Linguistic and Nonlinguistic Turn Direction Concepts

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Abstract. This paper discusses the conceptualization of turn directions along traveled routes. Foremost, we are interested in the influence that language has on the conceptualization of turn directions. Two experiments are presented that contrast the way people group turns into similarity classes when they expect to verbally label the turns, as compared to when they do not. We are particularly interested in the role that major axes such as the perpendicular left and right axis play—are they boundaries of sectors or central prototypes, or do they have two functions: boundary and prototype? Our results support a) findings that linguistic and nonlinguistic categorization differ and b) that prototypes in linguistic tasks serve additionally as boundaries in nonlinguistic tasks, i.e. they fulfill a double function. We conclude by discussing implications for cognitive models of learning environmental layouts and for route-instruction systems in different modalities.

Keywords: direction concepts, spatial knowledge, spatial language, route instructions

1 Introduction

Directions (angles) are basic spatial relations (e.g., Golledge 1995; Habel et al. 1995; Hintzman et al. 1981). The processing and representation of directional/angular information is essential for human spatial cognition, especially for wayfinding and the creation of mental spatial representations used in both linguistic and nonlinguistic tasks (e.g., Levinson 1996; Montello et al. 1999; Sholl 1988; Waller et al. 2004).

One of the first things we can observe about directional knowledge is that we do not conceptualize every potential direction that exists in our environments or to which our bodies could turn. That is, we do not demonstrate infinitely precise directional information. For most situations, qualitative information about directions—in the sense of a fairly small number of equivalence classes—is sufficient. The way this information captures quantitative information about direction, but only imprecisely or approximately, has been referred to as "qualitative metrics" (Frank 1996; Montello and Frank 1996).

Additionally, environments in which cognitive agents dwell can place supplementary constraints on possible turn directions. In city street networks which constrain possible turn directions, choices of precise angular information are rarely, if ever, necessary. Various studies show that even though humans may perceive angular information precisely, in city street networks—as well as in body and geographic spaces more generally—humans conceptualize and remember it with limited precision (e.g., Byrne 1979; Franklin et al. 1995; Moar and Bower 1983; Sadalla and Montello 1989; Tversky 1981). Verbal route instructions also reflect this qualitativeness; precise, very fine-grained, directional information is exceptional, not typical (Allen 1997; Denis et al. 1999).

If we consider directional categories to be conceptual spatial primitives, questions arise as to how many different categories of directions are necessary and how many categories humans employ in various tasks. Additionally, we can ask whether there are prototypical turning concepts around which less prototypical directions are organized (e.g., Vorwerg 2003). A question of specific interest is the difference between the conceptualization of directional categories in linguistic versus nonlinguistic tasks. In other words, does language influence the conceptualization of directions turns, and if so, how. The central topic of this paper is the question of how language influences the conceptualization of directional turns.

The rest of the paper is structured as follows: We provide a short overview of linguistic and nonlinguistic categorization of directions in spatial tasks. Subsequently we present the results of two experiments. Both use a grouping paradigm that allows us to identify conceptual structures on the basis of participants' similarity classifications. Experiment 1 applied a nonlinguistic task. Experiment 2 applied both a nonlinguistic task and a linguistic task in which participants were made aware that they would verbally label the directional classes. The results are discussed with respect to their implications for cognitive conceptual models of directions—as central parts in mental map theory, cognitive wayfinding assistance systems, and human-machine interaction.

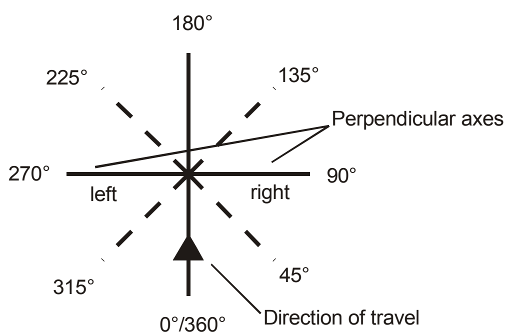

Fig. 1. Depiction of the direction terminology used in this article.

We follow the convention of using *italics* for examples of linguistic utterances such as *turn left*; SMALL CAPS are used to refer to a concept, for example, LEFT. To refer to turn directions unambiguously, we apply the following terminology depicted in Fig. 1. We use a full circle (360°) as reference. The counting of the angles starts at 6 o'clock in counter-clockwise direction. 6 o'clock is referred to as 0°/360°, perpendicular right (3 o'clock) is 90°, straight (12 o'clock) is referred to as 180°, and perpendicular left (9 o'clock) is referred to as 270°. Additionally we separate the perpendicular axis into a perpendicular left axis (270°) and a perpendicular right axis (90°). As the setting of the experiments is in the domain of route following, we have the additional perspective of turning as deviation from the main direction of travel (straight = 12 o'clock, 180°). A 90° right turn is equal to 90°, and a 90° left turn is equal to 270°, in our absolute terminology.

2 Linguistic and Nonlinguistic Categorization of Directions

The linguistic and nonlinguistic categorization of direction concepts is a highly active research area (e.g., Coventry and Garrod 2004; Crawford et al. 2000; Moratz and Tenbrink 2006; van der Zee and Eshuis 2003). Some of the main results, especially for linguistic categorization, can be summarized as follows:

1. Direction changes close to 90° left and right are referred to as (*turn*) *left* and (*turn*) *right* with little variation. Similar findings hold for the concept STRAIGHT, as in *directly straight*. In contrast, direction concepts beyond the main axes of left, right, and straight are not easily associated with a single linguistic term, and a plethora of composite linguistic expressions is used for referring to directions that are between the three main direction concepts—LEFT, RIGHT, STRAIGHT—in two-dimensional space. 'Hedge terms' are used to linguistically indicate gradation effects (Carlson-Radvansky and Logan 1997; Herskovits 1986; Landau 2003; Vorwerg and Rickheit 1998). We find expressions such as: *turn slightly right*, *go right 45 degrees*, *veer right*, *sharp right bend* and so forth[1].

2. The conceptualization of directions besides the main axes is not straightforward, and the sizes and the boundaries of sectors, or more generally, the semantics and applicability of corresponding spatial prepositions, are ongoing research questions (e.g., Coventry and Garrod 2004; Franklin et al. 1995).

3. The prominence of perpendicular axes as prototypes has been found in nonlinguistic tasks (Huttenlocher et al. 1991; Landau 2003; Sadalla and Montello 1989).

While linguistic analysis as a window to cognition allows us to shed light on the question of underlying conceptual structures, the influence of language on the conceptualization of spatial relations (and on cognition in general) is a subject of ongoing debate (Bloom et al. 1996; Crawford et al. 2000; Hayward and Tarr 1995; Hermer-Vazquez et al. 1999; Levinson et al. 2002; Malt et al. 2003, Munnich et al. 2001). There are, of course, extreme positions on the role of language in cognition: That it either completely determines nonverbal thought or that it has no influence at all. However, a majority of researchers probably subscribe to the idea that language has some influence on cognition, including specifically on the conceptualization of spatial relations, even though it is not completely determinative. These theories are often discussed under the term *linguistic relativity* (e.g., Gumperz and Levinson 1996)

[1] These example verbalizations are taken from a data set collected at the University of California, Santa Barbara. They were all instructions given for the same turning angle of 140.625°.

and sometimes further differentiated into weak and strong language-based approaches (Gennari et al. 2002). The question, however, concerns how profound this influence is and how it is manifested.

One of the major research approaches to addressing this debate is to compare different languages in their expression of spatial relations and how their expressions may in turn influence nonlinguistic thought (see, for example, Boroditsky [2001] and a reply by January and Kako [in press]). One of the criticisms that January and Kako (in press) bring forth is that effects of language on thought should be detectable not only in cross-linguistic studies but also within a single language. The study performed by Crawford et al. (2000) found such differences. In three experiments, they analyzed the role of the vertical axis in determining spatial relationships between a reference object and a target. In the linguistic task they used agreement ratings; in the nonlinguistic task, location estimates were employed. Focusing on the vertical axis, they concluded: "[W]e found an inverse relation between linguistic and nonlinguistic categorization of space. Specifically, the vertical axis, which serves as a category prototype in spatial language, serves as a category boundary in nonlinguistic organization of space." (Crawford et al. 2000, p. 234). It has to be noted, however, that serving as a prototype and serving as a boundary are not necessarily mutually exclusive. In other words, while in a linguistic task the boundary of a sector is different from a prototypical direction that represents the sector, in a nonlinguistic task prototype and boundary can coincide. This observation motivates our investigation of turn categorization in the present studies, consisting of two experiments in which we explore further the linguistic and nonlinguistic conceptualization of direction concepts in a navigation task. In contrast to the research by Crawford et al. (2000), our focus is placed on the horizontal axis.

3 Experiments

We conducted two experiments, both employing a grouping paradigm to assess the similarity—and thereby the underlying conceptual structures—of direction changes at intersections, i.e., turn directions. The first experiment[2] involves a nonlinguistic task in which participants group turns of various angles according to their similarity, followed by a linguistic task in which participants provide verbal labels for their groups. However, participants learn about the linguistic task only after the nonlinguistic task is finished. The second experiment comprises two conditions, administered as a within-subjects factor. The first condition replicates Experiment 1; participants group turns according to similarity, followed by verbal labeling. The second condition requires the same participants to repeat the nonlinguistic grouping task, but this time with the prior knowledge (acquired from participating in the first condition) that they would have to provide verbal labels for the groups. This design allows us to assess whether the linguistic component of the experiments influences similarity groupings and the conceptualization of turn directions.

[2] The first experiment reanalyzes a data set that has been reported in a technical report (Klippel et al. 2004) and places it in the context of linguistic and nonlinguistic conceptualization.

3.1 Experiment 1

In this experiment, we explored the underlying conceptual structure of directional knowledge. Specifically, we explored how many angular categories should be assumed as a basic set of equivalence relations for knowledge of directions in city street networks, and what the relation between angular sectors and axes is in this domain. We used a grouping task paradigm, which has long been an important method in psychology for investigating conceptual knowledge (e.g., Cooke 1999). The motivation behind the grouping task is that people primarily use conceptual knowledge to determine the similarity of given stimuli. Stimuli are placed into the same group of objects if they are regarded as similar, i.e., as instances of the same concepts; they are placed into different groups if they are regarded as dissimilar, i.e., as instances of different concepts. If other aspects of the stimuli and their presentation are controlled, as in our experiment, grouping tasks can provide important insight into the internal structure of conceptual knowledge. To conduct the experiment, we used an experimental tool developed by Knauff et al. (1997). The tool implements a procedure that is comparable to card sorting but automatically assists with generating experimental materials, presenting stimuli, and collecting responses as data.

3.1.1 Methods

Participants. Twenty-five students (9 female) from the University of Bremen were paid for their participation. Their average age was 25.6 years.

Materials. We used 112 icons to depict different ways to 'make a turn' at an intersection. We knew that participants would generally not distinguish turns differing by only 1°, and 360 different turn icons would make an unwieldy experiment in any case. So to design the icons, we applied the results of Klippel (2003) to the full 360° of two-dimensional space, adding bisection lines incrementally. We started with the prototypical egocentric direction concepts (excluding directly back) of 45°, 90°, 135°, 180°, 225°, 270°, 315°, and bisected the sectors several times until we had turns differing by increments of about 5° (5.625°). Each turn was depicted as a simple intersection with two branches (a path heading into the turn, and a path heading out of it). Turns in the back sector (angles between 337.5° and 22.5°) were excluded for graphical reasons, as very sharp turns were not clearly discriminable on the screen. This produced 56 distinct icons. We doubled the icons as a check on grouping reliability, resulting in 112 icons.

The icons were integrated into the grouping tool. Fig. 1 shows a screenshot of an ongoing experiment. The grouping tool divides the screen in two parts. On the left side, the stimulus material, consisting of all icons depicting possible turns at an intersection, are placed in a different random order for each participant. The large number of icons required scrolling to access all items. (Scrolling is a common procedure in interacting with computer interfaces; no problems were expected nor found during the experiments.) The right side of the screen is empty at the start; participants move icons to this side in order to group them during the experiment. The interface was kept simple so that participants could perform only the following four actions: Create a new group, Delete an existing group, Rearrange, Done.

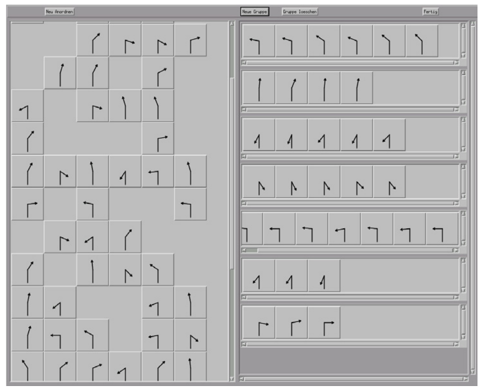

Fig. 2. The grouping tool (snapshot from an ongoing experiment) used in both experiments. On the left side, icons representing turns are presented in random order. On the right side, a participant has started to group icons according to her categories of turns.

Procedure. The experiment took place in a laboratory at the University of Bremen. Participants were tested individually. After arriving and obtaining some basic information, we explained to them the general procedure of the experiments and demonstrated the functionality of the grouping tool. Participants were advised to imagine the icons (in German: *Bildchen*) as schematic representations of possible turns at an intersection (in German: "*auf den Bildchen [werden] verschiedene Abbiegemoeglichkeiten an Kreuzungen schematisch dargestellt*"). They were told to place the icons on the left into groups on the right showing what they considered to be similar turning possibilities, in such a way as to maximize similarity within groups and dissimilarity between groups (in German: "*Bitte fasse dir ähnlich erscheinende Abbiegemöglichkeiten in einer Gruppe zusammen, d.h. das Abbiegen soll innerhalb einer Gruppe möglichst ÄHNLICH sein und möglichst verschieden zu den anderen Gruppen*").

After the grouping task, participants were asked to create verbal labels for each of the groups they had created, i.e., a linguistic description for the kind of turn represented by a group (in German: "*Bitte versuche im folgenden sprachliche Beschreibungen für die verschiedenen Möglichkeiten des Abbiegens zu finden, die Du in einer Gruppe zusammengefaßt hast*"). They were additionally advised to keep their description as short as possible.

3.1.2 Results

The groupings of each participant result in a 112 x 112 similarity matrix, the number of the icons used in this experiment on each axis. This matrix allows us to code all possible similarities between two icons simultaneously for all icons in the data set; it is a symmetric similarity matrix with 12,544 cells. Similarity is coded in a binary way; any pair of icons is coded as '0' if its two items are not placed in the same group and '1' if its two items are placed in the same group. The overall similarity of two items is obtained by summing over all the similarity matrices of individual participants. For example, if two icons (called A and B) were placed into the same group by all 25 participants, we add 25 individual ‘1’s to obtain an overall score of 25 in the respective cells for matrix position AB and BA.

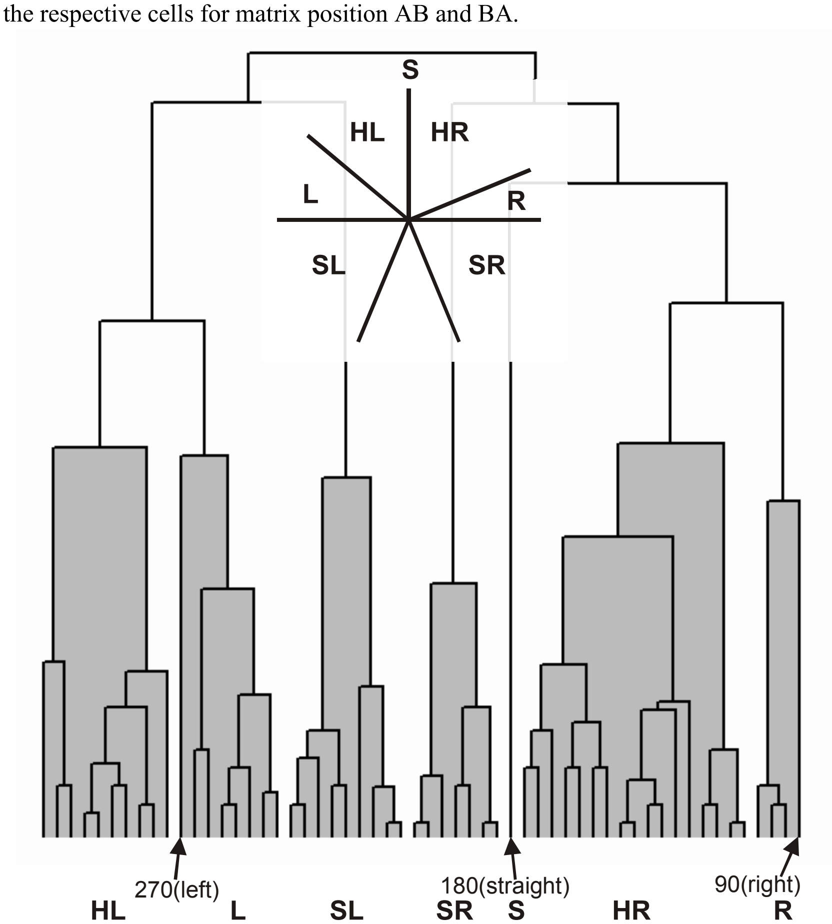

Fig. 3. Results of the cluster analysis in Experiment 1. Turn directions (180° is straight ahead) that are grouped into common clusters are shaded. We truncated the dendrogram at 56 clusters, which led to an under-representation of the width of clusters SL and SR in the dendrogram. The derived angular values are schematically represented in the directions model in the middle of the figure. Most importantly for the analysis here, there is clear perpendicular demarcation of the front and back plane indicated by the bold lines at 90° and 270°.

To analyze the categorical grouping data, we subjected the overall similarity matrix to a hierarchical cluster analysis with the software CLUSTAN. We applied average linkage (also known as UPGMA), as this method calculates the distance between two clusters as the average distance between all inter-cluster pairs. Average linkage is generally preferred over nearest or furthest neighbor methods (single linkage or complete linkage, respectively), since it is based on information about all inter-cluster pairs, not just the nearest or furthest ones. The cluster structure at the cut-off point for the seven-cluster solution is shown in Fig. 2. The dendrogram is truncated at 56 clusters, as the use of redundant pairs of identical icons had little effect on the similarity ratings—identical icons were placed in the same groups with only two single exceptions.

The following patterns emerge in these data. There are seven distinguishable direction sectors (categories). For convenience, we refer to them as HL (HALF LEFT, translated from the German expression *halb links*), L (LEFT), SL (SHARP LEFT), S (STRAIGHT), HR (HALF RIGHT), R (RIGHT), and SR (SHARP RIGHT). The sectors differ in angular size, with the widest being the sectors SR, HR, HL, and SL, less wide being sectors R and L, and the most narrow being the straight 'sector', which very precisely consists of only the single 'turn' of 180° (±2.8125°). This suggests that direction concepts depend on a combination of axes and sectors. Turns to the left and right are very nearly symmetric. Most importantly, while straight ahead (180°) remains a separate axis, the perpendicular axes (90°/270°) are grouped into the corresponding adjacent (front) sectors. This leads to a clear distinction between the front and the back plane at the perpendicular axes, with less discrimination among back turns than front turns.

From our own experience with verbal and graphical route directions and the conceptualization of turn directions (Klippel et al. 2004; Lovelace et al. 1999), we did not expect this clear demarcation at the perpendicular axes into front and back planes. However, this pattern has been noted by researchers interested in differences between linguistic and nonlinguistic conceptualizations of spatial relations (e.g., Crawford et al. 2000; Franklin et al. 1995). We therefore extend our analysis to verify that this demarcation is a robust pattern in our data. Following a suggestion by Kos and Psenicka (2000), we attempt to validate our interpretation of the cluster analysis by comparing different clustering methods. Fig. 4 shows the outcome of this comparison by juxtaposing three different clustering methods: single linkage, average linkage, and Ward's method. The analysis was performed using CLUSTAN with the default similarity measure of squared Euclidean distance. These three methods provide a range of possible clustering solutions and usually differ with respect to their outcomes (e.g., Aldenderfer and Blashfield 1984). Here, we are interested in possible differences with respect to the angle that indicates boundaries between sectors, i.e., the size of the sectors. Fig. 4 clearly shows the proneness of the single linkage method toward <u>chaining</u> as well as the characteristic of Ward's method to create compact clusters (for details, see Aldenderfer and Blashfield 1984). The parts of the dendrograms displayed show only the sectors that contain the perpendicular axes (90° and 270°) on the basis of a seven-cluster solution. For our purposes, however, we note two points of major importance:

- First, we confirm that across <u>all</u> methods, the perpendicular left-right axes at 90° and 270° are prominent. In fact, they provide the most prominent direction concepts in the sectors under investigation (the data are not collapsed, so there are two icons each for 90° and 270°).
- Second, <u>all</u> methods reveal the same pattern with respect to the perpendicular left-right axis: It provides the demarcation line between the front and back plane, and both axes are associated with turns in the front plane rather than those in the back plane. Even Ward's method, which is often applied in psychological research (e.g., Meilinger et al. in press) because it promotes compact and interpretable

clusters, does not change this pattern. (Ward's method did change the emergence of the straight cluster, but this is not our concern here.)

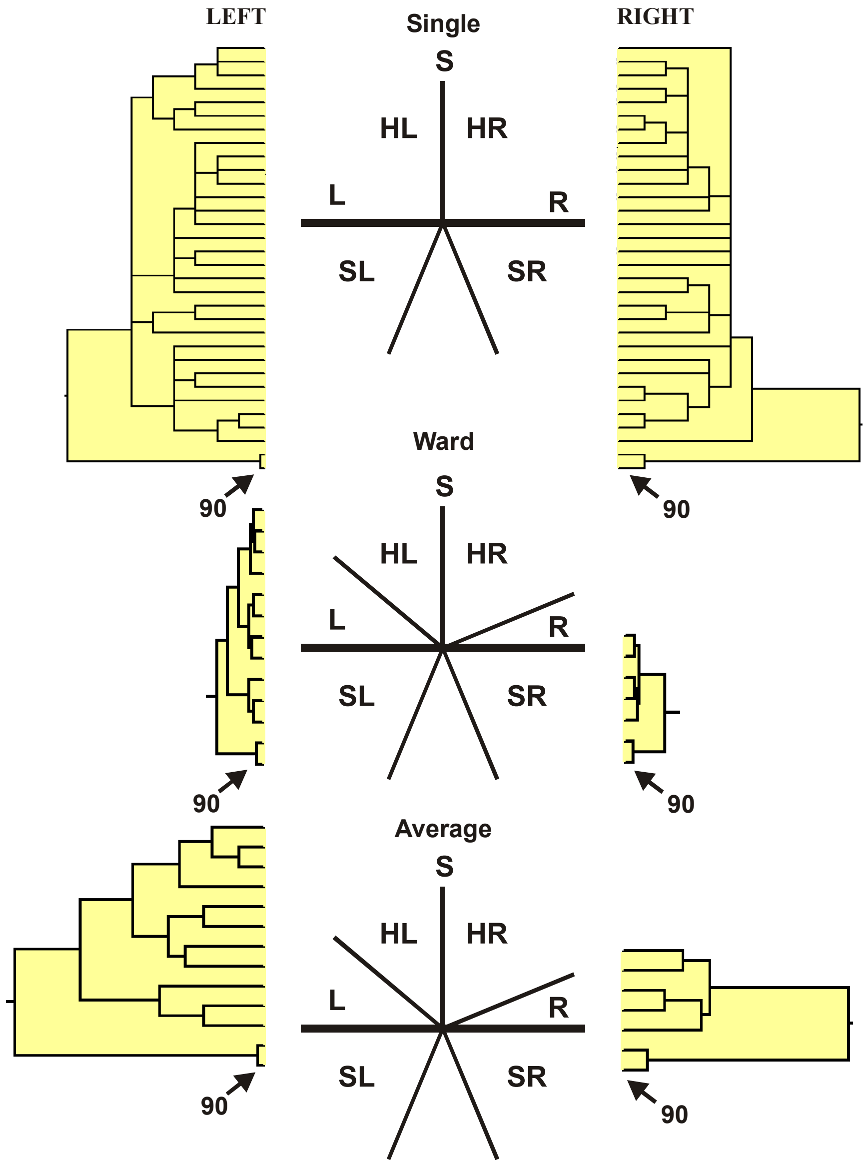

Fig. 4. Results for three methods of cluster analyses in Experiment 1: single linkage (as in the original analysis), Ward's method, and average linkage. The results for all three methods show the same pattern with respect to the perpendicular left- and right axes.

Results of the linguistic labeling task that participants performed subsequent to grouping the turns are not discussed in depth here. As an example, for a participant who created seven individual groups, we find: *gerade aus* (straight), *nach links abbiegen* (turn left), *nach rechts abbiegen* (turn right), *halblinks nach vorne abbiegen* (turn half left to the front), *halbrechts nach vorne abbiegen* (turn half right to the front), *scharf links nach hinten abbiegen* (turn sharp left to the back), *scharf rechts nach hinten abbiegen* (turn sharp right to the back).

3.1.3 Discussion

The results of Experiment 1 agree with previous research on prototypical, salient directions for the concepts RIGHT (90°), STRAIGHT (180°), and LEFT (270°) (e.g., Klippel 2003; Tversky and Lee 1998). More importantly, they are consistent (for LEFT and RIGHT) with the interpretation of linguistic and nonlinguistic spatial categorization derived from the work by Crawford et al. (2000), namely that axes which serve only as prototypes of linguistic categories serve additionally as the boundaries of nonlinguistic categories. Prototypicality of the perpendicular left and right axes is consistent with findings by Sadalla and Montello (1989), i.e., 90°, 180°, and 270° serve as prototype turns in a task that required participants to estimate the size of the turn they had just walked with a circular pointing device; both constant and variable errors were minimized around these axes.

We have to ask, however, what really influenced the similarity groupings that participants applied. Did they really treat this as a nonlinguistic task? Would the results have been different if participants knew in advance that they would have to create verbal labels for the groups that they created? Also, we can ask whether the design of the icons affected the categorization, particularly the fact that no sharp backward turns were provided to categorize? We conducted a second experiment to shed light on these questions.

3.2 Experiment 2

Experiment 2 employed the same setting, task, and materials as in Experiment 1, with a couple of modifications. We included some of the sharp backward turns, the back sector, that we left out in Experiment 1. Also, we did not double the icons this time, as we required participants to perform the turn direction categorization twice in two conditions. The first time, they did it in the same manner as in Experiment 1, not knowing in advance they would have to provide linguistic labels for the groups at the end. The second time, they repeated the categorization task again, but this time, they knew that they would have to verbally label the direction categories (the groups) after creating them. That is, participants were primed by the linguistic component of the first condition of the experiment before they performed the second condition. In this way, we could find out if an expectation to create verbally labeled categories would change the structure of the categories, as compared to when there was no expectation of producing verbal labels.

3.2.1 Methods

Participants. Twenty-four students (12 female) from the University of Bremen were paid for their participation in the experiment. Their average age was 24.9 years.

Materials. We slightly modified the design of the stimulus material from Experiment 1. We used the same angular increments (5.625°) for the turn icons, but we varied their overall appearance. Instead of using arrows we used regular lines without arrowheads (Fig. 5). Additionally, we included icons to represent turn concepts in the back sector. As it is barely possible, given the resolution of our system, to visually represent the sharpest backward directions, we still omitted icons for 0°/360°, 5.625° and 11.25°, and 354.375° and 348.75° (i.e., straight back and the two sharpest turns clockwise and counterclockwise). We also slightly modified the length of the legs to avoid the impression of a clock. Because participants would have to group the turns twice in two different conditions, and because we knew from Experiment 1 that doubling the turns had no effect on grouping, we did not double the icons in Experiment 2. Thus, each condition involved a total of 59 icons. Exactly the same grouping tool was used as in Experiment 1, with the same interface.

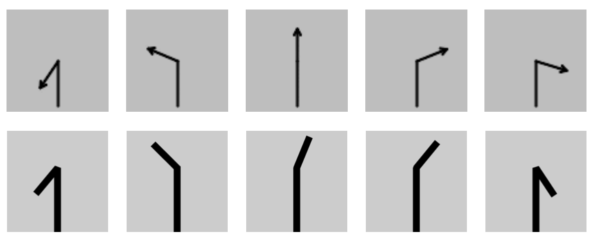

Fig. 5. Upper row shows example icons from Experiment 1; lower row shows example icons from Experiment 2.

Procedure. The procedure for Experiment 2 was the same as for Experiment 1, except that participants repeated the grouping task and the labeling task twice. That means participants performed the same two tasks twice with the only difference being that when they grouped the icons the second time, they would be aware of the linguistic component of the task. This results in the following sequence: Group the icons once, label the groups that were created, group the original set of icons again, label the newly created groups. Participants were not explicitly advised to pay specific attention to anything linguistic in the task. Otherwise, the instructions were the same as in Experiment 1.

3.2.2 Results

Participants created fewer groups in the second condition of the experiment (8.7) than in the first condition (10.3), although this did not quite reach statistical significance, $t(23)=1.99$, $p=.058$. We are particularly interested in whether knowing about the linguistic component of the task influenced the structure of the turn groups in the second condition of the experiment. Specifically, would the role of the perpendicular axis (90° for RIGHT, 270° for LEFT) change, either as a prototype or as a boundary? We therefore compared the results of the two conditions of Experiment 2 with each other and with the results of Experiment 1 with respect to the directional sectors the participants created. To make these comparisons, we assumed a seven-sector model and used the average linkage method in CLUSTAN.

Fig. 6 shows schematic depictions derived from the angular values found for the different sectors, for Experiment 1 and the two conditions of Experiment 2. We label them with the abbreviations for the sectors introduced above. The results for the first condition of Experiment 2 and for Experiment 1, in which participants had no prior knowledge of the verbal labeling task, are very similar. In particular, in both cases, the perpendicular axes of 90° and 270° demarcate the boundary of sectors coinciding with the demarcation of the front and back plane. The differences in the design of the icons between the two experiments apparently did not influence the role of the perpendicular axes; there was no difference in the boundary function of the turning directions 90° and 270° between Experiment 1 and first condition of Experiment 2.

In contrast, in the second condition of Experiment 2, this clear demarcation between front and back plane disappears. That is, the 90° and 270° turn directions are embedded in the sector but do not represent its boundary. For the RIGHT sector, 90° is in fact the bisecting line of the sector; for the LEFT sector, 270° is skewed toward the 'upper' end of the sector.

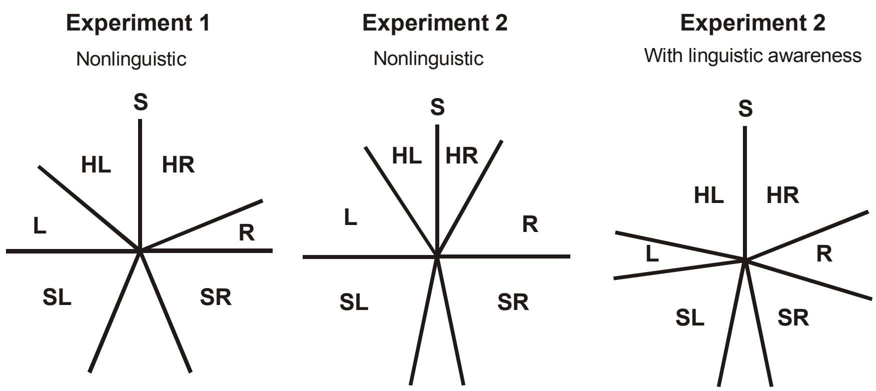

Fig. 6. Analysis of the directional categories using average linkage as a cluster method and assuming a seven-cluster solution. The figure compares the results of Exp. 1 with both conditions of Exp. 2 (without and with advance knowledge of the linguistic labeling task).

The third main axes, the one associated with the concept STRAIGHT, is unaffected by the experimental design. The presence or absence of a linguistic labeling task had no effect on the conceptualization of STRAIGHT as an axis—essentially a very narrow 'sector' of only one turn direction. We also find that the boundaries of the other sectors, particularly the diagonals between the main axes, vary, which agrees with many research results on the difficulty of locating them and on their gradation effects (e.g., Vorwerg 2003).

To provide deeper insight into the underlying conceptualization of the turn directions around the left-right perpendicular axes, we display the results of the hierarchical cluster analysis (average linkage, CLUSTAN) in Fig. 7. This figure is generated in the same way as Fig. 3 for Experiment 1. It reveals that in the second condition of Experiment 2, the 90° and 270° turn directions play different roles in their associated sectors. Here, they are embedded in the corresponding sectors instead of serving as their boundaries. In Experiment 2, one could question whether the seven-cluster solution in this analysis is the best cut-off point, but that is not the focus of this paper and would not affect our conclusion that the RIGHT and LEFT sectors are different when verbal labeling is expected, as compared to when it is not expected.

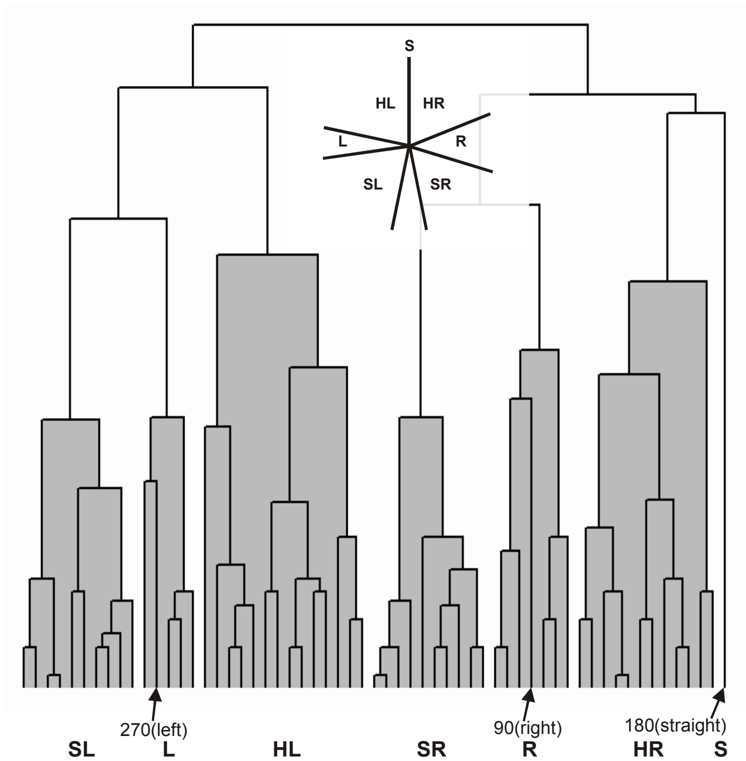

Fig. 7. Results of the cluster analysis for the second condition of Experiment 2, in which participants had advanced knowledge of the linguistic labeling task. Turn directions that are grouped into common clusters are shaded, assuming a seven-cluster solution. Most striking, the clear perpendicular demarcation of front and back planes that we found in Experiment 1 and replicated in the first condition of Experiment 2, has vanished. The 90° and 270° turns of perpendicular left and right are integrated into sectors and are not their boundaries.

To delve deeper into the underlying grouping processes in these tasks, Fig. 8 presents a portion of the raw data in order to further reveal the conceptual status of the perpendicular LEFT and RIGHT axes in the nonlinguistic first condition of Experiment 2 (labeled ‘without’ in the figure) and the linguistic second condition of Experiment 2 (labeled ‘with’). Fig. 8 shows frequency counts for the similarity groupings that were obtained for the 90° (right) turn direction with all other turn directions in the right half-plane (from approximately 16° to 174°). The highest count of being grouped together is obtained for the 90° value, of course, as every icon is placed in the same group with itself (there are no double icons in Experiment 2); hence, the maximum frequency value for this graph is 24. The frequency bars for the different turns illuminate the results presented above (compare to Figs. 6 and 7): In the nonlinguistic task, the similarity rating for 90° is higher toward the front plane (turns from 95° to 174°). In contrast, similarity ratings for the linguistic task yielded an even distribution around the 90° turn direction. Also, we observe a slightly higher tendency toward the back plane in the latter case. This means that in addition to the differences around the 90° turn direction, we also find differences at the boundaries of the half-plane, towards 16° and 174°.

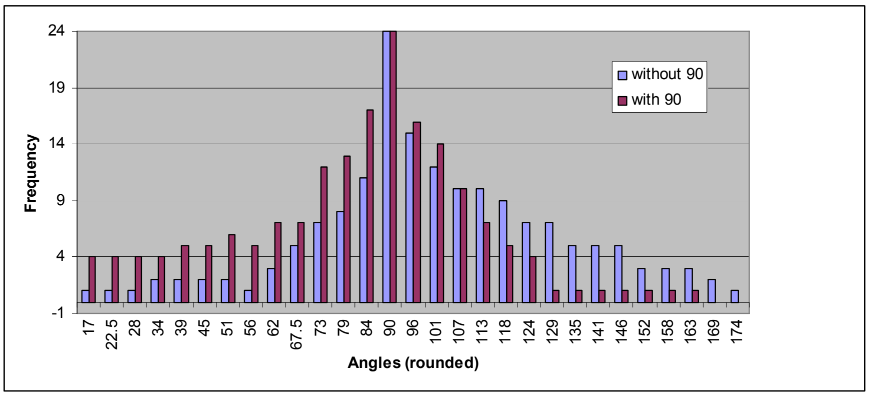

Fig. 8. Frequencies of similarity groupings by participants for the 90° turn (perpendicularly right) for the two conditions of Experiment 2, with and without advance knowledge of the verbal labeling task. As 24 students participated in this experiment, the highest possible similarity is 24 (Y-axis). The X-axis shows the angles displayed by the icons for the right side, ranging from 16° to 174° (rounded). Neither the straight angle (180°) nor any of the turns to the left side were ever placed into the same group as the 90° right angle.

4 General Discussion

We presented two experiments in this paper that examined how directional turns of various sizes are grouped into similarity classes. We are interested in the structure of these groupings that emerges when subjected to cluster analysis, and specifically if there are different underlying conceptual structures for turns depending on whether people expect they will have to verbally label the turns (as in giving route instructions) or not. In our first experiment, in which people were not informed about the verbal task, our results clearly indicate that the perpendicular right-left axes strongly demarcate between the front and back heading planes. Furthermore, these axes are associated with right and left sectors in the front plane, but not in the back plane. Thus, precise right and left turns apparently function as the boundaries of right and left sectors. These conclusions held across several clustering methods.

To validate these findings, we conducted a second experiment in which we repeated the tasks of Experiment 1, with a slightly modified stimulus set. This produced results that largely replicated those from Experiment 1, particularly with respect to the role of the right-left axes. However, we also repeated the grouping and labeling tasks in Experiment 2 with the same set of participants; because they had performed the verbal labeling task already, participants knew they would be generating verbal labels. Thus, their groupings might differ because of an expectation that the groups would have to correspond to verbal classes. In fact, the groupings did differ in this second condition. In particular, the right-left axes no longer emerged as sector boundaries, but as central tendencies of sectors. Our results therefore support the idea that there are differences in the linguistic and nonlinguistic conceptualization of directional turns. Given that it was only the awareness of a linguistic component in the second condition of Experiment 2 that created a different similarity grouping of turn directions, we conclude that there is, indeed, a difference between the conceptualization of directions in linguistic and nonlinguistic tasks. This difference most prominently manifests itself in the role of the perpendicular left and right axes. Our results seem to be in line with the findings from Crawford et al. (2000) that these axes change their function from demarcating the boundary (and the prototype) of a sector in nonlinguistic conceptualization to representing prototypes (but not the boundary) in linguistic conceptualization.

While Crawford and collaborators investigated the conceptualization of directions represented vertically and placed their focus on spatial relations that could be labeled as *above*, we investigated turn directions as part of a scenario in which they were part of a horizontal street network. Thus, one can account for the demarcation of front and back planes in our experiments by the nature of the test domain. If we adopt the movement perspective of an agent traveling along a street network, than front and back planes are sensibly demarcated in the way we found. As the name indicates, a turn of more than 90° left or right, i.e., into the sectors <90° or >270° (see Fig. 1), changes the overall direction from forward to backward. For the process of goal directed wayfinding, this is highly pertinent.

That we do not find this distinction in the second condition of Experiment 2, which entailed a linguistic component, might indicate that the conceptualization of directions affording verbalization relies on slightly different principles. It could be related to the linearization that is present in every linguistic description (Denis et al. 1999; Levelt 1989). If we think of a route as a sequence of individual decision points, and a linguistic description is provided for every single decision, focus is placed on each decision point as such, without respect for areas beyond the individual decision point. A nonlinguistic task, on the other hand, might focus on larger-scale aspects, in which the position of subsequent decision points is of interest.

Our experiments were not set up around an entire route or environment; their focus was completely on individual intersections. However, the distinction we suggest might contribute to a framework for the underlying cognitive processes for conceptualizing turns that would help explain these differences. Language is sequential, and the focus of verbal route instructions in the case of turn-by-turn instructions is on decision points that are associated with changes in travel direction. When performing the linguistic task of giving route instructions, therefore, this decision-point focus leads to the more classical characterization—in terms of qualitative directions—in which the linguistic concepts of LEFT and RIGHT serve as sectors centered around the orthogonal axes of 90° and 270°.

With respect to modeling directional knowledge generally, we can confirm that a combination of sectors and axes, as, for example, suggested in the double cross calculus by Freksa (1992), is a sensible approach. We clearly find that a) the concept STRAIGHT is an axis (independent of linguistic influences) and that b) the perpendicular left and right axes are playing a dominant role. We can also confirm the suggestions by Franklin et al. (1995), Montello and Frank (1996), and others that sectors have different sizes.

6 Future Work

The similarity classes established in these experiments are symmetric. If a participant places two icons into the same group, the two icons are treated as being equally similar to each other. Early research by Amos Tversky and his colleagues (e.g., Tversky and Gati 1978) showed that measured similarity relationships are influenced by several factors and are not necessarily symmetric. It would therefore be desirable to assess the similarity of turn directions with methods other than grouping that would allow for establishing asymmetries in similarity.

More important, however, would be research on the effect of contextual factors on turn similarity judgments. The experiments reported in this paper employed a simple, relatively decontextualized setting in order to focus on the differences between linguistic and nonlinguistic categorization. Research on the assignment of linguistic labels to spatial relations (also called spatial terms or projective spatial terms) has provided a great deal of evidence on the relevance of contextual factors. Several theoretical frameworks have been developed that characterize and formally describe these factors (e.g., Coventry and Garrod 2004; Regier 1996). Our own research on contextual factors in route instructions (Klippel et al. in press) confirms the importance of these factors for the case of a cognitive agent moving within spatial network structures. We found different conceptualizations depending on the complexity of movements in street networks, and the combination of structural and functional characteristics at an intersection (including the presence of landmarks) that provide a context in which certain actions take place. An example was the shift from a pure direction concept to a combination of coarse direction plus ordering at a complex intersection with turn branches that were themselves equivalent: *take the second left* instead of *veer left*. Another important example was the anchoring of actions by employing landmarks.

The degree to which these results, based on a linguistic analysis of direction concepts, are applicable to nonlinguistic conceptualization is an open question and requires more research. Results like those presented in this paper suggest we cannot assume that a linguistic analysis provides us with sufficient insights into the underlying nonlinguistic conceptual structure of actions taking place in city street networks. We may need a new approach challenging the assumption that a common conceptual structure underlies the linguistic and pictorial externalization of route knowledge (Klippel 2003; Tversky and Lee 1998).

An important research issue involves the implications of combining graphic and linguistic representations in navigation systems. For example, should the design criteria for mobile (in the field) assistant systems differ from those for offline systems on the basis of the influence of motion on the conceptualization of environmental information? Does a cognitive agent who is guided through a city street network with instructions for individual decision points build up a better overall mental map of the layout of the city if the instructions—verbal or graphical—are schematized according to the nonlinguistic direction model or to the linguistic direction model?

Finally, questions about designing for individual, cultural, and modality specific conceptualization strategies are ongoing concerns (e.g., Mark et al. 1995). We believe that research on formally characterizing cognitive processes should be diversified in light of evidence on individual and cultural personalization.

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