Two Path Prepositions: Along and Past

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Abstract. We present results from a series of experiments, where relevant factors for the use of path prepositions were examined. We were especially interested in the concepts behind the German prepositions "entlang" and "vorbei" (similar to "along" and "past"). After exploring the basic properties human beings attribute to these prepositions, we systematically varied those properties to investigate their impact on the selection process and the corresponding speech production latency. The results indicate that parallelism and distance between the outline of a reference object and a trajectory are key concepts in this context.

Key Words.
communication of spatial information, spatial reasoning, empirical studies, path prepositions

1 Motivation

Although path prepositions such as *along, across, past* are often part of path descriptions or navigational instructions, only limited effort has been put into investigating their properties and into modeling them (see [4], [9], [1], [8]). Most research emphasizes the importance of turns and relations/prepositions such as distance-dependent (e. g., "close to"), directional (e. g., "left of"), and topological relations (e. g., "in"). This imbalance is illustrated by the wide range of publications from different research communities on those relations (see, for example, [7], [3], [2], [14], [6], [10], [11], [16]).

This is unfortunate as path prepositions offer some unique means for route descriptions. On one hand, a lot of information can be conveyed using a single path relation [13]. Consider, for example, a path following the shape of a river. Describing it can be achieved by the simple use of "along", while otherwise a sequence of instructions would have to be generated. On the other hand, path prepositions relate to the *shape* of an object, whereas distance-dependent, and directional prepositions do not. Neither do topological relations, as they establish connections between sets. Therefore, path prepositions can enrich route instructions by introducing shape, and they can also contribute to reducing the complexity of route instructions.

A first model for the computation of path relations and prepositions was introduced by Blocher et al. [1]. The approach was based on the determination of a *conceptual trajectory*, that was extracted by means of abstraction from either a static path, a motion trace, or a tight group of objects. The authors focus on the abstraction process and describe the procedure of computing a path relation only informally. A categorization of path relations into *source oriented, goal-oriented, sub-path locating* and *path locating relations* is presented. Contextual factors (object sizes, speed, field of visual attention, communicative situation) are mentioned as being influential in the selection process of path relations. They then give a description of the computation for "along", which first calls for the identification of (a) suitable reference object(s) and/or clustering of several objects. This object (or cluster of objects) is then abstracted and a conceptual trajectory is extracted from its boundary. This trajectory is compared with the path to be described, and the "similarity" of both trajectories and their closeness determine the applicability of the relation.

A second model was proposed by Kray and Blocher [8], where they introduced the notion of *basic path relation* along the lines of Gapp's work on spatial relations [5]. They defined six basic path relations, each modeling a change (or lack of change) of either distance or angle. As they were primarily concerned with identifying the basic meanings of path relations, they focussed on the analysis of simple straight lines. Subsequently, they extended the model to the more general case of arbitrary shaped poly-lines. They also tried to identify fundamental concepts underlying some common (German) path prepositions, and map them onto basic path relations. Nevertheless, they cautioned that there is no 1:1-correspondence between path relations and prepositions, and that contextual factors need to be taken into account.

However, a systematic empirical study on the relevant factors for path prepositions is still lacking. We present such a study on the German path prepositions "entlang" and "vorbei", which can roughly be translated to the English prepositions "along" and "past"[1]. We selected those two candidates for several reasons: Firstly, both approaches predict that "along" requires parallelism between the path and the outline of the reference object, which allows for a direct verification. Secondly, "along" is frequently used, especially in urban environments, e. g., when giving instructions to follow a specific road [13]. Thirdly, "past" is not rigidly specified in the formal models and we wanted to investigate its fundamental characteristics. Finally, these two path prepositions can also function

[1] We will use these rough translations instead of the German prepositions throughout the paper to facilitate reading.

as the opposite of each other, and we were interested in whether this applies always or just in some specific cases.

It has to be mentioned that the linguistic properties of the terms used in this study were not the focus of our research. Therefore, we did not explicitly analyze, whether a term was used, e. g., as a preposition or an adverb. Throughout the paper, we denote all expressions, which describe a path relation in natural language, as 'path prepositions' (although they might not be used as prepositions in all cases). The term 'path relations' is used to identify semantical or geometrical relations between a number of path-like objects. However, Di Meola [12] has presented a linguistic analysis of the use of the German adposition "entlang" (along), where he he distinguished two components of its use: a PATH-GOAL-scheme, which refers to a change of locations while moving from a point of departure to a destination, and a LINK-scheme, which establishes a (static) relation between the path and a reference object (RO). He further suggested that the distance between the trajectory and the RO should be small and more or less constant in order to allow for the use of "entlang". In emphasizing the importance of parallelism and closeness of a trajectory to the RO, Di Meola's suggestions resemble ours in their geometrical aspects. However, unlike Di Meola, we grade the importance of parallelism and closeness: we assume that it is more important that a trajectory is parallel to the RO than that it is close – as long as the distance is small enough for perceiving the trajectory as being influenced by the RO.

The remainder of this paper describes the empirical study and its experiments in detail. In Section 2, we present a paper and pencil study, where subjects were asked to produce "ideal" trajectories for given path prepositions. The results from this experiment suggest that parallelism and closeness are important concepts, which we varied in the subsequent experiments. In Section 3 we first verified the importance of these concepts before systematically deviating from parallelism while manipulating closeness. The results from these experiments are discussed in Section 4. Section 5 sums up the paper and gives an outlook on future research.

2 Production of trajectories

The first experiment in the series was a paper and pencil study, where subjects were asked to produce "ideal" or "prototypical" trajectories for given German path prepositions.

2.1 Method

Subjects Exactly 28 students of the Saarland University took part in the experiment. All subjects were native speakers, and were not paid for their participation.

Material The experiment was designed as a paper and pencil test. Each item consisted of a reference object, a start point, an end point and a literal route description, e. g., "Gehe entlang des Gebäudes" (Go along the building). The subjects were also presented with a rating scale[2], on which the subjects could mark how easy (or difficult) they found the task of drawing the trajectory between start and end point. Each item was printed on a DIN A4-sized sheet of paper. At the top there was the written description, followed by a drawn frame sized 16 cm x 20 cm and the rating scale at the bottom of the sheet. The RO, the start point, and the end point were displayed within this frame.

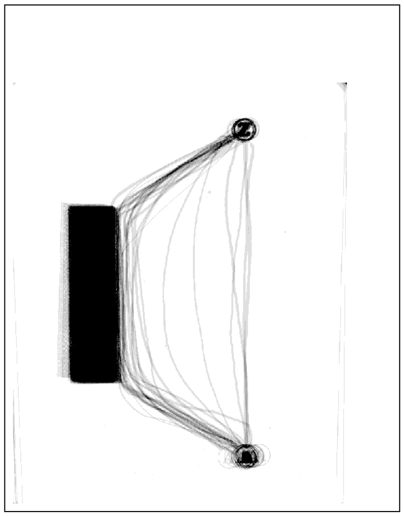
We will report the results for two different ROs: The first one was a rectangle sized 2 cm x 8 cm, the second one consisted of two rectangles (sized 2 cm x 8 cm, and 3 cm x 2 cm). These rectangles were arranged in such a way that they formed an "L-shaped object standing on its head" (cf. Figure 1). In the case of the plain rectangle, the start point was located 6 cm to the right and 4 cm in front (below) of the lower right corner of the RO. The end point was 6 cm to the right and 3 cm behind (above) the RO's upper right corner. In case of the L-shaped object the start point was 2.5 cm from the right and 4 cm in front of the lower right corner, the end point 3 cm the the right and 3 cm behind the upper right corner. Along with each of these two items we gave one of the following two descriptions: "Go along the building" or "Go past the building". The four resulting items of our interest have been tested in conjunction with other items. These other items differed in the shape of the RO and in the accompanying literal descriptions, e. g., "Go along the river" or "Go around the tower". Altogether, we designed 36 different items, each on separate sheet of paper. These 36 sheets were randomly shuffled and combined with a literal instruction for the experiment

Procedure The subjects were tested in two groups at the beginning of two lectures on computer science. Every subject received the 36 different items and the instructions for the experiment. They were told to read the instructions carefully and to wait for the start signal. After the signal was given, they had to draw what they thought is the best matching trajectory between start and end point for each of the given combinations of RO and description, and then to judge the difficulty of the task.

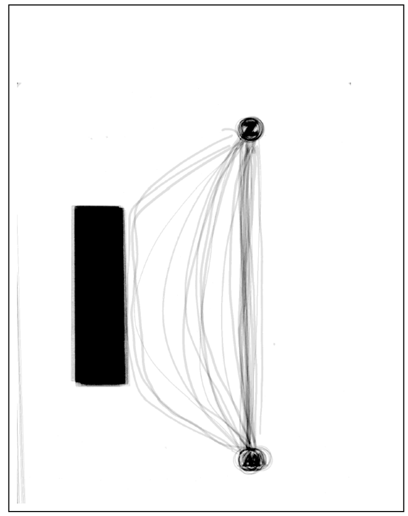
2.2 Results

The subjects' drawings were then digitized and prepared with image processing methods. We implemented a custom software system to compute critical parameters, which characterize the course of the trajectories in three regions: FA, the area in front of the RO; NA, the one next to the RO, and BA, the area behind the RO (cf. Figure 2). We calculated the distance of the trajectory t to the RO in discrete steps, and interpolated the area between the trajectory and RO in the regions of interest. In the context of the questions investigated in this paper, region NA is most relevant: If parallelism and proximity are significant in the

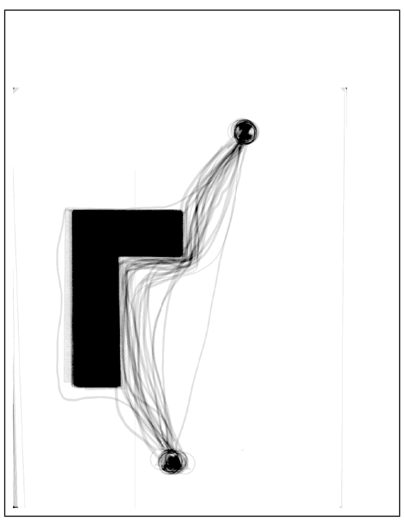
[2] We will not report the ratings that were given by the subjects in this paper.



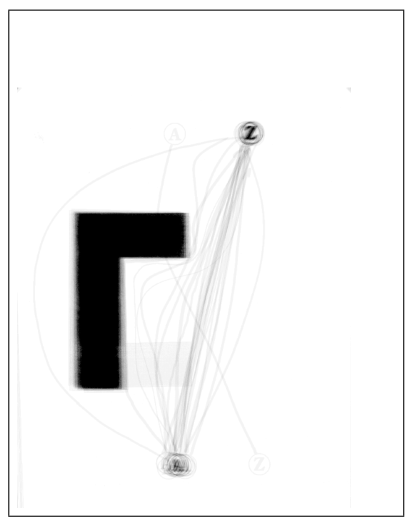
(a) “Go along the building”



(b) “Go past the building”



(c) “Go along the building”



(d) “Go past the building”

Fig. 1. The four cases of interest: Each picture shows a superimposition of the trajectories produced by the participants.

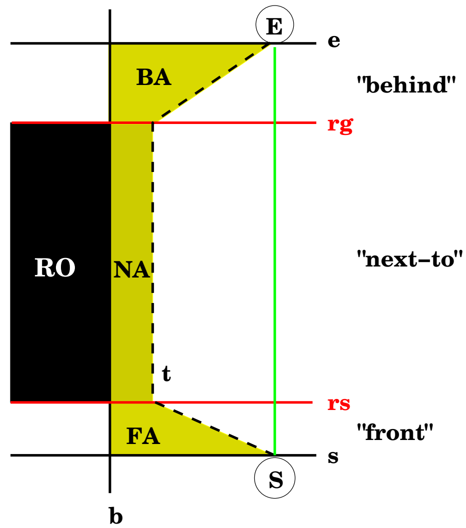


Fig. 2. Schematic description of the regions used for the analysis

case of “along”, the prototypical trajectory drawn to characterize “along” should be closer to the RO than the one drawn in the case of “past”, and its distance to the RO within NA should only vary minimally.

This is what we did indeed observe. On the average, the entrance point of the “along”-trajectory into NA (18 mm) was more proximal to the RO than the one for “past” (49 mm), $t(27) = 2.4, p < .05$. The same is true for the exit point (17 mm vs. 49 mm), and also holds for the average distance within NA (13 mm vs. 47 mm). Finally, within NA there was less variance in the case of “along” (5.02) than in the case of“past” (7.14), $t(27) = 2.39, p < .05$. Obviously, subjects moved closer to the RO with “along” in mind than with “past”. They kept a constant distance relative to RO in both cases. A similar pattern was observed for the L-shaped RO (cf. Figure 1). However, in this case it became apparent that the parallel course of the trajectory for “past” in the previous example was accidental: While the subjects still moved closer to the RO in the case of “along” (12 mm) than in the case of “past” (35 mm), $t(26) = 9.27, p < .001$, they only followed the shape of RO in the case of “along”. (A more detailed description of the results, including the other conditions that were realized in this experiment can be found in [15].) The results from this experiment suggest that parallelism and proximity are important concepts for the discrimination of the two German path relations “entlang” (along) and “vorbei” (past). To verify this hypothesis we designed a speech production experiment, where we systematically varied the shape of the RO, and the shape/curvature of the trajectory between the start and the end point.

3 Production of prepositions

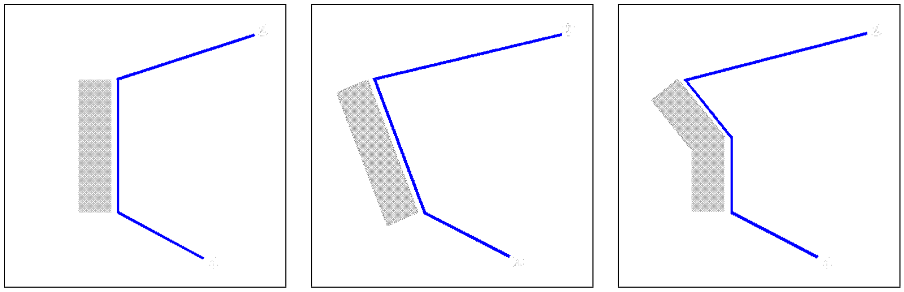
Following the discussion of the previous experiment, we prepared a speech production experiment, where we investigated how the concepts of parallelism and closeness influence the selection of one of the two path prepositions “along” and “past”.

3.1 Method

Subjects Sixteen students of the Saarland University took part in the experiment. All subjects were native German speakers and were paid for their participation.

Material Each layout consisted of an RO, a start point, an end point, and a trajectory connecting both points. We designed three different reference objects: a simple rectangle (2 x 8 cm), a rectangle of the same size, but tilted 20 degrees to the left, and another rectangle, which was bent in the middle to form a 160 degree angle. The start points for the trajectories were located 3 cm in front of (below) the RO’s lower right corner and 2 cm respectively 6 cm to right of it (cf. Figure 3). The corresponding end points were always located 3 cm behind (above) and 9 cm to the right of the RO’s upper right corner. Trajectories were drawn as lines of 1.5 mm width. For all items there was a mirrored counterpart with start and end points on the left side of the RO. Thus, 24 different layouts were developed. They differed in the kind of reference objects, in the location of the trajectory start point, and in the trajectory’s shape/curvature. Systematically varying these variables should reveal the importance of the aforementioned concepts of parallelism and closeness to the discrimination of the two path prepositions. The items were displayed on a 17 inch computer screen, with subjects seated one meter in front of the screen. The experiments were controlled by an IBM compatible PC running a Java 3D application, that was specifially built for the trials.

Procedure Subjects were seated in front of the computer screen. Each trial had the following structure: A short warning signal (a beep) was given. One second later, the subjects saw one of the items. They had been instructed to describe aloud and as fast as possible the curvature of the trajectory in relation to the reference object. Subjects were only allowed to use one of German path prepositions “entlang” (along) and “vorbei” (past). The subjects’ speech production triggered a voice key, which in turn caused the item to disappear from the screen, and the subjects’s choice to be recorded. After a break of one second, the next trial was started. Times were measured between the beginning of the presentation of an item and the beginning of the spoken response by the subject.



(a) (b) (c)

Fig. 3. A first look at the experimental layout

3.2 Results

The frequencies of the path prepositions used and speech production latencies were analyzed in order to obtain the results presented in the subsequent sections.

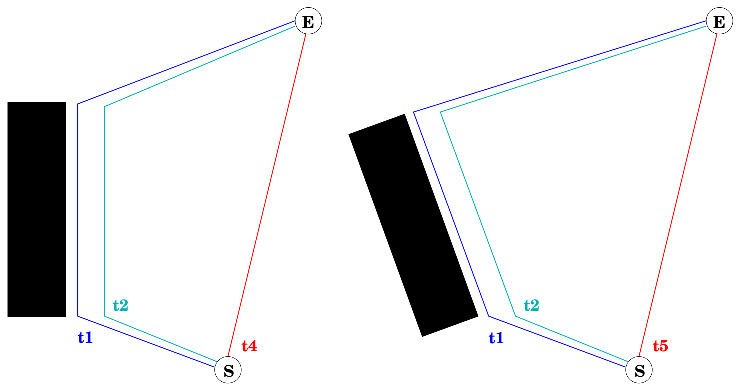
Parallelism and Closeness In order to more closely investigate the importance of these two concepts, we will report the results for the following two layouts of items: In case A, the RO was a rectangle, and we designed three different trajectories. Two trajectories were parallel to the shape of the RO. From the two parallel ones, trajectory *t1* was closer to the RO than trajectory *t2* . The third trajectory *t4* violated the concept of parallelism. In case B, the RO was a tilted rectangle. Again, we had two parallel trajectories *t1* and *t2*, where the first one was closer to the RO than the second one, and a third trajectory *t5*, which violated the concept of parallelism. The different layouts are shown in Figure 4[3].

Table 1. Percentages of subjects producing "along"

	Parallel		Nonparallel
	Distance		
	Close	Far	
Case A	87.5	77.3	10.9
Case B	89.9	87.5	3.9

The average frequencies of selecting "along" are reported in Table 1. A 2×3 analysis of variance of this data with the factors 'type of item' (Case A or B) and

[3] Not all trajectories that were used in the experiment are shown in the picture.



(a) Case A: RO and the trajectories *t1, t2,* and *t4*

(b) Case B: RO and the trajectories *t1, t2,* and *t5*

Fig. 4. Item sets in the preposition production condition

Table 2. Latencies of subjects producing “along” for parallel trajectories (in ms)

	Distance	
	Close	Far
Case A	744	790
Case B	709	748

'course of trajectory' (parallel and close, parallel and distant, and nonparallel) yielded a significant effect for the trajectory's course, $F(2,30) = 47.16, p < .001$. Post hoc comparisons showed that the frequencies were the same for the two parallel cases, and that they were much higher than for the nonparallel case. The production latencies (cf. Table 2) were compared for the same two factors in a 2×2 analysis; the latencies for 'along' with a nonparallel trajectory were excluded because there was an insufficient amount of data for this case. This analysis also yielded a significant effect for the course of the trajectory, $F(1,13) = 8.42, p < .05$, which demonstrates that subjects produced "along" faster when describing the closer trajectory than in the case of the more distant one.

From these results we can conclude that parallelism to the shape of RO is necessary precondition if a trajectory is to be described using "along". We can also infer that closeness has only a weak effect on selection, but the production latencies are slightly shorter for trajectories closer to the RO.

Deviation from Parallelism A further set of items consisted of those layouts, where the displayed trajectories differ in their deviation from a given RO's shape. The tilted rectangle serves as RO. The three trajectories *t3, t4, t5* differ in their deviation from RO (cf. Figure 5). All these trajectories violate the concept of parallelism to the RO. Trajectories *t3, t4* are partially parallel to each other, but not to the RO; *t3* is closer to RO than *t4*; trajectory *t5* leads away from the RO. Table 3 shows the frequencies and speech production latencies for the selection of "past" for the aforementioned combinations.

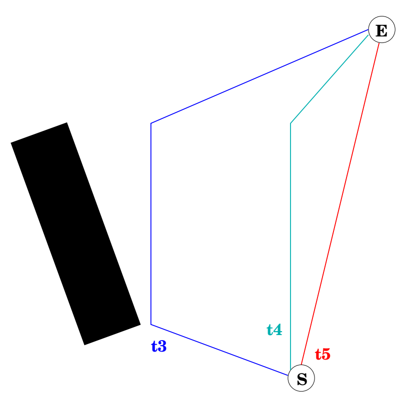


Fig. 5. Case B: RO and trajectories *t3, t4* and *t5*

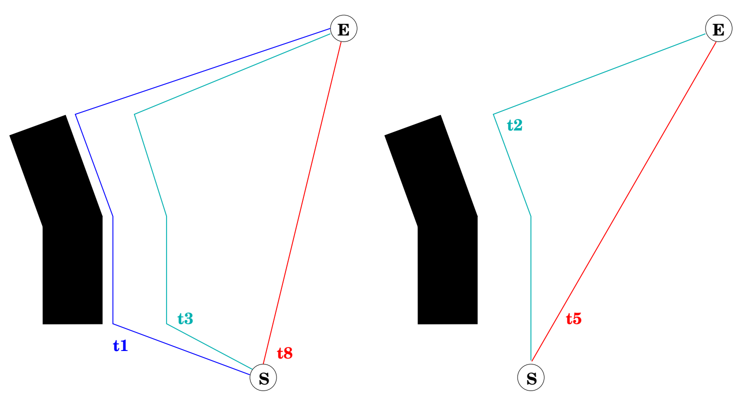
In case of the nonparallel trajectories "past" was more frequently used than "along". We therefore analyzed the frequencies and the production latencies for "past" – those for "along" were $1 - f(past)$ – in a one-way analysis with three

Table 3. Percentages/latencies of subjects producing “past” for trajectories in Fig. 5

	Nonparallel		Departing
	Distance		
	Close	Far	
Case B, frequencies	66.4	82.0	95.3
Case B, latencies	896	848	824

levels: (1) close and passing, (2) distant and passing, and (3) departing. Again, we obtained a significant effect for the course of the trajectory, $F(2,30) = 6.66, p < .01$ for frequencies, and $F(2,26) = 5.74, p < .01$ for latencies. “Along” was less frequently and more slowly used in the case of the passing trajectory that was close to the RO, than in case of the other two trajectories.

Partial parallelism In order to test whether the effects obtained in the former conditions can be replicated with a differently shaped RO, we first investigated five courses of trajectories. Three of them were parallel – one close to the RO (*t1*) and two farther away with a start point in different distances (*t2, t3*) – and two were nonparallel (*t5, t8*) with start points in different distances (cf. Figure 6).

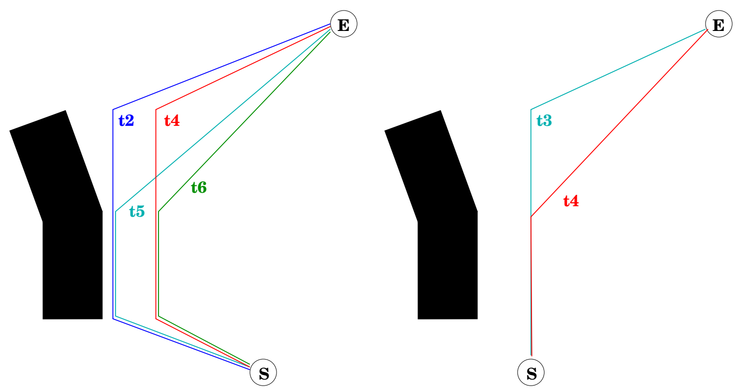


(a) Case C: RO and trajectories *t1, t3,* and *t8*

(b) Case D: RO and trajectories *t2,* and *t5*

Fig. 6. Parallel vs. parallel/departing trajectories

We observed a comfortable replication of our results: The parallel trajectories were described using “along” (89, 90 and 88 %, respectively), while the nonparallel ones were not (both 6 %), $F(4, 60) = 75.80, p < .001$. We then investigated trajectories, which were only partially parallel to the RO. Again, we manipulated the distances of the trajectories, and also the course of the path in the nonparallel part of it.



(a) Case C: RO and trajectories *t2, t4, t5* and *t6*

(b) Case D: RO and trajectories *t3,* and *t4*

Fig. 7. Partially parallel trajectories

In the region formerly denoted as NA, half of the path was parallel to the RO, while the other one was not. The latter part was either passing or departing (cf. Figure 7). The production frequencies of "along" were counted. These frequencies are shown in Table 4 depending on the courses of the trajectories.

Table 4. Percentages of subjects producing "along" for trajectories in Fig.7

	Start point far		Start point close
	Distance		
	Close	Far	Trajectory Far
Parallel then straight	61.7	47.7	47.7
Parallel then departing	52.3	43.0	40.6

We first compared these frequencies in a 2×3 analysis of variance with the factors 'degree of parallelism' (2) and 'distance' (3). In this analysis, only the degree of parallelism was significant, $F(2, 30) = 4.49, p < .05$. “Along” was produced more often to describe the proximal trajectories (57%) than to describe one of the two more distant trajectories (46% and 45%). No other effect was significant. The latencies could not be analyzed, since too few data points remained (due to the case-wise deletion of subjects in the repeated measurement analysis).

Next, we combined these partially parallel conditions and compared them with the averages of the other conditions, where trajectories were either completely parallel or nonparallel. We analyzed the data in a one-way analysis with the following levels: (1) completely parallel, (2) partially parallel and passing, (3) partially parallel and departing, and (4) nonparallel. The corresponding frequencies were 89%, 52%, 54%, and 6%, of which the difference was highly significant, $F(3, 45) = 26.91, p < .001$. The parallel trajectories were more often described as “along” than the partially parallel ones, which were not different, but these frequencies were still higher than those for the nonparallel trajectories. The latter ones were nearly exclusively described using “past”.

4 Discussion

There are two main results to be drawn from the series of experiments we conducted. On one hand, it has become clear that parallelism between a trajectory and the outline of a reference object is a necessary precondition for the applicability of “along”. In the path production experiment, the subjects took great detours in order to assure that their trajectory was at least partially parallel to the reference object. The subsequent trials, where subjects were asked to describe a trajectory by one of the path prepositions, supported this thesis. On the other hand, the effect of distance was not entirely clear. While closeness did yield faster response times in case of parallel trajectories, there were also trials where closeness induced a higher percentage of subjects choosing “along” in case of partially parallel trajectories. This implies that closeness is a secondary criterion that is called upon in cases where the degree of parallelism is not high enough to justify the selection of “along”.

However, the comparison of two specific items from the path production experiment indicates that parallelism is not sufficient in order to select “along”. In Figure 1 these two items are shown: the subjects were given the description “Go along the building” in case (a) and “Go past the building” in case (b). Obviously, both groups of superimposed trajectories are parallel to the outline, yet trajectories in (b) were produced to depict “past”. The reason for this result may well be that parallelism is the product of coincidence in case (b): the most direct route from source to target is a straight line that happens to be parallel to the reference object. This *accidental parallelism* may pose a problem to the computational modeling of “along” as its applicability seems to depend also on potential alternate routes. If this is the case, the direct mapping of a high degree of parallelism to this path preposition (which both models apply to some degree) may yield wrong results.

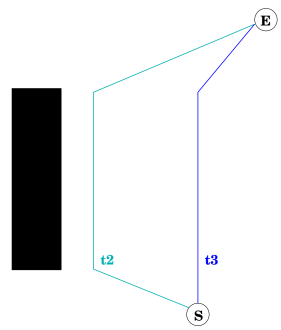


Fig. 8. Distance threshold

Another observation that may require the adjustment of the computational models concerns the degree of closeness: while parallel trajectories closer to the reference object yielded faster response times (at a similar selection rate) than trajectories that were farther away, there seems to be a threshold distance. Once a trajectory is farther away than that, "along" is almost never chosen. In Figure 8 both trajectories are equally parallel to the reference object, yet "along" is selected by 77% for *t2*, but by only 43% for *t3*. The determination of the threshold value and relevant factors that influence it are subject of further research. Throughout the different trials, "past" seemed to be the less specific case. "Past" was only consistently chosen, when the trajectory led straight from source to target (ignoring the shape of the reference object), or when it led away from the reference object. Otherwise, there was no clear trend as to when "past" was preferred over "along".

These observations can be interpreted in several ways. On one hand, "past" may have a less specific meaning, whereas "along" is defined more crisply. Therefore, "past" is only chosen when the more crisp case does not apply. However, there is evidence against this interpretation as production latencies were similar in cases, where both prepositions were applicable (not reported in this paper). On the other hand, there may be inconsistent perceptions of what "past" indicates. In Figure 1(b), most subjects drew a straight line from source to target to depict "past". However, quite a few drew lines closer to the building, which was the most frequent behavior in the "along" condition. Finally, "past" may be the *default* relation subjects use, when they just want the establish a relation between the trajectory and the RO, and are not willing (or unable) to specify it in more detail (e. g. when they intend to rule out a competing RO.)

From a different perspective, one may argue that the applicability of "along" depends on the *intention* of the producer. By using it instead of the less specific case of "past", a pragmatic goal is achieved such as making sure that the listener gets to see a certain sight, or does not get lost[4]. This argument can also explain the effects of distance that we observed: once a threshold distance is passed, the intention behind the use of “along” can no longer be fulfilled. This may also be the reason why subjects went to great detours in order to approach the RO when drawing trajectories for “along” (cf. Fig. 1(a)). Since neither of the two models presented in Section 1 currently incorporates a concept of intention, it may be worthwhile to extend them in order to accommodate such a concept. However, modeling intentions is quite complicated, as it would require the inclusion of, e. g., an explicit user model, a dialog history, etc.

5 Conclusion

We presented a series of experiments that were aimed at investigating the relevant factors for the selection of the German path prepositions “entlang” and “vorbei” (corresponding to “along” and “past”). In the paper and pencil trials, where subjects were asked to draw trajectories according to given prepositions, we identified the concept of parallelism and closeness as being of importance in this context. In the speech production experiments subjects were asked to describe a given trajectory using one of the two path prepositions. The results indicate that parallelism is a necessary precondition for the use of “along”, while closeness mainly influences the production latency. However, there were some problematic cases such as accidental parallelism and trajectories that are very far away from the reference object but still parallel. These cases indicate that further research is needed in order to completely model the path prepositions in question, and that current models need to be refined.

In the future, we plan to follow several research tracks to deepen our understanding of path prepositions. On one hand, there are currently several new experiments underway, where we investigate how dynamic trajectories will influence the selection of prepositions. Additionally, we are planning further trials on the impact of the presentation medium (verbal descriptions, maps, virtual walk-throughs). Furthermore, we want to examine the distance effect more thoroughly. On the other hand, we are in the process of finishing a prototypical implementation of a mobile system for navigational assistance, which incorporates a computational model of path relations. Once we dispose of a working system, we would like to conduct some field tests with ’real people in the real world’ in order to determine the appropriateness of the underlying model.

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[4] E. g., when the area is crowded and the object to walk along allows the listener to constantly reassure that he is on the right way.

References

[1] A. Blocher, F. Essig, A. Krüger, and W. Maaß. Towards a computational semantics of path relations. In P. Olivier, editor, *Spatial language: cognitive and computational perspectives*. Kluwer Academic Publishers, to appear.

[2] A. G. Cohn. Calculi for qualitative spatial reasoning. In J. Calmet, J. A. Campbell, and J. Pfalzgraf, editors, *Artifical Intelligence and Symbolic Mathematical Computation (LNCS 1138)*, pages 124–143. Springer, Berlin, 1996.

[3] M. J. Egenhofer and J. R. Herring. A mathematical framework for the definition of topological relations. In K. Brassel and H. Kishimoto, editors, *Fourth International Symposium on Spatial Data Hadling*, Zürich, Switzerland, 1990.

[4] A. Frank and M. Raubal. Formal specifications of image schemata - a step to interoperability in geographic information systems. *Spatial Cognition and Computation 1*, pages 67–101, 1999.

[5] K.-P. Gapp. Basic meanings of spatial relations: Computation and evaluation in 3d space. In *Proceedings of AAAI-94*, Seattle, WA, 1994.

[6] W. G. Hayward and M. J. Tarr. Spatial language and spatial representation. *Cognition, 55*, pages 39–84, 1995.

[7] A. Herskovits. *Language and Spatial Cognition - An Interdisciplinary Study of the Prepositions in English*. Cambridge University Press, Cambridge, UK, 1986.

[8] C. Kray and A. Blocher. Modeling the basic meanings of path relations. In *Proceedings of the 16th IJCAI. Morgan Kaufmann, San Francisco, CA*, pages 384–389, 1999.

[9] A. Krüger and W. Maaß. Towards a computational semantics of path relations. In *Workshop on Language and space at the 14th National Conference on Artifical Intelligence (AAAI 97)*, 1997.

[10] G. D. Logan. Linguistic and conceptual control of visual spatial attention. *Cognitive Psychology, 28*, pages 103–174, 1995.

[11] G. D. Logan and D. D. Sadler. A computational analysis of the apprehension of spatial relations. In P. Bloom, M. A. Peterson, L. Nadel, and M. F. Garrett, editors, *Language and space. Language, speech, and communication*. MIT Press, Cambridge, MS, 1996.

[12] C. D. Meola. Semantisch relevante und semantisch irrelevante Kasusalternation am Beispiel von entlang. *Zeitschrift für Sprachwissenschaft 17.2*, pages 204–235, 1999.

[13] B. Tversky and P. U. Lee. How space structures language. In C. Freksa, C. Habel, and K. F. Wender, editors, *Spatial Cognition*. Springer, Berlin, 1998.

[14] B. Tversky and P. U. Lee. Pictorial and verbal tools for conveying routes. In *Spatial Information Theory (Proceedings of COSIT 99). Springer, Berlin*, pages 51–64, 1999.

[15] H. Zimmer, H. Speiser, J. Baus, and A. Krüger. Critical features for the selection of verbal descriptions for path relations (in press). *Cognitive Processing*, 2001.

[16] H. D. Zimmer, H. R. Speiser, J. Baus, A. Blocher, and E. Stopp. The use of locative expressions in dependence of the spatial relation between target and reference object in two-dimensional layouts. In C. Freksa, C. Habel, and K. F. Wender, editors, *Spatial cognition. An interdisciplinary approach to representing and processing spatial knowledge*. Springer, Berlin, 1998.