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The verbalization of cognitive processes: Thinking-aloud data and retrospective reports

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Abstract

The present paper combines two lines of research from discourse analysis and psychology by investigating thinking-aloud data and retrospective reports related to a cognitively demanding task, namely, a variant of the well-known Traveling Salesman Problem involving navigation to a set of goals. The analysis addresses the linguistic variability emerging from a discourse-analytic comparison of three task variants corresponding to distinct perspectives on the cognitive processes involved. The investigation of systematic differences in relation to the given task and discourse setting leads to a better understanding of the relationship between language and underlying conceptions.

1 Introduction

Centering on the seminal work of Ericsson & Simon (1984), psychologists have been profiting from the investigation of linguistic representations of cognitive processes – such as thinking-aloud protocols and retrospective verbal reports – for at least a century. However, their interest focuses on the contents, not the linguistic features of the experimental subjects' verbalizations. On the other hand, linguists interested in the pragmatic aspects of language usage typically focus on discourse-related aspects, investigating language produced in natural discourse with a communicative aim. The present paper combines these two lines of research by investigating language produced in a psychologically motivated setting, using discourse-analytic methods. The crucial difference to classical research in pragmatics concerns the fact that language is investigated primarily with respect to the cognitive processes rather than the conversational aims that trigger particular linguistic choices (Dascal 1983). The conversational aims are then seen as operating *on the basis of* the cognitive processes involved in solving the task at hand. According to Caron-Pargue & Caron (1991), discourse production is necessarily based on the mental model (or the current cognitive processes) of the speaker, to be decoded and transferred to a corresponding mental model by the recipient. Therefore, linguistic representations of cognitive processes reflect both aspects (cognitive and conversational) simultaneously, though in different ways.

In the present approach, speakers are encouraged to spontaneously produce language in precisely defined tasks but without external influence as far as linguistic choices are concerned. A central basic assumption is that both subtle and obvious distinctions in language reflect underlying differences with respect to cognitive components and processes, as well as differences with respect to the intended addressee (if any) and the nature of the discourse task. Altogether, the investigation of systematic differences in relation to the given task and discourse setting leads to a better understanding of the relationship between language and underlying conceptions.

The specific aim in the present paper is to compare three different linguistic representations produced by one single speaker with respect to a cognitively demanding

problem solving task (the Travelling Salesman Problem): a thinking-aloud protocol collected during task performance, and two written representations, one of which involves reproducing reasoning processes during the task, and the second summarizing the most important outcomes of this experience by producing a task instruction for a friend trying to solve the same task efficiently.

2 The problem solving task: Travelling Salesman Problem

In the so-called "Travelling Salesman Problem", humans are confronted with a number of points or spatial goals which need to be connected in the shortest possible way before returning to the start position. This problem has been investigated in various ways and is of interest for researchers in various disciplines (Wiener & Tenbrink, in press). The current design replicates a purely behavioral experiment introduced and motivated in Wiener et al. (2007), but additionally requires participants to think aloud during the task and produce verbal reports subsequently. It uses a variant involving real navigation and a variety of different symbols, in contrast to more widespread versions in which identical points need to be connected by straight lines on a computer screen (e.g., Vickers et al. 2003). The current design offers a more naturalistic setting than the classical abstract TSP versions, and it is suitable for directly testing particular hypotheses concerning humans' strategies in solving this complex task. The present analysis will not focus primarily on particular strategies (but see Tenbrink & Wiener 2007, Tenbrink & Wiener subm.) since these may differ between individuals, but address the linguistic variability emerging from a discourse-analytic comparison of the three task variants. From this analysis, new insights emerge concerning the relationship between human cognitive processes and various kinds of linguistic representations.

Figure 1. Symbol field (left) with example "shopping list" (right)

2.1 Method

25 different symbols involving 5 different colours and 8 different shapes were arranged on a regular grid in a large experimental room, with an equal distance of approximately one meter between the symbols, which were represented on pieces of paper (17 cm^2) laid out on the ground (see Figure 1, left). The participants taking part in this study were asked to solve 18 different navigation tasks with 4 to 9 target places. For each trial, they were given a so-called ‘shopping list’ depicting the symbols of the start place and the target places in their relevant colours and shapes (see Figure 1, right). Their task was to navigate the shortest closed

trajectory connecting the start place with all target places, marking the places along the way. They were asked to try to 'think aloud' during the process; the spoken utterances were recorded and transcribed later. For each navigation task, the experimenter recorded the sequence in which the target places were visited.

After solving the 18 tasks, they were seated at a computer and asked to type in the answers to the following two questions (translated here from German):

1. Now that you have solved this task several times you are an expert concerning the question how it can best be solved. I now ask you for two more things. First: Please describe in as much detail as possible how you have solved the task, what you were considering while you solved it, and why you performed precisely in this way rather than another. Also, describe what, or which of the particular tasks, was easy and what was difficult for you during the task.
2. Second: Please write an instruction for a good friend of yours that allows him/her to solve the task as well as possible.

These questions were designed to trigger linguistic representations of the mental processes associated with the spatial task from memory, and by way of summarizing the outcome of their experience for the benefit of another person confronted with this task. Thus, three different ways of accessing subjects' cognitive processes via language were used, corresponding to three temporal perspectives: during the task, after the task, and before (having an imaginary friend perform) the task. It was expected that these three different kinds of linguistic representations would yield systematically different results based on the following considerations:

- According to Ericsson & Simon (1984), thinking aloud protocols involve a direct verbalization of cognitive processes in terms of successive states of information currently attended to, while retrospective reports represent parts of a "memory trace" developed on the basis of this cumulative information. The latter involve additional partial retrieval processes from long term memory that may lead to error and incompleteness, while the former are based entirely on short term memory and do not necessarily involve generalized cognitive processes.
- According to research in discourse analysis (e.g., Clark 1996), linguistic choices depend to a high degree on the conceptualization of the addressee, not least in spatial settings (Schober 1998). Therefore, the formulation without an addressee (in the thinking aloud version) should differ from the written account (for an unspecified addressee), while the formulation for a friend should exhibit further systematic distinctive features.
- Finally, the discourse task (or communicative goal) as such is formulated each time in a slightly different way, triggering a different conceptual perspective on the task, which should lead to different foci in the linguistic result. Similar effects have been shown for other kinds of spatial tasks, for instance, by Carroll & von Stutterheim (1993) as well as Senft (2001).

The following analysis is based on the linguistic data produced by one single participant, a 22-year-old female student.

2.2 Analysis

The analysis focuses on an in-depth comparison of the linguistic features of the three different task variants. In particular, the following criteria were investigated:

- *Structure and coherence*: Variability concerning discourse units, structural markers, and discourse relations
- *Information scope and granularity in conceptualization*: Variability concerning the presentation of information in terms of attention focus and levels of generalization
- *Conceptual mappings*: Variability concerning the mappings of conceptual structures and cognitive processes to language

Together, these three criteria highlight how the task of verbalizing cognitive processes is approached in relation to the problem solving task at hand, and in how far each of the participant's linguistic representations is suitable for an investigation of individual processes.

Table 1. Examples for each task

	TA (Thinking aloud)	**WT1 (Written task 1)**	**WT2 (Written task 2)**
1	*OK, dann gehe ich mal los zu dem ersten Symbol, zu dem Stern* 'Okay, then I'll start by going to the first symbol, to the star'	*Am leichtesten waren für mich die Aufgaben, die wenig Symbole und möglichst ähnliche Farben hatten.* 'For me, those tasks were easiest that had only few symbols and similar colours.'	*Als erstes sollte man versuchen, sich die Symbole einzuprägen.* 'First, one should try to memorize the symbols.'
2	*obwohl das ja eigentlich nich näher dran ist* 'although it is not really closer by, you know'	*Ich habe mir das Feld meistens in 2 Seiten aufgeteilt, um "ökonomisch" zu laufen.* 'I typically partitioned the field into two sides, in order to go "economically".'	*Man kann sie zwar nachgucken,* 'Although one is allowed to look them up,'
3	*ok dann geh' ich als erstes zu dem Stern* 'okay, then I go first to the star'	*Ich habe geguckt welche Symbole auf der einen Seite sind* 'I checked which symbols are on one side'	*aber das verlängert das Ganze schon erheblich* 'this prolongs the whole thing considerably'
4	*dann geh' zu dem grünen Kreuz* 'then go to the green cross'	*und diese zuerst abgearbeitet,* 'and completed these first,'	*und man kommt leichter durcheinander.* 'and one gets confused more easily.'
5	*ähm, dann geh' ich zu dem blauen Kreuz* 'uhm, then I go to the blue cross'	*anschließend bin ich zur anderen Seite gegangen* 'then I went to the other side'	*Dann teile das Feld in Sektionen auf,* 'Then, separate the field into sections,'
6	*und dann geh' ich zu dem Stern, dem gelben* 'and then I go to the star, the yellow'	*und habe auf dem Weg dorthin immer darauf geachtet, dass ich kein Symbol vergesse.* 'and along the way there, I always took care not to forget a symbol.'	*und merke dir welche Symbole in welchem Bereich sind.* 'and keep in mind which symbols are in which area.'
7	*und jetzt lauf' ich zurück zum Anfangspunkt. Ja.* 'and now I go back to the starting point. Yes.'	*Besonders schwer fand ich sich die Symbole einzuprägen* 'I found it especially difficult to memorize the symbols'	*Denke immer daran, möglichst wenig zu laufen.* 'Always remember to walk as little as possible.'

2.3 Results

As a first step, the data were segmented into informational units. For the thinking aloud data (henceforth TA), this included transcription and segmentation on the basis of informational units that at least potentially correspond to a "possible sentence" (Selting 2000). Since these

units are typically smaller than a written sentence that may contain more than one piece of relevant information, also the written tasks (henceforth WT1 and WT2) were segmented not on the basis of punctuation but in terms of informational units. This segmentation yielded 321 units in the TA data (2.966 words), 12 in WT1 (116 words), and 8 in WT2 (65 words). Thus, as could be expected due to the length of time spent thinking aloud, WT1 yielded a more condensed linguistic product than TA, and WT2 is even more condensed than WT1. Even at first sight, the linguistic data in each task differ considerably from each other. Table 1 gives the first seven lines of each task (in TA this corresponds to the first trial) for illustration (translations are only approximate, reflecting content rather than exact linguistic form).

Clearly, the TA data are characterized by the participants' current attentional focus on particular subgoals within the task procedure, while the retrospective data reflect generalizations across trials and subgoals. In the following I discuss each of the three criteria motivated above in turn.

2.3.1 Structure and coherence

All three data sets contain a high number of explicit structural markers. Table 2 summarizes these in terms of associated discourse markers based predominantly on Halliday's (1994) terminology. The numbers represent normalized frequencies, i.e., percentage of occurrence in relation to the overall number of informational units.

Table 2. Discourse markers

Conceptual category	temporal structure	conceptual complexity	causality / reasons	processes and sub-tasks	topic shifts / signals of conceptual chunking	known content
Associated discourse relation	temporal enhance-ment	elaboration, matter & concessive conditional enhancement	causal or manner enhance-ment	extension or matter enhance-ment	conversa-tional manage-ment	inform-ational dis-course marking
Examples for linguistic realizations	*als erstes, zuerst, danach, dann, jetzt* 'first, then, now'	*also, bzw., jedoch, aller-dings, obwohl* 'accordingly, however, while, nevertheless'	*da, weil, um zu, also, damit* 'because, in order to, thus, therefore'	*und, auch, außerdem* 'and, also, addi-tionally'	*okay, also, ja, so* 'okay, so, well'	*ja* 'you know'
TA	47,04	6,54	13,40	30,84	14,64	4,67
WT1	33,33	8,33	16,67	41,67	none	none
WT2	37,50	25,00	none	25,00	none	none

In all three tasks, the frequency of *temporal markers* is extremely high. In the TA data, this concerns the explicit marking of current actions as they are pursued, either in terms of explicit action-accompanying comments ("now") or as belonging to a sequential order (e.g., "next"). In the written tasks, the speaker represents the order in which actions are to be pursued sequentially, generalizing over the individual trials. At a closer look, the temporal assessments are associated with actions on differing levels of granularity. In the TA data, the first temporal markings of initial ("First,…") as well as subsequent ("Then,…") actions occur together with particular symbols to be visited (e.g., "First, I'll go to the red drop"). Increasingly often,

however, these temporal allocations refer to regions within the field, as in "First, I'll go over to the right hand side.", which can be interpreted as part of a spatial strategy that the participant has gradually developed and is now utilizing. In WT1 and WT2, temporal structure is never associated with individual actions; allocations refer exclusively to generalized subtasks, of which the conceptualization of regions is the most prominent one. Thus, the retrospective report adequately represents the temporal structure of subtasks on the basis of the outcome of doing the same tasks repeatedly. WT2 adheres to strict temporal sequence in a more consistent way than WT1 does, providing a suitable "action plan" for the imagined addressee.

Markers of *conceptual complexity* (such as "in spite of", "nevertheless") are rare throughout. Only in WT2 (in order to formulate a suitable instruction for an addressee) does the speaker attempt to account for potentially complicating matters. However, no *reasons* are given for the instructions in WT2, in contrast to the other two tasks in which the participant does sometimes make reasons explicit. Overwhelmingly in the TA data, reasons concern the spatial vicinity of symbols to be visited next; a typical example is "I'll go there next because it is directly next to it". In WT1, reasons are related to the strategy of regionalizing the field. Thus, proximity of symbols seems to play a greater role in the low-level activities involved in the task procedure than in the generalizations summarized afterwards.

Informational units combined by "and" and the like express a parallel conceptualization of several *sub-processes and tasks*. The high frequency of discourse markers in this category reflects the multilayered demands of the problem solving procedure throughout all linguistic representations. No systematic differences in the usage of these markers between the three kinds of language data could be detected in the analysis.

Two kinds of discourse markers are peculiar for TA data. Interestingly, these are also the only aspects not listed in Halliday's categorization for discourse markers (and they are not straightforwardly translated). Discourse markers that serve to highlight *topic shifts* as well as *known information* are typical for spoken rather than written language. Typically, they are interpreted as marking *conversational management* (e.g., Fraser 2006), signalling features of the developing discourse structure to the interlocutor. In the present setting, however, the TA data are not produced for the benefit for an addressee, but merely reflect concurrent thought processes. Accordingly, they reflect topic shifts and informational status not for conversational purposes but as an expression of cognitive effects such as hierarchical structuring processes (cf. Bégoin-Augereau & Caron-Pargue 2003). In the TA data, topic shifts (as marked by "okay" and the like) occur frequently at the beginning or the end of a trial. In more than half of the cases, they occur together with a temporal marker, as in "okay, first I'll go to the yellow star." Occurrences of topic shifts *within* rather than at the boundaries of trials accordingly signal cognitive chunking processes; the participant conceptualizes distinct sub-parts of the task and expresses these linguistically using discourse markers. For example, at one point the speaker realizes having to go back to one symbol that had been forgotten on the path; after settling this the comment "Okay, mh,…" signals the completion of this subprocedure. Likewise, "so" often accompanies the completion of a particular subtask such as visiting one or several objects. While this externalization of cognitive chunking processes is already interesting in the present data from a qualitative point of view, a systematic comparison across a broader range of speakers will yield highly interesting comparative data for the investigation of generalizable cognitive processes as well as individual differences.

In contrast to dialogic settings, the occurrence of *ja* (marking known information) in the present situation does not signal a piece of information as *communicatively given* for an interlocutor (e.g., Diewald 2006). Instead, apparently this marker occurs whenever the participant states something particularly obvious, which concerns fairly often the presence of a symbol directly closeby. Thus, this kind of discourse marker reflects immediate, perceptual

processes that seem almost not to warrant verbalization at all as they represent directly accessible facts (cf. Ericsson & Simon 1984).

2.3.2 Information scope and granularity in conceptualization

Table 1 above shows that many of the early utterances in the TA data simply express the next target as the most prominent information to be conveyed. This represents the initial cognitive processes, which focus on the prominent task of visiting symbols without employing any strategies, reasons, or higher-level generalizations. Altogether, nearly one third (32.4%) of all TA units offer no further information content. A typical syntactic structure of such an utterance is, *dann geh ich zum gelben Dreieck* ('now I go to the yellow triangle'); i.e., a temporal marker, an action verb, and the next target symbol as information focus in utterance-final position, reflecting the speaker's current focus of attention (Talmy, to appear). This structure does not occur in the retrospective data at all. The remaining units in the TA data provide information of a different kind, sometimes intertwined with mention of the next target symbol to be visited (as in "directly beside me there is now already the green circle"). Such information often concerns reasons for actions, remarks about spatial distance or symbol clusters, and comments about the speaker's planned or completed behavior. These utterances are instance-based throughout; the information is typically attached to a current particular situation within the trial in which the conveyed content becomes salient. Only very rarely does the speaker stop to reflect about generalized problems: "well, that's what I think is most difficult: to remember what one has and what is still missing." However, even this idea is obviously triggered by the current situation. These results provide evidence that the participant was truly focused on the task and did not produce irrelevant or long-term memory based utterances (Ericsson & Simon 1984).

The written tasks, in contrast, almost exclusively contain generalized high-level information. Linguistically, the difference is reflected by the use of tense as well as markers such as *meistens* ('mostly'); while the TA data almost exclusively uses the present, the participant's report in WT1 is set in the past or perfect tense, and the "instructions" in WT2 use two different forms fulfilling the function of imperative (impersonal *man* with present tense, and the imperative). Interestingly, the one generalized remark in TA cited above is reproduced in WT1 almost verbatim, consistent with the hypothesis that retrospective reports may ideally represent those verbalizations that were already pre-formulated during the task itself (Ericsson & Simon 1984). Apparently, in the present data most of the generalizations formulated after the task were not fully developed (consciously) during the task itself. These generalizations stem from repeated occurrences of instance-based information content produced during the task, such as "going over to the other side" (referring to the region-based strategy gradually developed by this participant). Already in unit no. 83 does the speaker express awareness of repetition concerning this point, as evidenced linguistically by "again" ("then I now have to sort of go to the other side again you know"). This pattern is repeated in unit no. 177 ("now I have to go to the other side again") and again in no. 189 ("now I work my way to the left again") as well as no. 300 ("and now I have to go to the other side again, however"), thus iteratively reinforcing the generalization process. Not surprisingly, this well-supported procedure occurs as a generalized formulation in both written tasks.

2.3.3 Conceptual mappings

The most prominent reason for investigating linguistic representations of cognitive processes is to gain insights about the nature of the cognitive processes themselves. However, these are not represented in the same way in all three kinds of linguistic tasks. As the investigation of

information scope in the previous section showed, generalizations about high-level procedures can only be expected in retrospective reports. Problem-solving tasks are regularly solved by humans utilizing generalized heuristics which researchers in psychology are particularly interested in; the current TSP variant is no exception. As has already emerged from the analysis so far, the current participant gradually develops a region-based strategy which is increasingly alluded to in the TA data (21.5% of the TA units contain related references to spatial structure) and formulated most distinctively in the written representation intended for an interlocutor ("partition the field into sections"; WT1 contains reference to spatial structure in 41.67% of the units, and WT2 25%).

However, as Tenbrink & Wiener (subm.) show, humans do not restrict their problem solving endeavours to one particular strategy only. Other strategies and more low-level cognitive processes are also represented linguistically, though not necessarily in equally explicit terms. For example, 12.15% of the TA units contain reference to processes of *searching* symbols in the field and *controlling* with respect to the "shopping list"; these aspects are also represented in generalized terms in both retrospective reports.

Additionally, language reveals conceptual factors that are not in focus for a particular speaker. Unlike other humans confronted with this kind of task (e.g., Wiener et al. 2007, Tenbrink & Wiener subm.), the current speaker did not focus consciously on the symbols' features, shape and colour. Although about half of the informational units do in fact contain reference to either shape or colour or both, these references almost exclusively relate to the features of single target symbols. Thus, in contrast to other humans confronted with this task, attention was not focused on shared features across objects. The only hint at the presence of such a cognitive process can be found in WT1, where it is stated that trials containing fewer colours were easier to solve.

Another well-researched strategy called the "Nearest-Neighbor" (NN) heuristics (Wiener et al. 2007) involves continuously focusing on the nearest target location until all targets have been visited. Such a strategy almost never leads to optimal paths and has long been recognized not to be utilized by humans exclusively (e.g., Vickers et al. 2003). Nevertheless, to some degree this simple heuristic is still present for many experimental participants, and it is in fact strongly represented also in the current linguistic data, intertwined with other cognitive processes. Interestingly, while 18.07% of the units in the TA data contain reference to spatial vicinity, there is no such mention in the written tasks at all. In accordance with this, there is no indication in the TA data that the participant generalizes this aspect. All references of spatial proximity either provide linguistic assessments of perceived spatial relationships, or reasons for individual actions within the task. Both can be regarded as minor subprocesses within the general endeavour; they were not integrated into the participant's conscious generalization process reflected in the written tasks.

Finally, one further heuristics known from the TSP literature appeared to be just below the surface of the current speaker's consciousness, namely, imagining the course of the trajectory as a whole. This mental visualization process is known as a simplifying procedure involving a conceptualization of the ensuing path first on a coarse level of granularity before inserting individual targets (e.g., Tenbrink & Wiener 2007). However, this aspect became relevant only three times during the experiment for the current speaker, and each time in a different way (references mention first a *line*, then a *circle,* and finally a *curve*). No stable generalization occurs in the retrospective reports. Nevertheless, the participant mentions a related idea as a potentially supportive hint for the imagined addressee in WT2, as a concluding remark: "Before you set off you could already imagine the path you want to go in your mind."

3 Discussion

The comparative analysis of three different linguistic representations of cognitive processes shows that each of them offers a distinct perspective on the conceptualizations of the problem solving task at hand. The analysis started from expectations on three levels, based on results in psychology as well as discourse analysis: Differences in the linguistic representations were expected concerning memory and immediacy of cognitive processes, as well as concerning the effects of an intended addressee and the different discourse tasks. The results meet these expectations in the following way. While thinking aloud data are overwhelmingly instance-based and offer little insight into general procedures, they provide information about cognitive chunking as well as learning processes over a range of trials, along with a gradual shift of attention focus with respect to perception and action. They also reflect more low-level actions and cognitive processes that are not sufficiently reinforced to warrant being integrated into a retrospective account. Retrospective reports are suitable for a conscious summary of the effects of the learning processes involved; in spite of their density and brevity, they do adequately represent those cognitive processes that after a number of trials turned out to be most decisive for this particular person. Instructions formulated for an addressee are more suited to extract potentially useful additional ideas that were not necessarily decisive for the participant's own actions.

In spite of these systematic differences between discourse tasks, clearly a number of features of the elicited representations were peculiar to this particular participant. Related results (Tenbrink & Wiener subm., Wiener et al. 2007, Vickers et al. 2003) show that individuals vary greatly in the strategies they employ when solving the Travelling Salesman Problem. While the present linguistic data confirm that this speaker (like others) does not rely on one single strategy entirely, there is nevertheless a very prominent focus on the region-based strategy that is reflected consistently (although in different ways, as appropriate for the task differences) across all three linguistic tasks. This result provides a useful basis for extracting particular cognitive strategies employed by individuals, similar to earlier work investigating diversity in perspective and framework reflected in spatial discourse (e.g., Linde & Labov 1975, Carroll & von Stutterheim 1993). Levelt (1982) proposes that such individual preferences are due to different "cognitive styles"; however, recent work has shown that diverse linguistic representations can be triggered systematically by manipulations in the discourse task as well as features of the previous discourse (Vorwerg in press). However, neither of these results relate to a cognitively demanding problem solving task; rather, the main interest lies in the variability in *describing* a complex spatial situation as such. In the present case, the linguistic strategy employed by the speaker distinctly depends on the cognitive processes active in solving the current task. Since various conceptual strategies are available and differentially employed by participants, linguistic representations will accordingly exhibit a corresponding diversity. It remains to be examined in future work in how far these strategies can be triggered purposely by a manipulation of the task instruction, whether individual differences (such as handedness, spatial ability, gender, and the like) can be identified as triggers of different "cognitive styles" as reflected in language, or whether there is a consistent underlying conceptual task solving structure which can be modelled computationally, as attempted for the TSP, for instance, by Graham et al. (2000). In the latter case, a valid interpretation of diversity in linguistic representations would be that speakers differ in the relative weight they associate with particular cognitive sub-processes, as well as in the verbalization of thought in general. Our behavioral TSP results so far indicate, however, that individuals also differ substantially in their behavioral results; this (while needing further research) supports the view that linguistic representations are in fact reflections of cognitive processes, including the associated diversity, as suggested by Ericsson & Simon (1984).

4 Conclusion

This paper addressed the comparison of different linguistic representations of cognitive processes involved in a spatial problem solving task. The analysis revealed systematic differences concerning the linguistic features in relation to each communicative task and situation, as well as generalizable aspects specifying earlier results in discourse analysis as well as psychology for a spatial problem-solving situation. This work contributes to the understanding of multi-layered discourse in terms of cognitive processes as well as communicative aims.

In future work, these results will be quantified and validated across a larger set of participants and different task variations in order to gain more insight, on the one hand, about the relationship between cognitive processes and linguistic representation, and on the other hand, about the cognitive processes that are relevant for particular problem solving tasks.

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