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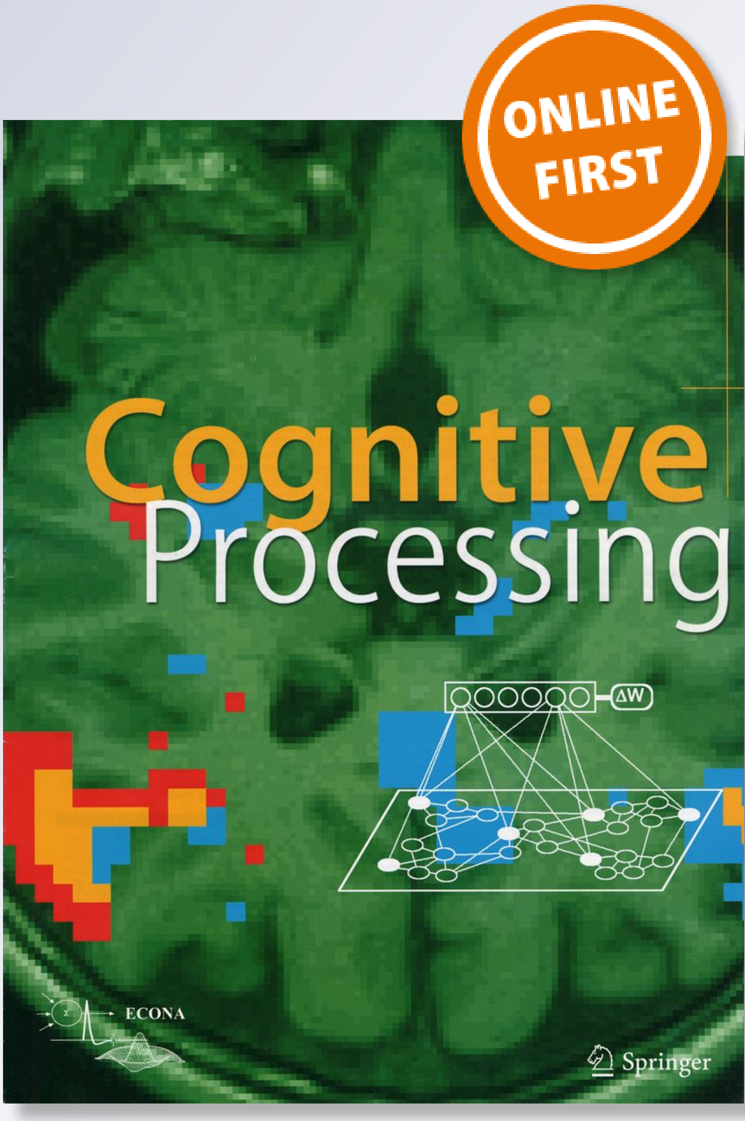

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RESEARCH REPORT

Perceptual load in sport and the heuristic value of the perceptual load paradigm in examining expertise-related perceptual-cognitive adaptations

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Abstract In two experiments, we transferred perceptual load theory to the dynamic field of team sports and tested the predictions derived from the theory using a novel task and stimuli. We tested a group of college students ($N = 33$) and a group of expert team sport players ($N = 32$) on a general perceptual load task and a complex, soccer-specific perceptual load task in order to extend the understanding of the applicability of perceptual load theory and further investigate whether distractor interference may differ between the groups, as the sport-specific processing task may not exhaust the processing capacity of the expert participants. In both, the general and the specific task, the pattern of results supported perceptual load theory and demonstrates that the predictions of the theory also transfer to more complex, unstructured situations. Further, perceptual load was the only determinant of distractor processing, as we neither found expertise effects in the general perceptual load task nor the sport-specific task. We discuss the heuristic utility of using response-competition paradigms for studying both general and domain-specific perceptual-cognitive adaptations.

Keywords Perceptual load · Cognitive adaptation · Distractor interference · Compatibility · Sport

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Introduction

A topic of major interest in psychology is how people focus attention efficiently on the task at hand without being distracted by task irrelevant information. Everyday life is full of examples demonstrating that task performance can be disturbed by external distraction, for example, being distracted from driving in a street with flashing billboards on the side, reading an article on an Internet news side with salient advertisements distributed around the article, or shooting a basketball free-throw when a flashlight goes off. In these kinds of situations, performance may suffer as a consequence of attention being drawn to the external distracting stimulus. A key question within selective attention research is whether the processing of irrelevant stimuli can be reduced or even prevented by either internal or external factors.

An early influential theory on the topic of selective attention was proposed by Broadbent (1958). Broadbent's selective filter theory of attention suggests that all stimuli in a scene are initially and involuntarily processed in parallel according to their basic physical features. Based on this initial analysis, a stimulus can either be selected for further processing or filtered out if it is identified as irrelevant for a person's current concerns on its basic physical properties (e.g., pitch, color, or orientation). According to Broadbent, this identification process is serial, involving processing of only one stimulus at a time. Various findings on phenomena such as dichotic listening (e.g., Moray 1959; Wood and Cowan 1995), the Stroop effect (Stroop 1935; MacLeod 1991, for a review), or the flanker effect (Eriksen 1995, for a review) have challenged the claims of Broadbent's theory by demonstrating that not all irrelevant information is filtered out of awareness and that there are situations in which people cannot avoid processing of

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irrelevant information. Therefore, several alternative theories have been proposed which are referred to as late selection theories (Deutsch and Deutsch 1963; Duncan 1980; Tipper 1985). The main tenet of late selection theories is that selective attention occurs later on in processing. In contrast to early selection views, late selection theories assume that the identities of all stimuli are involuntarily processed in parallel and not just the basic physical characteristics.

The early versus late selection debate has been central in the study of selective attention in the past several decades (see Lachter et al. 2004, for a review) and has caused a lot of controversy. Recently, Lavie and Tsal (1994); Lavie (1995) suggested a possible resolution of the long-standing early versus late selection debate in perceptual processing within their perceptual load (PL) model. According to their model, processing proceeds from relevant to irrelevant stimuli until capacity runs out. Under conditions of low PL, spare capacity inevitably "spills over" and irrelevant information is processed. Processing of irrelevant stimuli can be prevented when the attentional capacity is exhausted by the relevant task. Support for the model has been derived from various response-competition paradigms (see Lavie 2010, for a recent review) in which participants are required to make speeded responses indicating which of two pre-defined target stimuli (e.g., the letters X or N) are presented in a visual search array (e.g., a circle of letters). While engaged in the identification task, participants have to ignore a peripheral or central distractor stimulus. The distractor stimulus is always one of the two potential target stimuli. Therefore, trials can either be response congruent—distractor identical to target (e.g., target N and distractor N)—or response incongruent—distractor different than target (e.g., target N and distractor X). Typically, reaction times are faster in the response-congruent trials compared to the response-incongruent trials, which indicates that participants perceived the identity of the to-be-ignored distractor, and therefore, the distractor is said to produce response-competition effects or distractor interference. In the PL literature, this effect is usually referred to as compatibility effect. Interestingly, and in support of the PL model, distractor interference substantially diminishes in conditions of high PL—for example, by increasing the number of nontarget letters in the visual search array—compared to low PL.

Thus, Lavie (2005) claims that distractor processing depends on at least two separate mechanisms: (i) a fairly passive early selection mechanism that allows the exclusion of task irrelevant information at an early perceptual stage when the relevant perceptual processing load exhausts the available perceptual processing capacity; (ii) a more active cognitive control mechanism, depending on working memory that controls behavior in accordance with current goals to minimize intrusion from irrelevant stimuli, even in situations in which irrelevant stimuli were clearly perceived (as in situations of low PL). Numerous studies have provided support for the central claims of the PL theory in well-controlled laboratory settings (e.g., Bavelier et al. 2000; Forster and Lavie 2007, 2008; Gibson and Bryant 2008; Handy and Mangun 2000; Lavie and Fox 2000; Lavie et al. 2009; Paquet and Craig 1997; Rees et al. 2001). Although PL theory has received sound experimental support, the resulting conclusions have been based on a highly specific experimental paradigm.

The problems of paradigm-specific attentional research

Recently, attentional research paradigms have been criticized for having lost sight of real-world behavior and that some of the most prominent research paradigms in the study of attention "run the serious risk of excluding the exploration of questions that are crucial to a fuller understanding of human attention and behavior" (Kingston et al. 2003, p. 179). In this respect, Kingston et al. (2003) demonstrated that, for example, a small alteration to Posner's (1978) cuing paradigm that replaced the predictive arrows (pointing either to the left or right) of the original paradigm by predictive gaze behavior (schematic faces looking either to the left or right) dramatically altered the pattern of findings in the cuing paradigm. These findings challenged the apparently sound conclusion based on numerous studies that had exclusively used the original paradigm—that a central directional stimulus must be spatially predictive to result in a spatial shift of attention. Hence, Kingston et al. (2003) stated that "our research suggests that laboratory studies conceived and interpreted in isolation from real-world experience may do far worse than fail to generalize back to the natural environment; they may generate fundamental misunderstanding of the principles of human attention." Kingston and colleagues go on to suggest that this observation does not only account for the Posner cuing paradigm but that "the same conclusion holds for many other laboratory paradigms used to study attention, such as the visual search paradigm" (p. 179).

Hence, paradigm-specific research has been criticized (Meiser 2011) of being too narrowly focused on empirical effects in one particular paradigm and therefore often replacing the initial research question. In this manner, the paradigm "turns from the tool of research to the target of research" (Meiser 2011, p. 185). According to Fiedler (2011), a "good experimenter" has a good feeling to choose stimuli that will optimally demonstrate a hypothetical effect and that this stimulus selection procedure is usually treated as a skill rather than a problem. Of relevance to the present research, small alterations in the PL paradigm (Cosman and Vecera 2012) altered the typical finding that distractor interference is diminished under high levels of perceptual load. Thus, it is currently not clear how far reaching PL theory is and whether the findings might only be due to one highly specific paradigm and stimuli. Therefore, the predictive and explanatory range of a theory has to be extended to different paradigms and stimuli in order to provide converging evidence for the underlying concepts in question and demonstrating a theories universality (e.g., Shadish et al. 2002). One suggested remedy in this endeavor is creating tasks and stimuli that are representative of reality (Fiedler 2011) or are at least grounded in the real world (Kingston et al. 2003).

In addition, Vogel and Awh (2008) pointed out a further technique of using certain individual difference variables to constrain cognitive theory. If PL effects are caused by exhausted processing capacity, then they should further be affected by individual differences in perceptual processing capacity. Recent research has provided first evidence for such theorizing.

Compatibility effects in different populations

Several studies have demonstrated that reduced perceptual processing capacity leads to less distractor interference, even under fairly low levels of PL. For example younger children (Huang-Pollock et al. 2002) and elderly people (Maylor and Lavie 1998) showed reduced compatibility effects at fairly low levels of perceptual load as they have reduced processing capacity compared to adults. A similar effect has been reported for patients with brain damage in areas that have been linked to processing capacity (e.g., the parietal cortex, see Lavie 2005 for a review). On the other hand, some clinical populations that seem to have enhanced processing capacity such as patients with autism spectrum condition and congenital deafness (Lavie 2010 for a review) have been more prone to process irrelevant information, even in conditions of higher perceptual load (Bavelier et al. 2006; Remington et al. 2009). Of particular interest for the present study, Green and Bavelier (2003) suggest that perceptual processing capacity can be increased by action video game playing. Therefore, action video gamers show greater compatibility effects under high PL as their perceptual processing capacity is exhausted later and therefore can "spill over" to distractor processing in the high-load condition compared to people who do not play action video games.

The Green and Bavelier (2003) study seemingly contrasts with a recent study by Forster and Lavie (2007) with the compelling title "high perceptual load makes everybody equal" which demonstrated that people who differed in everyday distractibility indeed showed more distractor interference in the low-load condition but not in the high-load condition. Therefore, the authors concluded that high PL reduces distractor interference for everybody, regardless of individual differences, and that "perceptual load is a potent and universal determinant of distractibility" (Forster and Lavie 2007, p. 380). Taken together, the equivocal explanations and findings regarding the effect of individual differences on distractor processing under high PL suggest that further research is warranted to gain a better understanding on the effects of individual differences in PL tasks.

The present research

The rationale for the present research was twofold. First, we followed a recent call from Kingston et al. (2003); see also Fiedler 2011; Simmons et al. 2011) who pointed out the necessity of replicating effects found with one set of stimuli with different stimuli that are more representative of the real world to ensure that the phenomenon of interest does not only apply to a certain, highly controlled stimulus set but actually generalizes toward the behavior or phenomenon of interest. According to Lavie (2010), applied research on PL is only just beginning and should be enhanced in order to further understanding of the applicability of PL theory to complex settings and in turn be used to improve performance and productivity in a wide variety of everyday performance settings that require focused attention in interfering situations. In line with this argumentation, Forster and Lavie (2008) suggest that PL theory indeed has promising applied implications, both for predicting in which situations people are likely to be distracted—for example, a soccer player may be more distracted by a spectator waving a banner during the execution of a penalty kick (low load) compared to the high perceptual demands when dribbling the ball while scanning for open players—and potentially in devising interventions to avoid distraction—for example, by increasing the demands of perceptual processing. In consideration of the immense relevance of avoiding distraction in everyday life or in competitive sports, it is surprising that only limited endeavors have been undertaken in transferring the findings from PL theory to more unstructured, naturalistic settings. The present study presents a first attempt to expand PL theory from the highly controlled stimuli displays that have been used in the PL literature up to date to the applied field of sport.

The second rationale of the study was to explore the heuristic value of the PL paradigm in illuminating perceptual-cognitive adaptations that have been suggested to occur in the sports expertise literature (e.g., Starkes et al. 2001). A recurring finding within the expertise literature is that expert performers, such as chess players (Reingold et al. 2001) or team sport athletes (Cañal-Bruland et al.

2011) demonstrate superior perceptual processing for meaningful game configurations. Specifically, the sports expertise literature (e.g. Ericsson et al. 1993) has revealed several specific cognitive adaptations that occur in the acquisition of team sport expertise, suggesting that perceptual processing for meaningful sport-specific stimuli is facilitated among expert team sport athletes. This enhanced visual processing of expert athletes has even been demonstrated using highly schematic depictions of game situations for example, in basketball (Didierjean and Marmèche 2005) or soccer (Cañal-Bruland et al. 2011; Williams et al. 2006). In this respect, it has been argued that perceptual processing affords less perceptual processing resources when processing meaningful stimuli for expert athletes. Evidence for this assumption has been reported across various domains, including, for example, field hockey (Starkes 1987), American football (Garland and Barry 1991), and basketball (Allard et al. 1980).

Theoretically (e.g., Lavie 1995), it therefore seems plausible that meaningful sport-specific stimulus material may be perceptually not as demanding for expert athletes which in turn should be evident in larger distractor interference effects under high perceptual load (Green and Bavelier 2003), as these individuals have more perceptual processing capacity left over for distractor processing. In order to investigate the effects of PL and sport expertise on distractor interference, two groups of college students differing in team sport experience performed a general, sport-unspecific PL task (Beck and Lavie 2005) in Experiment 1 and a sport-specific PL task in Experiment 2. According to the predictions of the perceptual-cognitive expertise literature, experienced team sport players should not have any advantage on a general PL task as they should not have a greater perceptual capacity per se but might have a greater perceptual capacity for meaningful game configurations (e.g., Ericsson et al. 2006; Eccles 2006). This hypothesis is in line with the findings of Green and Bavelier (2003) but directly contrasts with Forster and Lavie (2007) claim that high PL is a universal determinant of distractibility and should not be affected by individual difference variables under high PL. For this reason, we attempted to directly compare these ambivalent hypotheses.

Experiment 1

One goal of Experiment 1 was to replicate findings from previous PL studies. In this endeavor, we chose the PL paradigm of Beck and Lavie (2005) to further scrutinize their finding that distractor processing at fixation is also modulated by the level of PL. Furthermore, in preparation of Experiment 2, differences in distractibility in the general PL task between experienced team sport players and novice players were explored. We expected to find a similar pattern of results between participants with hardly any competitive team sport experience and experienced team sport players due to the domain-specific advantage argumentation stated above. Specifically, we hypothesized that (i) the reaction times would be higher in the high-load condition than in the low-load condition; (ii) the percentages of errors would be higher in the high-load condition compared to the low-load condition; (iii) the reaction times would be greater in the incompatible than in the compatible condition; (iv) and most importantly for investigating the role of PL on the degree of distraction, that the compatibility effect would be greater in the low-load condition compared to the high-load condition. Further, (v) we hypothesized that the pattern of results for experienced team sport athletes should be similar to college students with no team sport experience.

Method

Participants

Thirty-five subjects between 15 and 35 years of age volunteered to participate in the experiment. The subjects had normal or corrected-to-normal vision and were naive to the experimental hypotheses. We chose 17 expert basketball players for the team sport group ($M = 22.7$, $SD = 6.1$ years of age) who had engaged, on average, in 13 years of deliberate practice at an amateur to semiprofessional level in Germany. 44 % were female and 56 % male. Thus, subject selection was in line with the recommendation of Ericsson et al. (2006) who stated that approximately 10 years of deliberate practice are necessary to differentiate expert athletes from novices. The novice group ($M = 23.1$, $SD = 3.3$ years of age) was 18 students (half women and half men) from the University of Heidelberg and had no competitive team sport experience, that is, did not engaged in deliberate practice in any major team sport. Informed consent was obtained prior to participation.

Apparatus and stimuli

For the stimuli presentation, E-Prime 1.2 (Psychology Software Tools Inc.) and a 15-inch computer screen with a resolution of 1,024 × 786 pixel was used. Subjects were tested in the computer laboratory at the University of Heidelberg. Participants were instructed to sit in a comfortable position leaning backwards on the back of the chair, so that the distance to the screen was the same for all the subjects and remained 60 cm during the whole experiment. Participants were separated by a divider allowing up to six subjects to be tested simultaneously.

The stimuli in the first experiment were similar to those used by Beck and Lavie (2005), Experiment 1 and 2). The subjects had to search a target letter (X or Z), appearing randomly but with equal probability in one of six positions in a circular arrangement on a radius of 2°. Additionally, the display contained a concentrically presented distractor letter, equally likely from the same response category as the target letter (compatible, e.g., X when target was an X) or from a different response category (incompatible, e.g., an X when target was Z). In the high-load condition, the target and distractor letter were accompanied by five non-target letters (S, K, V, J, and R; high PL, see right side of Fig. 1) that could appear in any of the six positions by chance but with equal probability. The low-load condition was realized by occupying the other five positions with small circles (low PL, see top left side of Fig. 1). At a viewing distance of 60 cm, the object's horizontally angular size was 0.36° and 0.54° vertically. The irrelevant distractor had a middle-to-middle distance to the other letters of 2°. The distractor was slightly larger than the other stimuli in the display, with a vertical and horizontal visual angel of 0.43° and 0.67° to guarantee a clear physical distinctiveness. A set of 72 different stimuli was developed to counterbalance the presentation of target letter (2), target position (6), distractor letter (2), and distractor position. All stimuli appeared in a light gray color and were presented on a black background.

Procedure

Participants performed the PL task starting with two example blocks (one high and one low load) of 12 trials, followed by eight experimental blocks of 72 trials alternating between blocks with low and high load. Half of the subjects started out with a high-load block, the other half with a low-load block. A fixation point of 1,000 ms was displayed before each trial located in the center of the screen immediately followed by the task display with the circular letter arrangement and distractor. The task displays were presented for 100 ms. Subjects were told to ignore the distractor letter and to indicate as quickly and as accurately as possible which of the target letters appeared in the circle. The distractor always showed up on fixation (Beck and Lavie 2005). Participants responded to the target stimuli either by pressing "n" or "c" on the keyboard. Half of the subjects were instructed to press "n" for an X target and the other half should press "c" to rule out any effects of the key assignment. A new trial was triggered by the participant's response or response omissions within 2 s. After each trial, feedback about incorrect responses or omissions

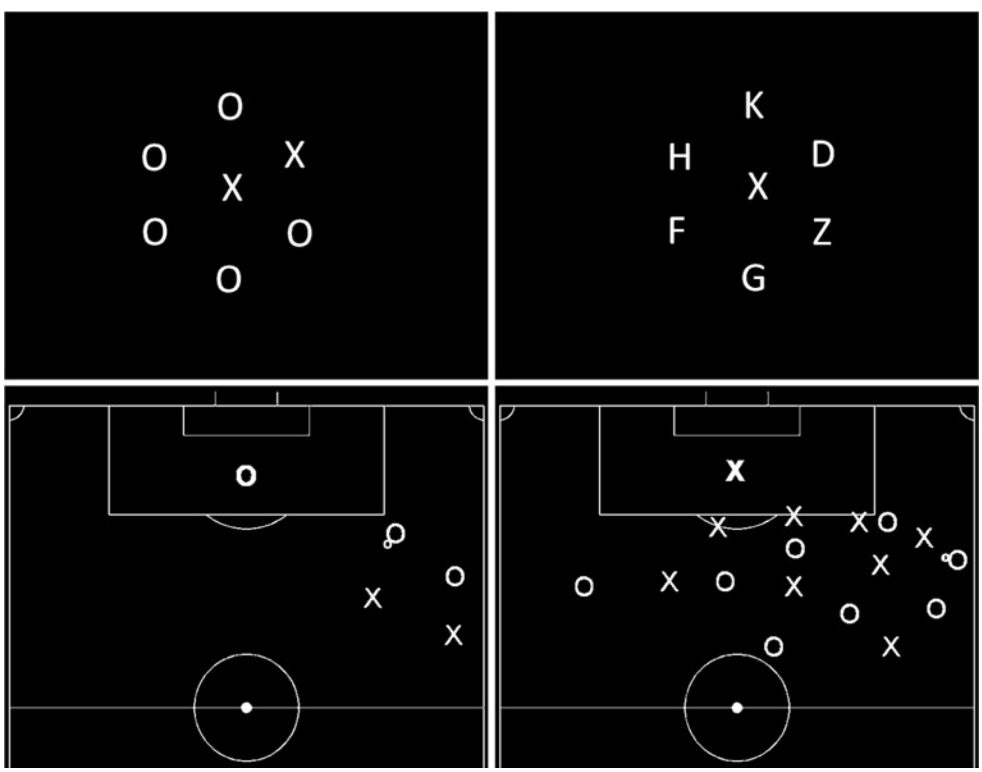

Fig. 1 Example stimuli used in Experiment 1 and 2. The top row displays sample stimuli of the general PL task and the bottom row of the soccer-specific PL task. The left column displays sample trials of the low perceptual load and compatible conditions and the right column high perceptual load and incompatible condition

was given by means of a computer sound. After each block, participants were reminded of the key assignments.

Data analysis

For each participant, mean RTs and error rates were computed as a function of PL (high vs. low), compatibility (compatible vs. incompatible), and team sport experience. Practice trials, incorrect trials, and trials with RTs over 2 s were excluded from the RT analysis. Two mixed design analysis of variance (ANOVA) with repeated measures on both within-subject independent variables (load and compatibility) and the between-subject independent variable team sport experience on both RT and errors was conducted.

Results and discussion

Overall RT performance

Table 1 displays the mean RTs and error rates across all conditions. The mixed design ANOVA with the within-subject factors (PL and distractor compatibility) and the between-subject factor expertise on RTs revealed a main effect for load ($F(1,33) = 72.089$, $p = .0001$, $\eta_p^2 = 0.686$) pointing out a slower performance under high load (693 ms) than low load (607 ms). This confirms the successful manipulation of PL. There was also a main effect for compatibility, $F(1,33) = 179.835$, $p = .0001$, $\eta_p^2 = 0.845$. As expected, RTs in conditions of incompatibility (676 ms) were increased compared to compatible conditions (623 ms). A significant interaction between load and compatibility, $F(1,33) = 6.227$, $p = .018$, $\eta_p^2 = 0.159$, reflecting reduced compatibility effects under high load was found (Table 1). These results support the key assumption of the load theory and approve that the processing of the irrelevant distractor depends on the perceptual capacity left over by the main task.

Overall error rates

The mixed design ANOVA on error rates showed a main effect of load, $F(1,33) = 12.839$, $p = .001$, $\eta_p^2 = 0.280$; and compatibility, $F(1,33) = 23.809$, $p = .0001$, $\eta_p^2 = 0.419$, in the same direction as the RTs (Table 1). No significant interaction was found.

Expert-novice differences

The mixed design ANOVA on RTs with the between-subject factor expertise (expert and novice) and within-subject factors compatibility (compatible and incompatible), and PL (high and low) revealed no significant main effects (Expertise: $F(1,33) = 1.021$, $p = .320$, $\eta_p^2 = 0.03$) for the factor expertise and expertise also did not significantly interact with load (Load × Expertise: $F(1,33) = 0.021$, $p = .886$, $\eta_p^2 = 0.001$; Load × Compatibility × Expertise: $F(1,33) = 0.327$, $p = .571$, $\eta_p^2 = 0.01$). The ANOVA only revealed a significant interaction between expertise and compatibility (Compatibility × Expertise: $F(1,33) = 4.757$, $p = .036$, $\eta_p^2 = 0.126$) indicating that the expert athletes were slightly more affected by the compatibility manipulation. An equivalent ANOVA on error rates did not reveal any main effects or interactions. In conclusion, the pattern of results is in line with the hypothesis (v).

Experiment 2

In Experiment 2, we tested whether the predictions of PL theory transferred to a newly created sport-specific PL task. The first four hypotheses were equivalent to Experiment 1. In addition, we attempted to explore whether individual

Table 1 Experiment 1: Mean reaction times (RTs, in ms) and error rates (Err, in %) as a function of perceptual load and compatibility, as well as distractor effects (I–C) on the general perceptual load task

	Distractor compatibility				Compatibility effect	
	Incompatible (I)		Compatible (C)		I–C	
	RT	Err	RT	Err	RT	Err
Novice						
Low load	616.1 (62.9)	6.0 (4.3)	564.6 (54.7)	2.7 (2.2)	51.5	3.3
High load	692.3 (121.1)	11.2 (7.1)	656.1 (118.3)	5.9 (5.2)	36.2	5.3
Expert						
Low load	653.1 (96.3)	6.0 (3.7)	587.4 (86.1)	3.2 (2.2)	65.7	2.8
High load	735.0 (110.6)	7.7 (7.3)	679.0 (102.4)	5.4 (2.5)	56.0	2.3

Standard deviations of mean in parentheses

($n = 35$)

differences regarding the experience with the perceptual processing stimuli would influence the pattern of results, especially in the high-load condition. According to Forster and Lavie's (2007) argument that PL is a universal determinant of distractibility, no differences in distractibility should be evident as a function of sport expertise, whereas the perceptual-cognitive expertise literature in the field of sport suggests that the perceptual processing demands should be diminished when experienced soccer players are confronted with meaningful soccer constellations and thus free capacity will "spill over" to distractor processing. Hence, if the expert athletes have a greater capacity for processing meaningful game configuration (as verified by expert ratings), then this should result in greater compatibility effects in the high-load condition just as in the Green and Bavelier (2003) study with expert video game players compared to a group of participants without this domain-specific knowledge. Thus, we hypothesized that (v) experts show faster RTs than novices in all conditions (Voss et al. 2010, see also Chaddock et al. 2011); and (vi) that distractor processing should occur to a similar degree in the low-load condition among expert and novices but to a greater degree in the high-load condition among experts compared to novices, since experts should have spare perceptual capacity left over in the high-load condition.

Method

Participants

Thirty new subjects between 15 and 38 years of age volunteered to participate in the experiment. The subjects had normal or corrected-to-normal vision and were naive to the experimental hypotheses. Half ($N = 15$; 10 male and 5 female) of the participants were novices in relation to the perceptual processing task, that is, they had no competitive team sport experience and had thus had not engaged in deliberate practice in any team spot. Their average age was 24 years (SD = 3.2 years of age). The other half ($N = 15$; 9 male and 6 female) were amateur to semiprofessional soccer players ($M = 21.8$ years; SD = 2.6 years of age) who had been engaged in deliberate soccer practice for 12.6 years. Informed consent was obtained prior to participation.

Apparatus and stimuli

The stimuli presentation and apparatus were identical to Experiment 1.

Development of sport-specific stimuli We attempted to create the new stimulus material both similar to key features of the original material of Beck and Lavie (2005) and as closely related to sports as possible. Expert coaches and athletes collaborated in the creation of the stimulus material to assure the creation of meaningful game configurations. In addition, two expert coaches rated all of the created stimuli on a five-point Likert's scale assessing how representative it was of a game constellation occurring during a soccer match (1, not at all representative and 5, highly representative). We only selected game constellations that had been rated as highly representative by both coaches.

Key features and similarities to the original stimuli We identified the following key features of the original stimuli that had to be included in the new stimulus material to test PL theory: (i) Every stimuli had to contain one of two possible target stimuli positioned among irrelevant stimuli; (ii) the irrelevant stimuli had to be different from the target stimuli; (iii) manipulation of PL (high vs. low) by the amount of irrelevant stimuli in the visual display; (iv) manipulation of response compatibility: the visual display had to contain a response-compatible or a response-incompatible distractor at fixation that was clearly physically distinctive to both the target and the irrelevant stimuli.

Realization of the key features in the sport-specific stimuli The created stimuli consisted of two teams represented by Xs and Os (as this is common on tactic boards in team sports; Gorman et al. 2011) with one team in possession of the ball (cf. Fig. 1). The soccer-specific stimuli were also presented on a black background in a light gray color. Additional to the general stimuli, the specific stimuli included the lines of a half soccer court in order to enhance the soccer-specific context and allowing the presentation of meaningful soccer constellations. Altogether, a set of 100 different displays was created.

I. *Every stimulus had to contain one of two possible target stimuli positioned among irrelevant stimuli.* Participants always had to search for the target in possession of the ball and decide whether it was—technically speaking—overlapping with an X or an O. At a viewing distance of 60 cm, the object's horizontally angular size was 0.48° and 0.48° vertically.
II. *The irrelevant stimuli had to be different to the target stimuli.* The target was an X or an O overlapping with a small o representing the ball. The irrelevant distractors were Xs and Os that did not overlap with the small o.
III. *PL could be manipulated by the amount of irrelevant stimuli in the visual display.* PL (high and low) was manipulated by the number of players in the scene, either two Xs versus two Os in the low-load condition

or eight Xs versus eight Os in the high-load condition. In a first study (Schmid 2008), we ran the same experiment using basketball-specific stimuli. The load manipulation involved a one-versus-one situation for the low-load condition and a five-versus-five situation for the high-load condition. As distractor interference effects were almost identical in both conditions, we concluded that the high-load condition was not perceptually demanding enough—as the player with the ball seemed to pop-out due to his distinctiveness—which is required to test the predictions of PL theory. In order to increase the perceptual demands in the high-load condition, we created the new stimulus material using soccer as more players compete simultaneously in this sport. Preliminary testing revealed that eight-versus-eight players for the high-load condition and two-versus-two players for the low-load condition were necessary to reduce distractor interference as function of load among novices which was a requirement to test our hypotheses.

IV. *Manipulation of distractor compatibility.* Compatibility (compatible vs. incompatible) was manipulated by the identity of the goalkeeper in the penalty area that either matched or mismatched the team in possession of the ball. An example of a compatible trial was an O in possession of the ball and the to-be-ignored distractor (goalkeeper) was also an O. The irrelevant distractor had a minimum distance of 0.62° to the other stimuli. To guarantee a clear physical distinctiveness of the distractor, it was slightly larger (cf. Beck & Lavie, 2005) than the other stimuli in the display, with a vertical and horizontal visual angel of 0.57° and 0.67°, respectively. The distractor was equally likely to be compatible or incompatible.

Necessary differences to the original stimuli The actual task of the participants involved important changes compared to the original Beck and Lavie (2005) task. The basic idea of the new task was that participants had to identify which team was in possession of the ball—instead of identifying if a certain letter was present in a search array—by pressing corresponding keys on the keyboard, whereby the ball was equally likely to appear in possession of an X-team member or an O-team member. A further major difference between both sets of stimuli was the arrangement of the objects on the screen, as can be seen in Fig. 1. For the benefit of the meaningful game configurations, the stimuli were not arranged in a circle anymore. This made it also impossible to keep up an equal distance between the target and the distractor. In order to remain a certain degree of regularity among the stimuli and in order to limit the attentional focus, the stimuli were arranged within one half of the soccer field and always outside the penalty area. This assured a separation of the to-be-ignored distractor stimulus (the goalkeeper) and the meaningful game configurations, as the distractor was the only stimulus that was always present in the penalty area.

Procedure

The procedure was almost identical to Experiment 1, with the described changes. Participants were instructed to press the "n" key if an X was in possession of the ball or the "c" key if an O was in possession of the ball as quickly and accurately as possible. Preliminary testing with the newly created stimulus material revealed several issues with the task. First, the presentation time of the newly created stimuli seemed to be to short, especially in the high-load condition, since too high rates of no response given or errors were evident. This was probably due to the fact that the stimulus material was more complex than the general PL task (cf. Fig. 1). For this reason, we increased the stimulus presentation time from 100 to 350 ms. Otherwise, the procedure was identical to Experiment 1.

Results and discussion

Data analysis

We ran the same analysis as in Experiment 1.

Overall RT performance

Table 2 displays the mean RTs and error rates across all conditions. The mixed design ANOVA with the within-subject factors (PL and distractor compatibility) and the between-subject factor expertise on RTs revealed a main effect for load, $F(1,28) = 168.143$, $p = .0001$, $\eta_p^2 = 0.857$, indicating slower performance under high load compared to low load and confirming the successful manipulation of PL. There was also a main effect for compatibility, $F(1,28) = 9.91$, $p = .001$, $\eta_p^2 = 0.263$. As expected, RTs in conditions of incompatibility were increased compared to compatible conditions. Most importantly, the two-way mixed ANOVA revealed a significant interaction between load and compatibility, $F(1,28) = 7.677$, $p = .01$, $\eta_p^2 = 0.215$, reflecting reduced compatibility effects in the high-load condition compared to the low-load condition. These results support the key assumption of the load theory—using a considerably different task and stimuli compared to Experiment 1—and confirm that the processing of the irrelevant distractor depends on the perceptual capacity

Table 2 Experiment 2: Mean reaction times (RTs, in ms) and error rates (Err, in %) as a function of perceptual load and compatibility, as well as distractor effects (I–C) on the soccer-specific perceptual load task

	Distractor compatibility				Compatibility effect	
	Incompatible (I)		Compatible (C)		I–C	
	RT	Err	RT	Err	RT	Err
Novice						
Low load	711.7 (82.34)	8.9 (0.9)	678.5 (77.70)	9.5 (0.8)	39.2	−0.6
High load	821.4 (104.7)	23.0 (10.2)	809.0 (104.6)	23.3 (7.3)	12.4	−0.3
Expert						
Low load	764.1 (90.98)	8.1 (0.7)	728.6 (78.74)	5.5 (0.5)	35.5	2.6
High load	846.4 (109.4)	23.6 (12.3)	856.1 (105.6)	24.5 (1.1)	−9.7	−0.9

Standard deviations of mean in parentheses

($n = 30$)

left over by the main task. Thus, the predictions of PL theory held up in the newly created representative soccer task.

Overall error rates

The mixed design ANOVA on error rates only showed a significant main effect of load, $F(1,28) = 109.161$, $p = .001$, $\eta_p^2 = 0.796$. All other main effects and interactions were nonsignificant (all $p > .3$).

Expert-novice differences

The mixed design ANOVA with the within-subject factors (PL and distractor compatibility) and the between-subject factor expertise on RTs revealed no significant main effects (Expertise: $F(1,28) = 1.795$, $p = .191$, $\eta_p^2 = 0.06$) or interactions (Load × Expertise: $F(1,28) = .772$, $p = .387$, $\eta_p^2 = 0.027$; Compatibility × Expertise: $F(1,28) = .760$, $p = .391$,, $\eta_p^2 = 0.026$; Load × Compatibility × Expertise: $F(1,28) = 1.045$, $p = .315$, $\eta_p^2 = 0.036$). An equivalent ANOVA on error rates did not reveal any main effects or interactions. Thus, we could not provide any evidence for a domain-specific processing advantage of experienced soccer players. The expert participants neither showed faster overall reaction times nor increased distractor interference in the high-load condition as hypothesized. At a first glance, the results seem to support Forster and Lavie's (2007) hypothesis that high PL makes everybody equal, which will be discussed in more detail in the "General discussion."

General discussion

The aim of the present study was twofold: First, we attempted to extend the knowledge base regarding the application of PL theory by demonstrating that PL theory is not only applicable to a very specific paradigm and set of stimuli but transfers to more realistic contexts. Second, we attempted to explore the heuristic utility of the PL paradigm in expertise research to investigate expertise-related perceptual-cognitive adaptations.

Following the call of Kingston et al. (2003), see also Fiedler 2011; Meiser 2011) who emphasized the necessity of replicating effects with different tasks and stimuli to ensure that the phenomenon of interest does not only apply to a highly specific experimental paradigm, we demonstrated that distractor processing is influenced by PL also in a more complex, unstructured setting in which the search stimulus (the ball) was not identical to the irrelevant distractor but only overlapped with either the defensive (X) or offensive players (O, cf. Fig. 1). In this respect, the present study adds to the first attempts (Forster and Lavie 2008) of applying PL theory by demonstrating that the theory seems applicable beyond the original paradigm—very simple and highly structured stimuli displays (see Lavie 2010 for a review)—to more realistic, complex stimuli.

According to Kingston et al. (2003), this is not a trivial research step but a research necessity, especially in attentional research as several paradigms have failed to extend beyond the original paradigm that was used to formulate a theory. Fiedler (2011) further stresses the necessity to replicate original findings with different stimuli with reference to Tversky and Kahneman's (1973) seminal research on the availability heuristic in which participants were asked to judge the frequency of words with the letter "k" in the first position and in the third position. The findings suggested that participants falsely estimated the frequency of words starting with "k" as much higher as words with "k" in the third position, apparently because words starting with a certain letter are available in memory more readily compared to words containing a letter somewhere in the middle. Importantly, systematic replications and extensions with other letters in the alphabet failed to support this theory (Sedlmeier et al. 1998). Hence, demonstrating that PL theory held up using newly created stimulus material representative of soccer indicated the applicability of PL theory to more real-world contexts which is an essential prerequisite for the second aim of the study.

The second aim of the study was to assess the heuristic value of the PL paradigm in illuminating perceptual-cognitive adaptations associated with team sport expertise. In this endeavor, we built on previous studies that have used populations differing in general perceptual processing capacity to demonstrate that people with enhanced general processing capacity are more prone to distractor processing as their spare capacity "spills over" (e.g., Green and Bavelier 2003). Based on the perceptual-cognitive expertise literature (Ericsson et al. 1993), we speculated that this effect should also be evident when the processing demands are reduced due to familiarity with the stimulus material, as expert soccer players are assumed to have a greater capacity for processing meaningful game configurations (e.g., Williams et al. 2006). Experiment 2 did not provide any evidence for the assumption that the newly created stimulus material was less demanding for experienced soccer players as distractor interference was almost identical to novices in both load conditions and therefore was not indicative of spare perceptual capacity of expert players due to acquired perceptual-cognitive adaptations (e.g., Ericsson et al. 2006). Thus, the perceptual processing task might not have tapped the domain of expertise of the participants. Although we had experienced coaches assist in the creation of meaningful game configurations and previous studies found expertise effects using similar schematic stimulus material (e.g., Didierjean and Marmèche 2005), the task of identifying which team (represented by Xs and Os) was in possession of the ball is not an usual requirement in team sports such as soccer.

Nevertheless, response-competition paradigms seem a useful heuristic tool for identifying hypothesized cognitive adaptations as Green and Bavelier (2003) showed for action video game players and therefore also seem suitable for showing domain-specific adaptations by making the processing task specific to the domain of expertise. Although the present study was not successful in this respect, future research should investigate group differences on distractor interference within PL paradigms that use stimuli that are more representative of the perceptual processing demands of the respective group. The present study provided a first attempt in creating a task that was assumed to be less challenging for one group of participants due to acquired perceptual-cognitive adaptations and would therefore result in increased distractor interference. Given the absence of an expertise-related effect, which might have been caused by insufficient domain relevance of the soccer task, future research should create tasks that are more representative of the visual processing demands in their respective fields of expertise. In addition, considering the ambiguous findings concerning perceptual-cognitive adaptations in sport (see Furley and Memmert 2011 for a recent review), the field of soccer might not have been ideally suited for initially testing the heuristic utility of the PL paradigm in expertise research. For example, the domain of chess with its well-established perceptual-cognitive adaptations of expert players (Chase and Simon 1973; de Groot 1965) seems to render the creation of meaningful stimuli material in chess easier and more representative of the cognitive processing demands of chess. Hence, the field of chess might have been better suited to test our idea that distractor interference should be enhanced for expert performers because their perceptual processing capacity is exhausted later for meaningful stimuli due to domain-specific perceptual-cognitive adaptations (Ericsson et al. 1993). It is our hope that researchers recognize the heuristic utility of the PL paradigm in future expertise research.

In conclusion, this article adds to the developing body of the literature on PL theory by transferring the predictions of the PL model to a more complex applied setting and examining the influence of expertise-related differences on the perceptual processing task. Future research should continue to investigate the applied daily implications of PL theory as researchers have widely neglected this to date (Lavie 2010). Given the importance of focused attention and avoiding distraction in everyday life and in competitive sports, future applied research on PL theory should help to improve performance and productivity in various real-world settings. Recent research supports this idea by providing first evidence that mind wandering can be significantly reduced during tasks of high PL (Forster and Lavie 2009).

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