How to Convey Perceptual Skills by Displaying Experts' Gaze Data

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Abstract

Complex tasks with a visually rich and dynamic component, like classifying locomotion patterns in moving, colorful fish, require the acquisition not only of conceptual but also of perceptual skills. In a previous study expertise differences were examined on a performance and process level by means of eye tracking and verbal protocols. It revealed that experts attended more to relevant aspects of the stimulus compared to novices and used knowledge-based shortcuts for classifying the locomotion patterns. The current study examined a method to convey perceptual skills of a didactically behaving expert to novices by means of showing them a display of the expert's gaze data recorded while he performed the task. Results show that this type of modeling example influences visual attention and enhances performance.

Keywords: eye tracking; expertise; modeling; gaze display

Complex tasks with a dynamic and *visually* rich component require not only the acquisition of conceptual but also of *perceptual* skills. This paper presents studies on fostering perceptual skills in novices by displaying to them how an expert distributes his visual attention while performing such a task. First, an in-depth task analysis will be made by discussing the properties of complex visual tasks and expertise differences in performing such tasks, with a focus on a previous study by the authors (Jarodzka, Scheiter, Gerjets, & Van Gog, 2009). Then, an empirical study is reported were the possibilities of training the respective skills by means of modeling examples were investigated.

Complex Tasks with a Dynamic, Visual Component

Complex Tasks (Van Merriënboer, 1997), like computer programming or statistical analyses, are composed of sub-skills that all need to be used and coordinated simultaneously. In order to achieve a certain level of expertise, Van Merriënboer suggests that instruction should be based on authentic, complex learning tasks, to train learners to apply and coordinate the necessary sub-skills.

In addition, many complex tasks, like the interpretation of weather maps (Canham & Hegarty, 2009) or x-rays (Lesgold et al., 1988), involve dealing with visually rich displays. In particular, these tasks require users to observe and interpret transient information, which rapidly changes over time (e.g., aircraft control panels; Ellis, 1986). This transience imposes high cognitive demands onto learners (Lowe, 1999). Hence, the fact that complex tasks often involve the interpretation of stimuli that are both visually rich *and* dynamic may cause serious complications for their processing. The question arises how experts compared to novices are able to cope with these demands when processing the information required for task performance.

Expertise Effects in Processing Complex Stimuli

Common methods for assessing skill differences in experts and novices involve recording verbal reports and eye movements during task performance. In processing complex stimuli, novices attend to saliency rather than to those aspects that are relevant for task performance (Lowe, 1999). On the other hand, people with a higher level of expertise are able to process complex stimuli more efficiently by quickly focusing their visual attention onto the relevant aspects of the task while ignoring potentially salient, but irrelevant information (e.g., Canham & Hegarty, 2009; Jarodzka et al., 2009; Lesgold et al., 1988; Lowe, 1999). Lesgold and colleagues (1988) termed this ability of experts 'perceptual knowledge'. To conclude, the (perceptual) processing of complex stimuli does not only depend on the mere saliency of its single features, but also on the cognitive background of the observer (Henderson, 2007).

Expertise Differences in Classifying Fish Locomotion. While most of the previously mentioned studies have provided important insights on expertise differences when accomplishing complex visual tasks, only the study by Jardozka et al. (2009) investigated them in perceptual processes (i.e., eye movements) on *dynamic* stimuli. Moreover, the investigation of visually rich, but static stimuli has been conducted on a coarse level using single basic eye tracking parameters (e.g., number of fixations). However, performing a complex task is not necessarily well reflected in these single parameters, because the skills required are likely to be composed of multiple sub-skills that are better described by sequences of steps. Thus, for the study of complex dynamic skills, expertise differences should be investigated at a more sophisticated level including sequence analyses to get a better insight into the task and the skills required (Jarodzka et al., 2009).

Both in the previous study by Jarodzka et al. (2009) and in the study reported in this paper, expertise differences were investigated for the description of locomotion patterns of fish swimming. This task was chosen, because it is dynamic and has a visual rich component, thus, perceptual strategies are very likely to play a crucial role in task performance.

Participants in the previous study were experts, that is, professors, or PhDs, and novices, that is, biology freshmen, who had basic knowledge of fish anatomy, terminology and locomotion pattern, but had very little if any experience with classifying different locomotion patterns. Participants watched videos of swimming fish, for which they had to describe the locomotion pattern afterwards.

The results indicated that, not surprisingly, novices were slow and inaccurate in their performance, while experts were more accurate and accomplished the task faster. Furthermore, the eye movements of the participants were tracked, while they watched the videos. This measure was meant to provide further insight into the perceptual processes underlying the performance of this task. Analyses of the eye tracking data revealed that novices attended more to irrelevant parts of the videos compared to experts. Moreover, participants' gaze paths were compared according to the sequence in which they attended to relevant and irrelevant parts of the stimulus. A sequence analysis based on the Levenshtein distance showed that experts' gaze paths were more heterogeneous than those of novices. That is, the experts seemed to deploy a variety of different task approaches, whereas the novices choose rather similar approaches to the task. The differences in perceptual approaches between experts might be due to the fact that not only years of experience in a domain, but also the quality of this experience is important (Ericsson & Lehmann, 1996). Hence, different learning histories may result in different task approaches (Medin, Lynch, Coley, & Atran, 1997).

Moreover, participants watched the video with their own eye movements superimposed on it after task performance, and verbalized the thoughts they had during their first viewing (Van Gog, Paas, Van Merriënboer, & Witte, 2005). This measure gave insight into the conceptual processes underlying the performance of this task. Results showed that novices described few areas of the stimulus, whereas experts verbalized many task relevant areas. Furthermore, experts expressed their thoughts predominantly by using many technical terms.

Moreover, results showed that experts used knowledge-based shortcuts to classify the locomotion patterns. That is, compared to novices they more often attended to features required for classifying the fish itself (and not for its locomotion pattern), which then allowed them to retrieve knowledge on its locomotion pattern. For novices, this type of knowledge-based shortcut was not available, so they needed to rely on attempts to identify locomotion-relevant features directly. This effect was found on a conceptual level (indicated by verbal reports) as well as on a perceptual level (indicated by eye movements).

Training Skills to Process Complex Stimuli

The study of Jarodzka et al. (2009) yielded important conclusions with regard to the main research question underlying the current study, namely whether and how an expert's perceptual skills can be conveyed to novices. Those conclusions refer to the kind of knowledge novices lack, the possibilities of conveying different aspects of this knowledge, and design issues of the instructional material.

Unsurprisingly, novices were shown to have deficiencies with regard to conceptual knowledge, as indicated by their slow and inaccurate task performance. More interestingly, novices attended to irrelevant features, and described too few areas relevant for the locomotion; thus they lack perceptual skills for which they need support.

The question arises of how to convey this required knowledge to novices. Many instructional materials directly or indirectly convey expert knowledge to learners (Feldon, 2007). A method that has proven to be effective is demonstrating to a novice how an expert performs a task, while the expert gives access to the processes s/he conducts while solving a problem. Hence, the expert's behavior serves as a model for the novice (cf. modeling in cognitive apprenticeship approach; Collins, Brown, & Newman, 1989). Depending on the task different behaviors need to be modeled. If a novice wants to learn a practical domain like crafts it will be necessary that the expert's actual behavior is shown to the learner. However, some tasks, like solving a mathematical equation require mainly cognitive processes, since the actual behavior that is the writing down of the solution is not the crucial process that needs to be modeled.

In order to convey the knowledge needed to perform the current task, modeling examples were chosen, since they have shown to be highly effective for instruction (Atkinson, Renkl, Derry, & Wortham, 2000). Here novices are shown a worked-out expert solution procedure often including the explanation of how and why a certain solution step is performed (Van Merriënboer, 1997). However, modeling examples have proven to be effective for conveying conceptual aspects of expertise. However, as already mentioned, expert performance in the tasks of interest often also comprises perceptual skills. Thus, an important question is whether these perceptual aspects of expertise, that is, top-down processing of stimuli, could also be conveyed to novices. There are no proven methods available so far to convey perceptual knowledge. Verbalizations are only partly useful, because experts do not always have conscious access to where they are looking, that is, this can be a result of implicit knowledge (cf. Chi, 2006).

As mentioned earlier, instructional modeling is characterized by the idea to grant novices access to the crucial processes conducted by an expert. While this idea has so far been applied only to skills that can either be verbalized or observed in overt behavior, we propose that it can also be applied to perceptual skills. In particular, it is suggested that novices can be trained at a perceptual level by displaying to them an expert's distribution of visual attention (i.e., the eye movements) while s/he is performing a task. By doing so, the novices' attention may be guided towards relevant perceptual information during the study of worked examples (Van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2008). The current study aims at investigating the effects of this new modeling example method, namely, displaying an expert's gaze, on novice learners' performance and perception.

With regard to the question of how to design such a gaze display, further conclusions can be drawn from the previous study by Jarodzka et al. (2009). Since, experts have been shown to use shortcuts, the question is how to influence eye movements of experts, so they will forgo them. A hint towards the answer is a study of Richardson and Dale (2005). They investigated the relationship between eye movements, speech production, and speech comprehension. They found that if a speaker is asked to describe a simple scene, s/he will fixate the objects in the order in which they are mentioned, around 900 ms before naming them. Based on these results it was decided to have the expert first watch an unknown scene before describing it in a second step.

Another design issue concerns the question of whether the gaze display should be based on an average generated from multiple experts' eye movement recordings or whether the processes of only one carefully chosen expert should be shown to novices. As the previous study showed, experts were rather heterogeneous in terms of the task approaches they chose (cf. Medin, 1997), thus, it seems advisable to use the process data of only one carefully chosen expert for modeling purposes. How this expert was chosen is described in the Methods section of the experiment that is outlined in the reminder of the paper. This experiment was conducted to evaluate the effectiveness of the instructional modeling approach by comparing a condition with worked examples only (control group) to a condition that consisted of both, worked examples to convey mainly conceptual knowledge as well as gaze displays to train perceptual skills.

Although there is hardly any research on the effectiveness of gaze displays for conveying perceptual skills, some findings are reported that hint towards the effectiveness of displaying expert's gazes. Richardson and Dale (2005) found that the strength of relationship between a speaker's and a listener's eye movements predicts speech comprehension of the listener. That is, the better the listener's eye movements matched those of the speaker during describing a scene, the better s/he was able to understand what the speaker was talking about. The authors conclude that this might be an indication that the listener is using visuospatial information to cognitively structure the information in the same way as the speaker. Accordingly, if displaying expert's gazes could make a novice follow experts' eye movements, the novice should can be expected to have a better understanding of the experts' verbalizations.

Hypotheses

Differences are hypothesized concerning the perceptual aspects of task performance in that the gaze display group will outperform the control group. Moreover, both groups should differ in terms of their perceptual processes. Participants receiving the gaze display should attend faster to task relevant aspects of the stimulus (i.e., the time spent on the stimulus until attending to the relevant AOIs for the first time should be shorter) and maintain their attention for a longer time there (i.e., the total dwell time on the relevant AOIs should be longer), compared to the control group.

Experiment

Method

Participants and Design. 51 students of the University of Tuebingen, five of whom had to be excluded due to poor eye tracking data quality and outlier analyses (M=23.02 years, SD=3.30; 32 female and 14 male), were randomly assigned to one of two groups: (1) worked example only (control group, CG; n=24), (2) worked example including gaze display (GD; n=22). Participants had no prior knowledge of the task.

Task and Material. The stimulus materials consisted of four digital videos in an audio video interleave format, sized 360*480 pixel (corresponding to 3.74*4.98 inches) depicting single swimming fish, each deploying a different locomotion pattern. Each video included a spoken description from an expert of the corresponding locomotion pattern, which was the same for both conditions. The visual presentation of the videos differed across conditions in the following manner. The CG watched unaltered videos. Participants in the GD condition received perceptual guidance based on the eye movements of the expert. The raw eye movement were preprocessed, because the eye position as measured by the eye tracker hardly ever stays constant from one sample to the next; the fixational instability of the oculomotor system, minor head movements, and noise in the camera system of the eye tracker all contribute to the effect that the measured eye position exhibits a substantial jitter around the true eye position. In order to reduce this jitter, raw gaze data was filtered with a temporal Gaussian lowpass filter with a support of 200 ms and a standard deviation of 42 ms. In the Gaze Replay condition, a solid yellow dot (with an RGB value 255, 255, 0) of radius 16 pixels was placed at the position of the first (temporally filtered) gaze sample for each video frame (fig. 1). The dot size was small enough that it did not occlude relevant information permanently.

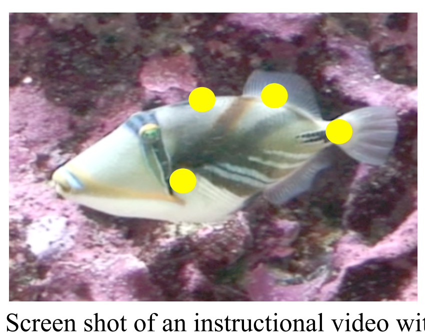

Figure 1: Screen shot of an instructional video with GD.

The used model is an expert in terms of fish locomotion, since he is a professor of marine zoology. Furthermore, the model is an expert in terms of instruction, since he has lots of teaching experience on fish locomotion behavior at a University level as well as a diving instructor. Thus, the model knows from experience where problems for novices occur. Moreover, the model was instructed to behave in a didactical manner by shifting his focus away from the content to the learner. This was done according to Jucks Schulte-Löbbert, and Bromme (2007) by self-assessment questions (e.g., "It is important that the student knows what each term means.")

Measures. Performance was assessed by means of a free description of the locomotion pattern after having watched each of the four testing videos. The construction and scoring of the performance measures was derived from a task analysis. To describe a locomotion pattern, the following guidelines should be applied (Lindsey, 1978). First, it has to be decided which part of the body is used to produce propulsion. This can be either the body itself or the fins. Hence, the free descriptions were scored according to naming correctly all crucial parts, resulting in a maximum of four points. Second, it has to be decided how this part moves. This can be either in an undulating (i.e., wavelike) or an oscillating (i.e., paddle like) way. Accordingly, the free descriptions were scored according to describing correctly the movement of the respective body part, resulting in a maximum of four points. Both aspects were assumed to assess perceptual knowledge, for which we had assumed the training group to outperform the control group. Moreover, two perceptual process measures from eye tracking recordings were obtained while learners studied the testing videos, namely, the time already spent on a stimulus before a locomotion-relevant AOI of the stimulus was attended to for the first time and the overall time spent on the relevant AOI of the stimulus.

Procedure. The experiment was run in individual sessions of approx. 60 minutes. It began with a questionnaire on prior knowledge and demographic data. Then, participants were given the technical term for the locomotion pattern followed by the corresponding learning video. This procedure was repeated for four locomotion patterns.

The testing phase started by adjusting the eye tracking system to the individual features of the participant based on a nine-point calibration, which was repeated before each new testing video. Before watching the videos, participants received the following instruction: "While watching the video, please look carefully at the way the fish swims. Subsequent to watching the video, you will have to describe the fish's locomotion pattern." Then, a fixation cross appeared for two seconds followed by the testing video, which lasted four seconds. Participants watched the video while their eye movements were recorded. After having watched the video, participants were asked to describe the locomotion pattern of the depicted fish verbally. The verbal data were recorded by Camtasia 3.0 software using a standard microphone attached to the stimulus PC. Eye movements and verbal data were recorded with a Tobii 1750 remote eye tracking system (www.tobii.com). This procedure was repeated for all four testing videos.

Results

Gaze Data. The gaze data analyses are based on raw data, because smooth pursuit is very likely to occur while watching dynamic displays, but no algorithms for detecting it are available in current eye tracking software so far. Eye tracking data were logarithmized for further analyses. An ANOVA was conducted for each gaze measure with the factor gaze display (with vs. without). First, both groups differed in the time spent on the stimulus before inspecting the relevant areas of the stimulus for the first time ($F(1, 44)=6.73$, $p=.01$). That is, participants in the control group took more time in milliseconds until they first looked at the relevant part of the stimulus than the group with gaze display (CG: M =741.91 ms, SD=331.98; GD: M=547.39 ms, SD=140.66). Second, both groups differed in the overall time spent on the relevant areas of the stimulus ($F(1, 44)=4.48$, $p=.04$). That is, participants in the group with gaze display spent more time in milliseconds looking at the relevant parts of the stimulus than the control group (CG: M=529.57 ms, SD=354.91; GD: M=692.27 ms, SD =313.89). Figure 2 presents the gaze data.

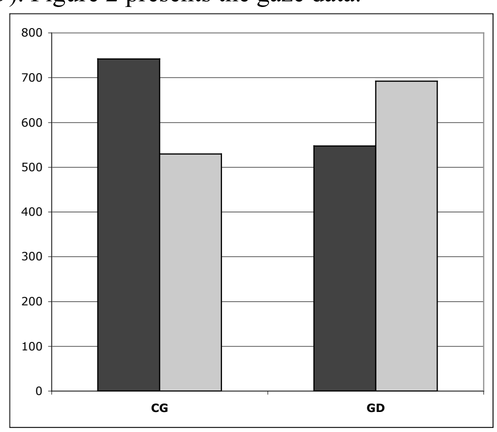

Figure 2: Time in ms until attending to relevant AOIs (dark grey) and dwell time spent on relevant AOIs (light grey).

Performance Data. An ANOVA was conducted for each performance measure with the factor gaze display (with vs. without). Contrary to our expectations both groups did not differ in being able to identify the body part relevant to the locomotion pattern. Both groups were quite good in this respect by naming over three of four times the correct body part (CG: M=3.27, SD=0.82; GD: M=3.34, SD=0.54). However, the groups differed significantly in interpreting this observation, when describing how this body part moves ($F(1, 44)=5.60$, $p=.02$), that is, the group with gaze display outperformed the control group (CG: M=1.46, SD=1.10; GR: M=2.18, SD=0.95). Figure 3 presents the performance data.

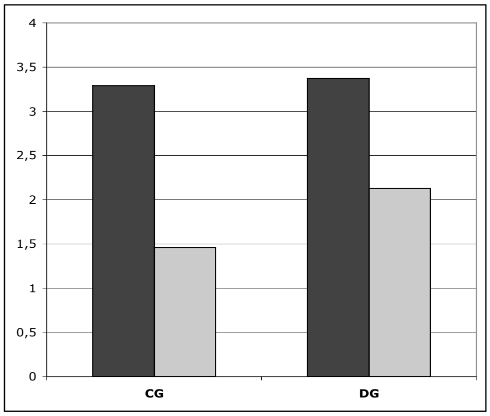

Figure 3: Number of identified body parts relevant to the movement (dark grey) and number of correctly described ways of movement (light grey) for both groups.

Discussion

The current study revealed that a modeling example based on displaying an expert's gazes to novices was successful in training aspects involved in accomplishing complex tasks with a rich visual component. At a process level, eye tracking analyses revealed that perceptual skills were enhanced through the training. First, participants, who received a gaze display, took less time until they attended to the relevant parts of the stimulus for the first time compared to the control group. Second, the gaze display group spent more time on the relevant areas of the stimulus. With regard to performance data, it could be shown that participants were quite good at the first step of the task performance, that is, finding out what the relevant aspects of the stimulus are (i.e., what are the crucial body parts for the locomotion pattern?). Both groups named the correct relevant area over three out of four times. Thus, it is not surprising that both groups did not differ in this performance aspect. The main difference between the trained and the control group occurred in the second step of the task performance, namely in observing and interpreting the perceived relevant area (i.e., how does the crucial body part move?). Participants with gaze display could interpret the perceived area more often correctly than the control group.

In sum, solving the first step of this task, namely perceiving the relevant out of the irrelevant areas of the stimulus seems to be feasible after a short verbal description of an expert. However, solving the second step of this task, which is the ability to interpret these relevant areas is related to the ability to perceive the relevant areas more quickly and to inspect them for a longer time. This perceptual skill is supported by gaze display. It is yet unclear, whether the perceptual skill facilitates the first step and thus leaves time and resources to solve the second or whether the perceptual skill facilitates the second step itself. A limitation of these results is that they examine the effect of a gaze display only in a short run. Further research should investigate, whether this effect still holds in longitudinal terms.

The study reported here showed that two issues are crucial when modeling experts' behavior. First, the task needs to be analyzed in detail. This can be done by comparing experts and novices while performing the task. A method that has proven to be appropriate to access the concept-based part of the task performance are verbal reports. However, some tasks require additionally perceptual skills. In order to get a better insight into perceptual processes of a task performance, eye tracking has proven to be the method of choice. The combination of both measures gives a good insight into the deficiencies of novices' task performance.

Second, the kind of the modeling should be chosen according to the results of this task analysis. A common problem is that experts perform a task using shortcuts. However, modeling shortcuts to people lacking the knowledge underlying these shortcuts is useless. Thus, experts should be instructed to behave in a more "didactical" manner. One possibility to achieve this is presented in the current study, where the expert's focus was manipulated successfully from a content to a recipient focus. Still, it has to be noted that although shortcuts are undesired for modeling purposes to novices, they are critical skill at a higher level of expertise. Thus, for training intermediates, it might be a benefit to present expert's shortcuts instead of omitting them. Furthermore, the task analysis should reveal at what level the behavior of novices should be modeled. Some tasks require sophisticated perceptual skills. The current study showed a way to successfully model these perceptual skills and thereby enhance task performance. Gaze display fosters the skill to perceive the relevant out of the irrelevant information more quickly and longer. This skill is related to a better performance in interpreting the perceived area. Another question that further research should address is whether incorporating the strategies of several experts would be beneficial. This could be done by presenting multiple examples, each presenting the same problem but with a different solution strategy, since the presentation of multiple examples has been shown to be beneficial for learning (Atkinson et al., 2000).

Moreover, the results of these studies provide important implications for learning scenarios, where gaze data cannot be applied easily so far (e.g., traditional classroom). The first study showed that for tasks with a complex and visually rich component, learners have deficiencies on a perceptual level. The second study showed that those deficiencies can be overcome by successful attention guidance. Thus, an instructor that teaches such a kind of task (like marine biology) should emphasize perceptual task aspects in a teaching unit and explicitly guide the attention of the learners' to the relevant parts of the display.

However, there are indications that the effectiveness of gaze displays in examples may depend on the type of task or domain as well as the way the gaze is displayed. In another study on gaze displays in examples on procedural problem-solving tasks (Van Gog et al., 2008), it was found that the combination of gaze display and verbal explanations had detrimental effects on problem-solving performance on the test compared to either gaze display and verbal explanations, verbal explanations only, or behavior modeling only. The gaze data were assumed to communicate information on the problem-solving strategy. However, this problem-solving relies much less on perceptual skills than the task used here, and hence, the eye movement data may have required too much interpretation on the part of the learner. Thus, the effect of a gaze display should be even stronger in a domain that relies even more on perceptual skills, like medical diagnoses. Second, the display of the expert's eye movements in the Van Gog et al. (2008) study was implemented with the eye tracker software. This means that the eye movements were displayed as a dot that enlarged or contracted to reflect changes in fixation duration. This might have had the effect that the eye movements themselves attract attention because of this movement, whereas the attention should be directed at the task feature the fixation is targeted at. Moreover, other types of gaze displays should be investigated in the future. A more sophisticated, spotlight-like display of eye movements is to blurr out non-attended information and leave the attended areas unaltered (Dorr, Vig, Gegenfurtner, Martinetz, & Barth, 2008). This kind of gaze display might model the eye movements of the learner in a non-intrusive way by guiding them away from irrelevant to relevant parts. Whether the type of task or the nature of the gaze display is the more important determinant of success of including eye movements in examples, is a question for future research.

In sum, a carefully prepared gaze display is a promising method to enhance performance in complex tasks with a visually rich and dynamic component. Still, this method should be investigated under conditions, where the perception and its interpretation are more complex in order to assess its full potential.

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