participants to execute erroneous egocentric transformations. This implies that the automatic adoption of others' perspective can be observed not only in level-1 VPT but also in level-1 SPT tasks. This suggests a similarity between level-1 VPT and level-1 SPT. In contrast, previous studies reported the spontaneous adoption of level-2 spatial perspective (Freundlieb et al., 2016; Tversky & Hard, 2009) but not level-2 visual perspective (Surtees et al., 2016). This inconsistency, seen in the context of the discussion in the previous section, suggests that level-2 VPT and level-2 SPT may be characterized by different processes. Using the facing bias as a probe (i.e., adopting a front-back symmetrical human-like figure) might help to elucidate the different kinds of perspective-taking and their automaticity.

However, it is important to note that our conclusion of the facing bias that occurs in a SPT task still remains speculative and premature. Future research will thus need to collect evidence that is more direct. In addition to a replication using a within-participant design, investigations of the link to interpersonal traits (e.g., social anxiety) and the administration of a structured questionnaire may be promising approaches for future researchers. It is expected that confirming and exploring the facing bias will contribute to the domains of both spatial and

social cognition.

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