Influence of Domain Knowledge on Search Behavior

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Abstract. In multimedia learning environments learners often have to search for differences between two pictorial representations. The comparative visual search paradigm allows the examination of search strategies (e.g., gaze-shifts between pictures) and involved visual-short-term memory (VSTM) load. It has been reported that the distance between two pictures influences search strategies. In particular, there is a trade-off between gaze-shifts calculated from eye- end head-movements and VSTM load: Increasing this distance decreases the number of gaze-shifts between pictures, suggesting an increased VSTM load. In this study, we examined effects of domain knowledge on search strategies. Stimulus related knowledge should reduce the number of necessary gaze-shifts by enabling the encoding of larger information chunks. We replicated previous findings – an increased distance increases VSTM load. Additionally, we found an aptitude treatment interaction effect indicating a positive influence of domain knowledge on VSTM load and search time for participants with a smaller visual memory span.

Keywords: comparative visual search; visual short-term memory; gaze-shifts; domain knowledge

Introduction

The ability to search for differences between two pictorial representations is essential for learning. In chemistry, for example, students have to compare the color of a control strip with a color chart. From research on multimedia learning we know that learning benefits from an integrated presentation format that minimizes the distance between interrelated information sources (Ginns, 2006). The present study extents this research by examining how the distance between pairwise presented pictures and domain knowledge influence search strategies. Research using the comparative visual search paradigm showed that visual search tasks can be described by a trade-off between the number of gaze-shifts between two pictures, so-called “inter-hemifield gaze-shifts”, and the memorization of local visual stimuli in the visual short-term memory (VSTM; Hardiess, Gillner, & Mallot, 2008): Increasing the distance between two pictures decreases the number of gaze-shifts suggesting larger information chunks and higher VSTM load in those conditions. Till now the influence of domain knowledge was not examined in comparative visual search tasks. Several studies have shown that domain experts are able to encode larger information chunks (Chase & Simon, 1973; Reingold, Charness, Pomplun, & Stampe, 2001). In the current study we want to focus on the influence of domain knowledge on search strategies. More specific, besides the replication of the comparative visual search trade-off we hypothesized that domain knowledge increases search effectiveness, as participants are able to encode larger information chunks. The influence of domain knowledge might depend on learner related factors.

Method

Participants were 44 naïve college students (22 female) of the University of Tübingen, Germany. They were randomly assigned to one of two cells of the between-subjects factor ”information” that described whether participants received stimulus related or stimulus unrelated information. The experiment comprised three blocks. In the first block, participants had to search for differences between two stills of a mechanic pendulum clock (see Figure 1A). These stills were randomly presented on two of six displays with a distance of either 30°, 75° or 120° (see Figure 1B). In the second block, participants learned either stimulus related information, the basic physical principles of a mechanic pendulum clock, or stimulus unrelated information, the history and different designs of cuckoo clocks. A comprehension test ensured that all participants in the condition with the relevant information reached a comparable knowledge level. In the third block, participants were presented with another block of comparative visual search tasks. Altogether, the comparative visual search task consisted of 72 pairs of clockworks (36 in the first and 36 in the second block). A training phase at the beginning of the first comparative visual search block consisted of 8 clockwork pairs. In both comparative visual search blocks the clockworks were presented on two of six 19” monitors arranged on a hemicycle with one meter distance to the participant and 30°, 75° and 120° between the monitors (see Figure 1B). Finally, we measured participants’ spatial abilities with the Mental Rotation Test (MRT, Vandenberg & Kuse, 1978), and the Spatial Orientation Task (SOT, Hegarty & Waller, 2004). Visual memory span was measured with the Visual Patterns Test (VPT, Della Sala, Gray, Baddeley, & Wilson, 1997) and verbal span was assessed via the “Zahlen Merken” (digit span) scale from the Wilde Intelligence Test (Jäger & Althoff, 1983).

(A) (B)

Figure 1. clockwork still (A) and Illustration of the experimental setup (B).

Results and Discussion

In the comparative visual search task, the number of inter-hemifield gaze-shifts proportion of correct trials were analyzed (see Table 1). For each of those dependent variables a 2 (information; between-subjects) x 3 (distance; within-subjects) x 2 (block; within-subjects) mixed factor ANOVA was calculated. As hypothesized, larger display distances lead to fewer inter-hemifield gaze-shifts, $F(1.20, 50.30) = 133.39$, $p < .001$, replicating previous findings with complex learning material. In addition, we found an increased search time, $F(1.92, 80.60) = 5.60$, $p = .005$, suggesting that higher effort of gaze-shifts in large distance conditions involves higher VSTM load. There were no effects regarding proportion correct, $F < 1$. Consequently, our results confirm the suggestion of a combined “cost” of number of gaze-shifts and VSTM load (Hardiess et al., 2008).

Table 1: Number of gaze-shifts and search times. *M* and *SD* in parenthesis.

Distance	Gaze-shifts	Search time (in seconds)	Proportion correct
30°	18.07 (7.93)	22.15 (10.52)	0.64 (0.15)
75°	12.99 (5.71)	23.19 (9.67)	0.65 (0.17)
120°	9.61 (4.48)	23.83 (10.19)	0.64 (0.16)

“Information” – stimulus related or stimulus unrelated – showed no significant main effect or interaction with other factors for the number of gaze-shifts, all *p*s > .200. However, there was a significant main effect for block on proportion correct indicating higher performance in the second block independent of the “information”, $F(1, 42) = 58.20$, $p < .001$, (first block: $M = 0.59$, $SD = 0.14$ and second block: $M = 0.70$, $SD = 0.16$). This suggests a general change of search strategy that is independent of “information” resulting in increased search effectiveness. To analyze the influence of learner related factors (measured with the MRT, the SOT, the VPT, and the digit span scale) on the effectiveness of the "information", we calculated the difference between the first and the second block for the dependent measures proportion correct, search time, and number of inter-hemifield gaze-shifts. For each, a separate linear regression including the between-subjects factor "information" was calculated. There was a significant effect in the stimulus related information condition for the influence of visual memory span (measured with the VPT) on the number of gaze-shifts, multiple $R^2 = .43$, $F(1, 20) = 14.92$, $p < .001$, and on the search time, multiple $R^2 = .28$, $F(1, 20) = 7.72$, $p = .012$, but not on proportion correct, multiple $R^2=.070$, $F(1, 20)=1.5$, $p=.235$. This suggests that participants with a low visual memory span profited most from the stimulus related information as we observed fewer inter-hemifield gaze-shifts and lower search times in the second block. For the group with stimulus unrelated information these effects were not significant (all learner related factors: $F < 1$).

Conclusion

In sum, there are two central points. First, the findings of comparative visual search are not restricted to artificial stimulus material but also hold for complex learning materials. The second finding is related with the information participants learned between the two experimental blocks. Especially participants with a low visual memory span benefitted from stimulus related information. They were able to encode larger information chunks that eventually led to fewer inter-hemifield gaze-shifts. From research in the field of "graphics comprehension" we know that there is an interaction between bottom-up, data driven processes, and top-down, knowledge driven processes. According to other studies, we could show that not only bottom-up but also top-down processes have an influence on gaze behavior (Canham & Hegarty, 2010). These results extent findings from multimedia research focusing on the interplay of pictures and text (Ginns, 2006) by showing that the distance between two pictures, domain knowledge, and cognitive prerequisites are important factors that determine memory load.

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