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# Limitations of gaze transfer: Without visual context, eye movements do not to help to coordinate joint action, whereas mouse movements do

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ABSTRACT

Remote cooperation can be improved by transferring the gaze of one participant to the other. However, based on a partner's gaze, an interpretation of his communicative intention can be difficult. Thus, gaze transfer has been inferior to mouse transfer in remote spatial referencing tasks where locations had to be pointed out explicitly. Given that eye movements serve as an indicator of visual attention, it remains to be investigated whether gaze and mouse transfer differentially affect the coordination of joint action when the situation demands an understanding of the partner's search strategies. In the present study, a gaze or mouse cursor was transferred from a searcher to an assistant in a hierarchical decision task. The assistant could use this cursor to guide his movement of a window which continuously opened up the display parts the searcher needed to find the right solution. In this context, we investigated how the ease of using gaze transfer depended on whether a link could be established between the partner's eye movements and the objects he was looking at. Therefore, in addition to the searcher's cursor, the assistant either saw the positions of these objects or only a grey background. When the objects were visible, performance and the number of spoken words were similar for gaze and mouse transfer. However, without them, gaze transfer resulted in longer solution times and more verbal effort as participants relied more strongly on speech to coordinate the window movement. Moreover, an analysis of the spatio-temporal coupling of the transmitted cursor and the window indicated that when no visual object information was available, assistants confidently followed the searcher's mouse but not his gaze cursor. Once again, the results highlight the importance of carefully considering task characteristics when applying gaze transfer in remote cooperation.



## 1. Introduction

### *1.1. Benefits and difficulties of gaze transfer*

Remote cooperation poses a challenge in coordinating joint action, due to a lack of some nonverbal cues that are typically present during natural communication. When interacting face-to-face, eye movements play a significant role in avoiding misunderstandings. They are closely linked to processes of visual attention (Just & Carpenter, 1976) and therefore can assist in establishing a joint focus of attention (Bruner, 1981) and inferring the object of a partner's referring expressions (Hanna & Brennan, 2007). Trying to emulate this natural function of the eyes, one approach to resolving ambiguities in remote cooperation is to superimpose a person's gaze on the partner's screen as a cursor. Such gaze transfer has been shown to improve performance compared to purely verbal interaction during joint visual search (Brennan, Chen, Dickinson, Neider, & Zelinsky, 2008; Neider, Chen, Dickinson, Brennan, & Zelinsky, 2010) and cooperative problem solving (Velichkovsky, 1995). These gaze benefits have been explained by the potential of eye movement information to support a smoother coordination between the partners, enabling them to avoid redundant search (Brennan et al., 2008) or to use brief deictic verbal references instead of elaborate object descriptions (Neider et al., 2010; Velichkovsky, 1995).

It seems quite intuitive to assume that eye movements as an indicator of a person's visual attention should make it easier to understand what that person is doing or trying to communicate, and indeed, eye movements have been labelled as a “window into mind” (Velichkovsky & Hansen, 1996). However, there is recent evidence suggesting that gaze transfer is not as unproblematic as previous studies might suggest (Müller, Helmert, Pannasch, & Velichkovsky, 2013). In a joint puzzle task, the transfer of a gaze cursor from an expert to a novice was compared not only with purely verbal interaction but also with simple mouse pointing. Although there were no differences in overall performance between both types of cursor transfer, the mouse clearly outperformed gaze with regard to the cooperative process: Reactions to the gaze cursor were slower overall, and participants were especially hesitant to react to it in situations where this reaction posed the risk of

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an error. Along the same lines, using gaze increased the effort participants incurred while verbally referring to puzzle pieces. Taken together, these results are indicative of uncertainties about the gaze cursor's communicative function: It appears to be hard to determine whether a particular gaze is intended to be an instruction or merely a part of the person's search process.[1]

However, it would be premature to conclude that gaze transfer was only distracting without adding any value, because a puzzle tasks might not be optimally suited for the benefits of gaze transfer to emerge. There are at least two reasons for this. First, solving puzzles does not necessarily require a partner, which might have reduced participants' motivation to pay close attention to that partner's search process. Second, information about the search process is of limited value when the pieces are randomly distributed and only the correctly identified target piece needs to be communicated. In this setting, gaze is reduced to an intentional pointer. This inevitably raises the question in what way the abundance of information contained in eye movements could have led to any benefits at all. At the same time, these considerations raise the possibility that gaze transfer might be more helpful in settings in which the value of the information contained in it goes beyond that of explicit instructing.

### *1.2. Harnessing the potentials of eye movements in cooperative tasks*

In order to conduct a more appropriate comparison of gaze and mouse transfer, a genuinely cooperative task is required in which two interdependent partners need to be informed about each other's ongoing activity and visual attention. To construct such a task, we looked at real-world cooperative settings to extract their underlying mechanisms and apply them in a controlled laboratory experiment. One outstanding feature characterizing many cooperative settings is that participants assume asymmetric roles and perform complementary actions, with one of them creating the conditions for the other one to act. For example, consider a driver of a lifting ramp who moves that ramp to different parts of a building, enabling a window cleaner standing on the ramp to clean the windows in different areas. In more general terms, an assistant is providing the framework for his partner to work on the details of the joint task. Although the assistant does not necessarily possess the abilities to work on these details by himself, he certainly has to take his partner's activities into consideration in order to align his own actions to them and provide effective support.

We adopted the general idea of an assistant controlling his partner's workspace as it occurs in the lifting ramp scenario sketched above. In our computerized, abstract version of it, an assistant was in charge of moving his partner's field of view with his mouse while the rest of the screen was occluded, similar to the *moving window paradigm* (McConkie & Rayner, 1975). Thus, in our joint moving window (JMW) task, the partner (henceforth called *searcher*) was only able to see and act in a small, rectangular frame, while the rest of the display was covered by a black mask. Under these conditions, it is crucial that the assistant moves the window according to the searcher's needs. In the real world counterpart of the window cleaner on the lifting ramp, this knowledge may stem from the driver observing what parts of the building are currently being worked on and which are finished already, perhaps even inferring how long an ongoing action will take. In the JMW task, this is where gaze transfer comes into play. Eye movement parameters, especially fixation durations, are task-dependent (Land & Tatler, 2009; Rayner, 1998) and indicative of a person's mental processing activities (Velichkovsky, 2002). Thus, if the cognitive and spatio-temporal requirements vary over the course of a task, the searcher's eye movements presumably can be used as a cue to his ongoing activities. Therefore, we provided the assistant with a depiction of the searcher's gaze cursor.

The nature of this gaze transfer differs from that of the puzzle task (Müller et al., 2013), where eye movements had been used as a means of intentional communication. The results had indicated that observers cannot easily infer the communicative function of particular gaze instances, corroborating the suggestion from Human Computer Interaction (HCI) research that using isolated fixations as explicit commands can be problematic (Jacob, 1991). Alternatively, gaze transfer can reflect the person's "viewing behaviour" in a broader sense, serving as an indicator of his interest and ongoing activity, which presumably can aid an assistant to find out how to act in the most helpful way (cf. Qvarfordt, Beymer, & Zhai, 2005). When applied in this way, gaze transfer should visualize aspects of the partner's solution process that are not accessible when only looking at his intentional, manual actions (Ballard, Hayhoe, Li, & Whitehead, 1992). Therefore, in the JMW task we used gaze transfer as a byproduct of the actual solution process, directly representing the searcher's purposeful activity. To test whether this can lead to a *specific* benefit beyond that of a mere spatial indicator, we compared gaze transfer with mouse transfer. We did not include a condition without cursor transfer, because there already is plenty of evidence for benefits of gaze transfer over purely verbal interaction (Brennan et al., 2008; Müller et al., 2013; Neider et al., 2010; Velichkovsky, 1995). Thus, repeating this comparison in a task that is even more suited for gaze transfer did not seem particularly interesting.

While the function of gaze transfer in the JMW task differs from that in a puzzle task by not being an explicit instruction, it differs from collaborative search (Brennan et al., 2008; Neider et al., 2010) for the opposite reason. During collaborative search, the partner's gaze can be used as a source of additional information that is monitored peripherally while two people are doing the same thing in parallel. Conversely, the JMW task is a decision making task in which two partners contribute their own specific abilities in order to reach a joint solution. It requires the assistant to understand the searcher's gaze in terms of the underlying cognitive processes and the joint goal. To increase this role of inferring cognitive processes and activities from gaze even more, our task was composed of several component operations that differed in the required level of processing (Craik & Lockhart, 1972) and the corresponding eye movement parameters (Velichkovsky, 2002). Specifically, the searcher had to perform colour discrimination, count the number of objects of different shapes and calculate the sum of numbers. A prestudy confirmed that these subtasks differed in the eye movement parameters they produced, with longer fixations and smaller saccades for the latter subtasks. Thus, in the present paradigm, closely observing the partner's eye movements should be informative about his current activities.

There is a significant boundary condition for the usability of any indicator of task-related mental processing: The solution process itself must be comprehensible. This requires certain knowledge about the necessary actions and the way they relate to task-relevant objects in the environment. In this context, a particularly interesting variable is the visibility of task-relevant objects for the recipient of gaze transfer. In principle, it is possible that gaze can be used to infer the partner's locus of attention in a merely spatial manner, which could be concluded from previous studies using joint visual search (Brennan et al., 2008; Neider et al., 2010). However, when applying gaze transfer to support the small-scale coordination of joint action, the ability to make inferences about a partner's visual attention should depend on knowing what he is attending *to*. Therefore, we varied whether the assistant was provided with partial information about the stimulus material (i.e. the relevant screen areas and object locations), or no information.

[1] Note that there is a confound when ascribing differences between gaze and mouse to the information they transfer: The cursors also differ in terms of their movement profiles. Therefore, one could argue that gaze transfer might not be difficult to interpret per se but simply too fast and variable, and in that way more distracting. These two accounts, i.e. the amount of information versus movement, cannot easily be disentangled, because additional information (e.g. about search processes) necessarily manifests in movement. An option would be to vary the characteristics of the cursor movement somewhat, for example by smoothing gaze or adding random noise to the mouse cursor. Such manipulations are beyond the scope of the present paper, but the issue should be kept in mind when interpreting the results.