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Endogenous attention and illusory line motion depend on task set

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ABSTRACT

Task set has been shown to determine some important cognitive operations like conscious perception [Rafal, R. D., Ward, R., & Danziger, S. (2006). Selection for action and selection for awareness: Evidence from hemispatial neglect. *Brain Research, 1080*(1), 2–8], and the exogenous orienting of spatial attention [Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 1030–1044; Lupiáñez, J., Ruz, M., Funes, M. J., & Milliken, B. (2007). The manifestation of attentional capture: Facilitation or IOR depending on task demands. *Psychological Research, 71*(1), 77–91]. In the present study we investigate whether endogenous attention would also be task-dependent. We use an illusion of movement, the illusory line motion [Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993). Focal visual attention produces illusory temporal order and motion sensation. *Vision Research, 33*(9), 1219–1240] to explore this question. Our results revealed that endogenously attending to detect the appearance of a target produce different consequences in modulating the illusion of movement than endogenously attending to discriminate one of its features. We suggest that endogenous attention is implemented differently depending on the task at hand, producing different effects on perceptual integration.

1. Introduction

Task set is usually defined as the cognitive demands required for interacting with the environment, a form control that is developed by instructions or by the current demands of the task at hand (see e.g., Folk, Remington, & Johnston, 1992). For example, the cognitive preparation of an observer to look for something in a messy room would be different if the observer knows which object she/he is looking for (her/his red hat), than if she/he is looking for a hat that has never been seen before. In the former case, a task set can be implemented with the properties of the known object (shape, colour), to try to make the search more efficient.

Task set has been shown to influence cognitive operations like the exogenous orienting of spatial attention (Folk et al., 1992; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Lupiáñez, Ruz, Funes, & Milliken, 2007), and conscious perception (Rafal, Ward, & Danziger, 2006). Neglect patients, for example, are not conscious of stimuli located on their left when simultaneously presented with stimulation on their right. This phenomenon, known as extinction, is not completely stimulus-driven because it can be modulated by the task at hand. Thus, when the stimulation presented on their left and right share the same response, left stimuli are more likely to be extinguished than when the same visual stimulation is associated with different responses (Rafal et al., 2006). This suggests that conscious perception depends on our aims while interacting with the environment (O'Regan, 2001).

More specifically related to attentional orienting, task set has also been proposed to determine how external stimuli attract attention (exogenous orienting). Using the well known cuing paradigm (Posner & Cohen, 1984), it has been demonstrated that facilitation and Inhibition of Return (IOR; a mechanism that produces slower responses at previously stimulated or explored locations when the time interval between the cue and target is long enough) depend on the task at hand (Lupiáñez et al., 1997). Thus, when the task involves the discrimination of visual features such as shape or colour, facilitation is larger and IOR appears later than if the task only requires the detection of the target's appearance. This evidence suggests that task set, or the preparation to interact with the environment in certain manners, determines how attention is captured exogenously (see also Folk et al., 1992).

The aim of the present paper is to explore whether endogenous attention would also be implemented differently depending on the task at hand. The spotlight's metaphor considered attention as a beam that enhances the representation of attended locations (Posner, 1980). This metaphor has led researchers to assume that endogenous attention is always implemented in the same way, for example reducing external noise in the perceptual system (Lu & Dosher, 2005) or affecting the decision of where to respond (Klein & Shore, 2000). However, it could be the case that endogenous attention is not always implemented through the same process, but its implementation could be task-dependent. That is,

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endogenously attending to discriminate a target could be different, and activate different processes, than endogenously attending to detect its appearance. In order to test this hypothesis, the illusion of movement known as the illusory line motion (ILM) will be used.

ILM consists of an unreal perception of motion when a line is presented all at once near a previously cued or stimulated location (Hikosaka, Miyauchi, & Shimojo, 1993). Under this stimulation conditions, the line appears to be drawn away from the cued location. The most accepted explanation about the ILM effect is based on the prior entry law (Titchener, 1908). This hypothesis suggests that the orienting of attention to the cue produces a gradient of accelerated arrival times at high levels of perceptual processing around its location. When a line is presented all at once across this gradient, the difference in arrival times across the line is interpreted by motion perception systems as a drawing of the line over time. Following this explanation, it could be hypothesized that similar ILM effects should be produced no matter whether attention is oriented exogenously by external events, or endogenously, through internally generated spatial expectancies, as both endogenous and exogenous attention has been proved to accelerate arrival times of attended information (Shore, Spence, & Klein, 2001).

A different hypothesis about the ILM is related with *impletion* (Downing & Treisman, 1997). Impletion refers to a filling-in process by which the visual system interprets ambiguous information. For example, if two objects are presented sequentially at different locations, with the appropriate timing, observers would perceive only one object moving from the first stimulated location to the second (see e.g., Lakatos & Shepard, 1997), instead of perceiving two different perceptual events. This hypothesis postulates that when a peripheral cue is presented, it is integrated with the edge of the line, and thus the line is perceived as a growing of the cue from that location (Downing & Treisman, 1997). Therefore, the impletion account posits that ILM is not caused by attentional processes but by the perceptual integration between two events. Therefore, ILM should not be produced by endogenous attention if there is no peripheral object with which the line could be integrated.

There is still an open controversy about whether or not endogenous attention can induce the perception of ILM. Indeed, a recent series of studies have reported conflicting, or even opposite, results (Christie & Klein, 2005; Downing & Treisman, 1997; Schmidt, 2000). The experimental manipulation of the ILM is delicate because two measurements are necessary: The perception of movement and the allocation of attention. To do so, a secondary task is generally used to investigate whether or not endogenous attention was correctly allocated. In the studies cited above, ILM trials are intermixed with letter discrimination trials in which no line is presented. This secondary task allows for an objective measure of where attention is oriented. Schmidt (2000) demonstrated that endogenous attention modulated the ILM effect using a secondary discrimination task. However, Christie and Klein (2005) have more recently demonstrated that endogenous attention did not produce the ILM effect when attention was directed to a position in space by an arrow cue, but it produced a slight modulation when endogenous attention was object-based. They concluded that ILM is very slightly produced by endogenous attention and only when attention is oriented to objects and not to space. This result is consistent with the impletion account, as attention to an object would allow the system to integrate it with the line. Note that in contrast to Schmidt that reported positive results, Christie and Klein used a secondary detection task to measure the allocation of attention.

In the ILM studies reviewed so far, it is implicitly assumed that endogenous attention is oriented in the same way whatever the task at hand. Some studies have used a secondary task that involved the discrimination of a single feature (Downing & Treisman, 1997; Schmidt, 2000), while in Christie and Klein's (2005) study the task involved the detection of the target's appearance. In the current study, we aim at testing the hypothesis that task set affects how endogenous attention is implemented. If endogenous attention is implemented differently depending on the task at hand, its effect on ILM would depend on the secondary task used to measure whether endogenous attention was truly oriented according to the instructions.

In the present experiments, we used a design in which a peripheral cue is followed by a static line containing a coloured dot in one of its edges. The secondary task involved a speeded response to the dot. Task set was manipulated by requiring different groups of participants to either detect the appearance of the dot or to discriminate its colour (detection versus discrimination tasks). In all cases, after this response, participants had to rate the perception of ILM. Endogenous attention was manipulated by making the cue predictive of the dot location. In Experiment 1, the cue predicted, in different blocks of trials, that the dot would appear at either the same location of the cue or at the opposite location. Thus, participants had to endogenously attend to either the cued location or to the location opposite to the cue. Note also that when the cue predicts the opposite location, observers might try to avoid attentional capture from the peripheral cue in order to effectively orient endogenous attention to the opposite location. In Experiment 2, a non-predictive cue block was also introduced, in which attention would be oriented in a purely exogenous manner.

We manipulated endogenous attention using peripheral and not central cues for two reasons: (1) This manipulation has proven to be very effective in studying the independent effects of endogenous and exogenous attention as well as their interaction (Chica & Lupiáñez, 2004; Chica, Lupiáñez, & Bartolomeo, 2006; Chica, Sanabria, Lupiáñez, & Spence, 2007; Lupiáñez, Decaix, Siéroff, et al., 2004). (2) It would allow us to test the predictions of both the attentional account of ILM and the impletion account. The attentional account will predict that ILM would be produced by both exogenous and endogenous attention. When the cue predicts the target to appear at the opposite location, exogenous and endogenous attention would be oriented at different locations, and participants might try to avoid the exogenous capture of the peripheral cue. The attentional account of ILM would predict that the ILM effect induced by the peripheral cue should then be reduced. However, following the impletion account (Downing & Treisman, 1997), the ILM effect is expected to be almost entirely driven by the peripheral cue. However, endogenous attention should modulate the effect of the peripheral cue differently depending on task's demands. As discrimination tasks require a deeper processing of targets' features, we expect a maximal integration between the cue and target (Lupiáñez et al., 2007), producing a larger modulation of ILM in discrimination tasks than in detection tasks. In Experiment 1, we also manipulated the duration of the cue before the line was presented (100 or 1000 ms). We did so to create two different conditions of impletion. The impletion account would predict larger ILM effects when the time between cue onset and target onset is short (Lakatos & Shepard, 1997), and this effect might be unaffected by the endogenous orienting of attention.

2. Experiment 1

In all the previous experiments discussed in Section 1, the secondary task to measure whether endogenous attention was oriented according to the instructions was introduced in different trials to the ILM trials. That is, in some trials, the cue was presented followed by a line and participants rated the perception of motion; in other trials, a different target was presented after the cue and participants detected its appearance or discriminated one of its features. Using this method, it is assumed that the orienting of attention produced by the cue is manifested equally in the two types of trials, although they use completely different targets with different task demands. In order to avoid this problem, in the current experiments, we presented a peripheral cue followed by the line, which contains the target (i.e., a colour dot in one of its edges). Participants were asked to quickly respond to the dot first, and then rate the perception of ILM without time pressure. In the same trial, we are thus able to measure whether endogenous attention is oriented according to the instructions (producing faster and/or more accurate responses to the dot), and whether attention modulates the perception of ILM.

The experiment consisted of two blocks of trials. In one of them, the cue predicted the target to appear at the same location as the cue, so that endogenous attention was oriented to the cued location. In the other block of trials the cue was counter-predictive, so that endogenous attention was oriented to the opposite location to the cue. If endogenous attention modulates the perception of ILM, more ILM should be perceived when endogenous attention is oriented to the cued location. Additionally, in order to study whether the task set generated in detection and discrimination tasks has distinct effects on the perception of ILM, some participants were asked to detect the appearance of a dot (Experiment 1A) while others had to discriminate its colour (Experiment 1B).

3. Experiment 1A (detection task)

3.1. Method

3.1.1. Participants

Twenty naïve observers (mean age of 23 years, 3 males, 3 left-handed) participated in the experiment. All of the participants in this and the following experiments were recruited from the University of Granada, and participated in the experiment for course credit. All of them reported to have normal or corrected to normal vision and non-known neurological problems. All the experiments were conducted in accordance with the ethical guidelines laid down by the Department of Experimental Psychology, University of Granada.

3.1.2. Apparatus and stimuli

The stimuli were presented on a 15-in. colour VGA monitor. An IBM compatible PC running E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) controlled the presentation of stimuli, timing operations, and data collection. The participants sat at approximately 57 cm from the monitor in a dimly illuminated booth. At the beginning of each trial, a fixation point (a grey plus sign, $0.4^{\circ} \times 0.4^{\circ}$) was displayed at the centre of the screen, on a black background. Two grey circles (1.4° diameter) were displayed 1.8° above fixation and 3.8° to the left and right. As a cue, the outline of one of the circles turned white for 50 ms and became thicker (the circle's diameter was of 1.6°) giving the impression of a brief flash. The target was a line (6.2° in height) joining the two circles. The line contained either a red or green square ($0.4^{\circ} \times 0.4^{\circ}$) in one of its edges. A 50 ms tone was used to provide response feedback.

3.1.3. Procedure

Every trial was self-initiated by pressing the space bar. The fixation point and the two circles were then presented. After 1000 ms, the peripheral cue was randomly presented at either the left or the right marker for either 100 or 1000 ms. The target (the line plus the dot) was then displayed for 100 ms. The dot was either red or green and could appear at either the left or the right edge of the line. We use the term "cued trials" to refer to those trials in which the dot was presented at the same location as the cue, and "uncued trials" for those trials in which the dot appeared at the opposite location to the cue (see Fig. 1). Catch trials, in which no dot was presented inside the line and no response was required, accounted for 16% of the trials. Participants were asked to detect the appearance of the dot as fast and accurately as possible. Half of the participants detected the target by pressing the "z" key with their left hand whereas the other half pressed the "m" key with their right hand. If no response was detected within 2000 ms of target appearance, auditory feedback was provided for 50 ms. The same auditory feedback was used for anticipatory responses. After this speeded response to the dot, the sentence "¿Has percibido movimiento?" ("*Did you perceive motion*?" in Spanish) was displayed at the centre of the screen, and participants were asked to press one out of four keys (a, s, k, l). These keys were labelled as "Collision" (motion from the two markers to the centre), "Left", "No Motion", and "Right", respectively. Participants were encouraged to take as much time as needed to respond to this question, and were informed that there was no correct or incorrect answer. After this response, they were asked to place their fingers in the "z" or the "m" key (depending on the response mapping condition) in order to get ready for the next trial.

There were two blocks of trials. In one of them, the cue predicted that the dot would appear at the same location on 75% of the trials in which the dot was presented (predictive cue block). On the remaining 25% of the trials of this block, the dot appeared at the location opposite to the cue. Thus, in this block there were 75% cued trials (cue and dot at the same location) and 25% uncued trials (cue and dot at different locations). In the other block of trials, the cue predicted that the dot would appear at the opposite location on 75% of the trials (counter-predictive cue block). On the remaining 25% of the trials of this block, the dot was presented at the same location as the cue, thus leading to 75% uncued trials and 25% cued trials. Note, therefore, that in the predictive cue block, cued trials are endogenously attended whereas in the counter-predictive cue block, uncued trials are endogenously attended. Participants were informed about the predictive value of the cue and encouraged to take this information into account in order to respond fast and accurately to the dot. The order of presentation of the blocks was counterbalanced within participants.

Each block consisted of a total of 190 trials preceded by 24 practice trials. Thirty trials in each block were catch trials. For each block, and for each cue duration condition, there were a total of 60 trials in which the target appeared at the location predicted by the cue (endogenously attended location), and 20 trials in which the target appeared at the non-predicted location (endogenously unattended location).

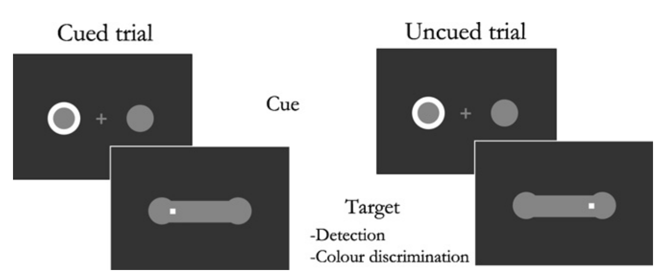

Fig. 1. Example of cued and uncued trials in the experiments. In cued trials, the dot appears at the same location as the cue, while in uncued trials the dot appears at the opposite location. When the cue predicts the same location of the dot, cued trials are endogenously attended, while when the cue predicts the opposite location of the dot, uncued trials are endogenously attended. Half of the participants detected the appearance of the dot, while the other half discriminated its colour.

3.2. Results

Participants that did not perceive ILM were eliminated from this and the following experiments. Participants that rated ILM toward the cue in all conditions were also eliminated assuming that they mistook the instructions to use the scale. Only one participant had to be eliminated in this experiment for rating the movement toward the cue. One further participant was excluded from the analysis due to the lack of data in atleast one of the conditions. Misses (1.51% of trials) and false alarms (responses to catch trials, 2.88% of trials) were eliminated from the RT analyses. RTs faster than 200 and slower than 1200 ms were considered outliers and were not analysed (3.06% of trials).

3.2.1. RT results for the secondary task

Mean correct RTs were submitted to a repeated-measures analysis of variance (ANOVA) with the factors of cue predictiveness (predictive versus counter-predictive cue block), cuing (target dot at the same location as the cue—cued location trials—versus at the opposite location—uncued location trials), and cue duration (100 and 1000 ms), all manipulated within participants. The analysis revealed a main effect of cue duration, $F(1,17) = 24.85$, $MSE = 2932$, $p < .001$, with RT being faster when the cue was presented for 1000 versus 100 ms. The interaction between cue predictiveness and cuing was significant, $F(1,17) = 10.17$, $MSE = 2092$, $p = .005$. This interaction revealed the fact that participants were orienting their attention endogenously according to the instructions and the predictiveness of the cue. When the cue predicted the dot to appear at the cued location (predictive cue block), RTs were faster for cued versus uncued trials ($M = 544$ and 575 ms, respectively), and when the cue predicted the target to appear at the opposite location (the uncued location, counter-predictive cue block), RTs were faster for uncued trials than for cued trials ($M = 572$ and 590 ms, respectively; see Table 1). None of the other main effects or interactions were significant.

3.2.2. ILM results

Left and right responses were re-coded as either towards or away from the cue (depending on the cue location). Thus, ILM ratings were re-coded in 4 values: 0 (no movement), 1 (movement away from the cue), −1 (movement towards the cue), and collision (movement from the two markers to the centre). Mean illusory rating scores (excluding "collision" responses) were submitted to a similar ANOVA with the factors of cue predictiveness, cuing, and cue duration, all manipulated within participants. In this analysis, only the main effect of cuing was significant, $F(1,17) = 5.43$, $MSE = 0.93$, $p = .032$, revealing that ILM ratings were higher for uncued versus cued trials. Neither the main effect of cue predictiveness, $F < 1$, nor the interaction between cue predictiveness and cuing, $F < 1$, or cue predictiveness and cue duration, $F(1,17) = 1.21$, $MSE = .02$, $p = .28$, were significant, revealing that endogenous attention did not affect the perception of ILM (see Fig. 2 and Table 1). In particular, it is important to remember that the RT results revealed that endogenous attention was oriented to the location of the cue in the predictive cue block, and to the opposite location in the counter-predictive cue block. However, endogenous attention did not modulate the perception of the illusion.

A similar analysis of the mean collision responses showed a main effect of cuing, $F(1,17) = 4.51$, $MSE = .02$, $p = .048$, with more collision responses for cued versus uncued trials. The main effect of cue duration was also significant, $F(1,17) = 9.90$, $MSE = .01$, $p = .005$, with more collision responses when the cue was presented for 1000 versus 100 ms.

3.3. Discussion

The results of the present experiment have revealed that participants were faster detecting the appearance of the dot at the location predicted by the cue (both in the predictive and the counter-predictive cue block), indicating that endogenous attention was

Table 1
Mean data of the secondary task and the ILM in Experiment 1A (detection task) and 1B (discrimination task) for each experimental condition of cue predictivity (predictive and counterpredictive), cuing (cued and uncued), and cue duration (100 and 1000 ms)

	Predictive				Counterpredictive			
	Cued		Uncued		Cued		Uncued	
	Mean	*SE*	Mean	*SE*	Mean	*SE*	Mean	*SE*
Experiment 1A(detection task)								
Cue duration 100 ms								
RT	565	[30]	592	[38]	620	[32]	595	[32]
Cuing effect	**27**				−**25**			
ILM	0.50	[0.162]	0.83	[0.032]	0.48	[0.154]	0.90	[0.038]
Collision	0.16	[0.069]	0.11	[0.057]	0.13	[0.059]	0.08	[0.035]
Cue duration 1000 ms								
RT	523	[32]	559	[36]	560	[32]	551	[33]
Cuing effect	**36**				−**9**			
ILM	0.48	[0.159]	0.81	[0.058]	0.40	[0.161]	0.83	[0.049]
Collision	0.20	[0.075]	0.16	[0.066]	0.20	[0.066]	0.13	[0.053]
Experiment 1B(discrimination task)								
Cue duration 100 ms								
Acc	97%	[0.62]	94%	[1.00]	96%	[1.24]	95%	[0.83]
RT	893	[41]	975	[53]	885	[40]	876	[42]
Cuing effect	**82**				−**9**			
ILM	0.80	[0.064]	0.69	[0.081]	0.47	[0.151]	0.64	[0.135]
Collision	0.14	[0.072]	0.08	[0.052]	0.10	[0.047]	0.07	[0.029]
Cue duration 1000 ms								
Acc	95%	[0.95]	94%	[1,00]	94%	[1.30]	95%	[0.64]
RT	833	[46]	905	[52]	865	[51]	850	[50]
Cuing effect	**72**				−**15**			
ILM	0.65	[0.134]	0.72	[0.062]	0.27	[0.130]	0.60	[0.139]
Collision	0.19	[0.085]	0.11	[0.068]	0.12	[0.060]	0.10	[0.053]

For the secondary task, mean RT (in ms) and accuracy (ACC) in the discrimination task, plus its standard error (in brackets), are shown. In bold, mean cuing effect for the RT (in ms). For the ILM responses, mean ILM and collision responses, plus its standard error (in brackets), are shown.

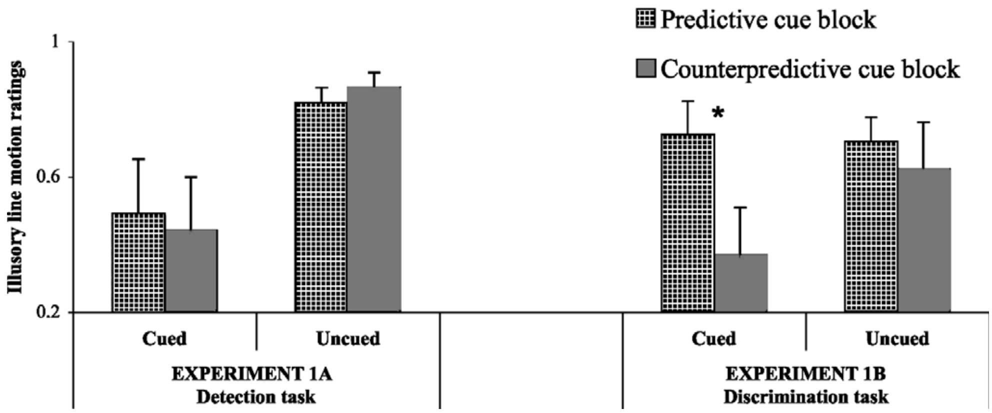

Fig. 2. Mean ILM ratings for cued and uncued trials as a function of cue predictiveness in Experiment 1A (detection task) and 1B (discrimination task). The asterisk represents statistically significant effects.

oriented according to the instructions. However, the perception of ILM was not modulated by endogenous attention. ILM ratings were similar when endogenously attending to the cued location versus attending to the location opposite to the cue (see Christie & Klein, 2005; for similar results using a detection task). Importantly, as stated above, this result argues against the attentional hypothesis about ILM (Hikosaka et al., 1993), which would predict that endogenously attending to the location opposite to the cue would reduce the ILM effect induced by the peripheral cue. In other words, if ILM was caused by accelerated arrivals times of processing at attended locations, when endogenous attention is oriented to the opposite location to the cue, the ILM effect produced by the cue should be reduced. Therefore, the ILM seems more plausibly explained by impletion (Downing & Treisman, 1997) or the integration between the cue and the line within the same object file. Another piece of evidence in favour of the impletion account was the fact that more collision responses were observed when the cue was presented for 1000 versus 100 ms. A larger interval between the onset of the cue and the target reduces the perception of ILM, probably because the integration between the cue and the target is impaired.

4. Experiment 1B (discrimination task)

In Experiment 1B, we ran a discrimination task in order to explore whether the modulation of ILM would depend on the task at hand.

4.1. Method

4.1.1. Participants

Twenty naïve observers (mean age of 22 years, 2 males, all right-handed) participated in the experiment.

4.1.2. Apparatus, stimuli, and procedure

Everything was the same as in Experiment 1A except for the following: No catch trials were included because they were not necessary to ensure adequate performance in the discrimination task. Participants were asked to discriminate the colour of the dot by pressing the ‘‘z” key with their left hand for one of the colours, or the ‘‘m” key with their right hand for the other colour. The response mapping was counterbalanced between participants. It is well known that RTs to discriminate the colour of a target are longer than RTs to detect the target's appearance (Lupiáñez et al., 1997). For this reason and in order to equate task's difficulty, in this experiment the line and the dot were presented until response.

4.2. Results

One participant was eliminated from the analysis for not perceiving the illusion and always responding ‘‘collision”. Two further participants were excluded from the analysis due to the lack of data in at least one of the conditions. Incorrect responses to the dot (4.69% of trials) were removed from the RT analyses. RTs faster than 200 and slower than 1700 ms were considered outliers and were not analysed (6.41% of trials).

4.2.1. RT and accuracy results for the secondary task

Mean correct RTs were submitted to a repeated-measures ANOVA with the factors of cue predictiveness (predictive versus counter-predictive), cuing (cued versus uncued location trials), and cue duration (100 and 1000 ms), all manipulated within participants. The analysis revealed a significant main effect of cue duration, $F(1,16) = 11.09$, $MSE = 5905$, $p = .004$, with faster RTs when the cue was presented for 1000 versus 100 ms. The main effect of cuing was also significant, $F(1,16) = 4.67$, $MSE = 7578$, $p = .046$, with faster RTs for cued than uncued trials. Importantly, the interaction between cue predictiveness and cuing was significant, $F(1,16) = 16.31$, $MSE = 4133$, $p < .001$, indicating that participants were faster responding to the endogenously attended location in both blocks. This interaction demonstrated that participants were endogenously attending according with the instructions. When the cue predicted the dot to appear at the cued location, RTs were faster for cued versus uncued trials ($M = 863$ and 939 ms, respectively), and when the cue predicted the target to appear at the opposite location, RTs were faster for uncued versus cued trials ($M = 862$ and 874 ms, respectively; see Table 1). None of the other main effects or interactions were significant.

A similar analysis of the mean erroneous responses revealed that none of the main effects or interactions reached significance. However, as can be observed in Table 1, the accuracy data revealed a similar pattern to the RT data.

4.2.2. ILM results

Mean illusory rating scores (excluding ‘‘collision” responses) were submitted to a similar ANOVA with the factors of cue predictiviness, cuing, and cue duration, all manipulated within participants. The main effect of cue duration was significant, $F(1,16) = 5.19$, $MSE = .06$, $p = .037$, with higher ILM ratings when the cue was presented for 100 versus 1000 ms. The interaction between cuing and cue duration was also significant, $F(1,16) = 4.57$, $MSE = .06$, $p = .048$, and showed that the perception of ILM decreased as cue duration increased for cued trials, $F(1,16) = 5.93$, $MSE = .09$, $p = .027$, but did not change for uncued trials, $F < 1$. Specially important for our hypotheses, the interaction between cue predictiviness and cuing was significant, $F(1,16) = 10.66$, $MSE = .06$, $p = .005$. This interaction revealed that endogenous attention only produced an effect on cued trials. On those trials, endogenously attending to the location of the cue enhanced the perception of ILM as compared to endogenously attending to the location opposite to the cue, $F(1,16) = 8.93$, $MSE = .24$, $p = .009$ (see Fig. 2). Thus, endogenous attention did modulate the perception of ILM when participants were performing a secondary discrimination task.

A similar analysis of the mean collision responses revealed that none of the main effects or interactions was significant.

4.3. Discussion

Our manipulation of endogenous attention has been successful to produce endogenous attentional effects in responding to the secondary task in both Experiment 1A (detection task) and 1B (discrimination task). Thus, endogenous attention was oriented to the location indicated by the cue. Importantly, endogenous attention did not modulate the ILM effect when participants were performing a secondary detection task, but it did when participants were performing a secondary discrimination task. This result is consistent with the previous literature, as the most recent evidence against the fact that endogenous attention affects the perception of ILM used a secondary detection task (Christie & Klein, 2005), while all the previous studies with positive results used a secondary discrimination task (Downing & Treisman, 1997, Experiment 2A; Schmidt, 2000, Experiments 1 and 2). This result is very relevant for the theoretical aim of the present paper. Endogenously attending to detect a target is implemented differently than endogenously attending to discriminate one of its features. More specifically, endogenous attention in the context of a discrimination task seems to increase the perceptual integration between the cue and the line, thus producing a stronger perception of ILM. Similarly to the results found in Experiment 1A, ILM was more strongly perceived when the interval between the cue and the target was short. These results support the impletion account, which would predict larger ILM in situations that maximize perceptual integration, such as short intervals between the cue and target (Lakatos & Shepard, 1997), and discrimination tasks (Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001).

5. Experiment 2

Experiments 2A and 2B were designed in order to improve the method of Experiment 1 and replicate the results. First, a scale from −3 to +3 (left to right movement) was used to rate ILM, allowing participants to rate, not only the direction of movement, but also its strength and speed. Second, it could be argued that endogenous attention modulated the perception of ILM in the discrimination task but not in the detection task because the line was presented until response only in the discrimination task. In the next experiments, the line was presented for 100 ms in both tasks. Third, in Experiment 1, we only used a predictive and counter-predictive cue block. Thus, it could not be disentangled whether the effect of endogenous attention was due to an increased perception of the illusion when attention was oriented to the location of the cue, or a decreased perception of the illusion when attention was oriented to the opposite location to the cue. In order to facilitate the interpretation of the results, a non-predictive cue block was added, in which the cue did not predict the location of the dot-target. Finally, in order to avoid any potential confound due to eye movements, the electro-oculogram (EOG) was recorded in half of the participants using electrodes to measure horizontal and vertical eye movements.

6. Experiment 2A (detection task)

6.1. Method

6.1.1. Participants

Twenty-eight naïve observers (mean age of 21 years, 5 males, all right-handed) participated in the experiment. The EOG was recorded in 16 of the participants.

6.1.2. Apparatus and stimuli

Everything was the same as in Experiment 1. EOG was recorded using electrodes situated lateral to and below the eyes. The experimenter could monitor the eye movements online, and control that participants were not moving the eyes during the experiment, informing them if eye movements were observed in the EOG.

6.1.3. Procedure

Everything was the same as in Experiment 1A except for the following. The fixation display varied randomly between 1000 and 1500 ms. Only a 300 ms cue duration was used. Previous research using this design has demonstrated that 300 ms is a long enough interval for endogenous attention to be oriented (Chica et al., 2006). Moreover, this interval is short enough to induce an ILM effect. Trials were not self-initiated by pressing the space bar as in Experiment 1, and the inter-stimulus interval was fixed at 1000 ms. Participants detected the appearance of the dot with one hand, and rated the perception of the movement using the computer mouse with their other hand (with the hand used counterbalanced across participants). A −3 to +3 (plus a "collision" button) scale was presented on the screen. Participants were asked to use the different values of the scale to rate not only the direction of the movement but also its strength and speed, i.e., a movement to the left would take its maximum value (−3) if the perception of movement was strong and fast; or its minimum value (−1) if a weak movement was perceived.

Three blocks of 160 trials each were run, all preceded by 20 practice trials. In the non-predictive cue block, the cue was not spatially predictive of the dot's location. In the predictive cue block, the cue predicted the dot to appear at its same location on 75% of the trials. In the counter-predictive cue block, the cue predicted the dot to appear at the opposite location on 75% of the trials. The order of the three blocks was counterbalanced within participants.

In the non-predictive cue block, there were 64 cued trials, 64 uncued trials, and 32 catch trials. In the predictive cue block, there were 96 cued trials, 32 uncued trials, and 32 catch trials. And finally in the counter-predictive cue block, there were 96 uncued trials, 32 cued trials, and 32 catch trials.

6.2. Results

Three participants were eliminated for not perceiving ILM in any condition and another three for rating ILM towards the cued location, probably due to misunderstanding the instructions. Misses (0.83% of trials) and false alarms (responses to catch trials, 2.18%) were eliminated from the analyses. RTs faster than 200 and slower than 1200 ms were considered outliers and not analysed (3.56% of trials).

The EOG was analysed offline and eye movements were considered to occur when an amplitude difference larger than 70 μV was detected. Eye movements were only observed in 3.35% of the trials.

6.2.1. RT results for the secondary task

Mean correct RTs were submitted to a repeated-measures ANOVA with the factors of cue predictiveness (non-predictive, predictive, and counter-predictive) and cuing (cued versus uncued trials). The only effect that reached significance was the interaction between cue predictiveness and cuing, $F(2,42) = 6.72$, $MSE = 905$, $p = .003$. When the cue was not predictive, RTs were faster for uncued versus cued trials ($M = 417$ and 426 ms, respectively). However, when the cue was predictive, RTs were always faster at the endogenously attended location, $F(1,42) = 9.95$, $MSE = 1221$, $p = .005$. When the cue predicted the dot to appear at the same location, RTs were faster for cued versus uncued trials ($M = 423$ and 437 ms, respectively). Moreover, when the cue predicted the dot to appear at the opposite location, RTs were faster for uncued versus cued trials ($M = 402$ and 435 ms, respectively; see Table 2).

6.2.2. ILM results

After re-coding left–right responses into towards–away responses, ILM ratings could take a range of values from 0 (no motion) to 3 (when the movement was perceived away from the cue) or −3 (when the movement was perceived towards the cue). Collision responses were also possible. Mean illusory rating scores (excluding "collision" responses) were submitted to a repeated-measures ANOVA with the factors of cue predictiveness (non-predictive, predictive, and counter-predictive), cuing (cued versus uncued trials), and eye movement measurement (measured versus non-measured eye movements). This latter between participants factor was included in order to explore whether eye movements measurement might modulate the observed pattern of data. The analysis revealed a main effect of cuing, $F(1,20) = 7.88$, $MSE = 2.06$, $p = .011$, with higher ILM ratings for uncued versus cued trials. However, the interaction between cuing and the measurement of eye movements was marginally significant, $F(1,40) = 4.27$, $MSE = 2.06$, $p = .052$, and showed that the stronger perception of ILM for uncued versus cued trials was only observed when eye movements were not measured, $F(1,20) = 8.71$, $MSE = 2.06$, $p = .008$, not being present in the group in which eye movements were monitored, $F < 1$. When eye movements were measured, and thus participants moved the eyes in a very low proportion of trials, ILM was similar when the dot was presented at the cued or the uncued location. It seems that the stronger perception of ILM for uncued trials in Experiment 1A was due to an eye movement to the uncued target (to the opposite location to the cue). If the eyes move to the uncued location (away from the cue), more ILM (which consists of a perceived movement away from the cue) would be perceived.

Regarding the endogenous orienting of attention, as in Experiment 1A, neither the main effect of cue predictiveness, $p = .26$, nor the interaction between cue predictiveness and cuing, $p = .27$, were significant. None of these interactions were modulated by the eye movement measurement ($F < 1$ and $p = .34$). Thus, replicating the results of Experiment 1A, from the RT analysis of the secondary task it can be concluded that endogenous attention was oriented according to the instructions. However, when participants were performing a secondary detection task, endogenous attention

Table 2
Mean data of the secondary task and the ILM in Experiment 2A (detection task) and 2B (discrimination task) for each experimental condition of cue predictivity (predictive, counterpredictive, and non-predictive), and cuing (cued and uncued)

	Predictive				Counterpredictive				Non-predictive			
	Cued		Uncued		Cued		Uncued		cued		Uncued	
	Mean	*SE*	Mean	*SE*	Mean	*SE*	Mean	*SE*	Mean	*SE*	Mean	*SE*
Experiment 2A(detection task)												
RT	423	[22]	437	[28]	435	[22]	403	[19]	426	[21]	418	[23]
Cuing effect	**14**				**−32**				**−8**			
ILM	1,53	[0,33]	2,27	[0,19]	1,31	[0,32]	2,19	[0,24]	1,79	[0,31]	2,43	[0,15]
Collision	0,00	[0,002]	0,01	[0,005]	0,02	[0,011]	0,01	[0,004]	0,01	[0,012]	0,01	[0,004]
Experiment 2B(discrimination task)												
Acc	93%	[1,24]	91%	[1,11]	89%	[1,67]	92%	[1,23]	91%	[1,43]	89%	[1,94]
RT	671	[24]	695	[26]	694	[26]	680	[24]	679	[25]	689	[26]
Cuing effect	**25**				**−14**				**9**			
ILM	1,85	[0,14]	1,81	[0,18]	1,52	[0,17]	1,89	[0,14]	1,59	[0,19]	1,74	[0,19]
Collision	0,01	[0,003]	0,01	[0,008]	0,00	[0,002]	0,01	[0,004]	0,00	[0,001]	0,00	[0,000]

For the secondary task, mean RT (in ms) and accuracy (ACC) in the discrimination task, plus its standard error (in brackets), are shown. In bold, mean cuing effect for the RT (in ms). For the ILM responses, mean ILM and collision responses, plus its standard error (in brackets), are shown.

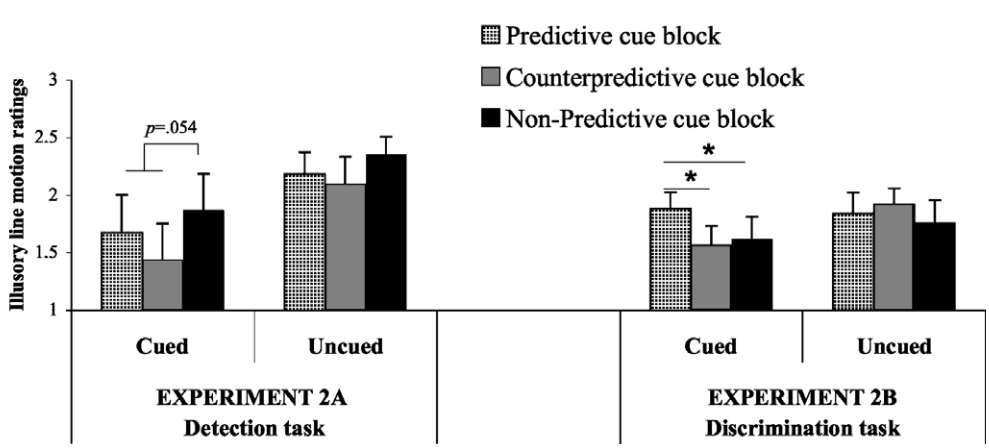

Fig. 3. Mean ILM ratings for cued and uncued trials as a function of cue predictiveness in Experiment 2A (detection task) and 2B (discrimination task). The asterisk represents statistically significant effects.

did not modulate the perception of ILM (see Fig. 3). In any case, visual inspection of cued trials suggest that ILM was more strongly perceived when the cue was not predictive than when the cue was spatially predictive (although the planned comparison was only marginally significant, $p = .054$). There were no differences in the perception of ILM when the cue predicted the target to appear at the same versus the opposite location, $F < 1$.

A similar analysis of the mean collision responses revealed that none of the main effects or interactions were significant.

6.3. Discussion

Experiment 2A has replicated the main finding of Experiment 1A: When participants adopt a detection set, even though responses to the dot are faster at the endogenously attended location, endogenous attention does not modulate the perception of ILM. In any case when the cue was made spatially predictive (of either the same or the opposite location to the cue) the perception of ILM decreased as compared with the non-predictive cue block. In the following experiment, we tried to replicate the result of Experiment 1B in which endogenous attention to the cued location did enhance the perception of ILM when participants were performing a secondary discrimination task.

7. Experiment 2B (discrimination task)

7.1. Method

7.1.1. Participants

Twenty-eight naïve observers (mean age of 21 years, 1 male, 4 left-handed) participated in the experiment. The EOG was recorded in 16 of the participants.

7.1.2. Apparatus, stimuli and procedure

Everything was the same as in Experiment 2A except that participants were asked to discriminate the colour of the dot using their middle and index finger of either their left or their right hand. The response mapping was counterbalanced across participants.

7.2. Results

One participant was eliminated for not perceiving the illusion in any of the conditions. Misses (1.90% of trials) and false alarms (responses to catch trials, 0.96%) were eliminated from the analyses. Incorrect responses (8.23% of trials) were also excluded from the RT analysis. RTs faster than 200 and slower than 1200 ms were considered outliers and not analysed (3.26% of trials). For the group in which eye movement were measured, only in 1.95% of trials participants failed to maintain fixation.

7.2.1. RT and accuracy results for the secondary task

Mean correct RTs were submitted to a repeated-measures ANOVA with the factors of cue predictiveness (non-predictive, predictive and counter-predictive cue block) and cuing (cued versus uncued trials). The interaction between cue predictiveness and cuing was significant, $F(2,52) = 8.54$, $MSE = 608$, $p < .001$. This interaction revealed the fact that when the cue was not predictive, RTs were faster for cued versus uncued trials ($M = 679$ and 688 ms). However, when the cue was predictive, RTs were faster at the endogenously attended location, $F(1,26) = 13.04$, $MSE = 785$, $p < .001$. Thus, when the cue predicted the dot to appear at the same location, RTs were faster for cued versus uncued trials ($M = 671$ and 695 ms), whereas when the cue predicted the dot to appear at the opposite location, RTs were faster for uncued versus cued trials ($M = 680$ and 694 ms; see Table 2).

A similar analysis of the mean accuracy responses revealed a similar cue predictiveness by cuing interaction, $F(2,52) = 3.45$, $MSE = .002$, $p = .039$. Responses were more accurate for cued versus uncued trials when the cue was not predictive. When the cue was predictive, responses were more accurate at the endogenously attended location (cued trials when the cue predicted the same location and uncued trials when the cue predicted the opposite location; see Table 2).

7.2.2. ILM results

Mean illusory rating scores (excluding "collision" responses) were submitted to a repeated-measures ANOVA with the factors of cue predictiveness, cuing, and eye movement measurement (measured versus non-measured eye movements). This analysis revealed a significant main effect of cue predictiveness, $F(1,25) = 3.30$, $MSE = .12$, $p = .045$. Participants rated the perception of ILM more strongly when attending to the cued location versus the opposite location ($p = .007$) or when the cue was not predictive ($p = .046$). No differences were found between the opposite and the non-predictive cue block ($F < 1$). Moreover, as in Experiment 1A, cue predictiveness interacted with cuing, $F(2,50) = 3.23$, $MSE = .17$, $p = .048$, revealing that the effect just described was only observed in cued trials (see Fig. 3). None of the other main effects or interactions were significant.

The analysis of the mean collision responses could not be performed due to a lack of variance.

7.3. Discussion

Replicating the results of Experiment 1B, the present experiment has shown that when participants are performing a secondary discrimination task, endogenous attention does modulate the perception of ILM. RTs to discriminate the dot revealed that endogenous attention was oriented to the location indicated by the cue. Additionally, when participants were endogenously attending to the location of the cue, ILM ratings were higher than when endogenous attention was oriented to the opposite location or when the cue was not predictive.

8. General discussion

In the present paper, we aimed at exploring the role of task set on the implementation of endogenous attention. We investigated whether endogenous attention is oriented in the same way when the system is prepared to detect the appearance of a target versus to discriminate one of its features. The results of the two experiments reported here seem to indicate that different processes were activated by endogenous attention depending on whether participants were attending to detect or discriminate the target, modulating perceptual integration differently.

ILM was used to explore the role of task set in the implementation of endogenous attention. This illusion is created after the presentation of a peripheral cue followed by a line, which is perceived as moving away from the cue. We manipulated independently the location of the peripheral cue inducing the illusion, and the allocation of endogenous attention, by using predictive peripheral cues of either the same location or the opposite location (a non-predictive cue block was also introduced in Experiment 2). The results clearly showed that the illusion is entirely produced by the peripheral cue, as the perception of the illusion never reversed when endogenously attending to the location opposite to the cue. This result indicates that ILM is due to an apparent motion or an impletion effect (Downing & Treisman, 1997). In the present experiments the allocation of attention was manipulated in different blocks of trials. When the cue predicted the target to appear at the opposite location, participants might try to avoid the exogenous capture produced by the cue in order to orient attention endogenously to the other location. However, this re-orienting of attention produced no effect in the perception of the illusion in either the detection or the discrimination task. That is, in both tasks, the perception of ILM was similar in the counter-predictive cue block as compared with the non-predictive block, indicating that even though participants knew that the cue predicted the target to appear at the opposite location, the perception of the illusion could not be reversed.

Importantly, although endogenous attention did not produce the illusion, it did modulate it when endogenous attention was kept at the cued location, indicating a role of endogenous attention on perceptual integration or impletion processes. The attentional modulation of ILM clearly depended on task set, i.e., on what participants were attending for. Endogenously attending to the location of the cue enhanced the ILM effect but only when participants were performing a secondary discrimination task. Our results have shown that endogenously attending to detect the appearance of the target does not facilitate the integration between the cue and the target that causes the perception of ILM. In fact, making the cue spatially informative (of either the same or the opposite location) tends to reduce the perception of the illusion, as compared with a non-predictive cue block (Experiment 2). Attending to detect the appearance of a target seems to prepare the system not to integrate information, which would benefit the detection of new events. Attending to discriminate target's features, however, seems to prepare the system to integrate information at the attended location or object, until enough information is accumulated to discriminate the relevant information.

In summary, the results of the present experiments lead us to conclude that endogenous attention is implemented differently depending on the task at hand. Although ILM is not produced by endogenous attention, it can be modulated if the task set of the participant favours the integration between the cue and the line. We can then conclude that endogenous attention is a flexible mechanism which implementation depends on the demands of the task at hand.

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