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Effects of eye movement modeling examples on adaptive expertise in medical image diagnosis

Andreas Gegenfurtner [a, *], Erno Lehtinen [b], Halszka Jarodzka [c, d], Roger Säljö [e]

[a] *Technische Hochschule Deggendorf, Germany*
[b] *University of Turku, Finland*
[c] *Open University of the Netherlands, The Netherlands*
[d] *Humanities Lab, Lund University, Sweden*
[e] *University of Gothenburg, Sweden*

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A B S T R A C T

Research indicates that expert performance is domain specific and hardly transfers to novel tasks or domains. However, due to technological changes in dynamic work settings, experts sometimes need to adapt and transfer their skills to new task affordances. The present mixed method study investigates whether eye movement modeling examples (EMME) can promote adaptive expertise in medical image diagnosis. Performance, eye tracking, and think-aloud protocol data were obtained from nine medical experts and fourteen medical students. Participants interpreted dynamic visualizations before (baseline) and after (retention, transfer) viewing an expert model's eye movements. Findings indicate that studying eye movement modeling examples had positive effects on performance, task-relevant fixations, and the use of cognitive and metacognitive comprehension strategies. Effects were stronger for the retention than for the transfer task. Medical experts benefitted more from the modeling examples than did medical students. Directions for future research and implications for related domains are discussed.

1. Introduction

Research on expertise has shown that expert performance is domain specific and hardly transfers to novel tasks or other domains (Bertram, Helle, Kaakinen, & Svedström, 2013; Gegenfurtner & Szulewski, 2016; Jaarsma, Jarodzka, Nap, van Merriënboer, & Boshuizen, 2015; Litchfield & Donovan, 2016). However, due to technological changes in dynamic work settings, experts face situations in which they need to adapt and transfer their skills to new task affordances (Gegenfurtner & Seppänen, 2013; Lehtinen, Hakkarainen, & Palonen, 2014). The present study investigates whether an eye movement modeling example (EMME; Jarodzka, Van Gog, Dorr, Scheiter, & Gerjets, 2013; Mason, Pluchino, & Tornatora, 2015; Seppänen & Gegenfurtner, 2012; Van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2009) can promote adaptive expertise.

1.1. Adaptive expertise

Expertise is often defined as being specific to the domain in which it has developed. Studies show that experts are more accurate in domain-specific task performance than novices (Ericsson, 2004; Gegenfurtner, Lehtinen, & Säljö, 2011; Jarodzka,

* Corresponding author. Technische Hochschule Deggendorf, Dieter-Görlitz-Platz 1, 94469 Deggendorf, Germany.
E-mail address: andreas.gegenfurtner@th-deg.de (A. Gegenfurtner).

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Jaarsma, & Boshuizen, 2015; Krupsinki, 2010; Szulewski, Gegenfurtner, Howes, Sivilotti, & Van Merriënboer, 2017). However, if domains or their constitutive elements like artifacts, work practices, or routines change, then experts need to adapt their knowledge and skills to the changing affordances. This adaptive expertise can be defined as the ability to modify expert routines to changing tasks in a domain (Gegenfurtner, 2013; Hatano & Inagaki, 1986). This transfer of expertise is not always successful and may be compromised by cognitive biases (Feltovich, Spiro, & Coulson, 1997; Gegenfurtner & Seppänen, 2013), thus experts may benefit from instructional guidance. However, little research exists on how experts can be instructionally guided when they are confronted with novel, unfamiliar situations. This is a relevant question in many technology-rich professional arenas. Exemplarily, the present study addresses this gap in the context of visual expertise in medicine.

Several recent studies illuminate visual expertise in medicine (Gegenfurtner, Siewiorek, Lehtinen, & Säljö, 2013; Gegenfurtner, Kok, Van Geel, De Bruin, & Sorger, in press; Gruber, Jansen, Marienhagen, & Altenmüller, 2010; Jarodzka, Holmqvist, & Gruber, 2017; Norman, Eva, Brooks, & Hamstra, 2006; Kok, 2016; see also Gegenfurtner & Van Merriënboer, in press). For example, Balslev et al. (2012) demonstrated that clinicians with higher levels of expertise ignore task-redundant information in patient video cases more often than participants with lower levels of expertise. Wilson and colleagues (2010) highlighted experts' strategic considerations to selectively allocate attentional resources to task-relevant information. Litchfield and Donovan (2016) showed that experts are less biased toward distracting information than novices are. Although these studies are highly informative about routine expertise in medicine, they are limited in informing us about adaptive expertise. The medical domain is very apt for studying adaptive expertise because technologies for producing medical visualizations are dynamic work artifacts that change, with new kinds of visualizations currently introduced to the medical workplace at a high pace (Gegenfurtner, Nivala, Lehtinen, & Säljö, 2009; Helle et al., 2011). An example of a newly introduced imaging technology is the combination of computer tomography (CT) and positron emission tomography (PET), which creates a new kind of fusion picture, PET/CT (Gegenfurtner & Seppänen, 2013; Seppänen, 2008). CT is a typical technology in radiology that visualizes human anatomy. In contrast, PET is a typical technology in nuclear medicine that visualizes metabolism and the functional processes of the body. Experts in these two domains, radiology and nuclear medicine, need to show transformative agency (Damşa, Froehlich, & Gegenfurtner, in press) and adapt their skills to the novel task affordances around PET/CT visualizations (Gegenfurtner & Seppänen, 2013). This is a classic scenario of adaptive expertise. However, little is known how we can instructionally guide experts to adapt. Evidence suggests that a transfer of expertise is possible in powerful learning environments. Specifically, Feltovich et al. (1997) indicated that medical experts may be able to flexibly adapt their biomedical knowledge to highly atypical cases. Hatano and Inagaki (1986) as well as Schwartz, Bransford, and Sears (2005) expressed similar conclusions, arguing that instructionally guided adaptive expertise (or "preparation for future learning") is possible in an "optimal adaptability corridor" (Schwartz et al., 2005). Building on this research, the present study aims to test whether transfer of expertise in the comprehension of visualizations can be promoted with modeling examples and if prior expertise in other fields of medicine mediates the effects of the intervention.

Several theories explain the processes that underlie expertise in the comprehension of visualizations. First, the information-reduction hypothesis (Haider & Frensch, 1999) focuses on the learned selectivity of information processing. This theory suggests that expertise optimizes the amount of processed information by neglecting task-redundant information and actively focusing on task-relevant information. Second, the theory of long-term working memory (Ericsson & Kintsch, 1995) focuses on changes in memory structures. This theory assumes that expertise extends the capacities for information processing owing to the acquisition of retrieval structures. If it is true that medical expertise increases the selective allocation of attentional resources and speeds the retrieval of knowledge stored in long-term memory, then these changes should be reflected in trackings of eye movements and recordings of think-aloud protocols.

1.2. Eye movement modeling examples

Modeling examples provide a solution procedure to a given problem and demonstrate the processes underlying task completion, which can then be observed by the learner (Collins & Kapur, 2014; Jarodzka et al., 2013; Mason et al., 2015; Van Gog et al., 2009). In visual tasks, some of these underlying mental processes include the allocation of attentional resources to task-relevant information. Therefore, one approach that is used in the research on modeling examples is to use gaze replays of the experts. By replaying the eye movements of experts, learners can observe where, for how long, and in which order experts fixate on information that is relevant to solving the task. Evidence suggests that eye movement modeling examples (EMME) are effective in guiding novices' attention and thought (Boekhout, Van Gog, Van de Wiel, Gerards-Last, & Geraets, 2010; Jarodzka et al., 2012, 2013; Kundel, Nodine, & Krupinski, 1990; Litchfield, Ball, Donovan, Manning, & Crawford, 2010; Mason et al., 2015; Nalanagula, Greenstein, & Gramopadhye, 2006; Seppänen & Gegenfurtner, 2012; Velichkovsky, 1995). However, Van Gog et al. (2009) found that EMME had detrimental effects on novice learning; these authors recommended testing the effectiveness of EMME with perceptually more complex tasks and under conditions of information transience (when task-relevant information appears and disappears). Following these recommendations, the present study uses a task that is perceptually complex because the visualization is three-dimensional and user-controlled. Second, the task includes transient information because the visualization is dynamic. The present study focuses not only on naïve novices but also includes a group of experts. This also allows testing whether eye movement modeling examples induce an expertise reversal effect (Chen, Kalyuga, & Sweller, 2017). Before we list the hypotheses of the study, the following section discusses instructional characteristics of eye movement modeling examples.