AWARENESS OF CUE UTILITY IS IMPORTANT IN PRODUCING THE PROPORTION VALID EFFECT, BUT CONSCIOUS AWARENESS IS NOT

by

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Abstract

The present experiments investigated the mechanism responsible for the *proportion valid cueing effect* (i.e., the difference in response times between valid and invalid trials increases in magnitude as the proportion of valid trials increases) in the covert orienting paradigm. This proportion validity effect (PVE) is believed to reflect the involvement of volitional control of visual attention. However, more recently research has suggested that the PVE reflects a form of implicit learning (i.e., wherein associations, developed outside of awareness, between the cue and target location determine how attention is distributed, Seger, 1994). I tested between these two accounts of the PVE by determining whether being aware of a cue's spatial utility influences the PVE using peripheral box cues (Experiment 1), central arrow cues (Experiment 2) and central non-directional shapes (i.e., cues that do not possess inherent directionality, Experiment 3). Critically, I manipulated whether participants were aware of the cue-target relations and determined whether this awareness influenced the PVE. Peripheral box cues produced a PVE that was independent and insensitive to participants' awareness of cue-target relations. On the other hand, central cues (i.e., both arrow cues and non-directional cues) produced PVEs that were sensitive to our manipulation of awareness regarding cue-target relations. However, central arrow cues produced a PVE that was *independent* of awareness, whereas non-directional cues produced a PVE that was *dependent* on awareness of cue-target relations. Taken together, the present studies have demonstrated that the awareness of the association between cues and target locations does contribute, under some circumstances, to the PVE. However, the extent to which the PVE is influenced by awareness of cue-target relations is dependent on the type of cue used to orient attention.

Preface

All research reported was conducted at UBC's Brain & Attention Research Laboratory, and was supervised by Dr. A. Kingstone. I was responsible for all program creation, completing or supervising data collection, performing data analysis and writing any work that resulted from the research. Ethical approval for this research was provided by UBC's Behavioural Research Ethics Board under the approval number of H10-00527 (see Appendix for certificate).

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Acknowledgements

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Chapter 1: Introduction

How people orient attention to important information while ignoring irrelevant information is a central question in attention research. Researchers have traditionally distinguished between two types of attentional orienting (Kuhn & Kingstone, 2009). Overt orienting involves visible eye or head movements, where the fovea focuses on the region of interest. However, covert orienting involves orienting attention without moving the eye (e.g., attending to a stimulus in peripheral vision). In the covert orienting paradigm (Posner, Nissen & Ogden, 1978), a cue (e.g., a peripheral onset or a central directional arrow) is used to direct visual attention to a particular location before a target is presented. When attention is directed to the upcoming target location (i.e., a valid trial) target responses are faster than when attention is directed to a non-target location (i.e., an invalid trial). One of the most robust findings in the covert orienting literature is that the cueing effect (i.e., the difference in RT between valid and invalid trials) increases in magnitude as the proportion of valid trials increases (e.g., Kingstone, 1992). This *proportion validity effect* (PVE) is believed to reflect the involvement of volitional control of visual attention. Specifically, individuals are thought to volitionally allocate attention to the cued location as a function of the cue's spatial utility (i.e., the degree to which the cue location predicts the target location). Recently, Risko and Stolz (2010) reported that the PVE does not depend on people noticing that the proportion of valid trials has increased, and therefore the PVE reflects a form of implicit learning (i.e., wherein associations developed outside of awareness between the cue and target location determine how attention is distributed, Seger, 1994). In the present investigation, I test these two accounts by determining whether being aware of a cue's spatial utility influences the PVE using peripheral box cues, central arrow cues and central non-directional shapes (i.e., cues that do not possess inherent directionality).

1.1 Exogenous v.s. Endogenous Orienting

Attentional orienting can be classified as either exogenous or endogenous (e.g., Yantis, 1998). Endogenous shifts of attention are slow and under volitional control, reflecting top-down control and a goal-directed process (James, 1890). Exogenous shifts of attention are rapid, occur automatically, thereby reflecting bottom-up control and a stimulus-driven process (Folk, Remington & Johnston, 1992; Jonides, 1981; Müller & Rabbitt, 1989; Posner, & Cohen, 1984; Posner, Cohen, & Rafal, 1982; Theeuwes, 1991; Yantis & Jonides, 1990). Each form of orienting is associated with a particular variant of the covert orienting paradigm, though this notion has been questioned more recently (Ristic, Friesen & Kingstone, 2002). Endogenous shifts of attention are thought to occur in response to a centrally presented symbolic cue (i.e., an arrow). For example, Posner, Nissen and Ogden (1978) demonstrated that targets are detected more quickly when a centrally located arrow points towards rather than away from the location where the upcoming target will appear. On the other hand, exogenous shifts of attention are thought to occur in response to peripherally presented cues that are displayed in the target location. For example, participants can read a target word faster when the location of the upcoming target word is marked by a briefly presented cue (Risko, Stolz & Besner, 2010). Another essential difference between endogenous-voluntary and exogenous-automatic cognitive processes concerns the role of consciousness. While an endogenous shift of attention would happen only in the presence of awareness, an exogenous shift can occur outside of awareness (Posner & Snyder, 1975).

1.2 The Volitional Control Account

In the covert orienting literature, the most widely accepted view is that the PVE results from endogenous shifts of attention (Bartolomeo & Chokron, 2002; Castel, Chasteen, Scialfa & Pratt, 2003; Danckert, Maruff, Crowe, & Currie, 1998: Enns & Brodeur, 1989; Jonides, 1981; Posner, 1980). Specifically, as the utility of a cue increases (i.e., as the proportion of valid trials increases), participants are thought to volitionally allocate visual attention to the cued location (either by allocating more attention to the cued location or more frequently attending the cued location) as a function of the cue's spatial utility (i.e., the degree to which the cue location predicts the target location, Risko & Stolz, 2010). As a result, the difference in response time between valid and invalid trials increases, thereby producing a larger cueing effect. Although the volitional control account is intuitively appealing, it is certainly not the only plausible explanation of the PVE. While this account of the PVE has been broadly accepted, an intriguing alternative explanation which does not attribute the PVE to a mechanism of volitional control has recently been presented - the implicit learning account (Risko & Stolz, 2010).

1.3 The Implicit Learning Account

The implicit learning account of the PVE suggests that the spatial utility of a cue is learned tacitly and attention is distributed without requiring participant awareness of cue-target relations (Risko & Stolz, 2010). While the implicit learning account is a relatively novel concept in the field of visual attention, it has been widely studied in other areas of cognition (Cleeremans, Destrebecqz & Boyer, 1998: Nissen & Bullemer, 1987; Reber, 1967; Seger, 1994). Two of the most popular paradigms are the sequence learning and artificial grammar learning tasks. In sequence learning, participants learn a sequence of numbers faster if there is an inherent structure built into a sequence, and learning occurs regardless of whether a participant is aware of the structure itself (Nissen & Bullemer, 1987). In artificial grammar learning, participants are able to learn the rules of the grammar without being able to explicitly describe the learned rules (Reber, 1967).

Researchers have also demonstrated that visual attention can be guided by information that participants acquire via implicit processes (Chua & Chun, 2003; Chun, 2000; 2003; Chun & Jiang, 1998; 1999; Endo & Takeda, 2005; Jiang & Leung, 2005; Olson & Chun, 2001; Peterson & Kramer, 2001; Tseng & Li, 2004). In the contextual cueing paradigm, participants search through a variety of random and repeated displays (i.e., displays where a contextual cue is embedded within the search display). The contextual cueing effect is the observation that participants benefit (i.e., a reduction in time to find the target) from the display structure of repeated displays. Critically, participants will benefit from the repeated displays regardless of whether or not participants are aware that the displays have been repeated. Chung and Jiang (1998) suggest that participants automatically encode the spatial relations between targets and cues to facilitate the deployment of attention during the task without awareness of having done so.

Similarly, research using the covert orienting paradigm has demonstrated that orienting can occur without awareness of the cue-target relations (Kentridge, Heywood & Weiskrantz, 1999; Lambert, Naikar, McLahan & Aitken, 1999; Lambert & Sumich, 1996; Risko & Stolz, 2010). One line of research has demonstrated that participants will orient to cues despite being unaware that a cue was ever presented. For example, Kentridge and colleagues (1999) showed that a hemianopic patient with blindsight (i.e., a condition where visual awareness within the scotoma is absent or limited), G.Y., could direct attention to a cued location without being aware of the cue that was presented. Specifically, G.Y. was presented cues in a blind field and then asked to detect a target that was presented in either a valid (68.35% of the time) or invalid location. Throughout the experiment, G.Y. was asked whether he had any experience of the cues, and he reported consistently that he did not. Despite having no awareness that visual cues were used throughout the experiment, G.Y. used the cues to orient attention faster and more accurately when the cues indicated the location of the target than when cues indicated the incorrect location of the target. The researchers concluded that the selection of information by attentional mechanisms and the conscious experience of the information selected must be independent processes.

Furthermore, Lambert and Sumich (1996) and Lambert and colleagues (1999), have demonstrated similar results using the covert orienting paradigm with normal adult participants. In a series of experiments, participants were presented one of two letters (i.e., X or T) either to the left or right of fixation. Participants indicated by button press once the target, which appeared in one of two cued locations, had been detected. Critically, each letter predicted a particular location of the upcoming target the majority of the time. Participants showed cueing benefits despite being unable to describe the cue-target relations or even acknowledge seeing the subthreshold letter cues in post-experiment questionnaires. These studies show that conscious awareness is not necessary for orienting attention.

1.4 Distinguishing Between Volitional Control and Implicit Learning

The volitional control and implicit learning accounts of the PVE are distinguished by whether or not participants need to be aware of cue-target relations. The volitional control account requires that participants have awareness of the cue-target relations and the implicit learning account does not. According to the volitional control account the participant becomes aware of a cue's ability to predict a spatial location, and the awareness of the cue’s utility in predicting spatial locations causes the adoption of a strategy that leads to an endogenous shift in attention in response to a cue. Thus, the distribution of attention is altered because of a volitional and conscious act. On the other hand, the implicit learning account suggests that the cue - target relation is learned implicitly and attention is allocated accordingly.

Recent research suggests that the role of implicit processes in generating the PVE may depend upon the specific cue (i.e., whether the cue is exogenous or endogenous) used to orient attention (Bartolomeo, Decaix & Siéroff, 2007; Risko & Stolz, 2010). In a recent series of experiments, Bartolomeo and colleagues (2007) had participants perform cue–target detection tasks with different proportions of valid and invalid trials, without being informed of these proportions. The authors found that the PVE occurred in a covert orienting paradigm independent of whether participants could verbalize the cue-target relationship or not. This finding is consistent with an implicit learning account of the PVE. However, this effect was only observed for peripheral cues and not central arrow cues. With central symbolic cues, only participants who could verbalize the cue-target relations showed the PVE. The authors suggested that implicit learning might be the best account for the PVE for peripheral cues but volitional orienting is largely responsible for the PVE for central cues.

However, Risko and Stolz (2010) demonstrated that the emergence of the PVE in both peripheral box cues and central arrow cues did not depend on an individuals' awareness of the proportion of valid trials. Specifically, Risko and Stolz (2010) had participants estimate how often a cue indicated the correct location of a target (i.e., the proportion of valid trials) during a typical two target location cueing task where the cue was either a central arrow cue or a peripheral box cue and the proportion of valid trials was either 50% or 75%. They demonstrated that participants' estimates of cue-target relations were unrelated to the magnitude of the individual cueing effects for both central arrow and peripheral box cues. Risko and Stolz (2010) suggest that the PVE reflects a form of implicit learning wherein associations between the cue and target, developed outside of the participant's awareness, determine how attention is distributed. Thus, the results from Risko and Stolz's (2010) studies suggest that orienting can occur without explicit awareness of cue-target relations and can instead occur implicitly for both peripheral cues and central cues. Taken together, the studies conducted by Bartolomeo et al (2007) and those conducted by Risko and Stolz (2010) both suggest that the PVE can be driven implicitly by peripheral cues, but there is disagreement on whether implicit process can also mediate the PVE for central cues.

In order to test whether the PVE reflects implicit learning, volitional control or a combination of both processes, one needs to test several properties of the PVE. First, one should determine whether the PVE is sensitive to explicit awareness of cue-target relations. Being aware of cue-target relations should not affect implicit learning as implicit processes should be able to work independent of, or in parallel with, top-down attentional processes (Cleeremans et al., 1998). However, being aware of cue-target relations should alter top-down attentional processes thereby altering the distribution of attention relative to when one is unaware of cue-target relations. To date, researchers have only assessed the relationship between subjective reports of cue validity and the PVE (Bartolomeo et al., 2007; Lambert et al. 1999; Risko & Stolz, 2010). Unfortunately, it is nearly impossible to determine whether the standard measure of 'awareness' (i.e., subjective report) is sufficient. There is no guarantee that participants will report all of their conscious knowledge and this becomes a particularity pertinent issue given that the conclusions in previous research hinged on a *failure* of participants to detect changes in cue-target relations. Further, it is unclear whether subjective reports are sensitive to all aspects of awareness that could influence the nature of the PVE (i.e., estimating the proportion of valid trials is different than simply being aware that a relationship between a cue and a given spatial location exists). For example, one can imagine how a different measure, such as response time, may index one aspect of the effect of awareness on the PVE (i.e., simply being aware that a cue predicts a given location) while a subjective report measures an entirely different and potentially unrelated aspect of awareness (i.e., being aware of the *frequency* with which a cue indicates the location of a target). This is not a problem specific to these studies but applies to all studies attempting to ascertain the relation between awareness and behaviour. In order to ensure a certain degree of awareness (without relying on subjective reports of awareness of cue-target relations) and determine causation, explicit awareness needs to be manipulated as a variable. Lastly, one needs to determine whether, and if so how, the PVE occurs for stimuli that do not possess pre-associations of validity. Implicit learning suggests any kind of cue-target relationship can be learned as long as the cue reliably predicts the spatial location of a target (Chun & Jiang, 1998). However, a volitional control account suggests that a certain degree of awareness of the cue-target relations would be required in order to effectively use a cue to orient attention. In fact, Risko and Stolz (2010) were criticized for their use of arrow cues since arrow cues are normally assumed to be 100% valid in real life (Chica & Bartolomeo, 2010). As mentioned previously, researchers have questioned whether endogenous shifts of attention occur in response to centrally presented arrow cues. Indeed, research has demonstrated that central arrow cues can produce automatic shifts in attention (Kuhn & Kingstone, 2009; Tipples, 2002; 2008), and this was apparent when participants overestimated the predictive value of the arrow cues even when the cues were not predictive (Risko & Stolz, 2010).

1.5 The Present Investigation

The present set of experiments sought to determine whether, and if so how, awareness of the associations between cues and targets would change the nature of the PVE by extending Risko and Stolz's (2010) work in several ways. First, I manipulated participants' awareness of cue-target relations (i.e., how useful the cue is a predicting the location of an upcoming target) rather than relying on participants ability to report cue-target relations. Risko and Stolz (2010) conclusions rest on a *failure* for participants to accurately report a change in the proportion of valid trials at the end of the study. Indeed, participants were unable to accurately estimate the proportion of valid trials (e.g., the average estimate of the proportion of valid trials in the 75% valid trials condition was 56%) and these estimates were not correlated to the magnitude of cueing effects. Here, at the outset of the study, I manipulated awareness by either encouraging participants to learn the cue-target relations or not in addition to asking participants to estimate the proportion of valid trials at the end of a block. Thus, one could be confident that awareness of the cue-target relations was varied as a factor of the manipulation, in addition to determining whether participants reported awareness of cue-target relations (i.e., as indexed by their estimates of the proportion of valid trials) is related to the magnitude of their cueing effects. If only participants who are aware the cue-target relations show a PVE this would be consistent with a volitional orienting account (i.e., a PVE that is produced by endogenous shifts of attention). However, if both participants who are aware and unaware of cue-target associations show a PVE this would be consistent with an implicit learning account (i.e., a PVE that is produced by exogenous shifts of attention). Additionally, if participants' estimates of the proportion of valid trials are related to the magnitude of their cueing effects, this would be consistent with a volitional orienting account; whereas no relation between participant estimates and their cueing effects would be consistent with an implicit learning account. However, these two accounts need not be mutually exclusive. For example, all of the participants could show a PVE regardless of whether or not they were aware of cue-target relations, however, the PVE could be magnified for those participants who are aware of cue - target relations. This finding would be consistent with both implicit and volitional learning accounts.

Second, in addition to assessing the PVE for peripheral box and central arrow cues, I also assessed whether awareness of cue-target relations influences the PVE with a non-directional cue. Chica and Bartolomeo (2010) suggest that a major criticism of the Risko and Stolz (2010) experiments was that the stimuli they used share a common characteristic that is critical for producing a PVE, and operates independent from awareness of cue-target relations. That is, a common characteristic shared by both the peripheral box cues and central arrow cues is inherent directionality (i.e., the ability to direct attention to a given location when the cue is not spatially predictive). Recent research suggests that both peripheral box cues and central arrow cues can produce automatic shifts of attention (Fischer, Castle, Dodd & Pratt, 2003; Friesen & Kingstone, 1998; Friesen, Ristic & Kingstone, 2004; Hommel, Pratt, Colzato & Godijn, 2001; Pratt & Hommel, 2003). This was demonstrated by Risko and Stolz (2010) given that cueing effects were observed for both peripheral box and central arrow cues when the cues were not predictive of target locations. As such, an important question that remains to be answered is a) whether orienting can occur for centrally presented non-directional cues that do not trigger reflexive shifts of attention and, if so, b) whether orienting will occur without explicit awareness of the cue-target relations. Critically, if awareness of cue-target relations is required to produce the PVE with non-directional cues I would expect that the PVE would emerge (granted participants are given enough exposure to the cue and target to learn/become aware of the cue-target relations that exist) when participants are aware of cue-target relations and be absent when participants are unaware of cue-target relations. The implicit learning account suggests that, provided participants have enough time to learn cue-target relations implicitly, the PVE should emerge regardless of whether participants are aware or unaware of the cue-target relations.

Chapter 2: Experiment 1: The Effect of Awareness of Cue-Target Relations on Orienting Elicited by Peripheral Box Cues

2.1 Introduction

Following Risko and Stolz (2010), in Experiment 1 participants were required to perform a typical cueing task in which peripheral box cues were used to direct attention. Critically, in addition to manipulating the proportion of valid trials and cue validity, to manipulate awareness I either instructed participants to determine the relations between cues and spatial locations (i.e., aware) or not (i.e., unaware). By manipulating awareness of the relations between cues and spatial locations one can be more certain of whether or not a given participant a) became aware of the association between cues and spatial locations and b) determined the frequency with which the cue predicted the correct location of the target (i.e., the proportion of trials on which the cue indicated the correct location of the target). Further, this methodological change allows us to use response times, in addition to subjective reports, to index the influence of awareness of cue-target relations on the PVE. According to the volitional control account, the PVE should be present when participants are aware of cue-target relations and absent when they are not. According to implicit learning account, the PVE should emerge regardless of whether participants are aware of unaware of cue-target relations.

In Risko and Stolz (2010), participants were assigned to either a 75% valid or 50% valid cue condition. In the present study, in addition to a 75% and 50% valid cue condition, I introduced a 25% valid condition. It remains unclear whether a directional cue will a) continue to orient attention accordingly or not and b) be perceived as a useful cue when the cue is *counter predictive* (e.g., when only 25% of the cues indicate the correct location of the upcoming target). When cues are directional, and I would expect them to perceive the 25% valid cues to be less useful than in the 50% (unpredictive) and 75% (predictive) valid conditions[1].

I also increased the number of trials in order to provide participants more time to learn the cue-target relations. When cues are informative (e.g., indicate a valid location more than 50% of the time) participants should learn the cue-target associations, whether by volitional or implicit means (Chun and Jiang, 1998). As the associations between the predictive value of the cues and the targets are developed over time, attention should be deployed to take advantage of cues ability to predict upcoming targets resulting in the PVE. This assumption leads to questions about whether participants in Risko and Stolz's (2010) study had enough time (192 trials in 10 minutes) to volitionally or implicitly learn cue-target associations. For example, if the cues that were used had not already possessed inherent directionality, there may not be enough trials to provide participants with enough experience of cue-target relations in order to learn, whether by implicit or explicit means, the directionality of a spatially reliable cue. Indeed Risko and Stolz (2010) were criticized for potentially creating experimental conditions that stressed an automatic process (Chica & Bartolomeo, 2010).

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[1] However, when cues do not possess inherent directionality, it is unclear whether participants will perceive counterpredictive cues (which are reliable predictors of upcoming targets) to be reliable or unreliable. Non-directional cues that are counterperdictive could be perceived as if they were either 25% valid or 75% valid depending on the cue-target relations developed, and the flexibility of these representations).

Fourth, I made SOA equivalent across all of the present experiments. In Risko and Stolz (2010), the SOA for peripheral box cues was only 150 ms (i.e., 50 ms presentation of the box cue followed by a blank screen presented for 100 ms), whereas the SOA for central arrow cues was 350 ms (i.e., 300 ms presentation of the arrow cue followed by a blank screen for 50 ms). Given that endogenous orienting takes longer than exogenous orienting (Jonides, 1981), it is possible that 150 ms did not provide enough time for endogenous orienting to occur. Thus, it is possible that by using such a short SOA, Risko and Stolz (2010) inadvertently allowed endogenous processes to influence the PVE for one type of cue (i.e., central arrow cues) and actually prevented endogenous processes from influencing the PVE for another cue (i.e., peripheral box cues). Indeed, the authors found no influence of awareness in the peripheral box cue condition which could indicate that either a) endogenous processes do not influence the PVE or b) that endogenous processes were unable to influence the PVE when only a 150 ms SOA is provided. In order to clarify this issue (and also determine whether endogenous processes can, under some circumstances, influence the PVE produced with peripheral cues), I increased SOA to 350 ms (i.e., 50 ms presentation of the box cue followed by a blank screen presented for 300 ms) for all of the present experiments.

In sum, Experiment 1 consisted of three blocks, and the proportion of valid trials in each block was either 25%, 50% or 75%. RTs were measured as an index of performance on the task. Critically, to manipulate awareness I either instructed participants to determine the relations between cues and target (i.e., aware) or not (i.e., unaware). Participants also estimated the proportion of valid trials after each block. A purely implicit learning account predicts that the PVE should be independent of the subjective reports of proportion or the awareness conditions. A purely explicit strategy account predicts that the PVE should only occur if participants are aware of cue-target relations as indexed by subjective reports or changes in the PVE as a function of awareness.

2.2 Method

2.2.1 Participants

Eighty participants were either given credit or paid $10 (CAD) for their time.

2.2.2 Design

The study used a 2 (cue awareness: aware and unaware) by 2 (cue validity: valid and invalid) by 3 (proportion valid: 25%, 50%, and 75%) mixed design where cue awareness was manipulated between participants and cue validity and proportion valid were manipulated within participants.

2.2.3 Apparatus

E-Prime 2.0 controlled the timing and presentation of stimuli and logged response accuracy and RTs. Stimuli were presented on standard 15” CRT monitors with 1024 by 728 pixel resolution. Participants viewed the monitor at a distance of approximately 60 cm.

2.2.4 Stimuli

The stimulus display consisted of a fixation cross (+) which measured 0.6 cm vertically and horizontally, located in the centre of the display. Cues were boxes (1.0 cm vertical, 1.4 cm horizontal) displayed 4.2 cm above or below fixation. The targets were either '%' or '#' measuring 0.9 cm vertically and 0.6 cm horizontally. Targets appeared 3.0 cm above or below fixation equally often. All stimuli were white and presented on a black background.

2.2.5 Procedure

All participants were asked to indicate by button press (either 'c' or 'm') whether a target was '%' or '#'. It was stressed that participants should try to keep their eyes at fixation at all times, and that both speed and accuracy were equally important in responding. The only procedural difference between participants was in the Awareness conditions. Participants in the aware condition were encouraged to determine the different relationships between box cues and targets in each block (i.e., in some blocks the cue would indicate the correct location of upcoming targets more than in others). Participants in the unaware condition did not receive any further instruction prior to beginning the task. Half of the participants were assigned to the aware condition and the other half were assigned to the unaware condition.

Each trial began with the cross, and after 500ms, a cue would appear either above or below the cross for 50ms. After the cue offset, the screen remained blank for 300ms. The target was then presented until the participant responded. Once the participant responded, another blank screen was presented for 500ms before the next trial began. Participants performed 16 practice trials and 3 blocks of 416 experimental trials for 1248 trials total. The proportion of valid cues in a given block was either 25%, 50%, or 75%, and the order of the blocks was counterbalanced across all participants.

After each block, participants were asked fill out a questionnaire which asked them to estimate whether there were more trials where the cue correctly or incorrectly predicted the location of the target, how confident they were of their answer (i.e., 'I'm sure' or 'I'm guessing'), and the proportion of trials on which the cue indicated the correct location of the target (i.e., proportion valid). The experiment took approximately 60 minutes in total. An example of the trial sequence for valid and invalid cues is provided in Figure 2.1.

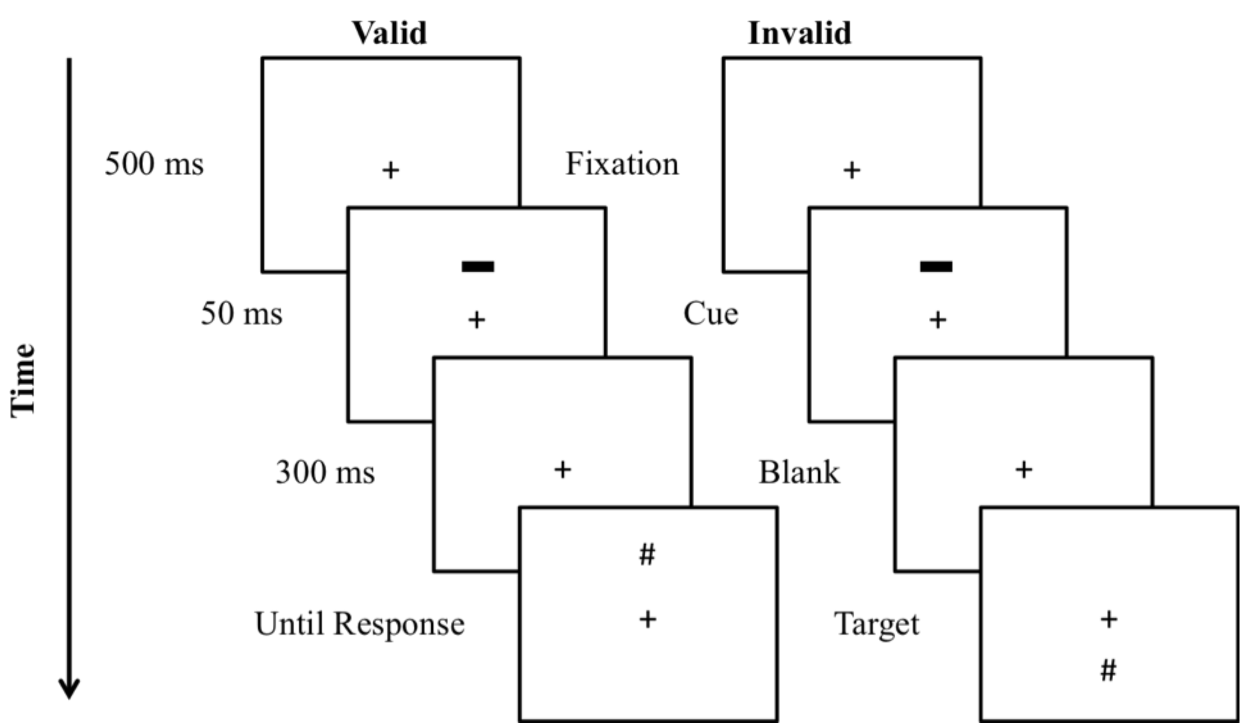

Figure 2.1. Example of the trial sequence of a valid and invalid trial in Experiment 1.

2.3 Results

2.3.1 Data Trimming Procedure

Prior to the RT and error analysis, the data were first subjected to a recursive trimming procedure that removed outliers on the basis of a cut-off criterion set independently for each participant in each condition by reference to the sample size in that condition (Van Selst & Jolicœur, 1994). The trimming procedure resulted in 4.3% of the RT data being discarded. Mean RTs and errors were analyzed using a three-way repeated measures analysis of variance (ANOVA) with cue awareness (2 levels: aware and unaware) as a between participant factor and cue validity (2 levels: valid and invalid) and proportion valid (3 levels: 25%, 50%, 75%) as within-participant factors. For all analyses in all experiments, if Mauchly's test of sphericity was significant ($p < .25$), relevant degrees of freedom were adjusted using the Greenhouse-Geisser (if $\varepsilon \leq .70$) or Huynh-Feldt (if $\varepsilon > .70$). Mean RT and cueing effects are presented in Table 2.1 and cueing effects are presented in Figure 2.2.

2.3.2 Response Times

There was a main effect of cue validity ($F_{(1,78)} = 63.048$, $MSE = 701.663$, $p < 0.001$), such that responses were quicker to validly cued targets (524 ms) than invalidly cued targets (543 ms). There was also a significant interaction between proportion valid and cue validity ($F_{(2,156)} = 27.791$, $MSE = 391.472$, $p < 0.001$), such that the effect of cue validity increased as proportion of valid trials increased: this is the PVE. No other main effects or interactions were significant (all F's < 2.2).

To further assess the interaction between cue validity and proportion valid the magnitude of the cueing effect was determined by subtracting response times in the valid condition from the response times in the invalid condition. Three two-tailed repeated measures t-tests (which after applying a Bonferroni correction for multiple comparisons had a familywise error rate of .05) were used to compare the magnitude of the cueing effects in each of the proportion conditions. Cueing effects were larger in the 75% valid condition (37 ms) compared to both the 25% valid condition (5 ms; $t_{(79)} = 6.871$, $p < 0.001$), and the 50% valid condition (6 ms; $t_{(79)} = 4.618$, $p < 0.001$). Cueing effects were also larger in the 50% valid condition compared to the 25% valid condition ($t_{(79)} = 2.754$, $p < 0.008$).

Table 2.1. Mean RTs (ms) in Experiment 1 as a function of Cue Awareness, Proportion of Valid Trials, and Cue Validity.

	Proportion of Valid Trials		
Cue Awareness	**25%**	**50%**	**75%**
Unaware			
Valid	521	546	509
Invalid	531	562	543
Difference	**10**	**16**	**34**
Aware			
Valid	521	526	522
Invalid	520	541	563
Difference	**-1**	**15**	**41**

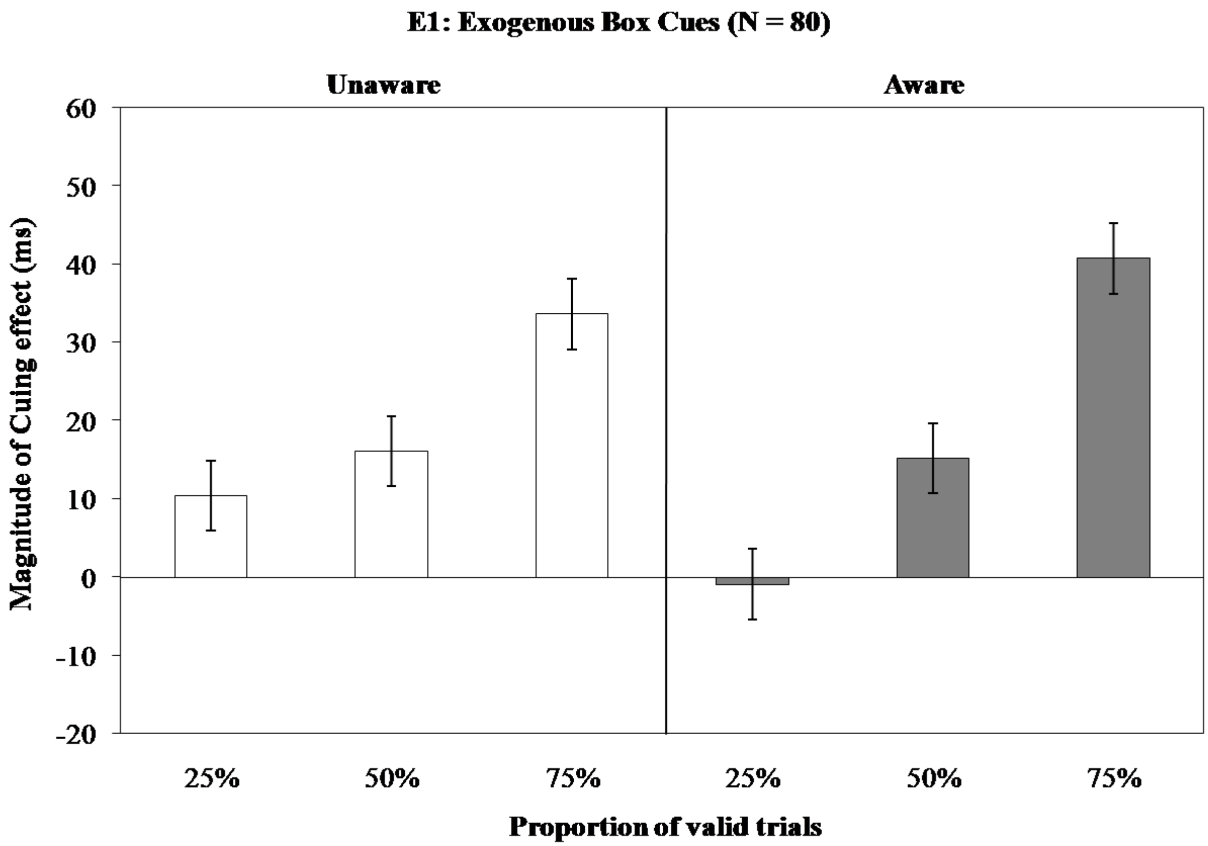

Figure 2.2. Cueing effects (RTs, in milliseconds) as a function of Cue Awareness (aware vs. unaware) and Proportion Valid (25% vs. 50% vs. 75%) in Experiment 1. Error bars represent the 95% confidence interval as defined by Masson and Loftus (2003).

2.3.3 Error

No main effects or interactions were significant (all F's < 2.8).

2.3.4 Participant Estimates

Participant estimates of the proportion valid in each block were analyzed using a two-way ANOVA with cue awareness (2 levels: aware and unaware) as a between participant factor and proportion valid (3 levels: 25%, 50%, 75%) as a within participant factor. Mean participant estimates are shown in Figure 2.3.

There was a main effect of proportion valid, ($F_{(1.69,133.37)}$ = 39.303, *MSE* =379.474, $p < 0.001$), such that participant estimates of the proportion of valid trials increased as the proportion of valid trials increased. No other main effects of interactions were significant (all F's < 2.5).

To further assess the main effect of proportion valid, three two-tailed repeated measures t-tests (which after applying a Bonferroni correction for multiple comparisons had a familywise error rate of .05) were used to compare the magnitude of the cueing effect to participant estimates in each proportion condition. T-tests revealed that estimates were significantly higher in the 75% valid condition (X = 65%) compared to both the 25% valid condition (X = 40%; $t_{(79)} = 7.244$, $p < 0.001$) and the 50% valid condition (X = 54%; $t_{(79)} = 4.336$, $p < 0.001$). Estimates were also higher in the 50% valid condition than in the 25% valid condition ($t_{(79)} = 5.767$, $p < 0.001$).

Additionally, one-sample t-tests were conducted to assess whether participant estimates of the proportion valid differed from the actual proportion valid. Estimates taken after the 25% valid block were significantly higher than 25% ($t_{(79)} = 6.251$, $p < 0.001$). Estimates for the 50% valid block were significantly higher from 50% ($t_{(79)} = 2.520$, $p < 0.05$). Estimates for the 75% valid block were significantly lower than 75% ($t_{(79)} = 4.909$, $p < 0.001$).

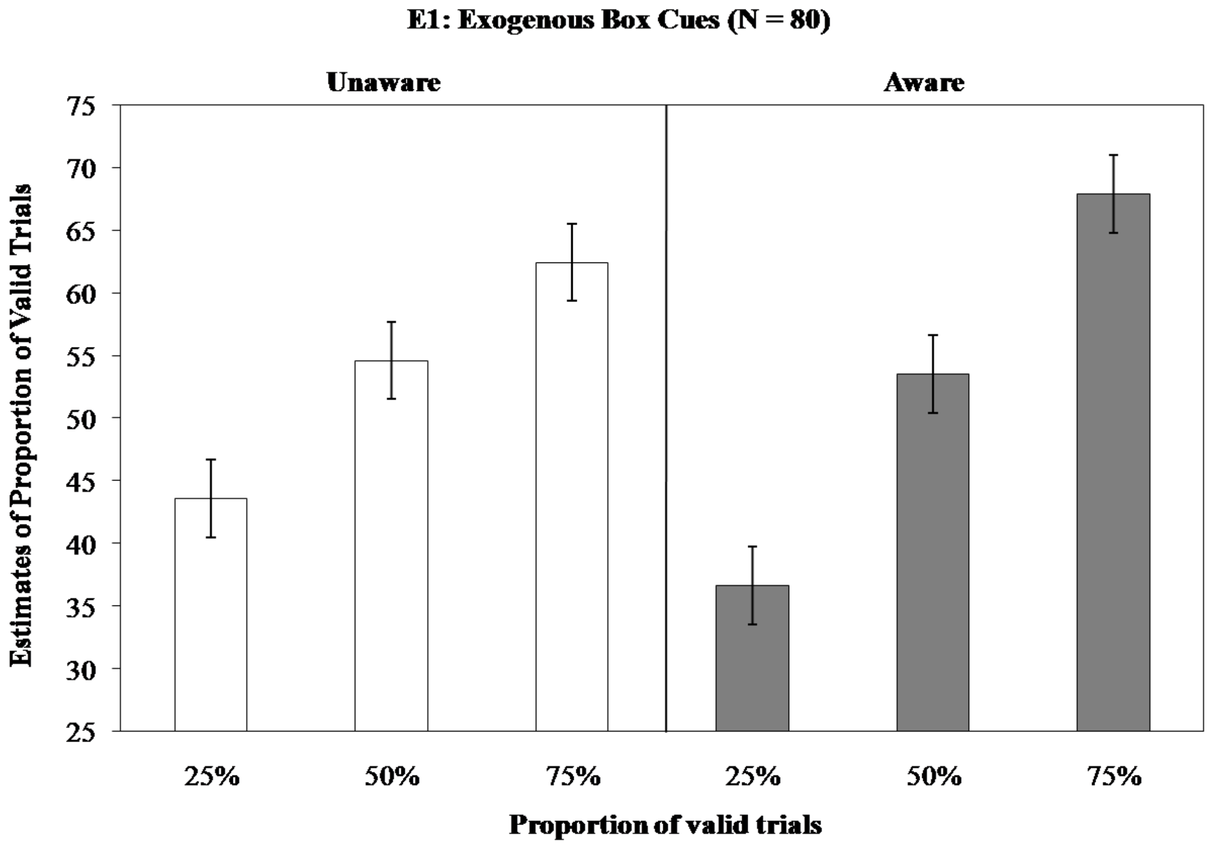

Figure 2.3. Participant estimates of the proportion of valid trials as a function of Cue Awareness (aware vs. unaware) and Proportion Valid (25% vs. 50% vs. 75%) in Experiment 1. Error bars represent a 95% confidence interval as defined by Masson and Loftus (2003).

2.3.5 Relation Between Participant Estimates and Performance

A Pearson correlation analysis was conducted in order to determine whether participant estimates of the proportion of valid trials in each block were related to the magnitude of their cueing effects in each block. The correlation between the participant estimates and the magnitude of their cueing effects was not significant in either RT or errors in the 25%, 50% or 75% valid conditions. Further, the same analysis was conducted on each cue awareness condition separately. The correlation between the participant estimates and the magnitude of their cueing effects was not significant in either RT or errors in the 25%, 50% or 75% valid conditions regardless of cue awareness condition.

2.4 Discussion

In Experiment 1 the magnitude of the cueing effect increased as the proportion of valid trials increased. Specifically, cueing effects were larger when 75% of the trials were valid than when only 50% or 25% of the trials were valid. Similarly, cueing effects were larger when 50% of the trials were valid than when only 25% of the trials were valid. In addition, when participants were asked to estimate the percentage of valid trials participants *underestimated* the actual proportion valid in the 75% valid condition, *overestimated* the actual proportion valid in the 50% valid condition, and *overestimated* the actual proportion valid in the 25% valid condition. Critically, in Experiment 1, participants' awareness of cue-target relations had *no influence* on the PVE, nor participant estimates of the proportion of valid trials. Further, I replicated Risko and Stolz (2010) critical finding that participants' estimates of the proportion of valid cues were not predictive of the magnitude of their cueing effect in response times. Taken together, these data suggest that the increase in the magnitude of the cueing effect, as the proportion of valid trials increases, occurs regardless of participant awareness of the predictive nature of the cue, which was manipulated between participants and indexed by estimates of the proportion of valid trials.

Chapter 3: Experiment 2: The Effect of Awareness of Cue-Target Relations on Orienting Elicited by Central Arrow Cues.

3.1 Introduction

Following Risko and Stolz (2010), in Experiment 2, I used a central cue (e.g., arrow) in place of the peripheral box cue used in Experiment 1. Central cues also demonstrate a PVE (Bartolomeo et al., 2007; Risko & Stolz, 2010). Thus, similar to Experiment 1, I can assess whether awareness of cue-target relations influences the emergence of the PVE. Recall that Bartolomeo and colleagues (2007) found that participants who did not demonstrate awareness of cue-target relations did not show a PVE, which lead them to conclude that awareness of cue-target relations is required in order for the PVE to emerge. Risko and Stolz (2010) were led to the opposite conclusion (i.e., that awareness of cue-target relations is *not* required in order for the PVE to emerge), by results that indicated that the magnitude of individual cueing effects were unrelated to participant estimates of the proportion of valid trials. However, Risko and Stolz's (2010) conclusion was based on participants *failure* to accurately report a change in the proportion of valid trials. To provide a stronger test of whether awareness of cue-target relations influences the emergence of the PVE, I manipulated awareness of cue-target relations by either instructing participants to determine the relations between cues and spatial locations (i.e., aware) or not (i.e., unaware) rather than relying on participants ability to report cue-target relations (as was the case in Bartolomeo et al., 2007; Risko & Stolz, 2010). According to the volitional control account, the PVE should be present when participants are aware of cue-target relations and absent when they are not. According to implicit learning account, the PVE should emerge regardless of whether participants are aware or unaware of cue-target relations.

3.2 Method

3.2.1 Participants

Eighty new participants from the University of British Columbia were either given credit or paid $10 (CAD) for their time.

3.2.2 Design, Apparatus, Stimuli, and Procedure

The design, apparatus, stimuli and procedure were the same as that used in Experiment 1 except that the cues were now centrally located arrows (0.8 cm vertical, 1.1 cm horizontal) which pointed up or down and the arrow cues appeared for 300 ms, and the blank screen was presented for 50 ms before the target appeared thereby keeping stimulus onset asynchronies (SOAs) identical in Experiments 1 and 2 (i.e., 350 ms).

3.3 Results

3.3.1 Data Trimming Procedure

Data analysis followed the same procedure as that used in the previous experiment and resulted in 5.07% of the RT data being discarded. Mean RTs and Errors were analyzed using a three-way repeated measures analysis of variance (ANOVA) with cue awareness (2 levels: aware and unaware) as a between participant factor and cue validity (2 levels: valid and invalid) and proportion (3 levels: 25%, 50%, 75%) as within-participant factors. Mean RT and cueing effects are presented in Table 3.1. Cueing effects are presented in Figure 3.1.

3.3.2 Response Times

There was a main effect of cue awareness, ($F_{(1, 78)}$ = 17.563, *MSE* =40431.294, $p<$ 0.001), such that responses were faster when participants were unaware (503 ms) than when they were aware (580 ms) of cue-target relations. There was a main effect of cue validity ($F_{(1,78)}$ = 21.193, *MSE* =2862.549, $p<$ 0.001), such that responses were quicker to validly cued targets (530 ms) than invalidly cued targets (552 ms). Additionally, there was a significant interaction between cue validity and proportion valid ($F_{(1.51,117.48)}$ = 11.760, *MSE* =2205.253, $p<$ 0.001), such that the effect of cue validity increased as the proportion of valid trials increased: this is the PVE. There was also a significant interaction between cue awareness and cue validity, ($F_{(1,78)}$ = 4.992, *MSE* =2862.549, $p<$ 0.03), such that the effect of cue validity was larger when participants were aware than when there were unaware of cue-target relations. Finally, there was a significant three way interaction between cue awareness, cue validity and proportion valid ($F_{(1.51,117.48)}$ = 3.422, *MSE* =2205.253, $p<$ 0.05). No other main effects or interactions were significant (all F's < 1.9).

To further assess the 3-way interaction between cue awareness, cue validity and proportion valid, the magnitude of the cueing effect was determined by subtracting response times in the valid condition from the response times in the invalid condition. Next, two separate one-way ANOVA's with proportion valid (3 levels: 25%, 50%, 75%) as a within participant factor were conducted for each cue awareness condition to assess how the proportion valid by cue validity interaction differed in each cue awareness condition. There was a main effect of proportion in both the aware, ($F_{(1.43,55.754)}$ = 8.022, *MSE* =8071.133, $p<$ 0.004), and unaware conditions, ($F_{(2,78)}$ = 4.743, *MSE* =873.390, $p<$ 0.02), such that the magnitude of the cueing effects increased as the proportion of valid trials increased.

Finally, for each cue awareness condition separately, three two-tailed repeated measures t-tests (which after applying a Bonferroni correction for multiple comparisons had a familywise error rate of .05) were used to compare the magnitude of the cueing effects in each of the proportion conditions. In the unaware condition, cueing effects were larger in the 75% valid condition (22 ms) compared to the 25% valid condition (2 ms; $t_{(39)}$= 2.864, p < 0.008). No other comparisons in the unaware condition were significant. In the aware condition, cueing effects were larger in the 75% valid condition (70 ms) compared to the 25% valid condition (2 ms; $t_{(39)}$= 3.162, p < 0.004), and the 50% valid condition (28 ms; $t_{(39)}$= 2.445, p < 0.02). Also, cueing effects were larger in the 50% valid condition compared to the 25% valid condition ($t_{(39)}$= 2.340, p < 0.03). Thus, the increase in the magnitude of the cueing effect as the proportion of valid trials occurs regardless of participants' awareness of the predictive nature of the cue, however, the PVE is magnified when participants are aware of the cue - target relations. This finding lends support to the idea that a volitional component can influence the nature of the PVE, but is not required to generate the PVE.

Table 3.1. Mean RTs (ms) in Experiment 2 as a function of Cue Awareness, Proportion of Valid Trials, and Cue Validity.

	Proportion of Valid Trials		
Cue Awareness	**25%**	**50%**	**75%**
Unaware			
Valid	498	499	494
Invalid	500	509	516
Difference	**2**	**10**	**22**
Aware			
Valid	564	558	566
Invalid	566	587	636
Difference	**2**	**28**	**70**

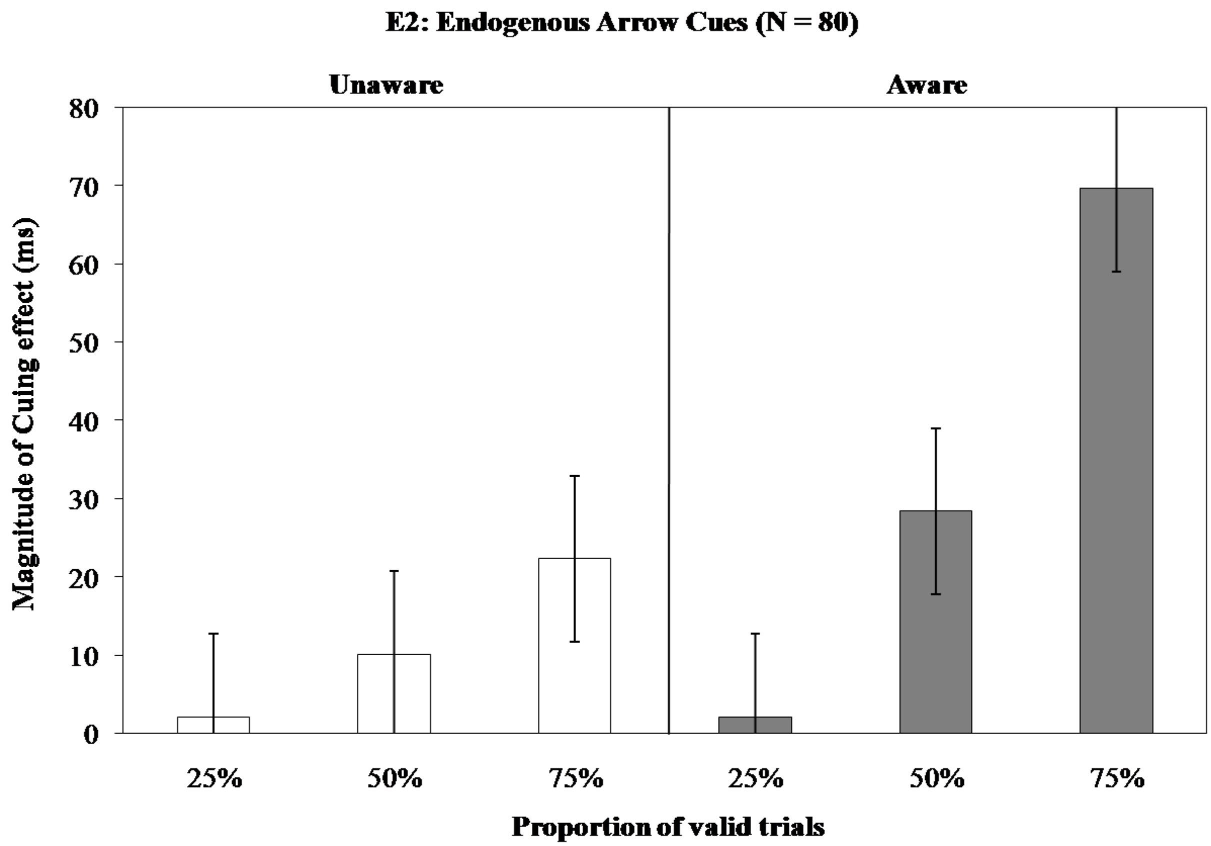

Figure 3.1. Cueing effects (RTs, in ms) as a function of Cue Awareness (aware vs. unaware) and Proportion Valid (25% vs. 50% vs. 75%) in Experiment 2. Error bars represent a 95% confidence interval as defined by Masson and Loftus (2003).

3.3.3 Error

No main effects or interactions were significant (all F's < 1.9).

3.3.4 Participant Estimates

Participant estimates of the proportion valid in each block were analyzed using a two-way ANOVA with cue awareness (2 levels: aware and unaware) as a between participant factor and proportion valid (3 levels: 25%, 50%, 75%) as a within participant factor. Mean participant estimates are shown in Figure 3.2. There was a main effect of proportion valid, ($F_{(1.506,156)}$ = 40.518, *MSE* =248.274, $p< 0.001$), such that participants estimates of the proportion of valid trials increased as the proportion of valid trials increased. No other main effects of interactions were significant (all F's < 1.2).

To further assess the main effect of proportion valid, three two-tailed repeated measures t-tests (which after applying a Bonferroni correction for multiple comparisons had a familywise error rate of .05) were used to compare the participant estimates in each proportion condition. The t-tests revealed that estimates were significantly higher in the 75% valid condition (64%) compared to both the 25% valid condition (42%; $t_{(79)}$= 8.187, $p < 0.001$) and the 50% valid condition (52%; $t_{(79)}$= 5.686, $p < 0.001$). Estimates were also higher in the 50% valid condition than in the 25% valid condition ($t_{(79)}$= 3.951, $p < 0.001$).

Additionally, two-tailed one-sample t-tests were conducted to assess whether participant estimates of the proportion valid differed from the actual proportion valid. Estimates taken after the 25% valid block were significantly higher than 25% ($t_{(79)}$= 7.439, $p < 0.001$). Estimates for the 50% valid block were no different than 50% ($t_{(79)}$= .985, p = .327). Estimates taken after the 75% valid block were significantly lower than 75% ($t_{(79)}$= 7.359, $p < 0.001$).

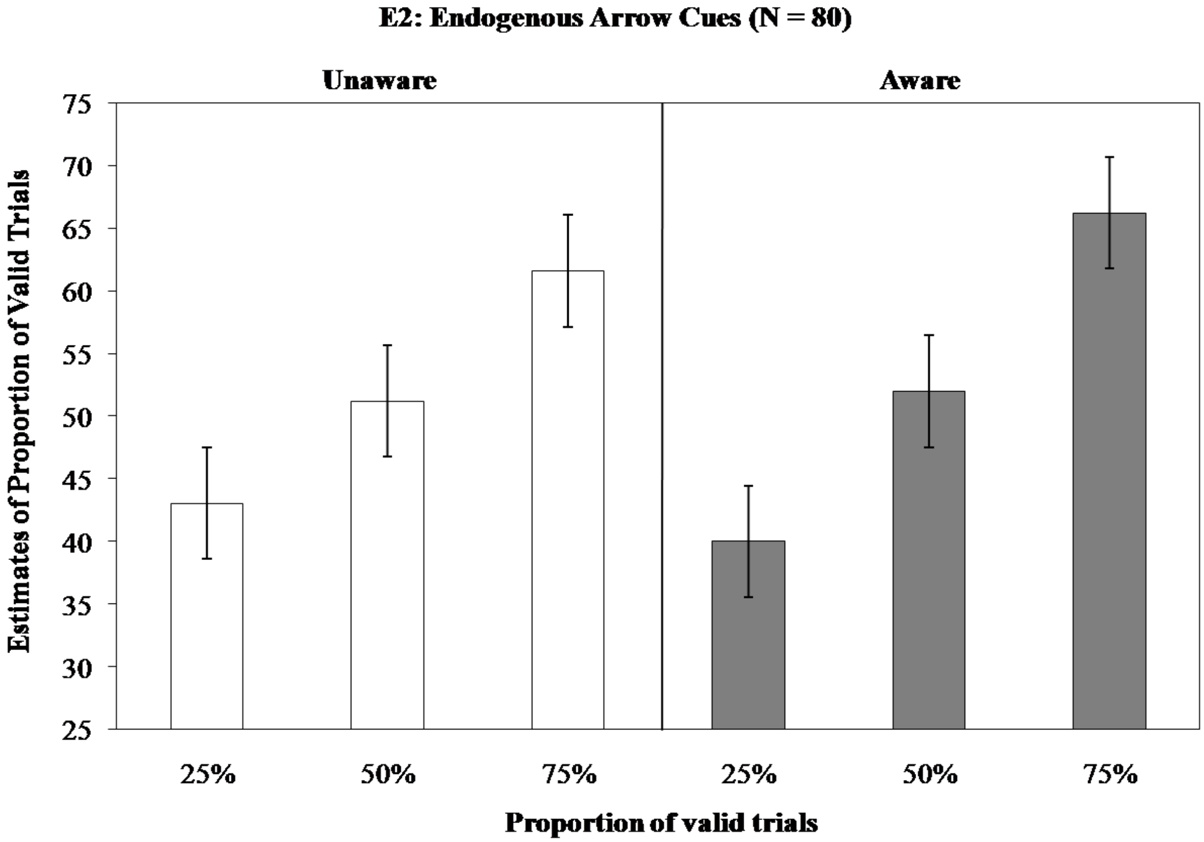

Figure 3.2. Participant estimates of the proportion of valid trials as a function of Cue Awareness (aware vs. unaware) and Proportion Valid (25% vs. 50% vs. 75%) in Experiment 2. Error bars represent a 95% confidence interval as defined by Masson and Loftus (2003).

3.3.5 Relation Between Participant Estimates and Performance

A Pearson correlation analysis was conducted in order to determine whether participant estimates of the proportion valid in each block were related to the magnitude of their cueing effects in each block. The correlation between the participants' estimates and the magnitude of their cueing effects (RT) was significant in the 25% condition (r = -.254, p < .03) such that participants with lower estimates had larger cueing effects. However, no other correlations were significant. Further, the same analysis was conducted on each cue awareness condition separately. The correlation between the participants' estimates and the magnitude of their cueing effects (RT) was significant in the 25% condition when participants were aware of cue-target relations ($r = -.254$, $p < .03$) such that participants with lower estimates had larger cueing effects. However, when participants were unaware of cue-target relations there was no relationship between participants’ estimates and the magnitude of their cueing effects in the 25% condition (r = -.099, p = .543). No other correlations were significant.

3.4 Discussion

As in Experiment 1, in Experiment 2 the magnitude of the cueing effect increased as the proportion of valid trials increased. Specifically, cueing effects were larger when 75% of the trials were valid than when only 50% or 25% of the trials were valid. Similarly, cueing effects were larger when 50% of the trials were valid than when only 25% of the trials were valid. In addition, when participants were asked to estimate the percentage of valid trials participants *underestimated* the actual proportion valid in the 75% valid condition, *accurately estimated* the actual proportion valid in the 50% valid condition, and *overestimated* the actual proportion valid in the 25% valid condition. As in Experiment 1, participants' awareness of cue-target relations did not influence participant estimates of the proportion of valid trials. Also, participants’ estimates of the proportion of valid trials were not predictive of the magnitude of their cueing effect in response times. Taken together, these data suggest that the increase in the magnitude of the cueing effect, as the proportion of valid trials increases, occurs regardless of participants awareness of the predictive nature of the cue, which was manipulated between participants and indexed by estimates of the proportion or valid trials.

Critically, unlike Experiment 1, in Experiment 2 participants' awareness (i.e., either aware or unaware of cue - target relations) of cue-target relations *did influence* the nature of PVE as indicated by the Cue awareness by Proportion valid by Cue validity interaction. This finding lends support to the idea that a volitional component can influence the nature of the PVE, but is not required to generate the PVE. Further, this finding also indicates that there is indeed something different in the way that central and peripheral cues orient attention. Although a combination between volitional and implicit processes drive the PVE for central cues in Experiment 2, there was no evidence of a volitional component (in either estimates or RT) of the PVE for peripheral cues observed in Experiment 1. Rather, the PVE for peripheral cues was driven by implicit processes.

The current findings also suggest a plausible reason for the conflicting findings (i.e., disagreement on whether implicit process can also mediate the PVE for central cues) of the studies conducted by Bartolomeo and colleagues (2007) and those conducted by Risko and Stolz (2010). The studies by Risko and Stolz (2010) required participants to report the proportion of valid trials (which requires awareness of both the relationship between cues and targets as well as the *frequency* with which the cue accurately indicates the correct location of the target) whereas Bartolomeo and colleagues (2007) required that participants only report whether there was a relationship between cues and targets. Risko and Stolz (2010) found no relationship between estimates of the proportion of valid trials and cueing effects with central cues. As such, the authors concluded that orienting can occur without explicit awareness of cue-target relations. However, Bartolomeo and colleagues (2007) found with central symbolic cues, only participants who noticed the relationship between cues and targets show the PVE. As such, the authors concluded that an explicit awareness of cue-target relations is largely responsible for the PVE for central cues. If the PVE is sensitive to being aware that cues indicate the correct location of targets (i.e., as participants were asked to do in Bartolomeo and colleagues, 2007), but not dependent upon knowing *how frequently* the cue indicates the correct location of targets (i.e., as participants were asked to do in Risko and Stolz, 2010), then the conclusions drawn from the results of both studies are indeed correct. Taken together, the present study and those conducted by Risko and Stolz (2010) and Bartolomeo and colleagues (2007) demonstrate that the PVE observed with central cues *can be* influenced by being aware of cue-target relations, but perhaps the awareness required to alter the PVE is different than was previously assumed and measured by Risko and Stolz (2010).

Chapter 4: Experiment 3: The Effect of Awareness of Cue-Target Relations on Orienting Elicited by Central Non-Directional Cues

4.1 Introduction

In Experiment 3, central non-directional cues were used instead of peripheral box or arrow cues. I investigated whether the PVE would emerge for stimuli that are not associated with a given spatial location. Specifically, I used a square and a diamond which, unlike arrow or peripheral box cues, do not possess inherent directionality (e.g., the cue does not lead to an increase of attention being allocated to a particular location or an increase in the frequency with which attention is redirected by the cue to a particular location when the cue is spatially unreliable). Inherent directionality is a property of a cue that is required in order for participants to a) display cueing effects and b) perceive the same cue as being more or less useful depending on how frequently the cue indicated the correct location of the target (e.g., as indicated by participants estimates of the proportion of valid trials in Experiment 1 and 2). Thus, in Experiment 3, when cues do not possess inherent directionality, neither cue (i.e., a box or diamond) will direct attention to a particular location at the outset of the experiment. As such, participants will not display reliable cueing effects unless a) the cue reliably predicts the location of upcoming targets (i.e., more than 50% of the time) and b) cue-target relations are learned via implicit or explicit means.

If a given non-directional cue (e.g., a diamond) indicates that targets will appear in one location (e.g., above fixation), then the other cue (e.g., a square) is indicating that targets will appear in the opposite location (e.g., below the fixation). For example, when the diamond indicates that targets will appear *above* the fixation on 75% of the trials then the box indicates that targets will appear *below* the fixation on 75% of the trials. Likewise, the diamond cue is followed by targets *below* the fixation on 25% of the trials and the box is followed by targets *above* the fixation on 25% of the trials. Given that the attentional system can be configured by the goals of the participant in such a way that the system responds selectively to a specific properties of a stimulus (Folk et al., 1992), I expect that participants will utilize the properties of the specific cue that maximizes their performance on the task. Thus, conditions where the proportion of valid trials differs from 50% will be perceived as useful/predictive given that one of the specific cues will always indicate a given target location more reliably than chance. As such, in Experiment 3, unlike Experiments 1 and 2 (where the inherent directionality of the cue can generate a 75% valid condition and a 25% valid condition), there will be one unpredictive condition which is when the cues indicate the correct location of targets 50% of the time and two predictive conditions where the cues indicate the correction location of the target 75% of the time. In the present experiment, both of the 75% conditions (e.g., in one the box will indicate the spatial location ‘above’ 75% and in the other the diamond will indicate the spatial location ‘above’), will be combined and treated as a single 75% condition[2].

In the 75% condition, unlike the 50% valid condition, the non-directional cue reliably predicts the spatial location of a target. Thus, in the 75% conditions participants could learn the cue-target relations (whether by explicit or implicit means) thereby displaying cueing effects. However in the 50% condition, I would not expect participants to display cueing effects given that no cue-target relation exists. Thus, it is possible for the non-directional

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[2] Prior to combining the two 75% valid conditions, analyses were conducted to determine whether these two conditions were similar and thus appropriate to combine together.

cues to produce a PVE (i.e., the magnitude of the cueing effect increases as the proportion of valid trials increases) if the participants are able to learn the cue-target relations in the 75% condition. According to the volitional control account, when using non-directional cues, the PVE should only be present when participants are aware of cue-target relations and absent when they are not. On the other hand, implicit learning suggests any kind of cue-target relationship can be learned outside of awareness as long as the cue reliably predicts the spatial location of a target (Chun & Jiang, 1998). According to the implicit learning account, if participants are given enough time to learn the cue-target relations then the PVE should emerge in the 75% valid cue condition regardless of whether participants are aware or unaware of cue-target relations conditions.

4.2 Method

4.2.1 Participants

Eighty new participants from the University of British Columbia were either given credit or paid $10 (CAD) for their time.

4.2.2 Design, Apparatus, Stimuli and Procedure

The design, apparatus, and procedure was the same as that used in Experiment 2 except that the cues were now centrally located diamonds or squares (1.6 cm vertical, 1.1 cm horizontal) and participants were also asked to estimate which location (i.e., either above or below fixation) the box/diamond cue indicated that an upcoming target would appear at the end of each block.

4.3 Results

4.3.1 Data Trimming Procedure

Data analysis followed the same procedure as that used in the previous experiments and resulted in 5.28% of the RT data being discarded. Mean RTs and Errors were analyzed using a three-way repeated measures analysis of variance (ANOVA) with cue awareness (2 levels: aware and unaware) as a between participant factor and cue validity (2 levels: valid and invalid) and proportion (2 levels: 50% and 75%) as within-participant factors. Mean RT and percentage error are presented in Table 4.1. Cueing effects as a function of cue awareness and proportion valid are presented in Figure 4.1.

4.3.2 Response Times

There was a main effect of cue awareness, ($F_{(1, 78)} = 9.244$, *MSE* =39668.366, $p < 0.003$), such that responses were faster when participants were unaware (512 ms) than when they were aware (580 ms) of cue-target relations. There was a main effect of cue validity ($F_{(1, 78)} = 5.743$, *MSE* =370.285, $p < 0.02$), such that responses were quicker to valid cues (543 ms) than invalid cues (549 ms). Additionally, there was a significant interaction between cue validity and proportion valid ($F_{(1, 78)} = 17.386$, *MSE* =698.483, $p < 0.04$), such that the effect of cue validity increased as the proportion of valid trials increased: this is the PVE. Finally, there was a significant three way interaction between cue awareness, cue validity and proportion valid ($F_{(1, 78)} = 4.836$, *MSE* =698.483, $p < 0.04$). No other main effects or interactions were significant (all F's < 1).

To further assess the interaction between cue awareness, cue validity and proportion valid, the magnitude of the cueing effect was determined by subtracting response times in the valid condition from the response times in the invalid condition. Next, two two-tailed repeated measures t-tests were used to assess how the proportion valid (2 levels: 50% and 75%) by cue validity interaction differed in each cue awareness condition. In the aware condition, cueing effects were larger in the 75% valid condition (25 ms) compared to the 50% valid condition (-13 ms; $t_{(39)} = 4.118$, $p < 0.001$). In the unaware condition, there were no significant differences between the 50% (-2 ms) and 75% (10 ms) proportion valid conditions (all t's < 1.6).

Table 4.1. Mean RTs (ms) in Experiment 3 as a function of Cue Awareness, Proportion of Valid Trials, and Cue Validity.

	Proportion of Valid Trials	
Cue Awareness	**50%**	**75%**
Unaware		
Valid	503	527
Invalid	502	517
Difference	**-1**	**10**
Aware		
Valid	582	572
Invalid	569	597
Difference	**-13**	**25**

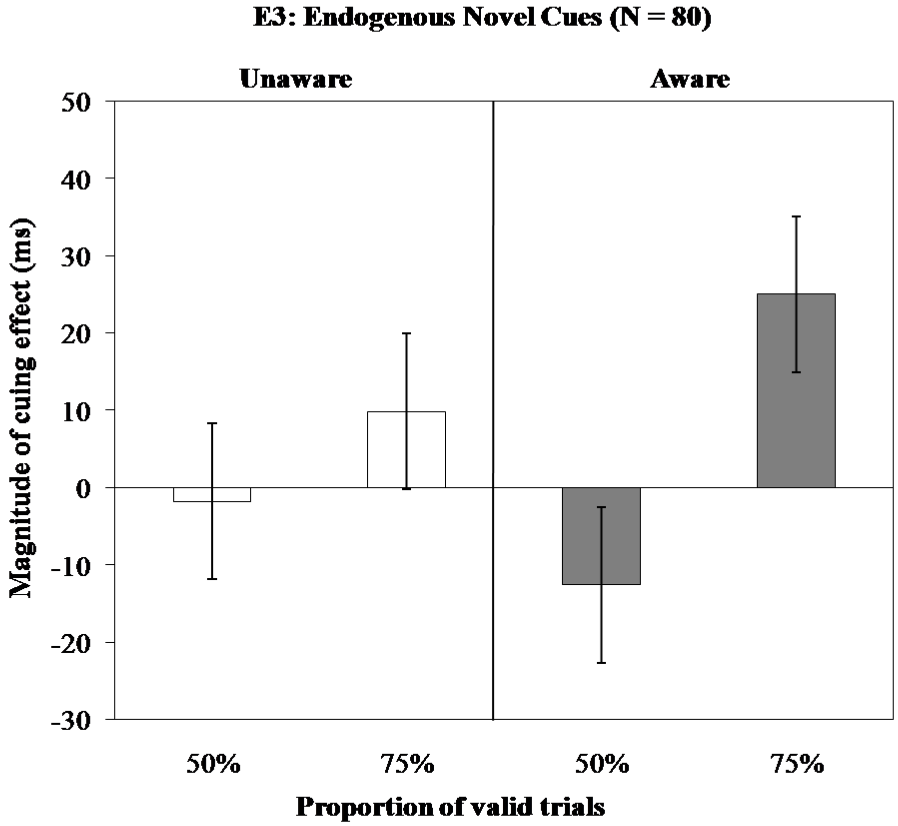

Figure 4.1. Cueing effects (RTs, in milliseconds) as a function of Cue Awareness (aware vs. unaware) and Proportion Valid (50% vs. 75%) in Experiment 3. Error bars represent a 95% confidence interval as defined by Masson and Loftus (2003).

4.3.3 Error

There was a main effect of cue validity ($F_{(1,\ 78)}$ = 10.723, *MSE* =2.916, p< 0.002), such that responses were less accurate to invalid cues (7.5%) than valid cues (8.2% ms). There was also a main effect of proportion valid ($F_{(1,\ 78)}$ = 10.723, *MSE* =2.916, p< 0.002), such that responses were less accurate when 50% of the cues were valid (8.3%) than when 75% of the cues were valid (7.4% ms). No other main effects or interactions were significant (all F's < 2.7).

4.3.4 Participant Estimates

Prior to data analysis, an average estimate of the two 75% valid conditions was generated for each participant[3]. Participant estimates of the proportion valid in each block were analyzed using a two-way ANOVA with cue awareness (2 levels: aware and unaware) as a between participant factor and proportion valid (2 levels: 50% and 75%) as a within participant factor. Mean participant estimates are shown in Figure 4.2. There was a main effect of proportion valid, ($F_{(1, 78)} = 12.428$, *MSE* =219.292, $p< 0.002$), such that participants estimates of the proportion of valid trials were significantly higher in the 75% valid condition (53%) than in the 50% valid condition (44%). No other main effects of interactions were significant (all F's < 0.5).

Additionally, two-tailed one-sample t-tests were conducted to assess whether participant estimates of the proportion valid differed from the actual proportion valid. Estimates for the 50% valid block were significantly lower than 50% ($t_{(79)}= 2.322$, $p < .03$). Estimates taken after the 75% valid block were significantly lower than 75% ($t_{(79)}= 11.480$, $p < 0.001$)[4].

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[3] Prior to generating an average estimate based on the two estimates provided by each participant, a t-test was conducted to determine whether the estimates differed significantly from one another. T-tests revealed that there was no significant difference between the two estimates provided for each 75% valid condition ($t_{(79)}= 1.561$, $p = .123$).

[4] There were no differences between the two estimates that were made in each of the 75% valid conditions. When the two separate estimates for 75% conditions are analyzed separately, neither of the 75% conditions were significantly different than 50% ($t_{(79)}= .243$, $p = .808$; and $t_{(79)}=1.861$, $p = .066$ respectively), and both were significantly lower than 75% ($t_{(79)}= 11.071$, $p < 0.001$ and $t_{(79)}= 8.198$, $p < 0.001$).

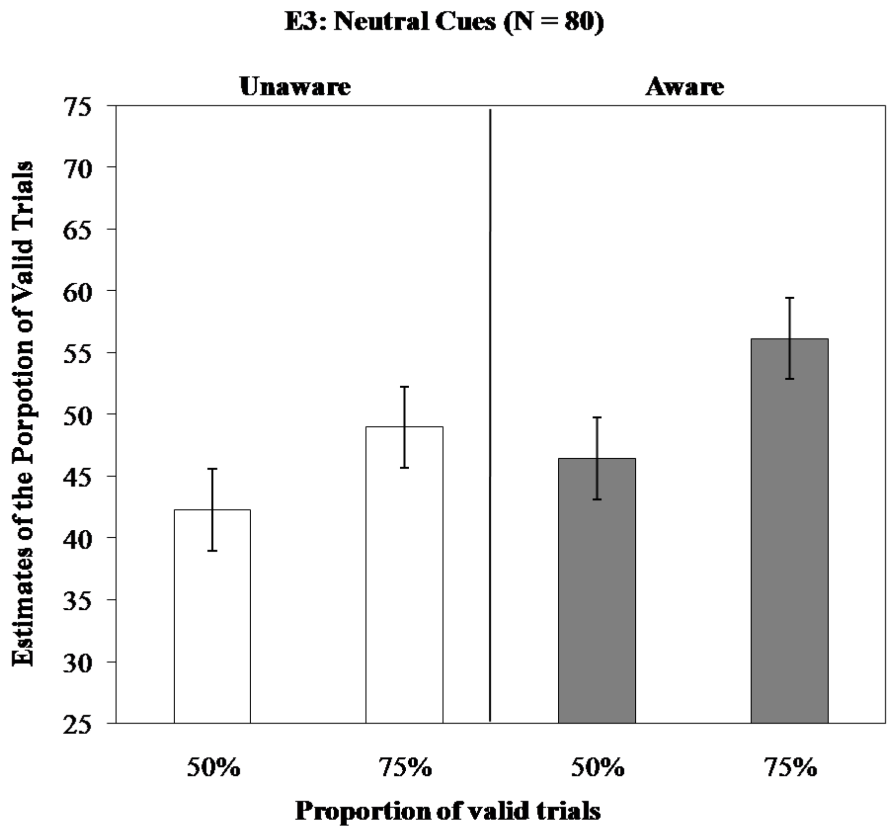

Figure 4.2. Participant estimates of the proportion of valid trials as a function of Cue Awareness (aware vs. unaware) and Proportion Valid (50% vs. 75%) in Experiment 3. Error bars represent the a 95% confidence interval as defined by Masson and Loftus (2003).

4.3.5 Relation Between Participant Estimates and Performance

A Pearson correlation analysis was conducted in order to determine whether participant estimates of the proportion valid in each block were related to the magnitude of their cueing effects in each block. The correlation between the participant estimates and the magnitude of their cueing effects (RT) was significant in the 75% valid condition (r = .252, p < .024) such that participants with higher estimates also had larger cueing effects.

However, no other correlations were significant in either RT or errors. The same analysis was then conducted on each cue awareness condition separately. The correlation between the participant estimates and the magnitude of their cueing effects (RT) was significant in the 75% valid condition when participants were aware of cue-target relations (r = .476, p < .003) such that participants with higher estimates also had larger cueing effects. However, when participants were unaware of cue-target relations there was no relationship between participants estimates and the magnitude of their cueing effects in either the 75% valid (r = .078, p = .630) or 50% valid (r = .039, p = .809) conditions. No other correlations were significant[5].

4.3.6 Discussion

In Experiment 3 the magnitude of the cueing effect increased as the proportion of valid trials increased. Specifically, cueing effects were larger when 75% of the trials were valid than when only 25% of the trials were valid. In addition, when participants were asked to estimate the percentage of valid trials participants *underestimated* the actual proportion valid in the 75% valid conditions and the 50% valid condition. As in Experiments 1 and 2, participants' awareness of cue-target relations did not influence participants' estimates of the proportion of valid trials. However, unlike Experiments 1 and 2, participants' estimates of the proportion of valid cues *were predictive* of the magnitude of their cueing effect in

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[5] The correlation between the subject estimates and the magnitude of their cuing effects (RT) was significant in both of the 75% conditions when subjects were aware of cue-target relations (r = .364, p < .02 and r = .326, p < .04 respectively) such that subjects with higher estimates also had larger cuing effects. Further, when subjects were unaware of cue-target relations there was no relationship between subjects estimates and the magnitude of their cuing effects (r = .150, p = .356 and r = .001, p = .993). No other correlations were significant.

response times in the 75% valid condition. Critically, participants' awareness of cue-target relations *did influence* the nature of PVE as indicated by the Cue awareness X Proportion valid X Cue validity interaction. Specifically, the increase in the magnitude of the cueing effect as the proportion of valid trials increased occurred when participants were aware of the predictive nature of the cues and this effect *did not* occur when participants were unaware of the predictive nature of the cue. Taken together, these data suggest that the increase in the magnitude of the cueing effect as the proportion of valid trials increases is dependent on participant awareness of the predictive nature of the cue, which was manipulated between participants and indexed by estimates of the proportion or valid trials. This finding lends support to the idea that a volitional component can influence the nature of the PVE, and that this volitional component may be required to produce the PVE when cue-target relations have not already been established.

Chapter 5: General Discussion

5.1 Experiment Summaries and Conclusions

In the present experiments, I investigated the mechanism responsible for the PVE in the covert orienting paradigm by manipulating whether participants were aware of cue-target relations (i.e., how frequently the cue predicted the upcoming target location) and determining whether this awareness influenced the nature of the PVE. I contrasted two theories. According to the volitional control account, awareness of cue-target relations plays a central role, whereas the implicit learning account suggests that awareness of cue-target relations is not essential for producing the PVE. Overall, the results from Experiments 1 through 3 provide support for both theories.

In Experiment 1, a PVE which was independent of participants' awareness of cue-target relations and participants' estimates of the proportion of valid trials, was demonstrated using *peripheral cues* that possessed inherent directionality. Thus, with peripheral cues, that are understood to elicit exogenous orienting (e.g., Posner, 1980), participants' awareness of cue-target relations was not an essential component to producing the PVE. I have demonstrated (along with Bartolomeo et al., 2007, and Risko & Stolz, 2010) that the PVE is not always produced via a volitional process. This is important as the PVE has been assumed to manipulate and measure the behaviour and brain mechanisms of volitional orienting across different populations and paradigms (e.g., the Stroop effect; Blais, Harris, Guerrero & Bunge, 2010). Experiment 1's results replicated the finding by Risko and Stolz (2010) that the PVE with peripheral box cues is not dependent on participants being aware of the cue-target relations, which was measured via participant estimates and manipulated by making participants aware of cue-target associations or not.

In Experiment 2, a PVE which was independent of participants' awareness of cue-target relations and participants' estimates of the proportion of valid trials, was demonstrated using *central cues* that possessed inherent directionality. Thus, even with central cues that are understood to elicit endogenous orienting (e.g., Kingstone, 1992), participants' awareness of cue-target relations was not an essential component to producing the PVE. This finding is important for a number of reasons. First, many researchers have assumed that the PVE, especially a PVE produced by central symbolic and spatially informative cues, reflects a form of volitional orienting. Second, the present finding highlights *the similarity* between the attentional effects of central cues and peripheral cues (Driver et al., 1999; Friesen & Kingstone, 1998). These findings are consistent with Risko and Stolz (2010) findings that the PVE generated by central arrow cues is not always produced via a volitional strategy.

However, unlike Risko and Stolz (2010), I also found that the PVE generated using central arrow cues was influenced by awareness of the cue-target relations (i.e., participants who were instructed to learn the cue-target relations showed a larger PVE than those who were not). Thus, awareness of cue-target relations can change the nature of the PVE despite being unnecessary for producing the PVE using central cues. This result speaks directly to the debate as to whether volitional processes contribute to the PVE produced by central cues. Thus, the findings of Experiments 1 and 2 also highlight *the differences* that exist between the attentional effects observed in central and peripheral cues as well as the similarities.

In Experiment 3, the PVE, which was *dependent* on participants' awareness of cue-target relations, was demonstrated using central cues that do not possess inherent directionality. Thus, participants' awareness of cue-target relations was an essential component in producing the PVE. As such, I have demonstrated that a volitional process *does* contribute to producing the PVE in some fashion when cues do not possess inherent directionality.

The results from Experiment 3, like those of Experiment 2, extend Risko and Stolz's (2010) findings and conclusions. Specifically, in contrast to their proposal that the PVE may not reflect volitional control, I found that the PVE generated using central non-directional cues is influenced by volitional control, and that this effect is sensitive to participants' awareness of cue-target relations as indicated by the positive correlation between participant estimates of proportion of valid trials in the 75% valid condition. It is important to emphasize that I have not demonstrated that cue-target relations cannot be learned implicitly (see Experiments 1 and 2) to yield a PVE. Nor have I demonstrated that implicit processes do not contribute to the generation of the PVE given that implicit processes can work independent of, or in parallel with, top-down attentional processes (i.e., Experiment 1 and Experiment 2, Cleeremans et al., 1998). What I have demonstrated is that awareness of cue-target relations can impact the generation of a PVE (Experiment 2) or be solely responsible for the PVE when no prior relations exist between a cue and a target (Experiment 3). These findings support the notion that conscious awareness of the spatial predictiveness of central predictive cues can engage (Experiment 2) or isolate (Experiment 3) a volitional component to the PVE. This is important because demonstrating that conscious awareness does produce, under some circumstances, a PVE independent of implicit learning validates much of the research literature that suggests there is a volitional component to the PVE. Nevertheless, most studies in the past have used directional central cues (like these in Experiment 2) under the assumption that central directional cues are only eliciting volitional shifts of attention. Contrary to the age-old assumption that central directional cues only engage volitional processes, Experiment 2 shows that directional central cues also engage implicit processes.

In sum, the present studies have demonstrated that the awareness of the association between cues and spatial locations does contribute, under some circumstances, to the PVE. However, the extent to which the PVE is influenced by awareness of cue-target relations is dependent on the type of cue used to orient attention. For example, peripheral box cues, believed to elicit exogenous shifts of attention, produced a PVE that was independent and insensitive to participants' awareness of cue-target-relations. On the other hand, central cues (i.e., both arrow cues and non-directional cues) produced PVEs that were sensitive to our manipulation of awareness of cue-target relations. However, central arrow cues produced a PVE that was *independent* of awareness, whereas non-directional cues produced a PVE that was *dependent* on awareness of cue-target relations (i.e., all participants showed a PVE when central arrow cues were used, but only those who were encouraged to determine cue-target relations showed a PVE when central non-directional cues were used).

5.2 Methodological Contributions

In addition to the above empirical contributions, the present set of experiments have made several methodological contributions. One issue that loomed over previous research (e.g., Bartolomeo et al., 2007; Risko & Stolz, 2010) was the uncertainty regarding the extent to which the measures of ‘awareness’ were sufficient. As previously mentioned, it is very difficult to determine whether subjective reports are sensitive to all aspects of awareness that could influence the nature of the PVE (i.e., estimating the proportion of valid trials is different than simply being aware that a relationship between a cue and a given location exists). Nor is there a guarantee that participants' report all of their relevant conscious knowledge when they are asked to do so. This becomes a particularly pertinent issue given that the conclusions regarding the involvement of volitional processes in the production of the PVE in previous research hinged on a *failure* of participants to report changes in awareness. Indeed, this problem applies to most, if not all, research attempting to ascertain the relation between awareness and behaviour. Detecting a difference between two different groups (i.e., rejecting the null) is a much stronger test of a hypothesis than failing to detect differences between groups (i.e., failing to reject the null). Thus, unlike previous studies, by *manipulating* awareness in the present studies I was able to measure the effect of awareness of cue-target relations in RT in addition to measuring awareness via the standard methodology (i.e., subjective reports/estimates of the proportion of valid cues).

In both the present studies and those conducted by Risko and Stolz (2010), participants estimates of the proportion of valid trials were unrelated to the magnitude of their cueing effects when using directional cues (i.e., peripheral box and central arrow cues). Given this result, Risko and Stolz (2010) concluded that participants' awareness of cue-target relations was not required to produce the PVE. However, in the present studies I showed that participants' estimates did not always change even when participants were made explicitly aware of the cue-target relations and this manipulation in awareness produced a RT change in the PVE. Thus I have shown that estimates fail to capture a significant component of the PVE that is driven by awareness. This leads to the speculation that our measure of RT may index participants awareness of cue-target relations (i.e., simply being aware that a cue indicates a given location in space) while a subjective report measures *the frequency* with which the cues indicate the correct location of the target. According to this notion, the present results suggest that being aware of the spatial utility of the cue (e.g., that the cue conveys spatial information) is required to orient attention with central arrow cues whereas grasping the frequency with which the cues indicate the correct location of the target is not. When a peripheral box cue is used, neither being aware of the cue-target relations nor the awareness of the frequency with which a cue indicates the location of the target are required to orient attention. In contrast, non-directional central cues require that participants are aware of the cue-target relations and the frequency with which the cue indicates the correct location of the target in order to orient attention. Taken together, the present study and those conducted by Risko and Stolz (2010) and Bartolomeo and colleagues (2007) demonstrate that the PVE observed with central cues *can be* influenced by being aware of cue-target relations, but perhaps the awareness required to alter the PVE is a more simplistic and less specific degree of awareness than was previously assumed and measured by Risko and Stolz (2010).

In sum, the present work replicated the finding that awareness of cue-target relations has no influence on the PVE generated by the use of peripheral cues. However, I also extended previous research in several ways. I was able to dissociate between two levels of awareness - one level of awareness that *does* influence the PVE produced by central cues and one that *does not.* This provides a potential reason for conflicting results in previous research regarding whether or not awareness is required for the PVE. Given that the PVE is more sensitive to being aware that cues indicate the correct location of targets (i.e., as participants were asked to do in Bartolomeo and colleagues, 2007), than knowing *how frequently* the cue indicates the correct location of targets (i.e., as participants were asked to do in Risko and Stolz, 2010), then the conclusions drawn from the results of both studies may be valid. Further, after dissociating the putatively different forms of awareness (i.e., awareness of cue-target relations and awareness of the frequency with which the cues indicate the correct location of the target), I demonstrated the circumstances under which each form of awareness would influence the PVE. Although both awareness of cue-target relations and awareness of the frequency with which the cues indicate the correct location of the target are required in order to produce a PVE when non-directional central symbolic cues are used, neither element of awareness contributes to the PVE produced by directional peripheral cues, and only awareness of cue-target relations is required to produce the PVE observed with directional central symbolic cues. This finding is important, given that it pinpoints the role of specific aspects of awareness in the PVE, the circumstances in which awareness of cue-target relations influences the PVE, and clarifies the conflicting findings of previous research. Finally, although I have extended Risko and Stolz (2010) research in many ways, the convergence between these two studies, despite changes in methodology (e.g., the addition of a 25% valid condition, the modification to SOA and, most notably, the manipulation of participant awareness), is encouraging.

5.3 Attentional Systems and Neural Networks Associated with the PVE

The findings of the present three experiments also shed light on an issue that has recently been hotly debated in the field of attention. Until the late 1990s it was believed for several decades that spatially nonpredictive peripheral onset cues triggered automatic (involuntary) shifts of spatial attention (sometimes called exogenous orienting); and central spatially predictive arrow cues engaged controlled (voluntary) shifts of spatial attention (sometimes called endogenous orienting). Then researchers discovered that spatially nonpredictive central symbolic directional cues, like eyes looking left or right (Driver et al, 1999; Friesen & Kingstone, 1998) or arrows pointing to the left or right (Ristic, Friesen & Kingstone, 2002: Tipples, 2002) will produce automatic shifts of spatial attention. This led researchers, such as Ristic and Kingstone (2006), to propose that spatially predictive central arrow cues engage both automatic and volitional orienting, rather than volitional orienting alone. While this issue is still very much under debate, the prevailing view is that central nonpredictive arrow cues engage automatic attention, and spatially predictive arrows engage both automatic and volitional attention. Spatially nonpredictive peripheral cues continue to be thought of as generating automatic orienting, although the neural mechanisms that subserve that form of orienting may well be subcortical and hence very different than the cortical mechanisms thought to support automatic orienting to symbolic arrow cues.

The present results seem to provide support for this view, in that each of the experiments of the present study could be understood to engage a different form, or combination of, attentional orienting. In Experiment 1, the peripheral cues would be expected to engage subcortical exogenous orienting (i.e., subcortical circuits that include the superiour colliculus and the pulvinar, Rafal et al., 1988), a form of orienting that would not be expected to supported by, nor dependent on, controlled mechanisms that are mediated by awareness. In Experiment 2, the central predictive arrow cues would be thought to engage both exogenous and endogenous orienting (mediated by cortical stuctures that form the dorsolateral forontoparietal attention network, Corbetta & Shulman, 2002), which converges nicely with the present finding that the PVE is composed of components that are both independent and dependent on awareness. Finally, in Experiment 3, the non-directional central cues that were used are thought to only engage endogenous orienting (Ristic & Kingstone, 2006), and this is supported by the finding that the PVE reflects only processes mediated by awareness.

In short, the differences in the PVE effects in Experiments 1-3 (i.e., implicit learning only in Experiment 1, both implicit and volitional processes in Experiment 2, and only volitional processes in Experiment 3) provide converging evidence for the theoretical position that the PVE in these three studies reflects the engagement of different forms, or combinations of, attentional processes: exogenous attention only in Experiment 1, exogenous and endogenous attention in Experiment 2, endogenous attention only in Experiment 3.

5.4 An Alternative Account of Orienting Elicited by Central Directional Cues

In Experiment 2, the central predictive arrow cues could have elicited attentional shifts that are mediated by a network of brain structures that are distinct from the brain structures implicated in exogenous and endogenous shifts of attention. Specifically, orienting to directional cues – such as arrows – is supported by the ventrolateral frontoparietal network that is critical for tracking behaviourally relevant contingencies (e.g., Corbetta, Patel & Shulman, 2008). Arrows fall into the domain of behaviourally relevant stimuli given that in real-life situations, these stimuli are meaningful and behaviourally relevant. Further support for this conclusion is provided by the fact that activity in the ventrolateral network has consistently been observed when participants orient their attention in response to complex symbolic cues like arrow direction (e.g., Doricchi, Macci, Silvetti & Macaluso, 2010; Green et al, 2009; Tipper et al, 2008).

Chapter 6: Conclusions

The present experiments have demonstrated that the awareness of the relation between cues and target locations does contribute, under some circumstances, to the PVE. However, the extent to which the PVE is influenced by awareness of cue-target relations is dependent on the type of cue used to orient attention. The present studies also provide converging evidence for the theoretical position that the PVE reflects the engagement of different forms, or combinations of, attentional processes which are dependent upon the cue used to elicit shifts in attention: only exogenous attention is engaged by peripheral box cues, exogenous and endogenous attention are engaged by arrow cues, and only endogenous attention is engaged by central non-directional cues.

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Appendices

Appendix A   Sample of Questionnaires Used in Experiments 1 - 3

A.1 Sample of Questionnaire Used in Experiment 1

1. Select the best option:
a. There were more trials on which the white box indicated the *correct* location of the target.
b. There were more trials on which the white box indicated the *incorrect* location of the target.

2. With respect to the previous question:
a. That's a guess
b. I'm sure

3. If you consider all of the trials you just completed, what percentage of the trials had white boxes indicating the *correct* location of the target? ____________.

A.2 Sample of Questionnaire Used in Experiment 2

1. Select the best option:
a. There were more trials on which the arrow indicated the *correct* location of the target.
b. There were more trials on which the arrow indicated the *incorrect* location of the target.

2. With respect to the previous question:
a. That's a guess
b. I'm sure

3. If you consider all of the trials you just completed, what percentage of the trials had arrows indicating the *correct* location of the target? ____________.

A.3 Sample of Questionnaire Used in Experiment 3

1. The square and diamond *may* indicate the location of an upcoming target (i.e., either above or below the fixation). Knowing this...
a. Which target location was indicated by the square?   Above   Below   Neither
b. Which target location was indicated by the diamond?   Above   Below   Neither

2. With respect to the previous question:
a. That's a guess
b. I'm sure

3. Select the best option:

a. There were more trials on which the square or diamond indicated the *correct* location of the target.
b. There were more trials on which the square or diamond indicated the *incorrect* location of the target.

4. With respect to the previous question:
a. That's a guess
b. I'm sure

5. If you consider all of the trials you just completed, what percentage of the trials had a square or a diamond indicating the *correct* location of the target? ____________.