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The interplay between methodologies, tasks and visualisation formats in the study of visual expertise

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1. Introduction

As underlined in the issue by Andreas Gegenfurtner & Jeroen Merriënboer (2017, this issue), *"Expertise can be defined as maximal adaptations to task constraints"* (Ericsson & Lehmann, 1996; Gruber, Jansen, Marienhagen, & Altenmueller, 2010). This definition implicitly emphasizes the multimodal dimension of expertise, both cognitive and perceptual. The study of expertise, notably visual expertise (or expert cognition in visual tasks), has a long research tradition, and several important discoveries and theoretical advances have been made and developed within the framework of Ericsson's 'Expert Performance Approach' (see Williams, Fawver, & Hodges, this issue*)*. However, the recent refinement and widespread use of technologies such as eye tracking, and the development of new methods such as direct brain investigations (fMRI, FNIRS etc.) have shed new light on "visual expertise" within the broad perception-cognition interplay system. This special issue on **"Methodologies for Studying Visual Expertise"** offers a unique opportunity to discover the diversity and complementarities of the methods and techniques used to analyse expertise and its development. In contrast to conventional special issues, it does not comprise empirical studies, but a series of research reviews presenting and analysing different methods or frameworks. Thus, the first paper offers a sort of methodological guide using Ericsson & Smith's (1991) "expert performance approach". This is followed by three papers analysing the use of eye tracking in visual expertise models, and a paper reviewing the use of methods such as EEG and fMRI to investigate the neural correlates of visual perceptual expertise. A paper on Receiver Operating Characteristic (ROC) analysis brings new insight to the well-known signal detection methods used in control and visual inspection tasks in industry. Finally, three papers review methods based on verbal reports and protocols used to investigate the conceptual and meta-cognitive levels of visual expertise. In the following sections, we will (i) describe the methodological contribution of each paper according to five main themes or criteria (see Table 1), and (ii) discuss the benefits, limitations, and particularly the opportunities offered by new developments in each methodology and their possible combinations.

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2. Methodological Contributions

As shown in Table 1, the methodological contributions and results differ for each criterion.

Table 1

Summary of each methodological review

Authors and **Method** investigated	**Visual expertise level** Process level/ models	**Tasks:** **-Goals, measures**	**Materials-stimuli** "artificial"/"realistic" Static *vs.* dynamic Interactivity, 2/3D	**Results**	**Groups of interest**
Williams, Fawver, Hodges Expert Performance Approach	- Multiple levels of performance (capture, process, learning) - Long-term working memory (Ericsson)	- Detailed measures of learning efficiency - Process tracing measures - Visual anticipation - Decision making (sports)	- Realistic, "quasi-ecological" scenes - Film-based simulation: static and dynamic visual stimuli	- Promise of virtual reality (embodiment), 2D -Transfer of expertise to several domains	- Experts, novices, learners, - How experts refine skills -Individual differences
Krupinski ROC analysis based on TDS	- Visual detection /discrimination - Less on process	-Target Detection and decision - Sensitivity, specificity, accuracy - Area Under the Curve metric	- "Realistic" (or modified) medical images: radiology - Industry (visual inspection of objects) - Static images (2D)	- Measures of sensitivity, specificity and accuracy	- Mostly experts and novices
Gegenfurtner Kok, van Geel, de Bruin, Sorger Functional neuro-imaging	- Neural correlates of visual perceptual expertise: - EEG - fMRI	-Target detection - Detection tasks - Decision making (manipulated images) - Viewing Judgments	- Artificial (Greebles) and realistic stimuli - Medical domain: radiology - Mostly static single images (2D) - No interactivity	- EEG: temporal adaptation of expertise: N170 - fMRI: spatial adaptation of expertise: FFA (Multiple brain areas: cortico-spinal activation, temporal and frontal gyri, left inferior frontal sulcus, posterior cingulate cortex)	- Experts Novices
Fox, Faulkner-Jones Eye tracking	- Eye movements -Top-down /bottom up dynamics: perceptual-cognitive	- Diagnosis - Focal disease detection - Gaze fixations, saccades, scan paths. - Errors	- Realistic medical stimuli - Radiology Target search, recognition Diagnosis - Mostly static single images (2D) - No interactivity - Hand-eye tasks in procedural skills: laparoscopic tasks	- Experts: fewer fixations, less time on AOIs - search-related tasks, top-down, less feed-back needed. - Holistic/analytic phases: gestalt - Guided/Hybrid search models - Unexpected paths Priority map, attentional priority -Assistive technology - Inattentional blindness - Missing rare events - Maintaining eye-gaze - Skills evaluation	- Mostly Experts Novices (learners)
Szulewski, Kelton, Howes	- Cognitive Load - CL quantification	- Medical Diagnosis - Decision making from visual scenes.	- Medical scenes - Visual laparoscopic tasks	- CL quantification - Pupil dilation (light condition limits)	- Experts Novices learners

Pupillometry Eye tracking			- Mostly static (some dynamic) - 2D, No interactivity		
Litchfield, Donovan -FPMWP -Flash-preview moving window paradigm	- Holistic model - Effect of initial glimpse on subsequent search behaviour - Interplay of holistic/analytic processes	- Target detection - Focal tumour detection - Decision making - Manipulation of the FPMWP variables/measures.	- Everyday visual scenes - Medicine: radiology images - Static 2D images - No interactivity	- Inconsistent effects - First preview impairs experts' performance	- Experts Novices
Helle Combination eye-tracking/ verbal reports	- Speech production - Visual search - Conscious and meta-cognitive level, performance levels	-Verbal reports: thinking aloud, - Retrospective thinking aloud	- Medical image interpretation - Radiology - Dermatology - Mostly static -2D	- Effectiveness: verbalization time limits <10sec.	- Experts (Novices)
Van de Wiel Interviews verbal protocols Focus groups	- Structured interviews - Conscious and (meta)-cognitive planning - Task representation - Size anticipation	- Free recall - Explaining reports - Coding verbal reports	- Medical images and scenes - Medical tasks: problem solving - Reasoning	- Insight into the tasks and materials to be selected - Guide	- Mostly experts
Ivarsson Ethno methodology	- Embodiment of visual expertise - Visual expertise grounded in body actions	- Communication of visual analysis tasks, diagnosis - Explanation, gestures - Video-tapes of experts	- Radiology (thoracic) images - Mostly static (reference to dynamic images)	- Embodiment results: effect of visual expertise or of explanatory task?	- Experts (few)

The next section discusses the specific contributions of the methodologies.

3. Lessons and opportunities of each methodology

3.1. Different levels of visual and cognitive processes

Two main levels of visual expertise are explored. First, fine-grained visual-cognitive processes and performance are addressed in the papers on eye tracking by Fox & Faulkner-Jones, Litchfield & Donovan, and Krupinski; in the paper concerning functional neuro-imaging by Gegenfurtner, Kok, van Geel, de Bruin, & Sorger; and in the paper about pupillometry by Szulewski, Kelton & Howes. Of particular interest is their analysis and description of the temporal course of the interplay between holistic and more analytic processing of the visual stimuli with their neural correlates. Secondly, the papers on verbal reports by van de Wiel and by Ivarsson introduce different top-down processing levels, which seem to be more conscious, and (meta)-cognitive levels. These include task representation, planning activities involving dimensions such as the extent of anticipation, and the heuristic level used to plan the visual search. The relationship between top-down and bottom-up processes is addressed in all the papers, but particularly by Helle who describes a methodology that is well-suited to this question, involving a combination of verbal reports and eye tracking.

The two neuro-imaging methods described by Gegenfurtner, Kok, van Geel, de Bruin, & Sorger involve different processing levels: temporal for EEG (N170), and spatial for fMRI (the Face Fusiform Area (FFA) and other brain regions).

In Szulewski, Kelton, & Howes' investigation of pupillometry, the authors describe how changes in pupil diameter across time reflect cognitive load levels and the relationship between cognitive load and expertise level. An important aspect concerns differentiating between the specific cognitive processes involved, and whether they are global or local. The authors refer to Sweller's distinction between ICL (Intrinsic Cognitive Load), ECL (Extraneous Cognitive Load), and GCL (Germane Cognitive Load). Is it possible to vary ICL, ECL and GCL using the same type of task and the same visual environment stimuli? However, it is more difficult to assess the specific involvement of different cognitive processes, such as information storage, manipulation of information, executive control, etc. It would be interesting to manipulate variables to test pupil diameter reactions when participants perform different types of task (memory, storage, cognitive control) involving different kinds or levels of information processing. For example, in the developing area of neuro-ergonomics, Durantin, Gagnon, Tremblay, & Dehais (2014) measured the cognitive load level of easy vs. difficult flight tasks for aircraft pilots using fNIRS (prefrontal dorso-lateral area) and pupil dilation, with similar results to those shown in figure 1 of Szulewski, Kelton, & Howes's (this issue).

Finally, in the visual search expertise models described by Fox & Jones (e.g. guided search model, priority map and hybrid search), measures such as saccades and scan path could be used to study chunking mechanisms. As shown in Table 1, different tasks are used for each methodology, yielding apparently varied results.

3.2. Task goals, task design and outcomes.

As shown in Table 1, in most of the methods reviewed in the nine papers, the results of previous research, and the nature of the cognitive and visual search processes involved, differ significantly and are sometimes inconsistent, even when the same visual material is used.

With medical images, such as chest X-rays, or in dermatology, the results of the experiments about the performance of experts and novices seem to differ for simple target detection (nodules), diagnosis, categorization, and decision making. In their review of studies of functional neuro-imaging methods, Gegenfurtner, Kok, van Geel, de Bruin, & Sorger found clear visual expertise effects in the use of EEG (N170) and fMRI (Fusiform Face Area FFA activity). However, they also suggest (in their Table 1) that the brain regions that are activated depends not only on the method (X-ray, fMRI etc.), stimuli (medical vs. non-medical) and expertise, but also on the type of task (e.g. viewing, detection, decision-making, reasoning, image manipulation) and task complexity. For example, the activated regions may not be associated with object recognition (e.g. FFA) but with attention and memory. As stated by the authors, "Cognitive neuroscience examining expertise in medical image diagnosis is promising but still in its infancy", and further research is urgently needed in this area. More generally, the question is raised about how tasks can be customized in order to assess specific processing mechanisms, without moving too far from the ecological process: in other words, the art of simplifying the task without changing it too much.

In their review of eye-tracking methods, Fox & Faulkner-Jones also found an effect of task type in top-down and bottom-up dynamics, when detecting *perturbations* or *deviance* from expectations. Similarly, task differences may also raise questions about the initial holistic phase of image processing in Nodine & Kundel's (1987) model.

Another crucial aspect of the effect of task design on performance and cognitive processes in visual expertise is illustrated in Litchfield & Donovan's review of the flash-preview moving window paradigm (FPMW). As described by the authors, in the FPMW paradigm (taken from Castelhano & Henderson, 2007), "observers are briefly shown a preview of the upcoming search scene and are subsequently asked to search for a particular target object whilst their peripheral vision is restricted to a gaze-contingent moving window". In the framework of the holistic model of image processing, a positive flash preview effect of the whole image

(250ms) has been shown in detection tasks in experts, but not, or much less, in novices. According to Litchfield and Donovan, *"It is within this initial glimpse of the scene –gist- that subsequent eye movements are guided* (Castelhano & Henderson, 2007) *with parafoveal and peripheral vision playing an important role in the early comprehension of the gist of a scene and in the detection of targets* (Henderson, Pollatsek, & Rayner, 1989)*"*. However, unexpectedly, experiments conducted with experts and novices using the FPMW method (Litchfield & Donovan, 2016; see also Donovan & Litchfield, 2013) found that experts were impaired at identifying target abnormalities (lung nodules, brain tumours, bone fractures) if shown a preview. As stated by the authors, "it is still unclear whether it is an expertise-specific advantage in global processing that specifically contributes to search guidance". These results of the FPMW method involving a particular visual activity raise questions and concerns about the holistic model. We can hypothesize that a potential negative effect of flash previews could also arise in the case of dynamic pictures, such as animations or videos: with this dynamic material, it could be necessary to stop earlier global processing in order to find the boundaries of temporal processes (e.g. meteorology maps, Lowe, 1999). This aspect will be discussed further below.

In the methods based on verbal reports, van de Wiel examined expertise using interviews and verbal protocols and found that the type of interview (the method) and the task determine the data that is collected and the results of the investigation.

Finally, regarding the ethno-methodology approach, Ivarsson followed a group of radiologists and radio physicists who were told to find, discuss, and formulate issues or problems ensuing from the implementation of new radiographic imaging technology. Using their visual expertise, they had to communicate their analysis of the image, not only verbally but also with gestures: this has been termed the "enacted production of radiological reasoning". Analysis of the data suggested that visual expertise was, partly at least, due to embodied practice and ability. However, and in relation with a task effect, we also suggest that the embodiment effects that are described as the main finding and purpose of the paper could be partially produced by the communication task, which involved gestures and bodily demonstrations. This effect does not necessarily mean that a visual radiological task (e.g. tumour detection) in everyday practice involves this type of embodiment. It is possible that the experimental task forced them to embody their analysis in order to explain and to be understood.

3.2.1. Making relations and drawing inferences

Many of the studies reviewed in the papers focus on visual search, and apart from the reviews and studies of verbal reports and the global expertise framework (Helle, van de Wiel, Ivarsson, and Williams, Fawver & Hodges), the task (with performance measures) involves the detection of targets or abnormalities. However, visual tasks involving more complex diagnoses or interpretation require making relations between two or more components of the visual scene, or between targets situated at more or less distant locations (see Schwan, 2013). In future research with eye-tracking and functional brain imaging methods, it would be very interesting to analyse how experts and novices process or construct such relations. This would be particularly relevant for developing learning tasks for students who are at a stage between novices and experts. Regarding this aspect of visual processing, Litchfield and Donovan, in their review of FPMW studies, make an interesting remark about the re-direction of eye gaze according to time-locked acquisition of new information during the visual processing of medical images. This raises a crucial question about dynamic chunking during these re-directions. How does the new information interact with previously acquired knowledge and re-direct or drive the new gaze on the visual scene? Processing relations efficiently could be even more important to interpret dynamic visual scenes. The visual format of images is the subject of the next section.

3.3. Format of the visual material and interactive features

Table 1 shows that in most previous research on visual expertise, especially in the medical area (except in William, Fawver & Hodges' paper) the format of the visual scenes is limited to conventional 2D images, often presented as a single image. However, with technological advances, images can now be dynamic: animation (realistic or virtual), dynamic scenes, videos etc. Medical images, such as CT images, can also be dynamic. For example, "on line" heart rate graphs can be presented dynamically on screen; ultrasound or scanner images show the opening and closing of heart valves, and long series of images can be scrolled down and synchronized by the user.

In their reviews, Gegenfurtner, Kok, van Geel, de Bruin & Sorger, and Fox & Faulkner-Jones observe that further research is needed on dynamic stimuli. Gegenfurtner et al. observed that it is surprising that the literature on the neural correlates of real-world visual perceptual expertise has not yet systematically compared how the brain processes of experts and novices differ when they view static vs. dynamic stimuli or two-dimensional vs. three-dimensional images. Fox & Faulkner-Jones also report that several studies involved the use of visual stimuli that require manipulation by the viewer, such as three-dimensional images and dynamic video recordings.

While the literature on dynamic image processing seems to be limited, the situation is very different in the field of learning and education, where a vast amount of research has been conducted in the last 20 years (see for example, Lowe, Schnotz, 2008; Bétrancourt, 2005; Mayer, 2005, 2014; van Gog & Schieter, 2010; Höffler & Leutner, 2007; Boucheix & Lowe, 2010, 2013; Lowe & Boucheix, 2008, 2011, 2016; Jarodzka, Scheiter, Gerjets & van Gog, 2010, amongst many others).

Bétrancourt and Tversky (2000) defined computer animation with its notions of dynamic stimuli and transience as follows: *"computer animation refers to any application which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user"* (p. 313). Thus, when presented with transient information, viewers (experts, novices or learners) must simultaneously store, process and link both previous and current information. Thus, the distinction between static and dynamic images should not be seen as an adjunct to conventional static visual scenes, but as different in nature, with temporal and transient information added to the spatial dimension. With static visual stimuli, the perceptual and cognitive processing unit is the object (or part of it), with its shape and spatial location, but with dynamic stimuli, the perceptual and cognitive processing unit is the event with its associated behaviour (Lowe & Boucheix, 2008, 2016; Kurby & Zacks, 2008).

Lowe & Boucheix (2008) proposed an animation processing model of explanatory dynamic visualizations in learners (the APM) based on studies that highlighted temporal processing (see also Boucheix & Lowe, 2016). Fig 1.

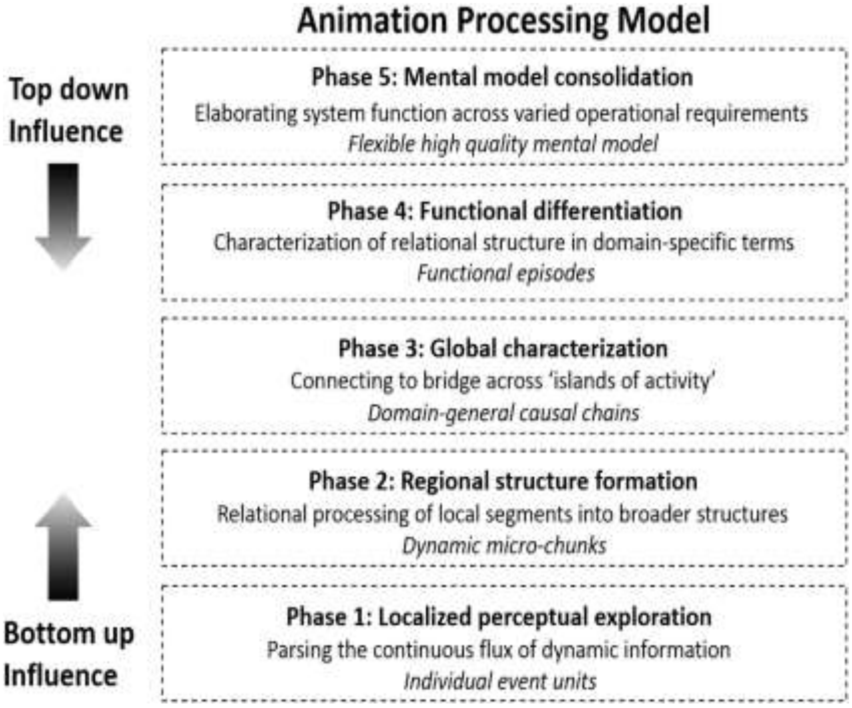

Figure 1. Summary of the main phases of the Animation Processing Model (Lowe & Boucheix, 2008.

According to the five-phase hierarchical Animation Processing Model, learning from animation is a cumulative process for building dynamic mental models in which events play a crucial role. Overall, this learning process can be divided into two broad types of activity: decomposition (APM Phase 1) and composition (APM Phases 2-5). A distinction is thus made between (i) analytic processing in which the learner must initially decompose the animation's continuous flux of information into the discrete event units (entities plus their associated behaviours) that provide the raw material for mental model building, and (ii) synthetic processing in which this raw material is cumulatively and iteratively composed into the higher order knowledge structures that comprise a mental model of the target subject matter.

The present commentary on the nine papers is not the place to present a theoretical model. However, it illustrates potential changes, especially with learners in the educational area (mostly novices) when using dynamic presentations (see also the work by Lowe on expert meteorologists, 1999). As observed by Fox & Faulkner-Jones on page 6: *"We now have the tools available to examine the effects of expertise upon the dynamic diagnostic process. The authors have examined pathology trainees at the early and late stages of training, and found support for the use of specific dynamic digital platforms in the acquisition of "expert" patterns of gaze (Fox et al., 2016)".*

In previous research with single static images, the main focus was on targets such as components or parts of objects. Studies on dynamic stimuli emphasized the regional level of processing with the idea of macro- or micro-dynamic chunks (Lowe & Boucheix, 2008; Boucheix, Lowe, Putri & Groff, 2013). It would be interesting to introduce a regional level in the flash-preview moving window paradigm presented by Litchfield & Donovan, in the framework of the Global-Focal search model (Nodine & Kundel, 1987). The relevance of the regional level clearly depends on the type and content of the images.

More generally, it would be interesting to test the expertise effect on dynamic stimuli processing using different methodologies. What would be the effect of dynamic stimuli on sensitivity, specificity and accuracy in the ROC analysis method (Krupinski), on eye-tracking measures (Fox & Faulkner-Jones), on eye tracking with verbal reports (Helle), and on the neuro-correlates of visual expertise? What about the brain regions and neural circuits involved in processing dynamic stimuli?

Finally, dynamic visualization may have interactive features such as user control; for example, the sequence of frames can be determined either by the designer or by the user. For example, an obstetrician-gynaecologist carrying out an ultrasound of the foetus of a pregnant woman, or a radiologist scrolling through a series of frames of a brain scan, can control the sequence of images in order to analyse them. What is the effect of expertise on the cognitive control strategies used to visualize the series of frames? The question is also raised of the interactions between top-down and bottom-up processing during the temporal sequence. Previous research in the educational and learning area (school children, students and also professionals) found that interactive features hindered rather than fostered the performance of learners *("what matters is what you see, not whether you interact"*, Keehner, Hegarty, Cohen, Khooshabeh & Montelleo, 2008; Bétrancourt, 2005; Boucheix, 2008).

This interactive aspect of user control is also raised in the case of 3D objects, as highlighted in Fox & Faulkner-Jones' review of eye-tracking methods and in Gegenfurtner et al.'s review of neuro-imaging techniques. Previous research on 3D-object processing has also revealed difficulties for learners. However, short training sessions seem to lead to significant performance improvement (Cohen & Hegarty, 2007, 2011).

3.4. Groups of Interest: Learners, learning and individual differences

3.4.1. Learners and Learning

Taking the Expert Performance Approach, based on Ericsson & Kintsch's (1995) long-term working memory theory, Williams, Fawver, & Hodges underline the need to address the issue of facilitating the acquisition of expert performance: *"In contrast to the growing research on expert performance across numerous domains, as well as significant research focusing on practice profiles of experts and novices, there remains a need for research on how expert learners continue to learn new skills and refine existing skills."*

It is also important to examine how visual expertise develops. Gegenfurtner et al. identified three research approaches: contrastive (expert vs. novices), developmental (training effect on neural activations), and conditional.

However, as shown in Table 1 (last column on the right), in many of the methodological reviews, it seems that most studies focus on experts and/or novices and not on learners at different learning stages. Longitudinal studies on the development of visual expertise could thus offer relevant insight into expertise development: how and when the cognitive processes involved in the visual search of images change, how eye movement patterns and scan paths change, how neural activations change, what develops and appears or disappears in learners' verbal reports at different professional stages.

As observed by Williams et al., one of the problems when assessing learning effects is the need for control groups (matched with experimental groups). Joint research with researchers in the educational field should thus be encouraged. As shown by Fox & Faulkner-Jones with regard to eye tracking, the top-down and bottom-up dynamics at different stages of learning could be very relevant in the study of expertise. For example, what is the learning process in the changes mentioned by Litchfield & Donovan: "visual search in medical image perception begins as: SEARCH & DETECT–RECOGNIZE–DECIDE, but with experience, this develops into: RECOGNIZE & DETECT–SEARCH–DECIDE”. The holistic visual search model, well suited to experts in the medical area, may not be entirely appropriate for learning complex animated graphics, where novices’ initial “glimpses” concern the most perceptually salient information, which may also be the least relevant (see Lowe, 1999, with meteorologists, or Boucheix & Lowe, 2006, 2010).

Table 1 also indicates that, in most of the methodological reviews, only a few studies have investigated or focused on individual differences in experts.

3.4.2. Individual differences

In their review, Williams et al. argue that there is a need for "*more process-oriented studies about changes during learning that explain or address differences or changes in outcomes"*. In their view, deliberate practice is not the only factor explaining expertise development. There are vast differences in the amount of practice carried out by experts who have the same performance level. Methodologies that record performance (objective measures) combined with verbal reports (more subjective measures) could help understand the course and development of the acquired expertise. Similarly, Gegenfurtner et al. wonder whether it is possible to *"reliably measure/objectify neural correlates of visual expertise with currently available functional neuroimaging methods and therewith explain inter-individual behavioral differences"* with respect to visual perceptual expertise.

3.4.3. Spatial abilities and visual expertise (in the medical area)

In none of the reviews (to the best of my understanding) are visual-spatial abilities considered to be a potential moderator of expertise, whatever the methodology used. However, a plethora of previous studies in this field showed that spatial abilities measured with standardized tests involving mental rotation of objects, spatial perspective taking, paper-folding tasks etc. had a significant effect on graphic and visual scene processing (for a review, see Hegarty, 2010; Hegarty, De Leeuw, & Bonura, 2008; Höffler & Leutner, 2010; Boucheix & Schneider, 2009; Boucheix & Chevrey, 2014). Investigating the relationship between spatial abilities and the development of expertise could provide fruitful information to further our understanding of professional development and training. Furthermore, all the standardized ability tests use static pictures of objects (e.g., Metzler figures). With the development of dynamic visual presentations, it could be relevant to use dynamic instead of static spatial ability tests (Porte, Boucheix & Bétrancourt, 2016).

4. Conclusion: Limitations of Methodologies for Studying Visual Expertise and the prospect of combined and synchronized methods

To conclude this commentary we will briefly remark on two interrelated aspects: the limitations of the methodologies and the interest of using and combining several methodologies in the same research.

4.1. Limitations of Methodologies for Studying Visual Expertise

In each of the papers, the limitations of each methodology are indicated, as illustrated below.

Gegenfurtner, Kok, van Geel, de Bruin & Sorger discuss the spatial limitations of EEG, and the temporal limitations of fMRI. Limitations regarding the distance from the scalp to the deep structures in the brain have been described for fNIRS. Until recently, designing more ecological visual situations has been a challenge in neuro-imaging. By contrast, Williams et al. describe how more ecological situations have been created in the expert-performance approach, such as film-based simulation to evaluate anticipation and decision-making in tennis (see figure 2, in the paper by Williams et al., this issue).

Fox & Faulkner-Jones and Litchfield & Donovan underline the well-known limitation of eye-tracking techniques, namely that only focal vision is recorded, and not peripheral vision. However, the role of peripheral vision can be analysed using the flash-preview moving window paradigm. Szulewski, Kelton & Howes describe how pupillometry requires strict lighting conditions. Helle, van de Wiel, and also to some extent Ivarsson, discuss the limitations of interviews and verbal protocols to assess tacit, implicit, and more or less "unconscious" aspects of expertise.

Finally, at a more general level, Gegenfurtner et al. highlight several possible caveats about the neuroscientific methods in addition to the limitations of spatial and temporal resolution, including ecological validity, reductive experimental bias and limited implications in the field of education. To some extent these limitations apply to many methodologies.

4.2. The prospect of combined and synchronized methods

In a recent review, Gegenfurtner, Kok, van Geel, de Bruin, Jarodzka, Szulewski & van Merriënboer, (2017) underlined *"the need to allow novel and unconventional combinations of methods to aggregate data material that transcends single paradigmatic boundaries".* As shown by Helle’s analysis of verbal protocol and eye tracking, the use of complementary and synchronized methodologies or techniques could be useful when investigating process-oriented visual expertise. However, the decision to use two (or more) methodologies should not be guided only by the mere idea of collecting more data, but by much more specific goal of research. For example, and as suggested in Gegenfurtner et al.’s review in this issue, the combination of pupillometry and EEG could provide interesting data and insight into the correlation between eye movements and neural activity. Similarly, recent research on cognitive load in the domain of neuro-ergonomics (e.g. aircraft pilots) combined eye tracking (with pupillometry) and fNIRS to understand the potential correlation between eye movements and pre-frontal (dorsolateral) activation during difficult piloting tasks (see Durantin, Gagnon, Tremblay, & Dehais, 2014; Dehais, Causse & Cegarra, 2017).

Using a technique called Eye Fixation-related Potentials (EFRPs), Thierry Baccino (see Rämä & Baccino, 2010) combined eye movement and EEG measures and showed that this technique could be a useful tool to study the temporal dynamics of visual perception and the processes underlying object identification.

Two other methodologies could complement the ones analysed in this special issue on visual expertise. The first is motion capture, which uses 3D motion sensors to record gestures and body movements, possibly in conjunction with other measures, such as eye movements recorded with mobile eye-tracking glasses. This could be useful to study new aspects of visual tasks involving gestures and hand-eye coordination (see figure 2 in Williams et al.’s paper, showing a film-based simulation used to evaluate anticipation and decision-making in tennis). Similarly, in arts, the processes underlying drawing or painting tasks could be analysed using a combination of eye tracking and motion capture (Perdreau & Cavanagh et al., 2013). The same coupling of methods could be used in the medical domain, for example in surgery or radiology. The second methodology concerns the recording of physiological measures such as heart rate and skin conductance. These could be particularly useful when studying the emotional aspects of decision-making and/or "intensive" cognition related to cognitive load. Similar methods have already been used in the field of car driving, for example in simulation tasks or to study the visual expertise of car drivers (Pépin, Jallais, Fort, Navarro & Gabaude, 2017).

Two more general concluding remarks can be made. Firstly, all the papers in this special issue contribute to a better understanding of the dynamics between top-down and bottom-up processes in visual expertise and of how perceptual expertise interacts with cognitive expertise. This has important practical implications. For example, in the field of education research, signalling and cueing effects in multimedia presentations have been extensively studied using eye tracking (see for example, Jarodozka, de Köning, Boucheix). One of the main results of these studies is that learners fixate the signalled or cued information in the right place and at the right time, indicating that the signalling effect works (see also, Mayer, 2014). However, this is not a guarantee that the information has been understood at a deep level. The second point concerns another practical issue of the research on the methodologies used to study visual expertise. In Gegenfurtner et al.'s review of neuro-scientific methods, they observe that *"it is a false belief that findings from EEG and fMRI would be directly applicable and informative for re-designing learning environments and curricula"*. Indeed, given the level of "reduction" in neuroscience experiments, we need to be very cautious about their practical implications. However, the continuous improvement of cognitive and neuro-scientific technologies in the future will give increasing opportunities to gain in-depth understanding of the processes underlying visual expertise. The nine articles in this special issue contribute to this progress.

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