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Updating spatial layouts mediated by pointing and labelling under physical and imaginary rotation

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The present experiments manipulated the modality in which participants communicated object directions (by pointing or verbal labelling) in a learned layout, and the mode in which they were required to rotate (physically or imaginary). The results showed that the pointing modality was strongly influenced by the mode of rotation (Experiment 1). Pointing was faster and more accurate in the physical than in the imaginary rotation. In addition, a different pattern of dimension accessibility was observed: equi-accessibility in physical rotation (front-back = right-left) and standard in imaginary rotation (front-back < right-left). By contrast, the verbal modality was less influenced by the mode of rotation. The same standard pattern of dimension accessibility and similar speed was obtained in physical and imaginary rotation. These results are explained by proposing a first-order embodiment, typical of ordinary pointing, which involves a low-cost sensory-motor updating of object positions and a second-order embodiment, most typical of language, which involves a represented (rather than physical) self and an object-to-frame high-cost updating.

Some animals develop a sophisticated spatial knowledge necessary for way-finding, migrating, establishing the boundaries of their territory, nesting and so on. Humans also have similar spatial skills when they avoid obstacles, navigate in the environment, or perceive and manipulate objects. However, only humans communicate a variety of spatial information to others by means of language. This peculiarity raises one important question addressed in this study: how language and spatial representation interface.

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A possible answer is that the same spatial representation system underlies both our interaction with the environment and our verbal communication about space. According to this view, language-based spatial representations would entail an embodied conceptualisation or a surrogate for experience (Clark, 1973; Glenberg, 1997; Johnson, 1987; Lakoff, 1987; Taylor & Tversky, 1992). Body-centred encoding of described layouts is suggested by studies of the accessibility of landmark locations arranged in the coordinate axes (Bryant, Tversky, & Franklin, 1992; de Vega, 1994; Franklin & Tversky, 1990; Franklin, Tversky, & Coon, 1992, Maki & Marek, 1997). For instance, Franklin and Tversky (1990) asked participants to learn a description of a layout and to mentally reorient themselves in this imaginary environment. Then they had to make speeded judgements about the location of landmarks prompted by the canonical direction labels. A standard pattern of dimension accessibility was obtained: The fastest responses were for objects placed in the head-feet dimension, followed by those in the front-back, and then in the right-left. The results indicated that the accessibility of a landmark's location is a function of where it is located within body-centred coordinates. Locations in the head-feet dimensions are easy to discriminate because this dimension involves two strong asymmetry cues: gravity effects and head-feet positions. Front-back is also quite ease to discriminate, as perceptual and motor activity differs in both extremes of the dimension. Finally, right-left might be the least discriminable dimension because the lack of asymmetry cues either in the world or in the design of the body. These results are interpreted as favourable to the notion that the meaning of spatial descriptions is "embodied" and similar to that derived from perceptual experience.

A different characterisation of the interface between language and space is that language-based representations markedly differ from those used in our interaction with the environment. The use of locative expressions involves some operations that probably are not necessary when people directly interact with environments. In particular, language may force speakers to choose a particular entity in the environment as an explicit frame with respect to which the target's position is to be expressed (Levelt, 1996). Furthermore, speakers have to map the target-frame relationships into the cardinal directions of language (de Vega, Rodrigo, & Zimmer, 1996; Johnson, 1987; Lakoff, 1987; Landau & Jackendoff, 1993). Consequently, verbal descriptions would involve some specific cognitive demands, or "thinking for speaking" operations (e.g., Slobin, 1987), that constrain or modify the resulting spatial representation.

In this paper we compare the localisation of landmarks mediated by direction labels with a similar task mediated by pointing, as a strategy to reveal how language constrains spatial conceptualisation. On the one hand, pointing to objects and describing their position are similar enough to make their comparison useful. In both cases there is a communication intention and a basic triadic schema with a speaker, an addressee, and a referent object. On the other hand, pointing provides a contrasting condition—a sort of baseline—to better understand the modality specific properties that emerge in verbal communication about space (de Vega et al., 1996). Thus, ordinary pointing is an indexical gesture which must be used in the current perceptual environment, the addressee must be present to focus on the pointed object, and the person who points always uses his or her own physical body as an implicit sensorimotor frame. By contrast, verbal communication is more flexible: People can describe the current perceptual environment, but also a memory-based or a fictitious environment, they can communicate layouts to an implicit or physically absent addressee, and they can choose an arbitrary frame (the speaker's own body, another person's body or an object) with respect to which the referent position is expressed.

De Vega et al. (1996) used the contrast between pointing and labelling modalities to explore the accessibility of the canonical horizontal directions. The same accessibility pattern for pointing and labelling (e.g., the standard one) would indicate that common embodied representations underlie the two modalities, whereas different accessibility patterns would indicate that language-based representations depart from those of non-verbal communication. The results obtained with labelling replicated the standard pattern reported in other studies (front-back faster than right-left), whereas with pointing the right-left responses were remarkably fast. This suggests that the standard pattern of dimension accessibility is not a universal feature of spatial representations, but a modality specific feature emerging from the processing of verbal descriptions.

However, there are some results in the literature that conflict with a simple modality specific interpretation. The classical paper of Hintzman, O'Dell, and Arndt (1981), using a multiple-choice pointing procedure, similar to the one used by de Vega et al. (1996), showed the same standard pattern for latencies which had been obtained in language-based studies. An important difference between the two studies is the mode of reorientation. In Hintzman et al., participants were asked to imagine themselves rotating and facing a given direction while their body remained still. By contrast, in de Vega et al.'s study participants were prompted to physically rotate to face a given direction. Thus, it seems that both the modality of communication (verbal and pointing) and the mode of rotation (physical or mental) may interact to modulate the resulting accessibility pattern of dimensions.

Another set of studies has manipulated the mode of rotation in a pointing task to analyse the difficulty of retrieving a novel perspective of a layout, collapsing data across pointing direction. The earliest data come from Angyal (1930) who asked blindfolded participants to point to the position of objects in a familiar room after physically rotating their bodies or after imagining they had rotated their bodies 180°. The participants' phenomenological reports and their pointing responses indicated that they did not have difficulties in updating the objects' positions in the physical rotation condition, but they found it extremely difficult to compute the new positions of the objects in the imaginary rotation condition. More recently, Rieser and his colleagues (Rieser, 1989; Rieser, Garing, & Young, 1994; Rieser, Guth, & Hill, 1986; Rieser & Rider, 1991) found that blindfolded participants were faster and more accurate in their pointing responses when they actually rotated to face a different orientation than when they merely imagined facing this new orientation. In addition, in the imagination task the latencies and errors increased as a function of the angular difference between their actual and imagined orientations, whereas performance in the physical rotation task remained constant across different angular orientations. According to Rieser (1989), in the physical rotation condition participants use proprioceptive feedback from locomotion that facilitates access to knowledge of the spatial structure from novel points, and little or no additional processing is involved. In contrast, in the imaginary rotation condition, participants have probably to make in the first place a mental rotation whose latency is a linear function of angular disparity (Farrell & Robertson, 1998), indicating that this process is an imagery analogue to physical rotation (Shepard & Cooper, 1982).

Similar differences between imaginary and physical rotation were obtained by May (1996), and by Farrell and Robertson (1998). May demonstrated that the sensorimotor information accompanying physical rotation should be adequate in order to facilitate updating. Thus, after several left and right turns that disoriented the participants with respect to their actual body positioning, they increased their response latencies and errors with respect to those obtained with ordinary physical rotation, although their performance was better than with the imaginary rotation. In turn, Farrell and Robertson demonstrated that the sensorimotor updating is mandatory. They introduced an ignoring condition in which participants physically rotated to face a new direction but had to try to ignore this rotation and to imagine that they were still facing the initial direction. The results showed a similar pattern of pointing latencies and errors in the imaginary rotation and in the ignoring conditions, suggesting that in the latter participants could not avoid making the proprioceptive updating, and they had to mentally "undo" this updating to re-establish the original orientation.

These studies strongly suggest that ordinary pointing benefits from the proprioceptive machinery that updates the perceptual environment around us. Despite our continuous reorientation and navigation in the environment, we manage to keep track of objects' positions in our peripersonal space in which our actions take place. Recent neurological studies confirm the automatic updating of the object-to-body relations after physical motions (Graziano, Hu, & Gross, 1997; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997). Some neurons in the ventral premotor cortex of monkeys automatically keep track of the sensorimotor "here and now", which means maintaining the constancy of the object positions with respect to the body, even in darkness. We suggest that this sensorimotor updating is also necessary for pointing, both when we signal to objects in the immediate visual field and when we signal to objects momentarily hidden (e.g., behind us).

The purpose of this paper is to test directly whether the modality effects observed for dimension accessibility are modulated by the mode of rotation (physical or imaginary). We assume that whereas pointing is strongly bound to the current body position, labelling is relatively independent of the body position. Therefore, performance in the pointing modality might be very sensitive to the mode of rotation: Participants in a physical rotation task should not find difficulties in computing the landmark positions because updating occurs automatically when they move their body; instead participants in an imaginary rotation task would have a conflict between the unchanged object-to-body relations and those demanded by the task. Thus, larger latencies and more errors in the imaginary than in the physical rotation mode should be expected. By contrast, performance in the verbal modality would be less sensitive to the mode of rotation, because in this modality the object positions are mapped into a mental framework rather than into the current sensorimotor framework. Therefore, similar latencies and error rates should be expected under both physical and imaginary rotation.

Another set of predictions concerns the patterns of dimension accessibility across communication modalities and modes of rotation. The verbal modality would be insensitive to the mode of rotation because it relies on a mental framework rather than on the current sensorimotor framework. Axial language determines that relativistic judgements between a target and a frame (e.g., the bike is to the right of me) are computed in the mental framework. These judgements are considerably harder for the right-left axis because the lack of discriminative cues between the two sides of the frame (e.g., the body). By contrast, in the front-back axis there are clear body and functional cues which permit discrimination between the two poles (Franklin & Tversky, 1990). Consequently, the standard pattern of dimension accessibility should be expected for physical (de Vega et al., 1996, Exp. 2a) and imaginary rotation (Franklin & Tversky, 1990).

The pointing modality would be sensitive to the mode of rotation. In physical rotation, participants actively use proprioceptive information from the actual movements of their bodies and, unlike in language, they do not need to establish relativistic judgements between a target and a frame. Instead, in imaginary rotation, they have to suppress proprioceptive information and rely on a mental framework, involving relativistic judgements between the target and the frame (the imagined body rather than the actual one), which are similar to those required by language. Therefore, we can expect a different pattern of accessibility in the two rotation conditions: fast right-left responses in the physical rotation (the reversed pattern obtained by de Vega et al., 1996, Exp. 1a), and slow right-left responses in the imaginary rotation (the standard pattern obtained by Hintzman et al., 1981).

In the present study, the basic procedures used in the pointing and the labelling tasks were designed to make them comparable. The experiments employed verbal descriptions of layouts similar to those of de Vega et al. (1996). In Experiment 1, participants learned the directions of landmarks and were tested for their locations by means of a four-choice arrow-key procedure. In Experiment 2, locative labels (front, back, right, or left) were used both to learn the landmark directions and to judge their positions at the test stage. At the learning stage, participants self-paced the sentences describing the landmarks either by pressing each time one of the four arrow-keys (Experiment 1) or by saying aloud one of the four direction labels (Experiment 2). At the test stage, participants were periodically asked to make physical or imaginary turns to face a given landmark, and at each new position they had to locate the direction of landmarks either by pressing the corresponding arrow-key (Experiment 1) or by saying the corresponding direction term (Experiment 2).

EXPERIMENT 1: POINTING WITH PHYSICAL OR IMAGINARY ROTATION

The purpose of this experiment was to examine the dimension accessibility in a pointing task, under physical or imaginary rotation. Previous studies with physical rotation tasks obtained a pattern of accessibility for directions in which only "back" was clearly slower than the other directions: front = right = left < back. When directions were grouped into dimensions either a reversed pattern (front-back > right-left; de Vega et al., 1996), or an equi-accessibility pattern (front-back = right-left; Rodrigo & de Vega, 1996) emerged. Consequently either a reversed or an equi-accessibility pattern should be expected for the physical rotation task in this experiment. A standard pattern should be expected for the imaginary rotation task in this experiment, replicating Hintzman et al.'s (1981) studies.

A potential confounding factor in the arrow-key pointing procedure is that response times could be influenced by motor biases. Although previous studies did not show such motor biases (de Vega et al., 1996, Exp. 1b; Farrell, 1979), we decided to introduce a control task. Prior to the experimental task, each participant performed a task involving speeded arrow-key responses to match arrow icons of the canonical directions presented on the computer screen.

Method

Participants. The participants were 63 introductory psychology students (44 females) from the University of La Laguna, who received course credit in exchange for their participation.

Material. Following de Vega et al. (1996) two narratives describing the layouts were used: the Square (with the town hall, the fountain, the sculpture, and the bandstand as landmarks) and the Fairground (with the dinosaur, the ferry wheel, the ship, and the castle as landmarks). Each narrative described first the general setting and the four landmarks as surrounding "you". A set of 24 sentences (6 for each landmark) was also constructed describing several visual features of the landmarks (e.g., the town hall has an arcade). However, no directional label was given at any moment.

Design. The experiment was a 2 × 2 × 4 × 4 mixed design involving Mode of Rotation (physical or imaginary) × Narratives (Square and Fairground) × Orientations (12, 3, 6, and 9 o'clock) × Directions (front, back, right, left). Mode of rotation was manipulated between-subject and the remaining variables were within-subject. Participants in the physical rotation task were asked to turn their body to face a given object and had to point to the true position of target objects. By contrast, participants assigned to the imaginary rotation task did not move from the initial orientation but instead they had to imagine that they had turned to face a given object, and had to point to target objects as if they had turned to this new orientation.

Experimental setting and procedure. Participants performed two consecutive tasks: the control task and the experimental task. The control task was designed to control for possible motor biases in the pointing responses, following de Vega et al. (1996, Exp. 1b). Participants entered a cabin and were seated in front of a computer with an expanded keyboard prepared for directional responses. The directional responses were made with the arrow-keys of the numeric keypad that had been visually enhanced by covering the surrounding keys with green cardboard. In addition, each of the four response keys was covered by a white square piece of paper with the corresponding arrow drawn on it. Participants were presented with an arrow icon on the screen pointing to one of the four horizontal directions, and they had to press the corresponding arrow key as soon as possible. They were requested to use the right-hand index finger for responses and to rest the finger on the key placed in the middle of the arrow keys (the key cap numbered 5) between trials. Participants performed a total of 100 trials distributed into five blocks of 20 trials with 5 trials per direction.

Once the control task was completed each participant was taken into the experimental setting. This consisted of a cylinder (radius = 1.5 m) made with opaque curtains hanging from the ceiling to the floor that provided a perceptually homogeneous environment from inside. The participant was seated in a chair with a portable computer equipped with an expanded keyboard in the centre of the setting. Four green circles (radius = 15 cm) were attached to the curtains, approximately at the participant's sight level, as cues of the four canonical positions. Participants were randomly assigned to each of the rotation conditions. In the physical rotation, the participant was seated in a rotating chair and the computer was placed on a moving table allowing the participant to turn his/her body as well as the computer when required. In contrast, in the imaginary rotation, the participant was seated in a fixed chair in front of a fixed table.

The procedure was similar to that described in de Vega et al. (1996, Exp. 1a) involving three phases. In the study phase, participants first read a short description of the layout and landmarks, and then self-paced information about the landmark positions at their will. Each time participants pressed an arrow key, a sentence describing the landmark in that position appeared in the middle of the screen, and the icon of the corresponding key was shown below. Participants read a total of 24 sentences (6 for each landmark). In the training phase, participants were given 16 verification trials (4 for each landmark). Each trial started with a name of a landmark shown on the screen, and participants were asked to push the corresponding arrow-key as fast as and as accurately as possible to indicate the position of the landmark. The response was followed by feedback. In the verification phase, participants were prompted to turn 90° (either physically performing or imagining the motion) to face a given landmark. In the physical rotation condition they were instructed to "turn 90° your body and the computer toward the [insert name of orientation landmark] and then imagine the landmarks around you". The four green circles around the participant were external aids to facilitate the physical reorientations. In the imaginary rotation condition, they were instructed to “turn 90° mentally toward the [insert name of orientation landmark] and then imagine the landmarks around you”. Then a block of 12 pointing trials followed with the same procedure as in the training phase, except that no feedback was given. For each narrative, seven turns were required starting clockwise (3, 6, 9, and 12 o’clock orientations) and then counterclockwise (9, 6, and 3 o’clock orientations) for the Square, and *vice versa* for the Fairground. Thus, a total of 168 verification trials (12 trials × 7 orientations × 2 narratives) were performed. Response latencies and accuracy measures were recorded by the computer for each trial. The order of the narratives was counterbalanced.

Results

Latencies 3 standard deviations from the participant’s mean (2.8 per cent of the data) as well as latencies for incorrect responses (13.5 per cent) were discarded. In addition, data from participants were eliminated, 4 in the physical rotation and 7 in the imaginary rotation task, because they made more than 30 per cent incorrect responses (most of them made very fast responses as if they were not following the instructions). Thus, the analysis of data were constrained to 26 subjects (17 females) for each rotation task. The principal analyses were performed on 144 verification items for each subject, corresponding to the non-trained orientations. Items of the trained orientation (12 o’clock) were submitted to a separate analysis (a total of 24 items). The two narratives did not differ significantly in either latencies or errors, and so we collapsed the data over this variable.

In the two experiments, analyses of variance (ANOVA) on latencies and errors were performed both for participants (F1) and for items (F2). In addition, analyses of covariance (ANCOVA) were performed on latencies for participants (F1), using as covariates each participant’s mean latencies for the four directions in the baseline task. Greenhouse-Geisser correction of the degrees of freedom was made whenever appropriate. Moreove, post hoc pairwise comparisons (Tukey’s HSD test) were carried out specifically in order to explore differences between pairs of directions. The baseline measures did not produce any significant effect as covariables, indicating that the experimental direction effects could not be confounded with motor biases. The alpha level was set at .05, unless otherwise indicated. Effects that are not mentioned are not significant.

Mean latencies and errors for each direction in the physical and imaginary rotation task, as well as latencies in the control task are presented in Table 1. Latencies and errors averaged across participants were positively correlated for the imaginary task, $r(24) = .75$, $p < .001$, and for the physical task, $r(24) = .41$, $p < .001$, indicating a lack of speed–accuracy trade-off in the data.

Pointing latencies. Mixed ANOVA showed a main effect of mode of rotation $F1\ (1, 49) = 11.8$, $MSe = 853{,}709$, and $F2(1, 132) = 143$, $MSe = 32{,}868$; participants in the imaginary rotation task were slower than those in the physical rotation task (1510 ms and 1316 ms, respectively). A significant effect of mode of rotation × direction was observed, $F1(3, 149) = 5.06$, $MSe = 34{,}705$, and $F2(3, 132) = 9.76$, $MSe = 32{,}868$. A test of simple effects was performed for each mode of rotation. Only in the imaginary rotation condition was a significant effect of direction obtained, $F(3, 150) = 7.21$, $MSe = 248{,}773$. Pairwise comparisons showed the following pattern for the imaginary rotation: front < back < right = left.

Further analyses were performed by grouping directions into the front-back and the right-left dimension. The interaction mode of rotation × dimension was significant, $F1(1, 49) = 6.68$, $MSe = 31{,}030$; and $F2$(1,

TABLE 1

Means and standard deviations for latencies (in milliseconds) in the layout and control tasks, and errors (percentage) in the layout for pointing (Experiment 1) and labelling (Experiment 2), as a function of direction

	Front	*Back*	*Right*	*Left*
Pointing (Exp. 1):				
Imaginary rotation				
Layout (SD)	1361 (452)	1470 (452)	1602 (706)	1591 (714)
Control (SD)	592 (95)	596 (107)	559 (94)	538 (85)
Errors	10.7	19.6	21.7	21.5
Physical rotation				
Layout (SD)	1342 (441)	1302 (457)	1334 (506)	1301 (455)
Control (SD)	568 (107)	588 (92)	551 (102)	543 (97)
Errors	8.0	11.0	9.0	9.0
Labelling (Exp. 2)				
Imaginary rotation				
Layout (SD)	1290 (274)	1358 (263)	1482 (367)	1516 (348)
Control (SD)	526 (87)	513 (105)	510 (101)	554 (112)
Errors	6.6	9.0	14.2	12.0
Physical rotation				
Layout (SD)	1337 (299)	1369 (289)	1484 (403)	1427 (265)
Control (SD)	495 (97)	477 (94)	496 (106)	517 (112)
Errors	9.7	11.7	17.6	16.9

132) = 23, *MSe* = 34,145. The test of simple effects showed faster responses in the front-back than in the right-left dimension, *F*(1, 50) = 9.37, *MSe* = 286,902 in the imaginary rotation, but not in the physical rotation. Figure 1a illustrates the dimension pattern of pointing in the two modes of rotation.

Pointing latencies decreased as a function of orientation (1517, 1452, and 1388 ms, for 3, 6, and 9 o'clock orientations, respectively), but this trend was not significant.

Pointing errors. Analysis on error data showed a main effect of mode of rotation, *F1*(1, 50) = 9.12, *MSe* = 563.42, and *F2*(1, 132) = 125, *MSe* = 46. Participants in the imaginary rotation made twice as many errors as participants made in the physical rotation (18 per cent and 9 per cent, respectively). A significant effect of mode of rotation × direction was also observed, *F1*(3, 150) = 7.93, *MSe* = 42.51, and *F2*(3, 132) = 8.88, *MSe* = 46. A test of simple effects was performed for each mode of rotation, revealing a significant main effect of direction in the imaginary rotation, *F*(3, 150) = 21.65, *MSe* = 119, but not in the physical rotation. The pairwise comparisons in the imaginary condition showed that: front < back = right = left.

When directions were grouped into the front-back and the right-left dimensions a significant effect of mode of rotation × dimension was observed, *F1*(1, 50) = 14.67 *MSe* = 26, and *F2*(1, 132) = 21, *MSe* = 42. A test of simple effects showed fewer errors in the front-back than in

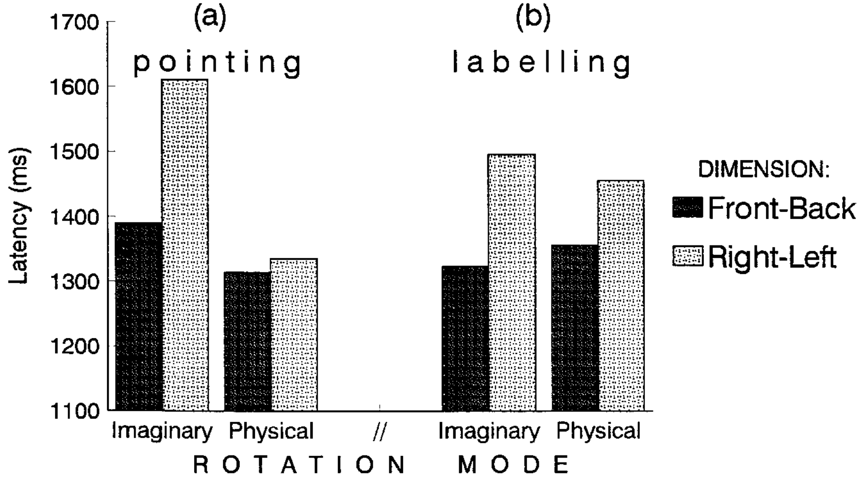

Figure 1. Experiments 1 and 2. Latencies as a function of dimensions and mode of rotation in (a) the pointing and (b) the labelling task.

the right-left dimension, *F*(1, 50) = 32.70, *MSe* = 111, for the imaginary rotation but not for the physical rotation (see Figure 2a).

Pointing errors remained quite stable across orientations (14.5 per cent, 13.6 per cent, and 13.5 per cent, for 3, 6, and 9 o'clock orientations, respectively).

Pointing latencies and errors in the 12 o'clock orientation. Because of the small number of items in this orientation (24) only very robust effects should be observed. Participants made more errors in the imaginary than in the physical mode of rotation (7 per cent and 3.7 per cent respectively), *F2*(1, 22) = 7.24, *MSe* = 17, showing the same trend as in the non-trained orientations. This mode of rotation effect is not surprising because the trained orientation was not tested in a static position but after doing three turns (either counterclockwise or clockwise).

Discussion

This study directly examined the pattern of dimension accessibility in pointing under physical and imaginary rotation. The results showed that participants were faster and more accurate in the pointing task when they had physically rotated their body than when they merely had imagined their body rotation, confirming other results reported with learned perceptual layouts (e.g., Farrell & Robertson, 1998; May, 1996; Rieser, 1989). Unlike some previous studies, we did not find any effect of the orienta-

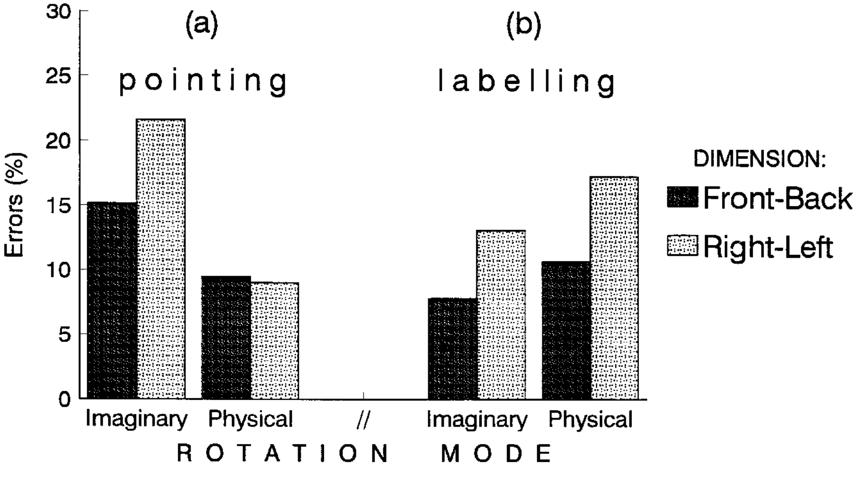

Figure 2. Experiments 1 and 2. Errors as a function of dimensions and mode of rotation in (a) the pointing and (b) the labelling task.

tion, either in the physical or in the imaginary rotation. This may be due to differences in the procedure of rotation: In other experiments participants moved back to the initial position after each reorientation, whereas in our case participants' reorientations were accumulative involving in every case a 90° rotation from the previous position. In addition, in those experiments each single trial usually involved a previous reorientation, whereas in the present study reorientation took place only once per each block of trials and thus participants kept the same point of view for 12 consecutive trials.

As expected, the patterns of dimension accessibility in each rotation mode differed. Participants were equally fast and accurate for the two horizontal dimensions (equi-accessibility pattern) when they were allowed to move their bodies. In contrast, participants were faster and more accurate for the front-back than the right-left dimension (standard pattern) when they imagined rotating their bodies. In addition a front-back asymmetry was observed in this condition. None of these trends can be attributed to motor biases, as participants' latencies in a control pointing task did not contribute significantly to the observed patterns.

The equi-accessibility pattern for physical rotation differs from the reversed pattern obtained by de Vega et al. (1996), but coincides with that obtained by Rodrigo and de Vega (1996) in equivalent experimental conditions. The standard pattern obtained for imaginary rotation is similar to that obtained by Hintzman et al. (1981) with a learned perceptual layout and an eight-choice pointing task (front-back faster than right-left and intermediate directions). This pattern is also similar to that obtained when verbal labels are used to locate landmarks (e.g., Franklin & Tversky, 1990).

To sum up, a critical factor modulating dimension accessibility in pointing is the mode of rotation. The next experiment moves to the verbal modality to analyse whether the mode of rotation has a similar or different influence on a labelling task.

EXPERIMENT 2: LABELLING WITH PHYSICAL OR IMAGINARY ROTATION

The purpose of this experiment was to examine dimension accessibility in a labelling task, under physical or imaginary rotation. To our knowledge, only one study has been conducted with physical rotation in the verbal modality, reporting the following pattern of accessibility for directions: front = back < right = left (de Vega et al., 1996, Exp. 2a). When directions were grouped into dimensions, the standard pattern emerged. A similar pattern has been obtained with imaginary rotation when the task demanded an egocentric perspective (Bryant et al., 1992; Franklin & Tversky, 1990) or a multiple perspective (de Vega, 1994; Maki & Marek, 1997). In all experiments either with physical or imaginary rotation, the standard pattern of accessibility for dimensions was obtained (front-back < right-left), but none has directly compared the two modes of rotation, with totally equivalent materials and procedures, as this experiment did.

As in Experiment 1 we controlled for possible response artifacts. Differences in the speech onset of the direction labels may bias the naming latencies of the direction judgments. No differences in naming latencies were found in English for the words up, down, left, and right (Farrell, 1979, Exp. 2). However, the Spanish direction words "frente" (front), "atrás" (back), "derecha" (right), and "izquierda" (left) involve a slight phonological bias in naming latencies, derecha = atrás < izquierda = frente, due to the features of the initial phonemes (de Vega et al., 1996). This phonological bias, however, was unrelated to the dimensional effects and was overridden by the experimental effects. In the present experiment, participants performed a control task in which they had to name the direction labels presented on the computer screen and the naming latencies were collected.

Method

Participants. Fifty-eight introductory psychology students (thirty-eight females) from the University of La Laguna received course credit in exchange for their participation.

Materials and design. The same narratives and materials of Experiment 1 were used in this experiment. The design was exactly the same as that in Experiment 1, involving 2 Mode of Rotation (physical or imaginary) × 2 Narratives (Square and Fairground) × 4 Orientations (12, 3, 6, and 9 o'clock) × 4 Directions (front, back, right, left). Participants in the physical rotation task were asked to turn their body to face a given object and had to name the direction words corresponding to the true position of target objects. By contrast, participants assigned to the imaginary rotation task did not move from the initial orientation but instead they had to imagine that they had turned to face a given object, and had to name the direction of a target object as if they had turned to this new orientation.

Experimental setting and procedure. The experimental environment was the same as in Experiment 1, except that the keyboard was not prepared for arrow responses. In addition the structure, number, and content of trials were exactly the same as in Experiment 1. Participants performed two consecutive tasks: the baseline task and the experimental task. The baseline task was designed to control for possible phonological biases in the naming responses, following de Vega et al. (1996, Exp. 2b). Participants entered a cabin and were seated in front of a computer prepared for registering the naming latencies. The session started with the calibration of the voice key for the participant. Participants were presented with a direction word in the middle of the screen corresponding to one of the four horizontal directions, and they had to read it aloud as soon as possible. On each trial, the direction word remained on the screen until the participant gave a naming response.

In the experimental task, participants were randomly assigned to each of the rotation modes. The participant was taken to the same cylindrical setting of Experiment 1, and was seated in a chair with a portable computer connected to another voice key. The voice key was calibrated for the participant. In addition, a tape recorder was used to register the participant's labelling responses. The procedure was similar to that described in de Vega et al. (1996, Exp. 2a) involving three phases. In the study phase, the participant first read a short description of the layout and landmarks, and then he or she gained information about the landmark positions naming a direction at will. Each time the participant named a direction, the experimenter situated behind him or her pressed the corresponding direction key to show a sentence, which described the landmark located in that direction. Each sentence appeared in the middle of the screen and the direction term named by the participant was shown below. In the training phase, each trial started with a name of a landmark shown on the screen, and the participant had to say the direction term (front, back, right, or left) as fast and as accurately as possible to indicate the position of the landmark. The response was followed by feedback. In the verification phase, participants were prompted periodically to turn 90° to face a given landmark, using the same instructions of physical or imaginary rotation as in Experiment 1, and then a block of trials without feedback followed. Labelling latencies were recorded directly by the computer and participants' responses were tape-recorded for further analysis of accuracy.

Results

Latencies 3 standard deviations from the participant's mean (1.8 per cent of the data), latencies for incorrect responses (12 per cent) and null responses (5 per cent of the data) were discarded. In addition, data from nine participants were eliminated (four in the physical rotation task and five in the imaginary rotation task, either because of technical failures of the tape recorder or because they had more than 30 per cent errors). The final sample included 23 participants (15 females) for the imaginary rotation task, and 26 participants (17 females) for the physical rotation task. The principal analysis of data was run on the 144 items for the non-trained orientations (3, 6, and 9 o'clock). Items of the trained orientation (12 o'clock) were submitted to a separate analysis. The two narratives did not differ significantly in either latencies or errors, and so we collapsed the data over this variable.

Mean latencies and errors for each direction in the physical and imaginary rotation task, as well as latencies in the baseline task are presented in Table 1. Latencies and errors averaged across participants were positively correlated for the imaginary task, $r(21) = .63$, $p < .001$, and for the physical task, $r(24) = .35$, $p < .001$, indicating the absence of a speed–accuracy trade-off in the data.

Labelling latencies. Mixed ANOVAs showed a main effect of direction, $F1(3, 140) = 13.62$, $MSe = 24{,}125$, and $F2(3, 132) = 5.47$, $MSe = 87{,}438$. The mean latencies for the four directions were: front = 1313, back = 1363, right = 1483, and left = 1471. The pairwise comparisons showed this pattern: front = back < right = left. The interaction mode of rotation × direction was significant only for items, $F2(3, 132) = 2.68$, $MSe = 27{,}019$. A test of simple effect was performed for each mode of rotation, showing a significant effect of direction both in the imaginary rotation, $F(3, 141) = 10.75$, $MSe = 258{,}097$, and in the physical rotation, $F(3, 141) = 4.60$, $MSe = 110{,}390$. The pairwise comparisons showed the general pattern (front = back < right = left) for the imaginary condition, and a similar pattern for the physical condition except that back did not differ significantly from left.

Further analyses were performed by grouping directions into the front-back and the right-left dimension. The interaction mode of rotation × dimension was significant only for items $F2(1, 138) = 5.57$, $MSe = 26{,}520$. The simple effects analyses showed the same pattern of labelling latencies (front-back < right-left) both in the imaginary rotation, $F(1, 47) = 20.70$, $MSe = 353{,}501$, and in the physical rotation task, $F(1, 47) = 8.07$, $MSe = 137{,}762$. Figure 1b, illustrates the dimensional patterns of labelling in the two rotation modes.

Labelling latencies significantly decreased as a function of orientation (1499, 1395, and 1358 ms, for 3, 6, and 9 o'clock orientations, respectively), $F2(2, 132) = 5.85$, $MSe = 166{,}231$. There is a possible confounding between the observed orientation effect and the blocks order. Therefore, we analysed separately the first three blocks of trials, and the final three blocks of trials. The latencies for the three orientations differed for the first three blocks (1600, 1469, and 1383 ms, for 3, 6, and 9 o'clock orientation, respectively), $F2(2, 66) = 5.97$, $MSe = 96{,}247$.

However, the latencies for the three orientations did not differ in the last three blocks (1398, 1322, and 1333 ms, for 3, 6, and 9 o'clock orientation, respectively). Consequently, the "orientation effects" were confined to the first three blocks of trials, which suggests that they were side-effects of practice rather than intrinsic effects of orientation.

Labelling errors. Mixed ANOVAs performed on error data showed a main effect of mode of rotation significant for items, $F1(1, 47) = 1.60$, $MSe = 377.72$, $p > 0.1$, and $F2(1, 140) = 13.24$, $MSe = 67.3$. Participants in the imaginary rotation task produced fewer errors than participants in the physical rotation task (10.5 per cent and 14 per cent, respectively). A main effect of direction was also obtained, $F1(3, 141) = 10.85$, $MSe = 53.7$, and $F2(3, 140) = 6.16$, $MSe = 139.4$. The error rates were: front = 8.1 per cent, back = 10.3 per cent, right = 16 per cent, and left = 15.4 per cent. The pairwise comparisons showed this pattern of accuracy: front = back < right = left.

When directions were grouped into dimensions fewer errors were found in the front-back than in the right-left, $F1(1, 47) = 15.84$, $MSe = 53.4$, and $F2(1, 142) = 18.06$, $MSe = 138.11$ (see Figure 2b). Labelling errors did not differ significantly among orientations (14 per cent, 9.6 per cent and 13 per cent, for 3, 6, and 9 o'clock orientations, respectively).

Labelling latencies and errors in the 12 o'clock orientation. Participants made less errors in the imaginary (10.8 per cent) than in the physical rotation task (17.3 per cent), $F2(1, 22) = 7.58$, $MSe = 16.2$. Participants gave also faster responses in the front-back than in the right-left dimension (1152 and 1296 ms, respectively), $F2(1, 22) = 4.60$, $MSe = 53{,}879$. Finally, participants showed a trend to make less errors in the front-back than in the right-left (11 per cent and 17 per cent, respectively), $F2(1, 22) = 3.66$, $MSe = 97.77$, $p = .068$. As in Experiment 1, we may notice that the rotation effect is not surprising because the 12 o'clock orientation was tested after three turns.

Discussion

The standard pattern of dimension accessibility was obtained in the two rotation modes: Front-back was faster and more accurate than right-left. The standard pattern was observed across all the orientations, included the learned orientation (12 o'clock orientation), and in the two rotation modes. The main difference between rotation modes in the verbal modality was that participants made more errors in the physical than in the imaginary rotation. None of these trends can be attributed to phonological biases, as participants' latencies in a control naming task did not contribute significantly to the observed patterns.

The experiment reveals that in the verbal modality, unlike in the pointing modality, the mode of rotation does not modify the pattern of dimension accessibility, which is the standard one. This result confirms partial evidence from other studies that had found the standard pattern in imaginary rotation (Bryant et al., 1992; de Vega, 1994; Franklin & Tversky, 1990; Maki & Marek, 1997) and in physical rotation tasks (de Vega et al., 1996). This experiment, however, provides a more direct confirmation of the invariance of dimension accessibility across rotation modes in the verbal modality.

REANALYSIS OF EXPERIMENTS 1 AND 2

Figures 1 and 2 illustrate that pointing and labelling produce a similar dimensional pattern with imaginary rotation, although they involve different dimension patterns with physical rotation. To test directly these cross-modality trends, we performed a reanalysis of the data introducing modality as a new variable. Thus, we will examine whether or not modality interacts with dimensions in each rotation mode. A lack of interaction—for a given rotation mode—would suggest that the same dimensional pattern exists both in pointing and labelling, whereas a significant interaction would indicate that the pattern of dimensional accessibility differs between the modalities. These analyses included data from Experiments 1 and 2, which is appropriate because the same materials, design, and pool of students were used in the two experiments. Absolute latencies in the pointing and the verbal tasks are not directly comparable because both tasks involve different response processes. Instead, we are concerned with the dimension × response modality interactions, under each rotation.

Absolute error rates are more comparable across modalities because they directly show failures in spatial judgements that, in principle, are unrelated to the response stages. The only exceptions to this rule are response related artifacts such as failures in the voice key or miss-typing in the pointing task, which were eliminated from the analysis. Therefore, we will examine the modality main effects as well as the interactions in the error analysis.

Comparison of latencies in pointing and labelling. Two separate response modality × dimension ANOVAs for imaginary and physical rotation, respectively were performed on latencies. With imaginary rotation, no interaction modality × dimension was found, demonstrating that the same standard pattern was shared by both modalities. By contrast, with physical rotation, a modality × dimension interaction was obtained, *F1*(1, 49) = 6.99, *MSe* = 13,233, and *F2*(1, 142) = 4.11, *MSe* = 47,404, indicating that the dimension pattern differed in the verbal (standard) and the pointing response (equi-accessibility).

Comparison of errors in pointing and labelling. Two separate ANOVAs for imaginary and physical rotation, respectively, were performed. With imaginary rotation, participants made more errors responding by pointing than by labelling (18 per cent and 10 per cent, respectively), *F1*(1, 47) = 10, *MSe* = 240.22, and *F2*(1, 142) = 98.46, *MSe* = 45.62. Furthermore, no interaction between response modality and dimensions was obtained, suggesting that the pattern of errors (front-back < right-left) was the same in pointing and labelling. By contrast, participants with physical rotation made fewer errors in pointing than in labelling (9 per cent and 14 per cent, respectively; significant for items), *F1*(1, 50) = .42, *MSe* = 238.67, $p > .1$, and *F2*(1, 142) = 26.11, *MSe* = 58.87. In addition, a strong response modality × dimension interaction was found, *F1*(1, 50) = 6.72, *MSe* = 37.76, and *F2*(1, 142) = 15.43, *MSe* = 58.87, resulting from a different pattern of errors in pointing (front-back = right/left) and labelling (front-back < right-left).

These analyses confirm that the same standard pattern emerged (both in latencies and errors) across response modalities with imaginary rotation, whereas different dimension patterns were observed in pointing (equi-accessibility) and labelling (standard) with physical rotation. It is also remarkable that pointing produced more errors than labelling with imaginary rotation, whereas pointing produced fewer errors than labelling with physical rotation. This might suggest that the computations involved in imaginary rotation are better performed in a language-mediated task, whereas the computations involved in physical rotation are better accomplished in a pointing task.

GENERAL DISCUSSION

The present experiments manipulated the modality in which directions were communicated (pointing or verbal labelling) and the mode of rotation (physical or imaginary). In previous studies it was observed that pointing and labelling directions determined different patterns of dimensional accessibility (de Vega et al., 1996), which suggested that embodied spatial representations may be different between the modalities. This study goes one step further, demonstrating that pointing was influenced by the mode of rotation (Experiment 1), whereas labelling was less influenced by the mode of rotation (Experiment 2). Pointing was faster and more accurate with physical rotation than with imaginary rotation. By contrast, labelling directions was similar under physical and imaginary rotation, though participants made more errors in the former condition.

A unitary notion of embodied spatial representations would predict a similar performance for pointing and labelling under imaginary and physical rotation. The results call for a revision of such a simple approach. We propose instead two kinds of embodiment for spatial representations that are compatible with our results: a first-order embodiment, which is anchored in current sensorimotor information, and a second-order embodiment, which is detached from sensorimotor information. First-order embodiment takes place when people compute object positions within a sensorimotor framework. This occurs when people navigate, avoid obstacles, reach for objects, or look in the direction of an object, typically in the current perceptual environment. A main feature of this first-order embodiment is that the updating of object positions, as the body moves around, relies on low-cost sensorimotor routines (Graziano et al., 1997; Rizzolatti et al., 1997). Proprioceptive cues of body motion automatically reallocate object positions. This updating is not constrained to objects in the visual field, but also applies to hidden objects (e.g., at the back, or occluded) and large-scale environments whose landmarks are not immediately perceived (Easton & Sholl, 1995).

The results of our Experiment 1 strongly suggest that pointing involves this sort of first-order embodiment, as the performance in pointing was better when the rotation of the current body position facilitates the sensorimotor updating, than when the imaginary rotation of the body makes irrelevant this updating. Other experiments reported in the literature also obtained different pattern of results for pointing under physical and imaginary rotation conditions (e.g., Farrell & Robertson, 1998; May, 1996; Presson & Montello, 1994; Reiser, 1989). Typically, after learning a perceptual layout, participants took longer to respond and made more errors when they merely imagined facing a different orientation, compared with when they actually rotated so as to face this new orientation. Furthermore, in the imaginary rotation task the participants' response latencies increased markedly with the angular magnitude of the rotation, whereas in the physical rotation task their latencies were insensitive to the angular magnitude of the rotation. The interpretation of such results is compatible with our notion of first-order embodiment. For instance, Farrell and Robertson (1998) conclude that in the physical rotation participants automatically update their changing spatial relationships as a result of self-movement, whereas in the imaginary rotation updating can be accomplished only by engaging in mental rotation. We should point out that our Experiment 1 used fictitious rather than perceptual layouts, so these results call for an extension of sensorimotor updating to pointing-mediated computations in fictitious layouts.

Second-order embodiment occurs when people compute object-to-frame relations within a mental framework. This entirely representational framework includes the objects or landmarks as well as the entity selected as a frame (either the self, another person, or an object). Even when the self is selected as a frame it should not be identified with the physical body. In fact, the represented self is "disengaged" from the current body position, and its "motions" are mental transformations (e.g., mental rotation) rather than physical motions. Consequently the updating of the layout following each "motion" in the mental framework does not benefit from the sensorimotor routines, but involves a high-cost mental computation of the new object-to-frame relations. Experiment 2 indicated that labelling involves this sort of second-order embodiment, as the performance was similar under physical and imaginary rotation. The actual body activity (either being still or moving) does not have appreciable effects on language-based spatial computations, which indicates that they are performed in an entirely represented framework. Otherwise, if participants were using a sensorimotor updating, their performance under physical rotation would improve as it did in the comparable pointing condition.

According to these arguments, pointing would be facilitated by physical rotation, and labelling would be facilitated by imaginary rotation (if any). Cross-modality comparisons yield data consistent with this claim: Pointing produced fewer errors than labelling under the physical rotation, and the reverse was true under the imaginary rotation. But how did participants deal with non-optimal conditions: pointing under imaginary rotation and labelling under physical rotation? In both cases participants' performance in terms of errors was impaired, indicating some sort of selective interference. When participants pointed to a landmark after an imaginary rotation strong interference between the actual and the imagined body position takes place, which increases latencies and errors. Similar interference effects have been reported in the literature. For example, blindfolded participants who pointed to objects in a previously learned layout from a point of view aligned to their body position were faster and more accurate than participants who pointed to objects after taking a contra-aligned point of view, different from their current body position (Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998; Shelton & McNamara, 1997). Farrell and Robertson (1998) asked their participants to physically rotate to face a new direction and they had then to try to ignore this rotation in their pointing judgements. The conflict between the proprioceptive information (from body rotation) and the imaginary information (the body should be considered still) impaired performance.

On the other hand, minor interference was observed (only on errors) in labelling under physical rotation. It may be possible that participants in this condition were receiving proprioceptive information that could be suppressed (with some additional effort) because it was irrelevant for mental framework-based computations.

Dimension accessibility

The overall differences in latencies and errors discussed here pointed to some operational features specific of pointing and labelling modalities. In turn the patterns of dimension accessibility are also informative about whether or not language-based spatial descriptions call for specific ways to access spatial information from memory. The standard pattern was found in labelling with both rotation modes (Experiment 2), whereas the equi-accessibility pattern was found in pointing-physical rotation (Experiment 1), which is the most representative of pointing in natural communication contexts. We may be tempted to conclude that the standard pattern is typical of language-based representations, and the equi-accessibility (or reversed) pattern is akin to pointing (e.g., de Vega et al., 1996).

However, a standard pattern, similar to the one obtained in the labelling tasks, was found in the pointing-imaginary rotation (Experiment 1). This may indicate that participants in this condition were using cognitive processes similar to those in labelling. Particularly they may have used a mental framework rather than the current sensorimotor framework to compute and update spatial relations. The mental framework involves a relativistic judgement of the position of the target with respect to a represented body which becomes autonomous from the sensorimotor body. To put it another way, pointing with imaginary rotation would induce a second-order embodiment, like in the typical verbal labelling condition. Interestingly, we may also notice that some spatial utterances with deictic terms such as "this" or "that" probably do not demand a mental framework computation. Like pointing, deictic terms involve an indexical rather than a relativistic function (e.g., Bühler, 1965). Therefore, the standard pattern would be associated with computing object-to-frame relations detached from sensorimotor information, which is most typical of verbal utterances (but not exclusively so).

Why is right-left particularly difficult when mental frameworks are involved? We propose that in this situation axes have to be assigned to particular features of the frame, e.g., the represented body (Logan & Sadler, 1996). Consequently the right-left symmetry of the body becomes a disadvantage in comparison with its front-back asymmetry. Notice that symmetry or asymmetry are not geometric features of the axes themselves, but they emerge from the mapping of axes onto the frame features (mostly its shape). In other words, in mental frameworks there is a sort of conjoining of geometric information from the "where" system and object information from the "what" system (e.g., Hermer-Vazquez, Spelke, & Katsnelson, 1999). By contrast, in sensorimotor frameworks, objects are directly located in the environment and their symmetry or asymmetry is irrelevant, because only the "where" system would be involved.

The contrast between labelling and pointing gave us the opportunity to reveal to some extent the "thinking for speaking" operations (Slobin, 1987) implicit in axial language. A general picture emerges from this and other studies in the literature reviewed in this paper. The parsing of physical situations in our interaction with the environment and even the parsing of situations mediated by pointing involves a first-order embodiment, which is directly anchored in a sensorimotor framework, uses proprioceptive information from the body for updating, and relies exclusively on the geometric information of the "where" system. By contrast, describing spatial relations requires one to choose a frame object, to map geometric axis onto the frame, to locate the target in the resulting topological regions, to ignore proprioceptive information, and to make mental transformations for updating. We do not feel that the latter operations override the embodied nature of mental frameworks. We propose, instead, that mental frameworks involve a second-order embodiment that requires an interface between the "what" and "where" systems.

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