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Expertise in basketball modifies perceptual discrimination abilities, underlying cognitive processes, and visual behaviours

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In this paper, the links between cognitive constraints, visual behaviours, and perceptual judgements are examined. Two experiments investigated the perceptual processes employed during same–different judgement tasks. In Experiment 1, experts' eye movements (i.e., number of fixations and fixation duration) were consistent across discrepant source and target conditions where the number of displaced elements was manipulated. In contrast, novices decreased the number of fixations employed as the number of elements displaced increased. The findings are consistent with the view that both experts and novices process information in a manner (relational or attributional) that constrains the type of visual search used (low or high sensitive to attributional change). In Experiment 2, manipulation of target presentation confirmed that recognition was viewpoint dependent for both expert and novice players. The degradation in performance was accompanied by a

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change in the visual search behaviours employed by experts, which confirmed the strength of the search–cognition–performance links.

Determining the similarity of various stimuli is a fundamental process in real-life situations. Problem solving, categorization, and recognition are all processes based on mapping between different features. These processes allow people to produce a number of adaptive behaviours. It is assumed that decision making involves comparison judgements (Medin, Goldstone, & Markman, 1995; Ross, 1987; Salvucci & Anderson, 2001). For example, in the domain of basketball, discrimination of game patterns is necessary to make the relevant choice in a given situation. Efficient discrimination enables players to produce differentiated behaviours as a function of the situation. Two main fields have dealt with the processes involved in comparison: Change detection and similarity/analogy. The first one has focused mainly on the relationship between perceptual processes and performance; the second one has developed theories about the higher level cognitive processes underlying the comparison. Our aim in this paper is to help understand the links between different levels of information processing involved in expert comparison. This endeavour also builds on studies of visual search in order to evaluate the proposed hypotheses. Consequently, we investigate the role of cognitive processes and eye movements in the discrimination of game configurations. In the following sections, we briefly review contributions from the fields of change detection and similarity in the understanding of expert comparison, and then propose our view, which is tested in the framework of two same–different judgement experiments.

THE PROBLEM OF SPARSE VISUAL REPRESENTATIONS AND EXPERTISE: EVIDENCE FROM CHANGE/DIFFERENCE DETECTION STUDIES

Research on change detection and change blindness has demonstrated that despite our feeling that we have a rich visual representation of the world, we effectively rely on a quite sparse representation. A great number of researchers have shown that important changes are often missed by observers (O'Regan, Rensink, & Clark, 1999; Rensink, 2002; Simons & Levin, 1997, 1998). However, this change blindness phenomenon is attenuated by expertise under some conditions. Werner and Thies (2000) have shown that expert American football players improved their detection performance when semantically relevant changes were produced across presented photos. Ripoll, Baratgin, Laurent, Courrieu, and Ripoll (2001) reported similar findings in a same–different task where the positions of various elements were changed. Discrimination performance was better in expert basketball players when they viewed schematic configurations that were semantically distorted. These change/difference blindness phenomena may arise because vision is an abstraction process by which we pick up almost only relevant information for subsequent action. O'Regan and Noë (2001; Noë & O'Regan, 2000) proposed that although many elements of the external world are reflected in the retina, individuals only perceive that to which they attend. That is, we can encounter many aspects of the world, but what we see depends on how we interact with the environment. This kind of approach can help understand expertise effects. It is likely that ''semantic'' changes that are well detected by experts concern properties that are relevant for their current engagement on the task. When changes occur on features that are irrelevant with regard to the current coupling between the expert and the environment, then those are poorly detected. Detection is more random in novices since they are not familiar with the tested domain. They are thought to rely on parts that are not particularly meaningful. However, in the studies on expertise and change or difference detection the link that is proposed between visual experience and the global cognitive processing is somewhat vague and too poorly specified. Some researchers have taken into account what they call ''cognitive forms of blindness'' (Simons & Chabris, 1999). For example, while working on inattentional blindness, Mack and Rock (2000) showed that participants often miss very large changes to displays when their attention is monitored by a primary task. In such experiments, the representation used by participants is strongly induced by a primary task (e.g., counting number of ball exchanges between players). We think that when this induction is not produced (i.e., when the individual has just to detect a difference or a change), coupling to the environment is more spontaneously related to the information structuring mechanisms that are specific to the level of expertise. The study of this coupling could allow us to better understand the relationship between vision and higher level processes. What does constitute expert cognitive engagement during the task? What information do novices rely on when making a judgement? Is there any characterization or biological embodiment of those links between vision and more abstract cognition? In order to answer these questions we tried to bridge the gap between data on change/difference detection and two related domains: The first is similarity/analogy, and the second is visual search.

SIMILARITY AND COGNITION

Similarity affects performance in many areas of cognition. From a cognitive point of view, similarity occurs when there is a match between many entities of stimuli properties (Sloman & Rips, 1998). Gentner and Markman (1997) propose that literal similarity emerges when ''both relational predicates and object attributes are shared'' (p. 48). Similarity is multidimensional in nature. Relational similarity refers to matching of the structure that unifies entities within a scene, an object, or other conceptual constructs. In contrast, attributional similarity is concerned with the matching between surface features, or descriptions of the entities. Depending upon the nature of the comparison performed, individuals search for relational and/or attributional similarities. During processing, both types of information can contribute to create a new mental state and to generate a decision. This is a reason why structural and hierarchical systems have recently been developed. According to Hummel and Holyoak (1997, p. 427), thinking is *structure sensitive*: ''Reasoning, problem solving, and learning (as well as language and vision) depend on a capacity to code and manipulate relational knowledge . . .''. This view of similarity emphasizes the need to take into account structure (i.e., parts of stimulus related together) when explaining comparison processes (Gentner & Markman, 1997; Markman & Gentner, 1993, 2000, 2001; Medin, Goldstone, & Gentner, 1993). This structural approach may explain differential processing in experts and novices during change or difference detection.

Some researchers have demonstrated that structure has a variable role in cognitive processing. Holyoak and Koh (1987) found in the domain of analogy that the involvement of structure is dependent upon the type of cognitive activity. While access relies upon both relational structure and surface similarities, mapping is supported mainly by relational structure analysis. Goldstone, Medin, and Gentner (1991) showed in the domain of similarity that participants rely differently on relations and attributes as a function of scene properties. If scenes are mainly ''relational'', then increasing relational similarity has more effect on perceived similarity than increasing attributional similarity. Conversely, if scenes are mainly ''attributional'', then increasing attributional similarity has more impact than increasing relational similarity. In this research, Goldstone and his colleagues provided evidence for different levels of cognitive processing as a function of scene properties. We propose that such findings relating to *stimuli-driven factors* of similarity can be accommodated with other *cognitively-driven factors*. That is, since the basis for relational similarity is the cognitive elaboration of objects or concepts (Gentner & Medina, 1998), expertise in the tested domain should be the condition for relational processing. These relations allow elements within a scene to be functionally gathered into perceptual (i.e., chunks) and conceptual (i.e., concepts) units. As a result of this process, other types of cues are developed and are then available for comparison (i.e., the units, composed of both elements and their relations). We think that this relational mode of processing described in this field could account for lower level processes observed in both experts and novices in difference detection tasks. More specifically, in basketball, representations of the game are constructed by players, both during the game, and beyond in a schematic way. Expert basketball players are exposed, on a daily basis, to game configurations drawn on boards and routinely have to take into account the relations between schematized players in order to subsequently position themselves on the field. As a result it is likely that this kind of cognitive processing, based on relations, occurs quite naturally, including when two configurations must be compared. If a real-world scene can be processed by the same individual at different levels of structure as a function of context (Laurent, 2002, 2003), and even if, in some cases, a discrimination judgement that is based on local features or dimensions can be realized with high accuracy (Biederman & Shiffrar, 1987; Goldstone, 1994), it seems that expert basketball players mainly process basketball stimuli on a configurational mode (Laurent & Ripoll, 2002). The meaningful character of the situation rises from the relative positions of the different elements within the display. As a result, our hypothesis is that, in difference detection tasks, experts couple to the environment by using sensorimotor contingencies that are guided by group-specific cognitive demands concerning the processing of relations.

SACCADIC EYE MOVEMENTS, SIMILARITY, AND CHANGE

The relational mode of processing described above could be reflected, at a behavioural level, in the saccadic activity of individuals making perceptual judgements. Many studies have employed eye-movement recording techniques in an attempt to explain cognitive processes (see Liversedge & Findlay, 2000; Rayner, 1998). The specific use of such a method in the context of change detection (Zelinsky, 2001) has confirmed other recent findings according to which there is an important visual search component in the change detection performance (Rensink, 2000). Zelinsky manipulated the number of potentially changed elements, and the orientation similarity between the changed objects. The number of fixations before a change detection judgement increased with the number of elements to compare and with the similarity between compared objects. Typically, in a change detection task, one single changed object has to be identified, and any additional object can be considered as processing noise. In addition, when objects are similar, detection becomes more difficult and requires more fixations, because more extensive search is needed to encode the relevant element. In Zelinsky's experiment, change detection difficulty, namely reflected in the number of eye fixations, was induced by the number of elements that needed to be processed and the similarity between the two compared scenes. In the context of the present research on difference detection in experts, we thought that this pattern could be modified because of the configurational mode of processing evoked. We expected that experts would employ a more consistent visual search strategy across similarity conditions than novices. Novices can be compared to Zelinsky's experimental participants who relied on an analytical encoding, each element being encoded individually. In Zelinsky's experiments, very different elements were displayed within the scene (e.g., a trumpet, a hammer) so that they could hardly be encoded as a whole or using a relational mode. The items were not systematically associated in real life. Similarly, in novice basketball players little is known about the meaning of the relations between players. These cognitive constraints would result in little binding of the entities within the scene. Novices were assumed to have their number of fixations during recognition closely related to the number of local elements displaced during the recognition phase of our experiments. If the search process is analytic, because of the attributional properties of the cognitive comparison, then increasing the number of differences should lead to an increase in the probability of fixating and detecting a local difference, and consequently to a decrease in the number of eye fixations needed for making a judgement. This kind of process is also consistent with other findings demonstrating that change detection involves fixating the region of change, both before and after the change occurs (Henderson & Hollingworth, 1999). If novices encode only isolated parts of the original configuration, they should also search for potential distortions of precise parts in the second configuration until they find them. In contrast, if experts rely on relations, they should be constrained as soon as the perceptual encoding process binds the different elements within the scene. This configurational mode of processing could be reflected in a more stable search strategy. In this case, the processing of relations between elements is required in order to compare the information under a format that can map onto the first relational representation stored in memory. We predicted that experts would organize their visual search during the recognition phase quite independently of the number of local elements manipulated. That is, even if detection accuracy improved with the increasing number of differences, the number of eye fixations employed during the recognition phase would not vary very much since a certain type of representation is consistently required each time a comparison is undertaken.

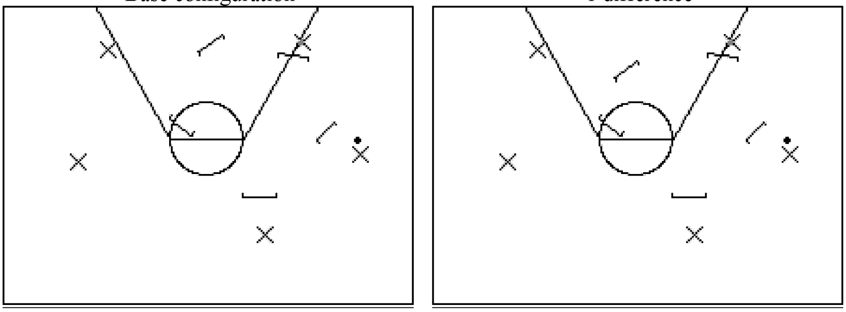
EXPERIMENT 1

Method

Participants. Seven expert (M = 24.83, SD = 2.51 years of age) and seven novice (M = 23.32, SD = 1.85 years of age) basketball players volunteered to participate in the experiment. The experts had been engaged in deliberate practice activities for more than 10 years and were involved in competition at the national level in France (‘‘National 3’’). The novice players were all students at the University of the Mediterranean and had no competitive basketball experience and very limited school and/or recreational playing experience. Informed consent was obtained prior to participation.

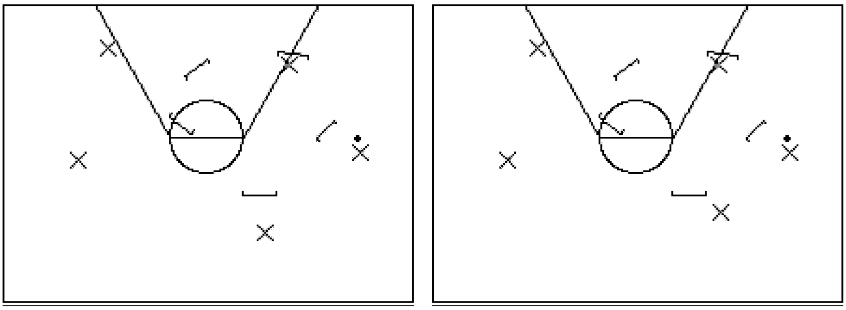
Equipment and materials. The experimental protocol was driven by Psyscope software running on a Powerbook G3 Macintosh. Response accuracy was recorded via the computer. Visual search behaviours were recorded using an eye-movement registration system (ASL 5000SU; Applied Science Laboratories; Waltham, MA). This is a video-based monocular system that works by collecting displacement data between the left pupil and corneal reflex using floor-mounted ‘‘pan-tilt’’ optics. This information is used to compute visual point of gaze with respect to a nine-point calibration grid projected onto the scene plane. A magnetic head tracker (6DFOB; Ascension Technology Corp., Burlington, VT) was used in conjunction with the floor mounted optics, allowing participants to move independently of the eye-tracking system and providing a more stable calibration procedure. Simple calibration procedures were performed to verify point of gaze before each participant commenced testing. Periodic calibration checks were performed throughout the experiment. The visual search data were recorded using both ASL Eyenal software and VHS videotape for subsequent analysis. Number of fixations and mean fixation duration for each source configuration and each target configuration were measured. Fixations were considered as periods during which point of gaze did not change by more than 1 degree of visual angle. Recording segments were obtained for each source and target. The recording segments provided both number of fixations and mean fixation duration between the onset of the configuration and its vanishing. Those data were then averaged for each condition so that further statistical analyses were possible.

The stimuli were schematic basketball configurations made up of crosses representing offensive players and lines representing defensive players (see Figure 1). A total of 48 pairs were coherent, that is, coherently organized relative to the logic of basketball activity as defined by a panel of coaches. Twenty-four were noncoherent (i.e., not coherently organized). The coherence here described can be related to a prototypical representation of situations where players are put in an already known configuration, usually practised with the coach. Noncoherent configurations were situations where one or several players were not well placed according to the common schemas usually practised in basketball (e.g., two defensive players near the centre of the field and five offensive players near the basket). Such ‘‘noncoherent’’ situations can occur on the field, but they are the exception rather than the rule. Moreover, such noncoherent representations are quite rarely represented in a schematic mode. In each coherence condition, configurations were gathered into identical (i.e., ‘‘0 difference’’) pairs (24 ‘‘0 difference’’ pairs overall) and ‘‘different’’ (i.e., ‘‘1 difference’’, ‘‘2 differences’’, and ‘‘3 differences’’) pairs (24 different pairs overall). Therefore, similarity between source and target was manipulated and could vary according to four levels: 0, 1, 2, or 3 differences. Each of the differences concerned either the position of an offensive or defensive player, and had a mean magnitude of 7.06 cm (*SD* = 0.62), which represented 1.30° of visual angle (*SD* = 0.11), in any plane. In coherent configurations each physical difference generated a semantic distortion, that is a change that modified a part of the meaning of the game by manipulating local relations of elements (i.e., break or creation of alignments between two players; see Figure 1). In each condition, the number of identical pairs of configurations was equal to the number of different pairs. The presentation order of the trials was randomized to reduce the potential order effects. A video-pro-



Base configuration

1 difference



2 differences

3 differences

Figure 1. Example of the stimuli used in Experiment 1 (coherent condition).

jector was used to present the stimuli on a 1.5 m × 1 m projection screen. The scene image subtended a visual angle of 17.6° × 13.9° at a viewing distance of 3.1 m.

Procedure. Participants had to judge whether the source and target stimuli were the same or different. They were instructed to respond quickly and accurately. No specific instruction was given in favour of ''same'' or ''different'' answers; each one was given the same weight in the instructional discourse. Feedback, as to response accuracy, was provided after the completion of each trial. The source stimuli were presented for 4 s followed by a mask for 2 s. The target stimuli then appeared and participants were required to respond by pressing a key to indicate whether the stimulus was identical or different to the source image. Participants were seated at a table and had their index fingers on two response keys of a keyboard corresponding to ''same'' and ''different'' responses.

Design. The data were analysed using factorial ANOVAs in which coherence (coherent vs. noncoherent), and source–target similarity conditions (0, 1, 2, 3 differences) were within-participant factors, and group (expert vs.

novice) was a between-participant factor. The dependent variables were *response accuracy* (percentage of correct responses), *number of eye fixations*, and *mean fixation duration* (seconds) during source and target processing. Significant effects were followed up using the Newman-Keuls procedure as appropriate. The alpha level for significance was set at $p < .05$.

Results

Response accuracy

Experts ($M = 74.36$, $SD = 6.52$) were more accurate than novices ($M = 62.57$, $SD = 6.52$), $F(1, 12) = 15.78$, $p < .05$, $\eta^2 = .04$, $\eta_p^2 = .57$, Cohen's $d = 1.81$. A source–target similarity main effect was observed, $F(3, 36) = 24.35$, $p < .05$, $\eta^2 = .19$, $\eta_p^2 = .67$. The participants' accuracy in the judgement was superior for 0 difference ($M = 79.63$, $SD = 13.61$) compared with 1 difference ($M = 45.83$, $SD = 17.06$), Cohen's $d = 2.19$, or with 2 differences ($M = 53.27$, $SD = 12.89$), Cohen's $d = 1.99$, all $p < .05$. Accuracy was also superior for 3 differences ($M = 73.81$, $SD = 10.52$) compared with 1 difference, Cohen's $d = 1.97$, or with 2 differences, Cohen's $d = 1.75$, all $p < .05$. There was no interaction between expertise and coherence, $F(1, 12) = 1.54$, $p > .23$, $\eta^2 = .01$, $\eta_p^2 = .11$. However post hoc tests were run, given that only one mean was expected to differ from the three others while all possible comparisons were to be realized (Howell, 1998; Wilcox, 1987). Post hoc tests were preferred to preplanned comparisons since the number of comparisons was important (Howell, 1998). Experts were more accurate, $p < .05$, Cohen's $d = 1.57$, in the coherent ($M = 83.94$, $SD = 10.36$) compared with the noncoherent ($M = 68.08$, $SD = 9.79$) condition. Moreover, in the coherent condition experts were more accurate, $p < .05$, Cohen's $d = 2.25$, than novices in the noncoherent condition ($M = 60.00$, $SD = 10.91$). The comparison between experts and novices ($M = 64.19$, $SD = 11.91$) in the coherent condition was close to significance, $p = .065$, Cohen's $d = 1.77$. Novices had not different levels of accuracy across coherence conditions, $p > .60$ (see Figure 2 for a global overview of accuracy profiles).

Eye movement parameters during source encoding

No significant differences were found in the number of fixations or mean fixation duration.

Eye movement parameters during target processing

Number of eye fixations. A source–target similarity main effect was observed for the number of fixations, $F(3, 36) = 5.07$, $p < .05$, $\eta^2 = .02$, $\eta_p^2 = .30$. In the 3 differences condition, participants employed fewer fixations than in the other conditions, $p < .05$. However, the Expertise × Source–target similarity interaction, $F(3, 36) = 4.91$, $p < .05$, $\eta^2 = .02$, $\eta_p^2 = .29$, and subsequent post hoc tests indicated that only the novice participants significantly decreased the

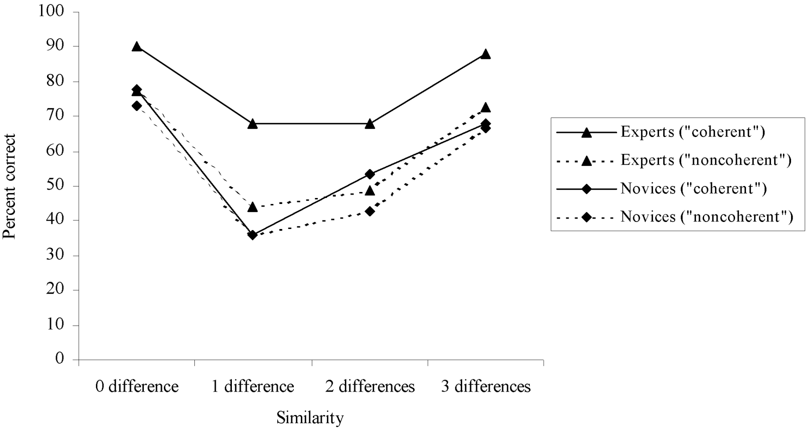


Figure 2. Mean accuracy as a function of expertise, coherence, and source–target similarity (Experiment 1).

number of fixations for 3 differences compared to 0 difference, Cohen's *d* = 0.83, 1 difference, Cohen's *d* = 0.68, and 2 differences, Cohen's *d* = 0.61, all $p < .05$ (see Figure 3). The novices employed more fixations than experts in the 0 difference condition, Cohen's *d* = 0.59, and in the 1 difference condition, Cohen's *d* = 0.51, all $p < .05$ (see Figure 3). The tendency in novices was to decrease the number of fixations as the source–target dissimilarity increased, whereas experts did not change the number of fixations employed (see Figure 3). This is supported by the results of a linear regression analysis (Figure 4) on the group means (y = –.5236x + 6.8613, $r = –.95$, $r^2 = .89$, where y is the number of fixations and x the number of source–target differences). In experts, no significant difference was found across source–target similarity conditions with regard to the number of fixations. Moreover, the linear regression analysis did not give any satisfactory result in regard to the group means observed across similarity conditions ($r = .097$ at best, $r^2 < .01$).

Data were then split into ''hits'' and ''misses'' categories in order to make it clear whether the greater number of ''misses'' in some conditions (i.e., in ''1 difference'' and ''2 differences'', or in novices relative to in experts) could inflate the number of fixations in those conditions through a more exhaustive search, and then influence *the profile* of the number of eye fixations as a function of source–target similarity and expertise.

A new ANOVA was run on the number of fixations for ''hits'' trials. This ANOVA revealed once again a similarity main effect, $F(3, 36) = 4.23$, $p < .05$, $\eta^2 = .03$, $\eta_p{}^2 = .26$, and an Expertise × Source–target similarity interaction, $F(3, 36) = 3.38$, $p < .05$, $\eta^2 = .02$, $\eta_p{}^2 = .22$. Participants employed more fixations when the source–target similarity was high (''0 difference'', $M = 5.70$,

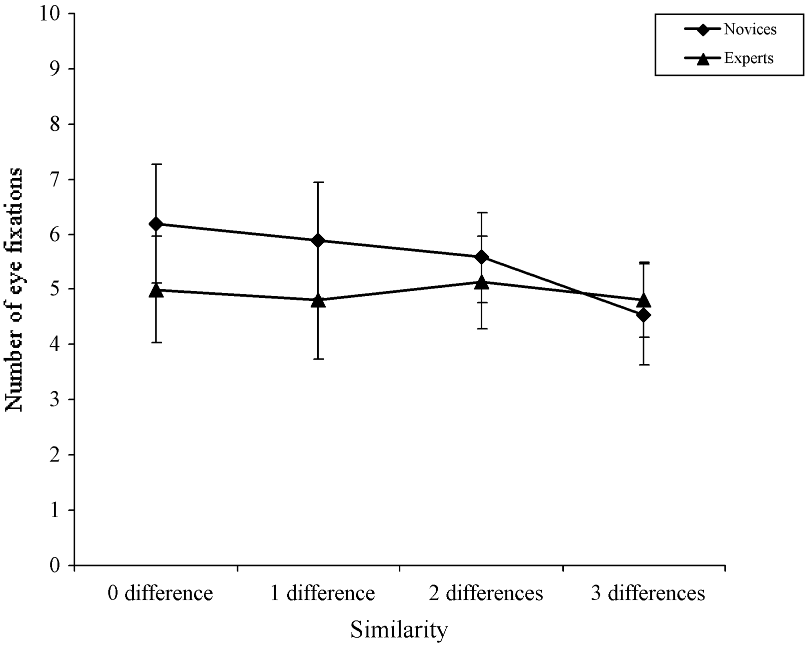


Figure 3. Mean number of eye fixations as a function of source–target similarity (0, 1, 2, and 3 differences) (Experiment 1).

SD = 2.11) than when it was low (‘‘3 differences’’, *M* = 4.43, *SD* = 1.63), Cohen’s *d* = 0.68. More marginal differences between ‘‘0’’ and ‘‘1 difference’’ (*M* = 4.84, *SD* = 1.87), Cohen’s *d* = 0.43, $p < .064$, ‘‘0’’ and ‘‘2 differences’’ (*M* = 5.15, *SD* = 2.31), Cohen’s *d* = 0.25, $p < .142$, and 2 and 3 differences, Cohen’s *d* = 0.36, $p < .14$, as well as linear regression analysis processed on the number of fixations at the mean level (y = –.3624x + 5.9099, $r = –.85$, $r^2 = .72$) tend to support the description of the phenomenon.

However, the Expertise × Source–target interaction indicated that this was due, for the greatest part, to the novice population. Novices employed a significantly higher number of fixations in the ‘‘0 difference’’ condition (*M* = 6.42, *SD* = 2.26) than in the ‘‘1 difference’’ (*M* = 4.89, *SD* = 1.31), Cohen’s *d* = 0.83, ‘‘2 differences’’ (*M* = 4.89, *SD* = 1.98), Cohen’s *d* = 0.72, or ‘‘3 differences’’ (*M* = 4.08, *SD* = 1.75), Cohen’s *d* = 1.16, conditions, all $p < .05$. Linear regression analysis revealed a strong negative link between the number of source–target differences and the number of eye fixations in novices (y = –.7006x + 6,8236, $r = –.93$, $r^2 = .86$), confirming what was obtained on overall data and excluding the hypothesis that the observed relation was simply linked to an inflation of missed data in some conditions in novices.

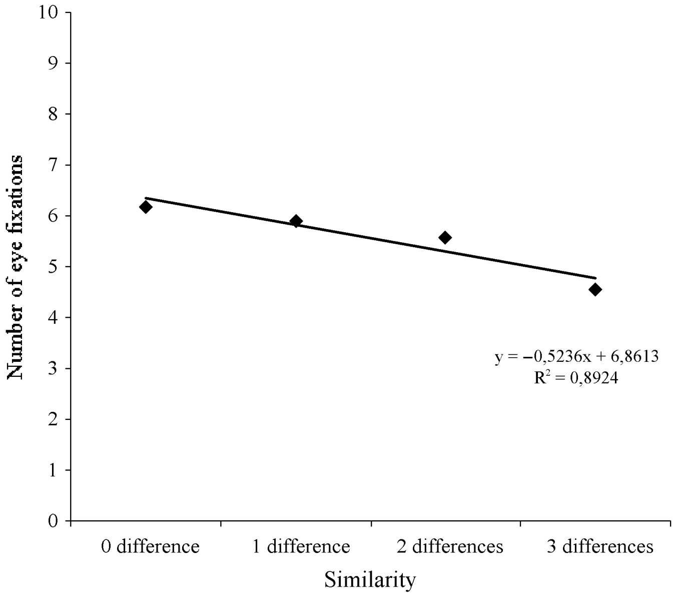


Figure 4. Linear regression analysis on mean number of fixations in novices in the various source–target similarity conditions (0, 1, 2, and 3 differences) (Experiment 1).

In contrast, no difference in the fixation number was found across conditions in experts. Linear regression analysis did not reveal any satisfactory simple linear regression model to represent a relation ($r = -.02$ at best, $r^2 < .0005$). Experts, however, employed a fewer number of fixations ($M = 4.98$, $SD = 1.83$) than novices, in the ''0 difference condition'' Cohen's $d = 0.50$, $p < .05$.

An analysis of the 'misses' trials produced a marginally nonsignificant Expertise × Coherence interaction, $F(1, 12) = 2.8$, $p < .12$, $\eta^2 = .008$, $\eta_p{}^2 = .19$. Significant ($p < .05$) post hoc tests showed that when experts dealt with coherent displays, they employed fewer fixations than novices in the same coherent condition or than novices in the noncoherent condition. A comparison with the number of fixations employed in the noncoherent condition was not very far from significance ($p < .092$).

Mean fixation duration. With regard to mean fixation duration, experts ($M = 0.537$, $SD = 0.229$) did not globally differ from novices ($M = 0.506$, $SD = 0.191$), $p > .05$. A source–target similarity main effect emerged, $F(3, 36) = 2.92$, $p < .05$, $\eta^2 = .02$, $\eta_p{}^2 = .20$. However, post hoc comparisons did not identify any significant difference, $p > .05$. Analysis of the Expertise × Coherence × Source–target similarity interaction showed that novices' fixation duration was less consistent than experts across similarity conditions, $F(3, 36) = 3.61$, $p < .05$,

$\eta^2 = .01$, $\eta_p^2 = .23$. In the noncoherent condition, novices employed a longer fixation duration for 3 differences (*M* = 0.705, *SD* = 0.309) than for 0 difference (*M* = 0.471, *SD* = 0.154), Cohen's *d* = 0.96, 1 difference (*M* = 0.469, *SD* = 0.209), Cohen's *d* = 0.89, and 2 differences (*M* = 0.446, *SD* = 0.136), Cohen's *d* = 1.08, between the source and the target, all $p < .05$. No differences were observed for the expert participants across conditions. The inconsistency in mean fixation duration in novices was observed in both ''hits'' and ''misses'' trials, but different effects were measured in the two cases. It was found that fixations were longer for ''1 difference'' (*M* = 0.761 *SD* = 0.448) as compared to ''2 differences'' (*M* = 0.424, *SD* = 0.120) in the ''coherent'' condition, Cohen's *d* = 0.73, when post hoc tests were applied to ''hits'' trials ($p < .05$). The analysis on ''misses'' trials revealed—still in novices—that fixations were longer in the ''3 differences–noncoherent'' (*M* = 0.727, *SD* = 0.381) as compared to the ''2 differences–noncoherent'' (*M* = 0.382, *SD* = 0.075), Cohen's *d* = 0.89, ''0 difference–coherent'' (*M* = 0.410, *SD* = 0.145), Cohen's *d* = 0.77, and ''3 differences–coherent'' (*M* = 0.428, *SD* = 0.08), Cohen's *d* = 0.77, conditions, all $p < .05$. This was also longer than experts' fixation duration in the ''2 differences–noncoherent'' condition (*M* = 0.416, *SD* = 0.111), Cohen's *d* = 0.78.

Discussion

Experts were better than novices at judging similarity between displayed configurations. This finding confirms previous research in the same domain (Ripoll et al., 2001) showing that expertise enhances discrimination abilities. Proposed explanations of the gap between experts' and novices' performances can be related to the involvement of representations that possess different levels of structure (Gentner & Medina, 1998; Markman & Gentner, 1993). Experts have, and make use of, rich and highly structured representations, whereas novices rely on weakly structured information. This interpretation is supported by our results for both response accuracy and visual behaviours. Experts are better when the configurations are coherent than when they are not, which shows that the nature of the links between elements is an important factor for expert comparison. In contrast, novices were not found to be affected by coherence, and even if the comparison between experts and novices in the coherent condition remains just above significance ($p = .065$), the effect was very large (Cohen's *d* = 1.77). Furthermore, experts and novices exhibit different visual search sensitivity to stimuli manipulation. In novices, the more similar the two stimuli, the more important the number of fixations employed during recognition. When the number of differences increases, the likelihood of finding attributional mismatches increases, while the observed number of eye fixations decreases. In other words, novices try to complete the comparison process by extracting information until a local physical distortion (i.e., concerning attributes) is found. This finding supports a *visual search style hypothesis*, since the linear relation between source–target similarity and the number of eye fixations holds even when the analysis is restricted to ''hits'' trials. As a result, the relation is determined by a group factor and search is ''stimulus driven'' in novices. Moreover, when they answer correctly (and only in this case), fixation duration is longer in the ''1 difference–coherent'' condition as compared to the ''2 differences–coherent'' condition. The extended processing of the single relevant element just before a correct answer may be another sign for such a local strategy in visual search.

Several authors (e.g., Henderson & Hollingworth, 1999; Hollingworth, Schrock, & Henderson, 2001) have demonstrated that fixation position has a major role in the detection of scene changes. In these studies, a change was likely to be detected when the changed element was fixated by participants both before and after it occurred. It is possible that, when the change is attributional in nature, or when the participant is novice, processing is focused on attributes within the scene and supported by fixation upon these attributes. This is also consistent with recent findings on visual span demonstrating that novices ''focused'' on the pieces rather than between the pieces (Reingold, Charness, Pomplum, & Stampe, 2001).

In contrast, the number of fixations employed by experts on the target is stable over similarity conditions. It seems that for these participants, processing requires a number of fixations that is independent of the number of elements displaced. This result supports our hypothesis that experts encode information in a rather stable way because of the cognitive constraints that weigh on processing. The need for extracting relations may guide them to process the information rather independently of local stimuli manipulations, since they are expected to extract global form. Moreover, greater independency of the number of eye fixations and fixation duration from attributional change, and fewer number of fixations than novices in some conditions could mean that experts' visual search is governed by a more covert orientation of visual attention. Diffuse attention may facilitate the intake of information in a more global way, and could explain the poor sensitivity to local changes. Once again, this is consistent with Reingold and colleagues' (2001) results revealing that visual span in expert chess players is larger than in novices, namely because they are able to bind stimuli by fixating between elements; they can process a larger number of elements by encoding the relationships between those elements. Binding stimuli dimensions involves picking up the relative positions of reference elements rather than the individual properties of these elements.

Finally, we did not observe any effect of expertise during source encoding. However, the experiment was conceived to test visual search sensitivity to stimulus variation (and its interactions with expertise and stimulus coherence), which implied the processing of the target. Other factors might have impacted upon the eye movements employed during source encoding (i.e., coherence, expertise). However, the highly constrained encoding procedure (a fixed 4 s time period) might have had a negative effect on behaviour variability during this phase.

In order to test further the relationship between cognitive constraints, visual search, and performance in discrimination, we performed a second experiment. It may be possible that the consistency in the number of eye fixations in experts was due to an automated mode of processing that was not linked to current cognitive constraints or detection accuracy. In this case, eye movement would not be directly coupled to the cognitive processing but rather a product of an independent ''economics'' of the oculomotor system. We reproduced part of the first experiment of the current paper but added a rotation factor to the design. In previous research, Ripoll and colleagues (2001) argued for view-dependent comparison processes in expert basketball players. The proposed hypothesis was that the relational process involved in experts is not abstract enough to cope with a rotation of the display. If their results are reproduced here, and if, as suggested, eye movements are strongly related to cognitive constraints and subsequent detection performance, it is likely that the reduction in accuracy in experts is accompanied by a corruption of encoding processes, embodied in eye movements. If eye movements are really coupled to cognitive processing, and that both cognitive processing and accuracy are disturbed by rotation in experts, then eye movements could also be disturbed. The disturbance in the expert's processing could be reflected in an increase in the number of fixations when rotation occurs, because of the difficulty in finding reliable cues for making the comparison. Moreover, the nature of the cognitive strategy used may change. In failing to map the two configurations, experts may shift from a relational to an attributional strategy. If so, similar results to that observed in novices could be found (i.e., increase in the number of fixations with source–target similarity).

EXPERIMENT 2

Method

Participants. Eight expert (*M* = 24.98, *SD* = 2.32 years of age) and nine novice (*M* = 24.54, *SD* = 2.63 years of age) basketball players were involved in this experiment. The two groups had similar experience and expertise levels to those employed in Experiment 1. Informed consent was obtained prior to participation.

Equipment and materials. The apparatus and experimental set-up were identical to those employed in Experiment 1. The source–target similarity factor was composed of only two conditions in Experiment 2: Identical (i.e., 0 difference between source and target) vs. different (i.e., 2 differences between source and target). One factor was added: Target rotation. The target could be presented without rotation or with a 90° (left or right) rotation relative to source.

The coherency of the display was manipulated as in Experiment 1. In total there were 80 trials.

Procedure. The procedure followed was the same as in Experiment 1.

Design. The data were analysed using factorial ANOVAs, in which coherence (coherent vs. noncoherent), source–target similarity (identical vs. different), and rotation conditions (no target rotation vs. target rotation) were within-participant factors and group (expert vs. novice) was a between-participant factor. The dependent variables were the same as in Experiment 1. Significant effects were followed up using the Newman-Keuls procedure as appropriate. The alpha level for significance was set at $p < .05$.

Results

Response accuracy

No expertise effect was found, $F(1, 15) = .42$, $\eta^2 = .0005$, $\eta_p{}^2 = .003$, $p > .53$. Participants were more accurate when the source and the target were identical ($M = 77.94$, $SD = 7.24$) than when they were different ($M = 47.84$, $SD = 9.35$), $F(1, 15) = 98.84$, $p < .05$, $\eta^2 = .14$, $\eta_p{}^2 = .40$, Cohen's $d = 3.6$. Accuracy was lower when the target was rotated ($M = 58.21$, $SD = 8.28$) than when it was not ($M = 67.98$, $SD = 7.63$), $F(1, 15) = 14.83$, $p < .05$, $\eta^2 = .02$, $\eta_p{}^2 = .50$, Cohen's d = 1.23. Finally, there was a Coherence × Similarity interaction, $F(1, 15) = 8.99$, $p < .05$, $\eta^2 = .01$, $\eta_p{}^2 = 39$. Performance accuracy was better in the different condition when the source and the target were coherent ($M = 52.82$, $SD = 10.57$) than when they were not ($M = 42.85$, $SD = 10.73$), $p < .05$, Cohen's $d = 0.94$. The scores for the identical condition did not vary with coherence, $p > .05$. However, when analysing the means of the marginally nonsignificant four-way Expertise × Coherence × Source–target similarity × Target rotation, $F(1, 15)$ = 2.08, $p = .17$, experts seem to be more accurate in the coherent, different, and nonrotated condition ($M = 63.75$, $SD = 22.64$) than they are in the noncoherent, different, and nonrotated condition ($M = 42.78$, $SD = 16.28$), Cohen's $d = 0.75$. In this coherent condition the experts are also more accurate than novices are in both the noncoherent, different, and nonrotated ($M = 42.22$, $SD = 17.87$), Cohen's $d = 0.75$, and the coherent, different, and nonrotated ($M = 52.72$, SD = 14.42), Cohen's $d = 0.42$, conditions (see Figure 5 for a global overview of accuracy profiles). Although the effects are marginally nonsignificant, the effect size measures are sufficiently large so as to indicate that these differences may nonetheless be meaningful.

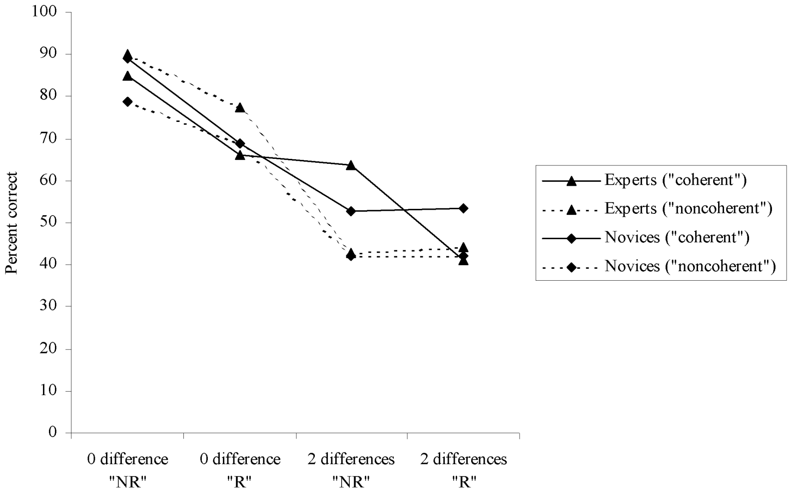


Figure 5. Mean accuracy as a function of expertise, coherence, source–target similarity, and target rotation (‘‘NR’’ = no rotation, ‘‘R’’ = rotation) (Experiment 2).

Eye movement parameters during source encoding

No significant effects were observed.

Eye movement parameters during target processing

Number of eye fixations. Participants employed more fixations when source and target were identical (M = 7.52, SD = 1.64) than when different (M = 6.94, SD = 1.50), $F(1, 15) = 11.58$, $p < .05$, $\eta^2 = .02$, $\eta_p{}^2 = .44$, Cohen’s $d = 0.37$. No Expertise × Source–target similarity interaction was observed. A higher number of fixations was observed when the target was rotated (M = 8.40, SD = 1.74) than when not rotated (M = 6.23, SD = 1.46), $F(1, 15) = 81.82$, $p < .05$, $\eta^2 = .27$, $\eta_p{}^2 = .85$, Cohen’s $d = 1.35$. Finally, an Expertise × Coherence × Target rotation interaction was found, $F(1, 15) = 7.52$, $p < .05$, $\eta^2 = .004$, $\eta_p{}^2 = .33$. Experts employed more fixations in the noncoherent and rotated condition (M = 8.81, SD = 1.56) when compared to the coherent and rotated condition (M = 8.18, SD = 1.21), $p < .05$, Cohen’s $d = 0.45$. In the noncoherent and rotated condition, experts employed more fixations than novices (M = 8.08, SD = 1.95), $p < .05$, Cohen’s $d = 0.41$.

When restricted to ‘‘hits trials’’, the analysis revealed a similar pattern of results, with only two main effects: Source–target similarity, $F(1, 15) = 16.1$, $\eta^2 = .03$, $\eta_p{}^2 = .52$, and target rotation, $F(1, 15) = 51.57$, $\eta^2 = .20$, $\eta_p{}^2 = .77$, all $p < .05$. Source–target similarity and rotation increased the number of eye fixations upon the target in both experts and novices.

Mean fixation duration. Mean fixation duration was longer when the target was different ($M = 0.454$, $SD = 0.104$) relative to when it was identical to the source ($M = 0.425$, $SD = 0.109$), $F(1, 15) = 7.11$, $p < .05$, $\eta^2 = 01$, $\eta_p{}^2 = .32$, Cohen’s $d = 0.27$. Moreover, mean fixation duration was longer when the target was not rotated ($M = 0.469$, $SD = 0.129$) than when it was ($M = 0.410$, $SD = 0.107$), $F(1, 15) = 9.87$, $p < .05$, $\eta^2 = .03$, $\eta_p{}^2 = .40$, Cohen’s $d = 0.50$.

When only applied to ‘‘hits’’ trials, the similarity main effect is retrieved, $F(1, 15) = 7.91$, $\eta^2 = .023$, $\eta_p{}^2 = .35$, $p < .05$. The rotation effect is not far from significance, $F(1, 15) = 7.18$, $\eta^2 = .016$, $\eta_p{}^2 = .17$, $p = .095$.

Cross-experimental analyses

Further analyses were conducted to help the interpretation of the current experiment. We examined whether the rotation factor could have contributed to changes in visual search behaviours and the decrease in performance accuracy for experts, especially in the ‘‘2 differences’’, coherent, and nonrotation condition. Experiment (1 vs. 2) and expertise (expert vs. novices) were entered in the ANOVAs as between-participant factors, and coherence (coherent vs. noncoherent) and similarity (0 difference vs. 2 differences) were within-participant factors. The dependent variables were accuracy, the number of eye fixations and mean fixation duration of the target, for correct answers (since what was questioned was an intrinsic adaptive change of strategy). Therefore, the ‘‘1 difference’’ and ‘‘3 differences’’ conditions of Experiment 1, as well as the ‘‘rotation’’ condition of Experiment 2, were not included in the analysis.

The analyses conducted on accuracy revealed three significant main effects. The experts ($M = 70.67$, $SD = 24.96$) were globally better than novices ($M = 64.02$, $SD = 23.93$), $F(1, 27) = 6.05$, $\eta^2 = .008$, $\eta_p{}^2 = .18$, $p < .05$. Participants were more accurate in ‘‘coherent’’ ($M = 72.43$, $SD = 22.87$) than in ‘‘noncoherent’’ ($M = 62.05$, $SD = 25.27$) trials, $F(1, 27) = 9.3$, $\eta^2 = .02$, $\eta_p{}^2 = .26$, $p < .05$. Accuracy was higher for ‘‘0’’ ($M = 82.9$, $SD = 15.7$) than for ‘‘2 differences’’ ($M = 51.59$, $SD = 22.72$), $F(1, 27) = 75.15$, $\eta^2 = .17$, $\eta_p{}^2 = .74$, $p < .05$. However, the experimental condition did not impact accuracy in the nonrotated trials analysed, $F(1, 27) = .32$, $\eta^2 = .005$, $\eta_p{}^2 = .012$, $p > .57$, nor did it interact with other factors (all $p > .21$).

The analyses conducted on the number of eye fixations of the target revealed a main effect of similarity, $F(1, 27) = 14.67$, $\eta^2 = .01$, $\eta_p{}^2 = .35$, $p < .05$, with participants employing more fixations for ‘‘0 difference’’ ($M = 82.9$, $SD = 15.7$) than for ‘‘2 differences’’ ($M = 82.9$, $SD = 15.7$) trials. An Expertise × Similarity interaction, $F(1, 27) = 4.66$, $\eta^2 = .003$, $\eta_p{}^2 = .15$, $p < .05$, and subsequent post hoc tests, $p < .05$, indicated that globally only novices in the ‘‘0 difference’’ ($M = 6.37$, $SD = 2.13$) condition employed a different strategy from their own behaviour in the ‘‘2 differences’’ condition ($M = 5.22$, $SD = 1.75$), Cohen’s $d = 0.42$, or from experts in both ‘‘0 difference’’ ($M = 5.72$, $SD = 1.88$), Cohen’s $d =$

0.23, and ''2 differences'' ($M = 5.34$, $SD = 2.61$), Cohen's $d = 0.31$, conditions. An Expertise × Experiment × Similarity interaction, $F(1,27) = 7.3$, $\eta^2 = .005$, $\eta_p^2 = .21$, $p < .05$ and subsequent post hoc tests, $p < .05$, indicated that experts employed a higher number of fixations in the ''0 difference'' condition in Experiment 2 ($M = 6.37$, $SD = 1.65$), relative to the ''0 difference'' condition in Experiment 1 ($M = 4.98$, $SD = 1.92$), Cohen's $d = 0.55$ (see Figure 6), although both were *nonrotated* conditions. Their fixation number in Experiment 2 is close to novices' ones in the ''0 difference'' condition, whereas it was significantly different in Experiment 1.

Finally, the analyses conducted on mean fixation duration revealed two measures close to significance: The decreasing effect of dissimilarity on duration, $F(1,27) = 2.95$, $\eta^2 = .002$, $\eta_p^2 = .10$, $p < .098$, already found in separated analyses in Experiments 1 and 2, and the Expertise × Experiment × Coherence interaction, $F(1,27) = 3.20$, $p < .085$, $\eta^2 = .003$, $\eta_p^2 = .11$. Post hoc tests gave evidence for a change in fixation duration in experts between Experiment 1 and Experiment 2 in the coherent condition. They employed longer fixations in the coherent condition in Experiment 1 ($M = 0.574$, $SD = 0.261$), than in the same coherent condition in Experiment 2 ($M = 0.435$, $SD = 0.105$), Cohen's $d = 0.49$, $p < .05$. Although the difference between experts and novices ($M = 0.439$, $SD = 0.147$) reached significance in Experiment 1 in the coherent condition, Cohen's $d = 0.45$, $p < .05$, experts did not differ from their novice counterparts ($M = 0.493$, $SD = 0.184$) under the same conditions in Experiment 2, $p > .70$.

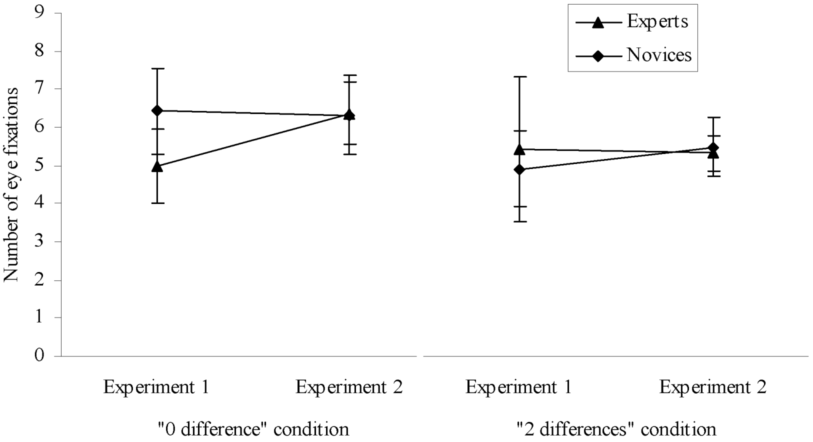


Figure 6. Mean number of eye fixations as a function of expertise, experiment, and source–target similarity (Experiments 1 and 2).

Discussion

Globally, experts did not perform better than novices in Experiment 2. Only in one condition, when configurations are coherent, not rotated, and different, were experts marginally better than their novice counterparts. Moreover, an analysis of effect size measures would also suggest that coherence slightly influenced the accuracy of novices. It might be because prototypical configurations are sometimes associated with features to which the perceptual system is globally sensitive (e.g., symmetry in defensive players' organization). The phenomenon, however, needs to be carefully interpreted and examined in the framework of further studies, since the accuracy level is only just above chance in this condition in novices.

Rotation dramatically affects response accuracy in both experts and novices. It appears that expert performance on this task was viewpoint dependent, and that the underlying comparison was altered by the conditions of target encoding. In particular, this finding lends support to the idea that there were difficulties in encoding the rotated target. Experts, like novices, increased their number of fixations in the rotation conditions. This increase was accompanied by a decrease in mean fixation duration. Given that rotation has a real cost for encoding processes when the target is rotated, and that performance of participants in those conditions is poor, the increase in number of fixations and decrease in fixation duration seem to reflect the difficulty in finding reliable cues for making a comparison. Participants would then search more extensively for confirmation indices, having not succeeded in finding relevant cues during initial fixations.

Moreover, our second hypothesis relating to the similarity effect in the number of fixations was supported. Contrary to what was observed in Experiment 1, inconsistency in visual search across similarity is a general phenomenon in both novices and experts. It may be an indication of a shift from the usual expert processing of relations to a *more* local strategy affected by the manipulation of the display, that is, an alignment based on attributes and smaller structures than in Experiment 1. The view is supported by at least three main points. First, experts faced encoding difficulties when the target was rotated, as shown by the reduction in accuracy, the increase in the number of fixations, and the tendency to decrease the mean fixation duration in this condition. Second, and contrary to what was observed in Experiment 1, increasing the similarity between the displays, led to an increase in the number of fixations, as observed in novices in Experiments 1 and 2. The expert encoding shifted from a *similarity-independent* mode to a *similarity-dependent mode*, that is, toward a ''stimulus driven'' strategy. This argues for a process relying on entities rather than on global structures. Third, the subsequent processing of *nonrotated* stimuli in experts was affected relative to that of Experiment 1, even when the target was *not* rotated. The increase in the fixation number in the ''0 difference'' condition is associated with a decrease in fixation duration in the coherent condition in Experiment 2, which indicates the adoption of a new search rate and certainly some difficulties in extracting stimulus structure. These results support our hypothesis that experts had their processing and search strategies globally affected, even when the target was not rotated. This give some arguments against the ‘‘economics’’ hypothesis according to which expertise would manifest through a globally automated search. It seems rather that search strategies are strongly linked to both expertise and the ecological context in which they are produced, such as viewpoint conditions.

GENERAL DISCUSSION

The aim of this research was to examine the links between cognition, eye movements, and difference detection performance. Grounding our work in the domain of basketball, we have shown by manipulating source–target similarity, that experts made greater use of strategy independent from local stimuli manipulations compared to novices. Their visual search is less affected by local manipulations of the stimuli. It has been demonstrated that this strategy was linked to cognitive constraints (i.e., relational processing) and was required for improving accuracy relative to novices. During target processing, experts maintain a fairly consistent visual search strategy as determined by the number and duration of fixations across source–target similarity conditions, while novices alter their search pattern as a function of the stimulus viewed. For novices, the number of fixations is tightly and negatively linked to the number of target elements displaced.

The results demonstrate a strong role for perceptual processes during similarity comparison. Participants, depending on their skill, search for a certain type of similarity, and this activity constrains the organization of visual search behaviours. These adaptations allow experts to more accurately discriminate between configurations. As a consequence, the perceptual and cognitive systems, if distinguishable (Pylyshyn, 1999), are strongly related. During comparison, the cognitive constraints of experts determine the perceptual inputs by orienting information extraction towards relations. It seems that experts organize their search quite independently of the stimulus, having their visual search *cognitively driven*. This independence relative to the distortion in local elements can be linked to results from a previous study in the same domain (Laurent & Ripoll, 2002) where experts were found to show sensitivity only to physical distortions that provoked alteration of category identity (i.e., of a conceptual characteristic emerging from relational analyses). In contrast, novices are unable to access the configuration’s structure. As a result, they rely upon the comparison between weakly associated attributes. This suggestion is supported by the data presented in Experiment 1 since the number of fixations during recognition is a function of the number of local elements displaced. The greater the number of elements displaced, the smaller the number of fixations during target processing. In this view, difference detection is closely associated to the fixation position of the eye (Henderson & Hollingworth, 1999; Hollingworth et al., 2001) and to the number of elements manipulated, both influencing the probability of finding an attributional mismatch. This interpretation tends to favour an overt strategy by which novices would continue to fixate different elements in order to find an attributional mismatch while processing information in or around the foveal region (Reingold et al*.,* 2001).

However, data collected in Experiment 2 imply that usable abstract and viewpoint-invariant information does not seem to characterize expert representation in the difference detection judgements performed. A perfect binding of the whole stimulus into a global form, abstracting and encoding all the information so that the representation becomes viewpoint invariant, is not possible in experts. It seems rather that expert representation is composed of structures, whose level of integration depends on the level of expertise. When rotation occurs, experts shift to a more attributional strategy similar to that used by novices. Despite those effects, it is assumed that the abstraction level of processing is *not* fixed. This claim is supported by the fact that Ripoll et al. (2001) reported different results with other basketball experts who were slightly better ranked. In their study, the degradation of accuracy as a consequence of target rotation was not observed in experts when source and target were *coherent* and *different*. It is possible to interpret these data as demonstrating expert ability to detect different relations even if rotation occurs and the display changes. Hence, our position argues for a continuity between representations of different-skilled individuals: From novice level, where similarity judgement is based upon comparison between entities that are weakly linked together towards elite levels of expertise, where comparison involves highly structured representations, and strong relations between elements. The gradual building and use of representations described here can be related to other works. At the perceptual level, Schyns and colleagues (Schyns, Goldstone, & Thibaut, 1998; Schyns & Rodet, 1997) advocate for a progressive learning of features that are composed of coarse structures and finer structures, whose organization evolves with experience in order to provide the individuals with more informative representation. At the behavioural level, Munakata (2001) proposes that the strength of the representation has a central explanatory role in cognitive science and can account for some commonly observed dissociations in performance: ''An alternative approach explains dissociations in terms of knowledge representations that are graded, rather than simply being present or absent, with certain tasks requiring stronger representations'' (p. 309). In the context of our experiment rotation placed strong constraints on processing, which require a high level of integration within the whole stimulus. It might be that only the most advanced experts in the processing of the relations could manage to capture relational mismatches (Ripoll et al., 2001), thereby explaining, by a level of expertise account, differences between our experiment and the previous one. For all these reasons, our view is clearly not the one of an exclusively view-based system. However, this research provides evidence against an abstract viewpoint-independent functioning, in showing that both performance and visual search strategies are disrupted by the change in viewpoint.

Further research should study different levels of expertise, or as suggested by Gauthier and Tarr (2002), ‘‘the acquisition of expertise’’. Such endeavour is justified by the fact that we need to better understand the onset of different aspects of expertise. It would be helpful to investigate simultaneously the evolution of the ability to deal with stimulus structure, and the parallel evolution in eye movement parameters. The underlying question is to know how such skills develop and how strong is the coupling between eye movements and the comparison process. This type of approach would provide a better understanding of the mutually supporting conceptual and perceptual-based processes (Goldstone & Barsalou, 1998).

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