Diplomarbeit

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Covert shifts and inhibition of return in

saccadic and manual responses

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für:

Marion

„the things I do for love…"

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1   Zusammenfassung

In jüngeren, unveröffentlichten Studien unseres Instituts, adaptierten wir das experimentelle Design von Deubel und Schneider [1996, Vision Research, 36(12), 1827-1837], um die Auswirkungen verdeckter Aufmerksamkeitsverlagerungen auf die Sakkadenlatenz zu untersuchen. Entgegen der Ergebnisse von Deubel und Schneider, fanden wir langsamere Reaktionen zu Zielreizen, die am Ort der verdeckten Aufmerksamkeitsverlagerung dargeboten wurden. Die vorliegende Studie wurde durchgeführt, um durch einen Vergleich von Sakkaden und Zeigebewegungen, diese Ergebnisse genauer zu eruieren. Wir fanden erneut IOR-Effekte, für Orte die das Ziel einer verdeckten Aufmerksamkeitsverlagerung waren, sowohl für Sakkaden, als auch für Zeigebewegungen. Wir interpretieren diese Ergebnisse im Rahmen einer Prämotor-Hypothese der Aufmerksamkeit und folgern, dass zwar eine enge Verbindung zwischen verdeckten Aufmerksamkeitsverlagerungen und dem Vorbereiten einer motorischen Reaktion existiert, die Aufmerksamkeit aber nicht an den Zielort der motorischen Reaktion gebunden ist. Ferner fanden wir für beide Modalitäten, dass Hinweisreize, die erinnert werden sollten, zu langsameren Reaktionen führten, als Störreize, die ignoriert werden sollten. Es werden die Implikationen dieser Ergebnisse für top-down und bottom-up Verarbeitung visueller Information diskutiert.

Schlagworte: Sakkaden, Augenbewegungen, Zeigebewegungen, Inhibition of Return, verdeckte Aufmerksamkeitsverlagerung, top-down, bottom-up

2   Abstract

In recent, unpublished studies of our institute, we adopted the experimental design of Deubel and Schneider [1996, Vision Research, 36(12), 1827-1837], to assess the effects of covert shifts on saccadic latency. Contrary to the results of the original experiment, we found slower reactions to target stimuli presented at covertly attended locations. The current study was conducted to investigate these findings further, by comparing saccades with manual pointing movements. We once again found IOR for recently attended locations, both in saccades and in manual responses. These results are interpreted in terms of a premotor theory of attention. We conclude that covert shifts are tightly coupled with movement preparation, but that attention is not necessarily locked at the location of the covert shift. Furthermore, we found slower reaction-times for to-be-remembered cues, compared to to-be-ignored distractors, for both modalities. The implications for top-down and bottom-up processes in visual search are discussed.

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3   Introduction

<u>A Tale Of Two Viewpoints</u>

Passing day after day in the library is quite a common occurrence for students nearing graduation. And this fate also befell me. I'm sitting among my colleagues, trying to write the discussion for my thesis. There is a key-point I am trying to make, but I need a citation. I have a vague idea where I might find the needed information - I know I read it somewhere... I'm combing through my literature, fully fixated on the search, when suddenly the door opens and a girl walks in. Almost like a reflex I look up and gaze at her. Realizing what I just did, I start asking myself: "Why did I look up? Don't I have something better to do?"
While I try to resume my reading, I'm brooding over that question

Suddenly, a little man, not taller than a Lego-man, appears on my desk. He wears a hat for some reason and shirt with the initials "J.T." imprinted upon it. He bows and says: "Of course you looked up. In visual search, every visual stimulus that pops into existence, initially captures your attention."

"No, no, no", another man of similar height yells from the other side, "you only attend to things you are looking for, not just because they're there!" The second little man comes towards the centre of the desk. His shirt bears the initials "C.F.".

"Oh, nonsense", J.T. replies, "everything in a visual scene that is salient, becomes evaluated. Why else would he have looked at that girl? Because he's searching for a girlfriend?"

"Actually, I have…", I try to interject, but C.F. interrupts me: "Let me take this, boy!" he says in a tone I don't quite approve of, and replies to J.T.: "Maybe he's just un-concentrated; he doesn't know what he is looking for. It's the broadness of his attentional search-set that let him look at that girl."

After a while of listening to their argument, I ask: "Does it have to be one thing or the other? Might it not be that the truth lies somewhere in the middle? Otherwise, this discussion will remain a paradox."
Both, J.T. and C.F. stare at me silently for a moment and then yell in one voice:
                                  "WHAT DO YOU KNOW!?"
And then, they resume their dispute.

While my two imaginations keep quarrelling, I decide to indulge another paradox:
My need for fresh air … and a cigarette.

3.1   Top-down and bottom-up processes in visual search

Our environment is extremely complex. Thousands of visual signals reach our eyes every moment. Not only for mere surviving, it is essential that we have mechanisms that filter the visual input and guide our eyes. However, the question arises as to how these mechanisms do work and based on what criteria they select visual stimuli for processing. The little tale from the last section outlines two of these attentional control modes: stimulus-driven (bottom-up) and goal-driven (top-down).

The necessity for attentional shifts arises from the design of our eyes. Although we have a visual field of about 150° per eye, sharp and detailed vision is only possible at the fovea centralis. This part of the retina has a visual field of only about 5°. Therefore, in order to really "see" something, we have to *foveate* (bring our fovea towards) it. Foveating or fixating a visual stimulus enables us to process it in detail and thoroughly. Retinal areas other than the fovea centralis can perceive visual signals only vaguely, but are quite sensitive to luminance changes (peripheral vision).

The reason for this, lies within the structure and distribution of our photoreceptors (i.e. cells, which convert light into bioelectrical signals) and ganglions (i.e. cells, which transport bioelectrical signals to the brain). In the peripheral retina, many photoreceptors provide input to a single ganglion. On the fovea however, each ganglion is connected only to a few photoreceptors. For this reason, the fovea centralis is capable of high resolution vision. This arrangement is actually quite efficient. If we had sharp vision throughout the retina, the brain areas that process visual signals had to be much, much larger.

Additionally, only at the fovea centralis we are able to perceive colour, due to cone photoreceptors which are distributed there with a high density. Rod photoreceptors, which are very sensitive to luminance, are spread over the whole retina, but also with the highest density close to the fovea centralis (parafoveal area, up to 10° of the visual angle).

We can only foveate one visual stimuli at a time. Therefore, we need to guide our visual search and prioritize within the visual field.

Visual attention can be guided purely stimulus-driven. Visual stimuli that are odd against the background, that appear or change suddenly, catch our eyes. We have the reflex to assess and evaluate them. This reflex is thought to have evolutionary roots. A red colour within a green bush could be a fruit. A sudden appearance could pose potential danger. More importantly, the orienting of attention towards such stimuli happens independently from search-intentions or tasks that have to be performed.

Especially the works of Jan Theeuwes and colleagues (Belopolsky, Schreij, & Theeuwes, 2010; Theeuwes, 1992, 2004; Theeuwes & Godijn, 2001, 2002; Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999; Theeuwes & Van der Burg, 2011) adopt quite a categorical position. They state that top-down sets are not able to outweigh the influence of stimulus-driven capture, at least not at early stages of visual attention. Furthermore, their results suggest that capture of attention is tantamount to capture of the eyes. In other words, attentional processes and eye movements seem to be coupled, a concept we will revisit later on.

Almost in opposition to the bottom-up account stands the top-down (goal-driven) approach. One of the most prominent studies in this domain was carried out by Charles Folk and his colleagues (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). They demonstrated that only stimuli, which match an established top-down search-set, capture attention. To support their hypotheses, they used the spatial cuing paradigm, where the location of a target[1]-singleton[2] is announced by a brief cue-singleton. The cue directs attention towards its location and facilitates subsequent target detection, if the target appears on the same location. According to the top-down account, this cuing effect should only occur, when the cue is similar (i.e. same colour, shape and/or orientation) to the target. Otherwise, it should be ignored. And indeed, the experimental data suggest that only cues with task-relevant features attract attention. This phenomenon received the cumbersome name "contingent involuntary orienting hypothesis", also abbreviated as "contingent capture". Top-down relies on cognitive control, sorting out the relevant information that enters our conscious mind. Thereby, we can overrule pure stimulus-driven capture of attention. For example, if we look for a specifically coloured item, only items with this search-relevant feature will attract our attention. All other items, however, will be ignored.

In many other behavioural studies (e.g. Ansorge & Heumann, 2003) contingent capture could be demonstrated. Additional evidence comes from neurophysiological studies (Ansorge, Kiss, Worschech, & Eimer, 2011; Eimer & Kiss, 2008; Kiss, Grubert, Petersen, & Eimer, 2012; Lien, Ruthruff, & Cornett, 2010), where it has been repeatedly demonstrated that search goals influence brain activity related to attentional selection and processing.

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[1] A visual stimulus to which a saccade has to be executed.
[2] A visual stimulus that is unique in colour, shape or orientation, compared to other stimuli on a visual display.

However, contingent capture could not be established in all studies. Belopolsky, Schreij and Theeuwes (2010) used an experimental design similar to Folk's design. The crucial difference was that the participants were informed about the feature of the target (onset or colour) before each trial (not just before each experimental block). Therefore, they should have adopted a goal-directed search strategy. Irrelevant (different feature as target) and relevant (same feature as target) distractors[3] were used to assess the strength of top-down set. The results showed that irrelevant distractors captured attention. A trial-by-trial analysis revealed that the feature of the previous target determined the search-set for the next trial. If the last target had an onset feature, participants were more likely to attend to onset distractors during the following trial. Importantly, even when no specific top-down set was established, the results yielded the same pattern. This phenomenon is known as intertrial priming (Maljkovic & Nakayama, 1994), a mechanism that biases visual search automatically (hence bottom-up) towards most recently encountered features. These findings argue strongly against the contingent capture account and in favour of a stimulus-driven control of visual attention.

According to Belopolsky et al. (2010), onset distractors elicited stronger attentional capture than colour distractors, implying that onset singletons are more difficult to ignore. Schreij, Theeuwes and Olivers (2010) come to a similar conclusion. They stated that onset stimuli always capture attention. If a colour target is preceded by an onset cue, the cue captures attention although it does not match the search-set.

Given this first look, top-down and bottom-up seem to be mutually exclusive. However, an increasing number of studies suggest that these two approaches coexist. They can be conceptualised as distinct or interdependent. Temporal factors may play an important role, as the next few studies show.

For some time, it was thought that attentional disengagement (i.e. dwell-times on stimuli) also relies on stimulus attributes. If a target stimulus and a distractor are presented at the same time, they strive for attentional capture (Godijn & Theeuwes, 2002). Assuming that the distractor is most salient, a saccade will be executed to its location. Afterwards, a corrective saccade redirects the gaze to the target. The time it takes to disengage the eyes from the distractor, should depend on its saliency.

Recently, Born, Kerzel and Theeuwes (2011) used various types of distractors in a visual search task. Participants were instructed to react to the onset of a predefined grey target stimulus among red placeholders. Occasionally, simultaneously with the target, a distractor was presented,

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[3] A visual stimulus that has to be ignored.

either in a unique colour (green), the colour of the placeholder (red), or the colour of the target (grey). As mentioned, according to stimulus-driven capture, green and grey distractors (new colours) should pop out and therefore attract attention. If the disengagement of attention from distractors is also subject to bottom-up control, the same patterns as for capture should be found. This would mean longer attentional dwell-times on distractors, which are presented in new colours. However, attention only lingered longer on distractors, if they were presented in the target colour. This suggests a top-down influence on disengagement. The distractor that was most similar to the target (and therefore matched the search-set) provoked the longest attentional processing. Initial capture seems to be subject to bottom-up control, while disengagement can be top-down influenced. This concept was subsequently referred to as "differential disengagement".

Van Zoest, Donk and Theeuwes (2004) analysed the time-course of stimulus-driven and goal-driven selection. Possibly, both mechanisms moderate capture, but top-down control might take more time to affect visual search, and therefore influences only later stages of attention. They presented a target among placeholders, on some trials simultaneously with a distractor. Although participants knew the specific features of targets and distractors beforehand, they were never able to ignore distractors. Performance deteriorated even if the distractor shared no feature with the target. Interestingly, faster reactions were more influenced by salience than slower reactions. This implies that short latency saccades are especially prone to bottom-up processes, whereas slower saccades might be more top-down controlled. This strengthens the notion of the coexistence of top-down and bottom-up processes, and their dependence on time. Van Zoest et al. (2004) point out that these findings do not yet clarify whether or not stimulus-driven and goal-driven processes are separable, or if they are rather two aspects of one single mechanism.

As can be seen, top-down and bottom-up should be seen as two ends of a continuum. It is established that both models coexist: The question rather is, under what conditions and at what stages of attention they do occur to what degree. The opening tale from the beginning can therefore be seen as exaggerated. It was chosen, however, to show how diametrical and almost dogmatic, top-down and bottom-up models can be represented. Results from experiments, even with the same experimental design, can be remarkably different and even contradictory. Sometimes the literature on visual search indeed paints the picture of a Gordian knot.

3.2   Inhibition of return – a cornerstone of visual research

Directing our eyes to objects is not the only manner in which we can attend to them. An eye-movement (overt attentional shift) can be preceded by a hidden attentional inspection (covert attentional shift). These covert shifts of attention were already mentioned by Helmholtz (1867) and describe the ability to pay attention to locations or objects in peripheral vision, without moving the eyes towards them. We look at something "out of the corner of our eyes".

An example for covert attention is a visual phenomenon called "inhibition of return" (IOR), initially demonstrated by Posner and Cohen (1984). They used a cuing paradigm where participants were to maintain their eyes on a central fixation-point and to press a key, as soon as a target stimulus appeared at one of two peripheral locations. On some trials, preceding the target, a cue was presented either at the same (valid cue) or at another (invalid cue) location as the subsequent target. This cue captured attention covertly, because the participants were not allowed to remove their eyes from the fixation-point, until the onset of the target. All cues were uninformative, meaning that they were equiprobable valid or invalid. For a stimulus onset asynchrony (SOA, i.e. the time-interval between cue and target) of less than 300 msec, target detection was faster if a valid cue was shown, compared to invalid cues or neutral trials (without cue). More importantly, if the SOA was longer than 300 msec, target detection was prolonged for valid cues. This time course applies to exogenous (bottom-up) orienting, evoked by a peripheral cue. Central cues (i.e. an arrow that points to one peripheral location) encourage endogenous orienting (top-down controlled), because attention to a location is not directed by salience, but rather by a search strategy. Because it takes more time to endogenously direct attention, facilitation begins later, but lasts also up to 1000 msec. IOR is usually not encountered with central cues.

This phenomenon of initial facilitation and subsequent inhibition is thought to be a mechanism that biases visual search away from previously attended locations and promotes novel locations in the visual array. Posner and Cohen's findings had a significant impact on the scientific community and triggered tremendous amounts of research (for reviews see Klein, 2000; Lupiáñez, 2010; Lupiáñez, Klein, & Bartolomeo, 2006; Samuel & Kat, 2003). According to the ISI Web of Science (Thomson Reuters, New York, USA), Posner and Cohen's original article was cited over 1170 times.

It is most important to mention that IOR is a phenomenon of visual search, not a theory. However, the term IOR is theoretically not neutral, but implies that attention is disengaged from cued locations and biased against reorienting. Posner and colleagues conceptualised the underlying

attentional mechanism as a spotlight that can only assess one spatial location at a time, and is moved across the visual field. This approach is particularly appealing because it tends towards the biological fundaments of overt attention in terms of the fovea centralis.

Two processes characterise the spotlight metaphor (hence also referred to as "two-factor-model"). One brings attention towards a location, facilitating detection, while the other directs attention away from recently visited locations, making visual search more efficient. The appearance of a cue causes the attentional spotlight to disengage from the fixation-point and to move to the cued position. If the target is shown at this location, detection is facilitated. If the target is shown at another location, attention has to reorientate, and to move to the new position. This procedure requires time, and results in reaction-time costs.

One prediction made by the spotlight metaphor is that at shorter SOAs, valid cues should lead to a reaction-time benefit. The study of Tassinari, Aglioti, Chelazzi, Peru and Berlucchi (1994) detected IOR at a SOA of 0 msec, a time-interval during which there is hardly time to disengage attention from cued locations. Danzinger and Kingstone (1999) employed a cuing paradigm (SOA 50 msec) with four positions in a circular array. In one experiment, the target appeared mostly (67 % of all trials) at the position clockwise to the cued location. Participants had therefore to disengage attention from cues and to redeploy it at the clockwise position. As expected, facilitation was found if the target appeared at the predicted location. Most importantly however, they found the slowest reactions if the target appeared at the cued location. Danzinger and Kingstone (1999) argue that IOR begins at the moment of the attentional capture by the cue. It can however be masked by the initial facilitating effects of the cue. Facilitation and inhibition may therefore be not just two sides of the same coin, but rather independent and counteracting processes.

Berlucchi, Chelazzi and Tassinari (2000) cast doubt on the necessity of attentional disengagement from cued locations (and hence the reorienting) in order to induce IOR. Using a cuing paradigm with peripheral and unpredictive cues, they instructed participants in some trials to attend covertly to a specific location relative to the cue. It was expected that attention would not be disengaged from this location. In other trials, participants were to divide attention equally among all four locations. Surprisingly, similar IOR effects were found for all experimental conditions. It seems therefore that disengaging attention is not a necessity for IOR to occur. These results cannot be reconciled with the above mentioned theoretical construct of the two factor model. It seems unlikely that IOR arises only due to attentional reorientation.

To shed further light on the mechanisms of IOR, it can be revealing to study the underlying neurophysiological processes. There is now ample evidence indicating that the superior colliculus

(SC) plays an important role in IOR. The SC is a structure within the midbrain and is known to control, amongst other things, certain types of eye movements and the pupil size (Klier, Wang, & Crawford, 2001). Most axons from retinal ganglion cells project, across the lateral geniculate nucleus and the optic radiation, to the primary visual cortex in the occipital lobe, where visual information is represented and actually "seen" by the brain. However, some of the retinal ganglions innervate the SC. This is called the retino-tectal pathway. For a closer review about the SC in visual search, see Shen, Valero, Day and Pare (2011).

Evidence for an involvement of the SC in IOR comes from Developmental Psychology, where IOR was found in new-borns and babies, well before to the maturation of cortical areas (Butcher, Kalverboer, & Geuze, 1999; MacPherson, Klein, & Moore, 2003; Varga, Frick, Kapa, & Dengler, 2010). Furthermore, IOR-like patterns were also investigated among birds (Gibson, Juricevic, Shettleworth, Pratt, & Klein, 2005) and are therefore thought to be a very basic mechanism of vision.

Dorris, Klein, Everling and Munoz (2002) trained monkeys to perform a simple IOR task (the SOA randomly varying between 200 msec and 1100 msec). By inserting microelectrodes into the monkeys' SC, they were able to directly analyse the neuronal processes. Surprisingly, while the saccade initiation was delayed for previously cued locations, the saccade related activity in the SC yielded no differences for valid and invalid cues. That means that the magnitude of the motor command itself is not diminished, but only delayed. However, the neuronal activity related to the target's presentation was indeed dependent on the location of the cue. In valid trials, discharge rates were decreased as opposed to invalid trials (see Dorris et al., 2002, figure 1b). During the SOA, there were higher discharge rates for previously stimulated neurons. This argues against the assumption that inhibition originates from the SC. Otherwise neuronal activity would be diminished immediately after cue onset. In a second experiment, Dorris et al. initiated saccades manually (by direct stimulation of respective neurons in the SC), after presentation of the cue. Saccades to the side of the cue were much faster than to the uncued side. This indicates that the SC itself is not inhibited.

Taken together, these results provide direct evidence that the SC is involved in IOR and is probably a necessary structure for the occurrence of IOR. However, it seems that the SC is not the site of IOR, but possibly receives attenuated input from higher cortical areas, most likely the prefrontal cortex (PFC).

Dukewich (2009) conceptualises therefore IOR (at least partly) as spatial habituation. As a very basic ability of the visual system, habituation describes a decrease in orienting responses to repeatedly presented stimuli, as long as they are identical. Usually, this mechanism is thought to depend on features like colour or shape and only to a lesser degree on spatial attributes. Taylor (1998) and Taylor and Klein (2000) rejected this concept, because it is incompatible with early facilitation. Dukewich (2009) replies however:

> for a response to exhibit habituation, an organism must first produce it. In the case of IOR, the
>
> response presumed to be habituated is attentional capture, based on the repetitive stimulation of
>
> a single location in space (p. 240).

This conceptualisation of IOR is appealing, because it can explain a variety of results of previous studies. Based on habituation being a universal ability of the visual system, it explains the involvement of the SC, a phylogenetically older part of the brain. The effects of habituation can however be moderated by cortical areas. A similar approach is also included in the model of Satel, Wang, Trappenberg and Klein (2011), who also argue for a reduced cortical input to the SC.

Gibson and Amelio (2000) emphasise the importance of top-down search goals in IOR. In their experiments, IOR occurred only when cue and target shared the onset feature (no IOR was observed with relevant and irrelevant colour cues at longer SOAs). If we conceptualise top-down regulations as higher cognitive functions, these are most likely controlled by the PFC. Top-down sets may therefore be responsible for the diminished input to the SC.

Tian, Klein, Satel, Xu and Yao (2011) analysed cue-elicited ERPs (event related brain potentials) of the PFC, and indeed detected activation during early stages of post-cue processing. They proposed a neuroscientifically founded model of IOR that relies on four interacting systems (see Tian et al., 2011, figure 7): Control (FEF[4]), Planning (PFC), Command (SC) and the Visual System (occipital lobe). An inhibitory tag for a cued location is generated in the SC and transmitted to the FEF. Simultaneously, the Control system of the FEF reduces the signal for motor preparation to the SC for the tagged location. Faster reaction-times for cued locations occur, if the target is detected before the reduced motor signal reaches the SC. Facilitation is therefore considered to be an attentional mechanism. When the reduced motor signal reaches the SC, IOR begins, but its

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[4] Frontal Eye Fields, an area of the PFC that plays a major role in the control of visual attention

manifestation depends on the relative strength of the attentional facilitation. Strong facilitation might mask initial inhibition.

Since Posner and Cohen's article, there is an on-going debate regarding whether IOR is an attentional or a motor mechanism. Most prominently Rafal, Calabresi, Brennan and Sciolto (1989) suggested that IOR is not generated by attentional capture, but by the oculomotor system, as a result of saccade preparation. Hunt and Kingstone (2003) analysed the impact of eye movements on IOR. In one experiment, the eyes were allowed to move to the target, in another experiment, the eyes had to remain on a central fixation-cross (only covert shifting was allowed). The results are clear-cut. IOR was found in both experiments. The results of the latter experiment cannot be explained by a purely oculomotor bias. Therefore, there seems to be an attentional component in IOR which is dissociable from motor IOR (see Berlucchi, 2006, for a similar argumentation).

Lupiáñez (2010) proposes a three-factor-model, based on the object file-theory (Kahneman, Treisman, & Gibbs, 1992). Object files store spatial and temporal information about visual objects. These files are updated continuously, when the relating object changes slightly. Upon larger changes a new object file is created. According to Lupiáñez (2010), two facilitating spatial factors (selection and orientation) and one detection cost factor (the similarity of cue and target) determine facilitation or inhibition of target detection. If e.g. a cue and a consecutive target have the same shape and spatial location, it would be likely that the target is absorbed in the object file of the cue (rather than creating a new object file for the target) and therefore its detection is hindered.

IOR is indeed a cornerstone of visual research. However, the theories and assumptions concerning the underlying mechanisms and mechanics are far from being consistent and conclusive. But as can be seen, the supposed simplicity of cause and effect in IOR is misleading. Some of the above discussed models of IOR imply that overt and covert mechanisms are closely related, or may even be a single mechanism.

3.3   About the relationship of overt and covert shifts of attention

Klein (1980) argued that a close link between covert and overt attention, would result in facilitated saccades to, and facilitated attentional processing at covertly attended locations. They found neither for endogenous cues, indicating that attention can be placed independent from

saccade preparation. Exogenous cues however, seem to attract attention and saccade preparation simultaneously, though this does not contradict the notion that they are controlled by distinct systems.

Stelmach, Campsall and Herdman (1997) used a temporal order judgement (TOJ) task, where participants had to report which of two targets, left or right from fixation, appeared first. In some experiments, preceding the targets, participants received the instruction to covertly attend to one side, move their eyes to one side, or remain in a neutral state at fixation. For all conditions, the temporal order judgement was around chance level. These results contradict the assumption that saccades are preceded by an attentional shift.

In another experiment, participants were to deploy attention at one location while saccading to another. The side to which attention has to be deployed was indicated by a central arrow, the side to which the saccades had to be executed was cued verbally. If participants covertly attended to the left side, they were able to detect the appearance of the left target sooner, regardless of to which side the saccade had to be executed.

Neuroscientific evidence for this independence account comes from Schall (2004), who found distinct populations of neurons for covert and overt shifting in the FEF.

One of the strongest relationships between covert and overt orienting is proposed by Rizzolatti, Riggio and Sheliga (1994). According to them, saccades and attention are controlled by the same mechanism. Covert shifts can therefore be seen as unexecuted saccades. They base their claim on the meridian effect (Rizzolatti, Riggio, Dascola, & Umilta, 1987). Participants were to fixate a box at the centre of the screen, and to respond to a target onset in one of the four numbered boxes in the upper half of the display. Indicated by a number in the central box, participants had to attend to the respective box covertly. Reactions were fastest, when the target appeared in the box which participants were attending. Interestingly, reactions took longest, when the target appeared in the hemifield opposite to the cue. Rizzolatti et al. argue that every saccade is preceded by an attentional shift which specifies the amplitude and the direction of the eye movement. If the target does not appear at the cued location the saccade programme has to be modified. For targets in the same hemifield, only the amplitude has to be adjusted, while for targets in the opposite hemifield, a radical redirection is necessary. Additionally, in another experiment (Sheliga, Riggio, & Rizzolatti, 1995) participants had to execute a horizontal saccade, while covertly paying attention to a lateral position. Trajectories of saccades were biased away from the cued location, meaning that the oculomotor system was activated, although no saccade to the lateral position was required. These results imply a strong link between saccade preparation and attention.

Based upon their results, Rizzolatti et al. constructed the premotor theory of attention (PMT), which claims that spatial attention is not a distinct system, but rather relies on the same circuits that determine motor behaviour.

Deubel and Schneider (1996) propose a tight coupling between saccade preparation and covert shifts of attention. They found that stimuli are best processed at locations to where a saccade was programmed (i.e. the location of the covert shift). Left and right from a central fixation-point, two letter strings were presented. Participants had to maintain their eyes at fixation, while preparing a saccade to a particular position within the string, indicated by a coloured central arrow. After the offset of the central cue, the saccade had to be released. Shortly (60 msec) after the initiation of the saccade, a discrimination target was presented at either the saccade-target location, near to the saccade-target or on the opposite side. Importantly, the discrimination target was only displayed for 120 msec. Thus, by the time the saccade landed, only coloured placeholders remained visible.

Performance in the discrimination task was best when saccade-target and discrimination target coincided, or were close to each other. In a second experiment, participants were informed in advance, where in the string the discrimination target would appear. It seemed however to be impossible for participants to deploy attention to a location other than the saccade-target. The paper by Deubel and Schneider has become one of the major arguments in favour of the PMT, based upon behavioural data.

Several results from neuroscientific studies support a strong link between covert and overt shifts. Ignashchenkova, Dicke, Haarmeier and Thier (2004) used single cell recordings in the SC of trained monkeys. They found that neurons in the SC code both, attentional shifts and eye movements. Visual and visumotor neurons (not motor neurons however) discharge during covert shifts. This activity was highly correlated with visual acuity. Visumotor neurons were also only active if spatial cues were used, not however if memory cues were used. Therefore, these neurons seem to be involved in spatial shifts of attention, regardless of whether a saccade is subsequently executed or not.

By using fMRI[5], de Haan, Moryan and Rorden (2008) were able to show that the brain regions responsible for covert and overt orienting overlap. They used a design where participants had to either to make a saccade, or to attend to a location without an eye movement. These shifts were

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[5] Functional magnet resonance imaging

endogenously driven. De Haan et al. especially took into account several weaknesses of previous studies. For example, they used the exact same task in the covert and the overt condition, to make sure they are comparable. Additionally, their statistical analysis suggests that the obtained results can be generalised for all participants. Both attentional shifts result in high activation of fronto-parietal networks (i.e. PFC). This can be considered as evidence in favour of the PMT.

Our experiment aims towards a further understanding of the link between covert and overt attention. Unpublished studies from our Institute used a paradigm similar to Deubel and Schneider (1996). We found that saccadic latencies are slower, when saccades are directed to the location of the covert shift. The present study was designed to elucidate our previous experiments, and to test out possible explanations.

4   Rationale for the experiment

We constructed an experiment, where we employed a dual task paradigm. Participants were to covertly attend to a location in order to perform a discrimination task, and to make a speeded reaction to a target-stimulus. This design was inspired by Deubel and Schneider (1996). Admittedly, our discrimination task served only the purpose of demonstrating the covert shift. We were not interested in the discrimination performance during saccade preparation, but only in the latency of target detection.

We used two types of singletons to indicate the location of a target: Cues, which had to be remembered, and distractors, which had to be ignored.

All cues and distractors were uninformative, meaning that the target appeared only with a probability of 0.25 on the same location. Thus, participants had strong incentive to disengage their attention from covertly attended locations. According to contingent capture (Folk, et al., 1992), only cues should draw attention, because they match a task-relevant top-down set. Therefore, in our experiment we expect a main effect of task on reaction-times towards the targets. Cues capture attention, because they are linked with a specific task that needs attentional processing. This processing takes time and attention is harder to remove. Hence cues should lead to slower reactions. Distractors however, should not capture attention, because they are not task-relevant.

Based on our previous studies, we expect a main effect of validity. Valid trials should be responded to slower than invalid trials. Further, an interaction between task and validity is likely. If distractors are ignored completely, it does not matter if they are shown on the position of a subsequent target or not.

By using a SOA of 300 msec, we expect a moderate IOR effect due to the proposed time-course by Posner and Cohen (1984). We explain the occurrence of IOR in terms of the PMT. According to the PMT, participants should prepare a saccade to the location of the cue. This saccade though, is not allowed to be executed. The motor programme should be cancelled. This cancellation occurs, due to the established top-down set, according to which cues are uninformative and the target is most likely to appear at another location. Whenever the cue was valid, a saccade has to be reprogrammed to the very location, it was just deleted from. This is thought to cause interference, resulting in severe reaction-time costs.

It was aimed to assess whether or not our experimental effects expand to other motor modalities than saccades. We conducted our experiment twice, once with saccades and the other time with pointing as reaction modality. In both of our experiments, we expect a main effect of task.

Given the assumption that the PMT primarily applies to the oculomotor domain, we should find these inhibitory effects for saccadic, but not or significantly less strong for manual pointing reactions. Accordingly, we expect, as for saccades, a main effect of validity for pointing, but to a lesser degree. Additionally, between saccades lies a refractory period of about 200 msec (Abrams & Dobkin, 1994), what makes efficient guiding necessary. This should not apply to pointing, thus these movements should be less directly influenced by attentional or motor mechanisms like IOR. Furthermore, Rizzolatti, Riggio, and Sheliga (1994) argued that space is coded differently for saccades and manual responses. Given that is the case, it seems unlikely that validity has the same impact on target detection.

5   Saccade-experiment

Participants

Fourteen undergraduate students (four male) from the Faculty of Psychology of the University of Vienna participated in the experiment. Their ages ranged from 18 to 28 years (mean age = 22.79, standard deviation = 2.64). All participants reported normal or corrected-to-normal acuity of vision. Participants were naive to the purpose of the experiment and had no prior experience with the design or the used stimuli. Every subject was tested individually in a single one hour session with a supervisor present in the room. In compensation they received partial course credit.

Apparatus

The experiment was run on an AMD Athlon Dual Core 5000B with a processor speed of 2.59 GHz, 2 Gb of RAM. As operating system, Microsoft Windows XP, Service Pack 3, was used.

Stimuli were presented on a 19'' CRT-Monitor (Sony Trinitron Multiscan G400) with a native resolution of 1280x1024 pixels, 32 bit and a refresh rate of 120 Hz. The monitor was powered by a NVIDIA GeForce GT 220 graphics board.

The experiment was programmed using Matlab 7.11.0, R2010b (The MathWorks, Inc., Natick, USA), the Psychophysics Toolbox Version 3 (Brainard, 1997), and was run with a resolution of 1024 x 768 pixels. Matlab was also used for the statistical analysis, and the results were cross-checked with SPSS 19.0.0 (IBM Corporation, Armonk, USA).

A second computer was used to monitor the Eyetracker. Eye movements were recorded using the EyeLink 1000 Desktop Mount (SR Research, Mississauga, Ontario, Canada) with a 35mm lens, a sampling rate of 1000 Hz and EyeLink software version 4.52. The eyetracker was adjusted by using a 9-point calibration before the experiment. Only the participants' right eye was tracked, and a chin- and forehead-rest fixated their head at a distance of exactly 57 cm in front of the screen. During the experiment the room was dimly lighted by a 20 Watt halogen bulb lamp behind the CRT-Monitor. For starting a trial and for the registration of the participants' answer in the discrimination task, a standard QWERTZ-keyboard (German language setting) was used.

Stimuli and procedure

Before the start of the experiment, several data were collected from the participant. These consisted of the participants' age, gender, handedness, and whether or not they were using corrective lenses or glasses during the experiment. The answers were registered via the keyboard. Afterwards, the eyetracker was calibrated and the instruction was presented, explaining the

course of the experiment and the tasks. Participants could pose questions, and had further on a full experimental block for practice (containing 65 trials) to make themselves familiar with the task and the stimuli. Figure 1 (p. 28) presents a graphical illustration of stimuli and procedure of the experiment.

All stimuli were presented against a black background (< 0.2 cd/m²). Each trial started with a grey (CIE color coordinates: 6.9, 16.8; 33cd/m²) fixation-cross (0.7° x 0.7°) at the exact geometrical centre of the screen. The fixation-cross was visible during the whole trial. Participants were to fixate the cross, and to press the space-bar whenever they were ready to start the trial. If the eyetracker could not receive a clear signal or a blink occurred at the time of the key-press, the trial did not start, but participants were instructed to re-fixate the cross and to try again.

The first screen was displayed for 50 msec and contained six figures with a size of 1.7° x 1.0°, outline 0.3°. They were presented on two central[6] positions (up and down) and four lateral[7] positions (upper/lower left/right), and were arranged in a circular array, with a radius of 7.0° around the central fixation-cross. Five figures were grey (CIE: 6.9, 16.8; 33 cd/m²) placeholders, while the other was a colour singleton. The singleton could be equiprobably a green (CIE: -30.2, 24.9; 27 cd/m²) distractor, or a blue (CIE: 46.9, -89.0; 25 cd/m²) cue. This could take place only at lateral positions with equal probability. The position of a cue or a distractor was chosen randomly and was counterbalanced across all trials. Participants were instructed to ignore distractors, but to remember the location of cues without saccading. If the eyes were removed from fixation, the trail was aborted and discarded from analysis. This instruction was used to induce a covert shift of attention towards the cue's location.

The first screen was followed by a blank screen, with only the fixation-cross visible, for 300 msec (SOA).

The second screen showed the same array of figures as in screen 1. The colour singleton in this screen was always red (CIE: 47.6, 41.1; 35 cd/m²) and was used as a saccade-target. The saccade-target could also only appear at one of the four lateral positions. With a probability of 0.25 the saccade-target was displayed at the same location as the cue/distractor (valid trial) and with a probability of 0.75 at a different location (invalid trial). For invalid trials the position of the

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[6] 0° and 180° from the vertical meridian
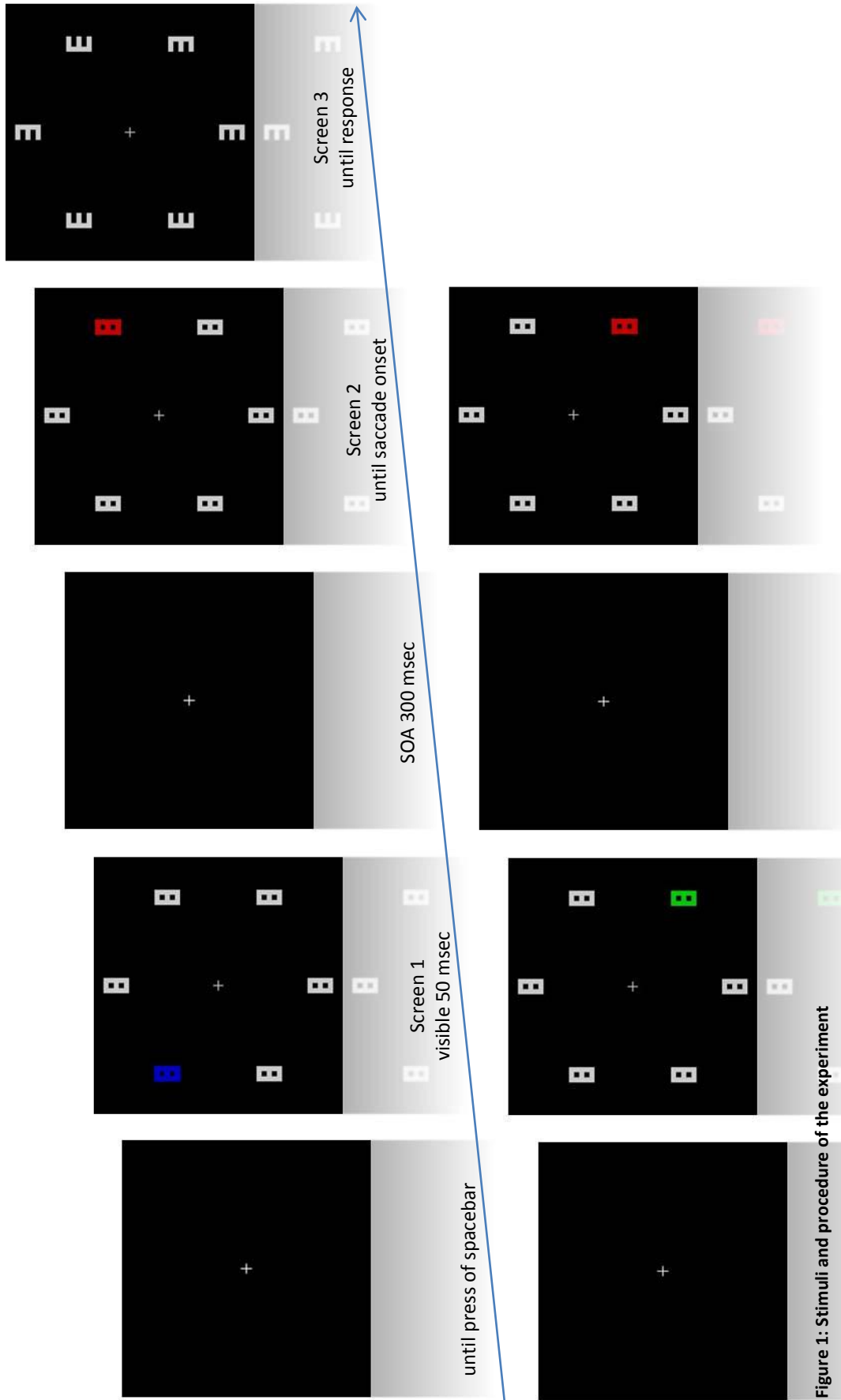[7] 60°, 120°, 240° and 300° from the vertical meridian

Figure 1: Stimuli and procedure of the experiment

The top panel depicts the "invalid cue" condition. The target (red singleton in screen 2) is not shown at the former location of the cue (blue singleton in screen 1). The discrimination task (screen 3) was only demanded for cues. The lower panel depicts the "valid distractor" condition. The target (red singleton in screen 2) has the same position as the distractor (green singleton in screen 1). For detailed explanations refer to subsection *"stimuli and procedure"*, on p. 27f.

saccade-target was chosen randomly among the remaining three lateral positions, and was counterbalanced across all trials.

Participants were instructed to fully concentrate and to execute a saccade to the saccade-target fast as possible after its appearance. If the saccade was initiated too quickly (< 100 msec), or too slowly (> 1000 msec), participants immediately received a feedback on the screen, and corresponding trials were excluded from the analysis. Only if the saccade landed on the saccade-target's position or within 1.5° around its outline, the reaction was counted as correct.

Only if the first screen showed a cue, a third screen was displayed, otherwise the next trial stated. Screen 3 was shown immediately after saccade onset and contained six grey (CIE: 6.9, 16.8; 33 cd/m²) characters (1.7° x 1.0°, outline 0.3°), that could equiprobably either be an E (capital "e") or a Ǝ (digital "3"). The identity of the character was chosen randomly and was counterbalanced across all trials. Participants were to identify the character on the former location of the cue. This task was used to control whether or not a covert shift of attention towards the cue was conducted. The answer was given via the keyboard, using the F-key for "E" and the J-key for "Ǝ". Participants had as much time as they needed to answer and were also allowed to look down on the keyboard. After the answer was typed in, the next trial started.

Design

The experiment consisted of six blocks, each containing 65 trails. Blocks were interrupted by breaks that could be finished by the participant. The whole first block was used for practice and was therefore excluded from the statistical analysis. During the practice block, participants received an on-screen feedback if their answer in the discrimination task was correct.

In sum, the experiment consisted of the two-levelled factor "task" (to-be-remembered-cue or to-be-ignored-distractor) and the two-levelled factor "validity" (invalid or valid). From this 2x2 design derive four different experimental conditions:

- valid cue
- invalid cue
- valid distractor
- invalid distractor

5.1   Results

In about 90.68 % of all trials, the eyetracker monitored the eyes correctly and collected data. As mentioned, trials with too slow or too fast saccades were excluded, as well as trials with wrong answers in the discrimination task, and trials, where the saccade did not land on the target. In total, 9.79 % of all trials were removed. One participant was removed completely, because the saccades were too slow in more than 50 % of all trails.

Table 1: Saccadic latencies

Means (M) and standard deviations (SD) of saccadic reaction-times, for all bins (rows) and all four experimental conditions (columns). Reaction-times were measured in msec after target onset.

	valid cue		valid distractor		invalid cue		invalid distractor	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Bin 1	178,06	46,88	193,22	47,55	186,45	17,76	176,95	19,80
Bin 2	235,73	70,91	244,35	65,31	217,88	29,55	205,45	32,77
Bin 3	284,55	81,08	285,51	72,00	248,79	40,88	240,19	48,11
Bin 4	349,38	95,87	329,65	81,70	298,91	64,65	274,24	63,11
Bin 5	485,92	128,11	446,20	111,35	408,88	116,83	373,73	98,88

For each of the remaining 13 participants, the reaction-times were divided into five bins (percentile analysis). The measured saccade speeds were sorted in an ascending order and this list was then divided in five equal parts. Table 1 contains the means and standard deviations for all bins in all conditions. Using the bin analysis, the experimental effects can be assessed for different types of saccades (van Zoest, et al., 2004). The moment of saccade-start (eyes' disengagement from fixation-cross) and the moment of saccade-landing (eyes' fixation on saccade-target) were analysed separately, to take account of differential effects. The results, however, yielded no differences. Henceforth, only the results for saccade-start are reported here. The accuracy, with which the saccades landed on the saccade-target, was explored as well.

Saccadic latencies

Reaction-times were measured as the time interval between target onset and saccade onset. A repeated-measurements ANOVA was conducted with bin (5 levels), validity (2 levels) and task (2 levels). The results yielded a significant main effects for validity, $F(1, 13) = 21.72$, $p < 0.001$, and task, $F(1, 13) = 7.20$, $p = 0.019$. Significant interactions between bin and task, $F(4, 52) = 13.21$, $p <$

0.001, and bin and validity, $F(4, 52) = 8,84$, $p < 0.001$, implied that the experimental effects had a different impact within single bins. For this reason, a separate analysis for each bin was conducted. Figure 2 represents a graphical illustration of the saccadic latencies per bin and condition.
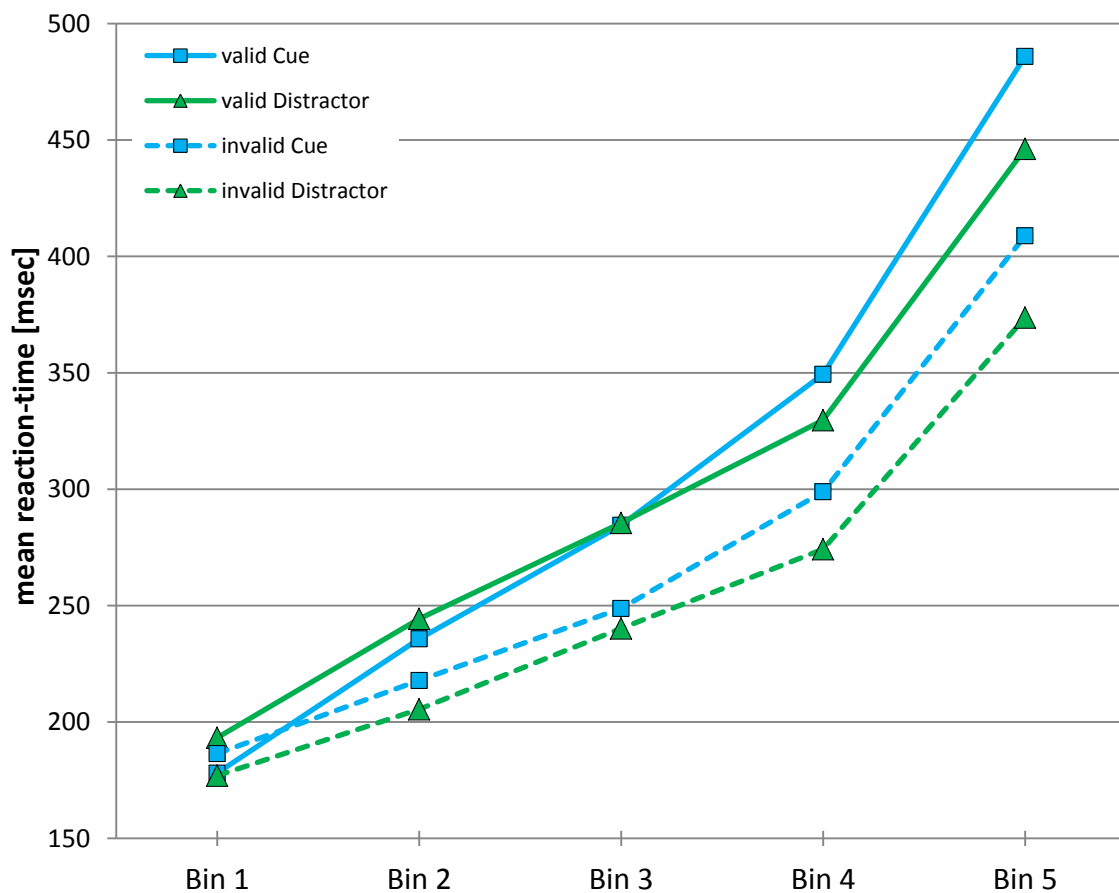

Figure 2: Saccadic latencies

Mean reaction-times of saccades (ordinate) as a function of bin (abscissa) and experimental condition (separate lines). Blue lines indicate trials with cue, green lines trials with distractor. Solid lines signify valid trials, dashed lines invalid trials. For exact data and standard deviations refer to Table 1. All reaction-times were measured in msec after target onset.

Bin 1 showed neither an influence of validity nor of task (both Fs < 0.81, both ps > 0.38). But the interaction validity*task became highly significant at $F(1,13) = 14.61$, $p = 0.002$. Pairwise comparisons revealed that valid cues were significantly faster responded to, than valid distractors ($t(13) = -2.56$, $p = 0.024$), whereas invalid cues showed significantly slower reaction-times, than invalid distractors ($t(13) = 4.04$, $p = 0.001$). Note however that one should not attach too much importance to the significant interaction, because the omnibus ANOVA showed no significant triple interaction of validity*task*bin ($F < 0.84$, $p > 0.505$).

Bin 2 yields a significant main effect for validity, $F(1,13) = 6.00$, $p = 0.029$, but not for task ($F < 0.17$, $p > 0.684$). The invalid distractor condition provoked the fastest reactions, significantly faster than valid distractors ($t(13) = -3.55$, $p = 0.004$), valid cues ($t(13) = -2.35$, $p = 0.035$), or invalid cues ($t(13) = -3.07$, $p = 0.009$). As in bin 1, the interaction validity*task reaches significance, $F(1,13) = 7.64$, $p= 0.016$. Valid distractors were reacted to faster than invalid cues ($t(13) = 2.20$, $p = 0.046$). For the importance of this interaction, the same restrictions apply as in bin 1.

In Bin 3 we have only an effect of validity, $F(1,13) = 17.00$, $p < 0.001$, but neither for task nor the interaction (both Fs < 1.22, both ps > 0.29). Invalid trials provoke faster reactions both for the cue and the distractor condition, as can be seen in Figure 2.

Bin 4 showed a large main effect for validity, $F(1,13) = 39.55$, $p < 0.001$, as well as for task, $F(1,13) = 10.04$, $p = 0.007$. No interaction was found ($F < 0.19$, $p > 0.671$). The trend from previous bins of faster reactions in invalid trials continues in bin 4, but now we can also see an influence of the task. Cues that had to be remembered show a greater hindrance in reaction-times, in relation to distractors that had to be ignored.

In bin 5 the influence of task became more prominent, $F(1,13) = 12.59$, $p = 0.001$, and the main effect of validity, $F(1,13) = 18.00$, $p = 0.001$, was present as well. The interaction did not reach statistical significance ($F < 0.03$, $p > 0.873$). The patterns of results were the same as in bin 4.

As can be seen, in bin 4 and 5 (i.e. slower saccades), the influences of the four conditions on saccadic reaction-times are fully developed. Only for valid cues, we find facilitation in bin 1. Valid distractors on the other hand, never facilitate target detection, but always display inhibition. To further elucidate the effects, the factors task and validity were grouped and plotted separately. Figure 3 (p. 33) illustrates the results. The inhibitory effect of validity becomes stronger, for later bins. We can see that task has no influence in bins 1 to 3, but cues induce slower reaction in bins 4 and 5 (indicated by positive values).
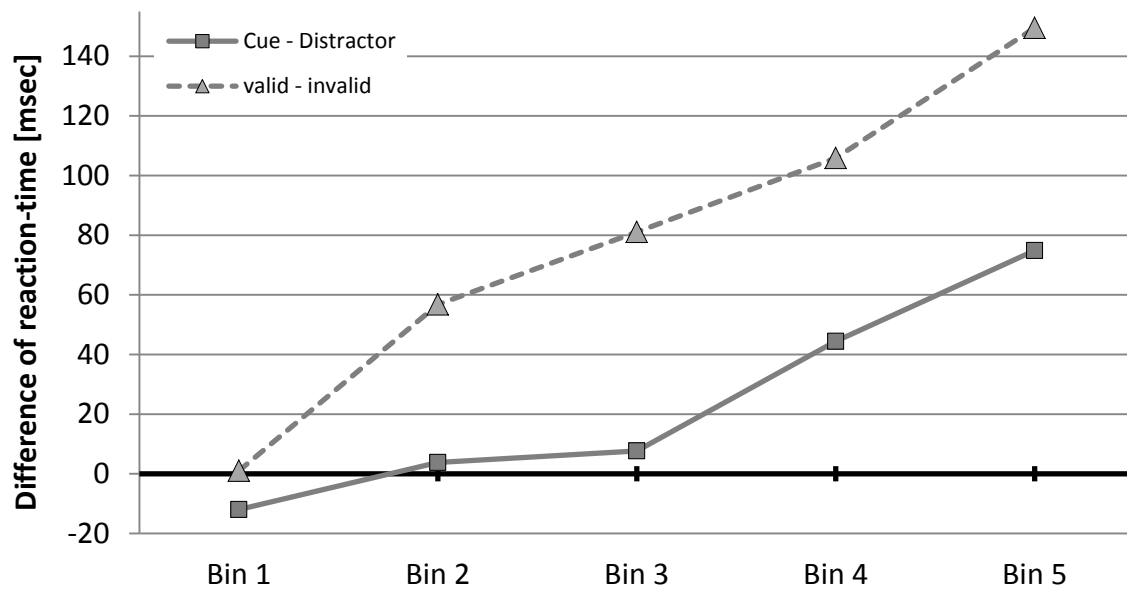
Figure 3: Differences of saccadic reaction-times

Solid lines show the differences between cues and distractors. Reaction-times for distractors were subtracted from cues. Positive values represent slower reactions for trials with cue. Dashed lines show differences between valid and invalid trials. Reaction-times for invalid trials were subtracted from valid trials. Positive values represent slower reactions for valid trials.

Saccadic accuracy

The accuracy of saccades was analysed in order to control for trade-off effects. It is possible that the faster reactions for invalid distractors are explained by their lower accuracy. Accuracy was measured in terms of how many pixels away from the geometrical centre of target the saccade landed. A 5x2x2 repeated measures ANOVA was computed with the factors bin, validity and task. Indeed, a significant main effect of validity, $F(1,13) = 8.78$, $p = 0.011$, was found, while task and none of the interactions showed a significant influence (all Fs < 1.95, all ps > 0.186). Solely the factor bin failed closely to exceed statistical significance, $F(4,52) = 2.30$, $p = 0.071$. Pairwise comparisons reveal that a significant difference between valid and invalid trials, can only be found in bin 1, $F(1,13) = 7.47$, $p = 0.017$. As Figure 4 shows, the reactions in invalid trails were less accurate than in valid ones.
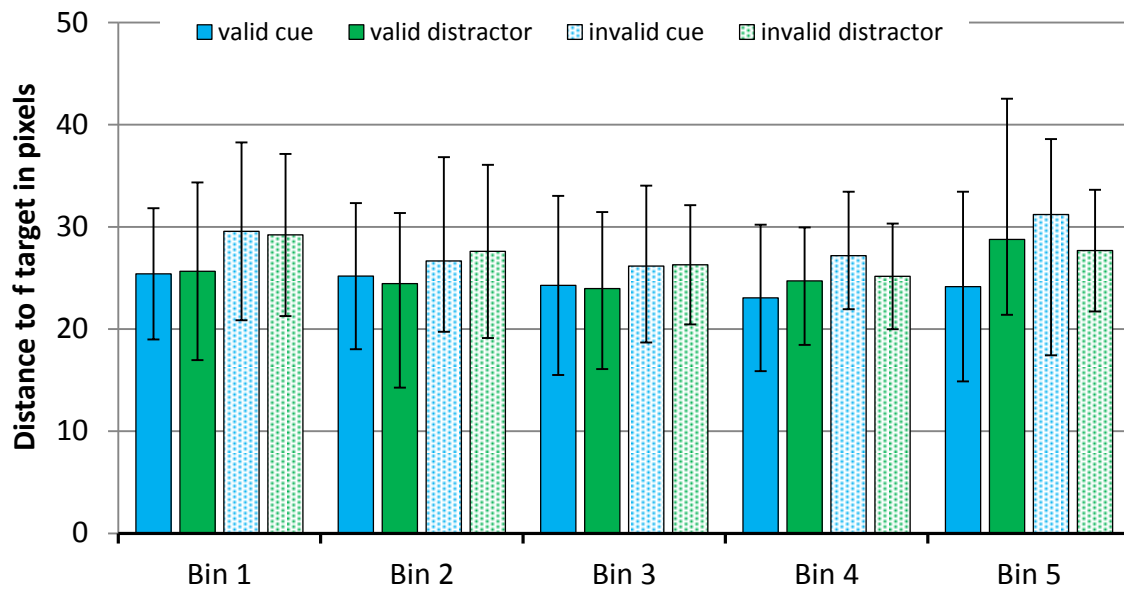
Figure 4: Accuracy of saccades

The ordinate contains the mean distance between the geometrical centre of the target and the location where the saccade was registered. Separate bars indicate experimental conditions. The error bars are standard deviations.

5.2   Discussion

The following argumentation focuses solely on the saccades and the related IOR-results. These results will be discussed in front of different literature. For the comparisons between saccades and pointing, as well as for the discussion of the main hypotheses, refer to the general discussion (chapter 7, p. 52).

Inhibition of return

We see strong IOR effects for valid (i.e. recently attended location) trials. This is at odds with the work of Posner and Cohen (1984), because according to them, inhibition should only begin at a SOA of 300 msec, whereas in our case it is already fully developed. However, a closer review of IOR related literature shows that the results regarding inhibition in the cuing paradigm can be remarkably different.

First, it seems that the time-course of IOR is dependent on the modality of the motor reaction. Many IOR experiments used manual reactions (mostly key-presses) for the registration of the participant's detection-responses. By using this method, the cross-over between facilitation and inhibition starts indeed at 300 msec (see Samuel & Cat, 2003, figure 1). However, if a saccade is

used as reaction modality, IOR develops more quickly (see Klein, 2000, figure 3). It can be argued, that this is due to a more direct connection between input and reaction modality. Participants use input from their eyes for a reaction with their eyes. No shifting between modalities is required. This modality shift effect (MSE) was recently studied by Miles, Brown and Poliakoff (2011). They present empiric evidence that cue-stimuli do not capture attention to their modality in an automatic manner, meaning that targets preceded by same-modality cues showed no difference in reaction-times, compared with targets preceded by different-modality cues (see Miles et al., 2011, experiment 1). However, they showed that the modality of preceding target did affect reaction-times towards following targets, resulting in benefits, if the targets had the same modality. By specifically directing attention to the cue (Miles et al., 2011, experiment 2) the target-target effect could be diminished for saccades. In other words, once attention is endogenously directed to a specific modality, it lingers there for a brief period of time, unless it is redirected. This is thought to be a top-down process that facilitates subsequent processing of stimuli, and can explain our results.

Furthermore, targets and cues/distractors in our experiment did not only share the modality, but also the shape. Hu, Samuel and Chan (2011) argued recently that IOR can be influenced by features other than that of space. Their results show additional reaction-time costs for feature repetition, such as colour (experiments 2 and 3) or shape (experiment 4). However, these costs only occurred when cue and target shared the same position. Location seems to have a unique status in visual selection, possibly because it is a stimulus feature as well as an attribute of the motor response (Dukewich, 2009). Additionally, space has a unique status in target detection (Chica, Taylor, Lupianez, & Klein, 2010). The IOR effects of shape could be explained by simple repetition blindness[8] (Kanwisher, 1987). Though, a closer look on the results of Hu et al. (2011) reveals that the effects of shape are still present at SOAs of more than 1500 msec. This cannot be reconciled with repetition blindness.

Hu and Samuel (2011) replicated the experiment of Hu et al. (2011), but used a discrimination task instead of a simple detection task. The location based IOR yielded similar results for both tasks, with a faster developing inhibitory effect in the detection task. However, non-spatial attribute repetition shows very different results for detection and discrimination. For detection similar results as those of classic IOR were obtained, but only when cue and target shared a location as well as features. In contrast, discrimination shows early facilitation regardless of whether or not cue and target had the same position, as long as they shared a feature (for an

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[8] i.e. the tendency to overlook similar items when they are presented in a fast, serial sequence

illustration, see Hu & Samuel, 2011, p. 793, figure 4). Therefore, the effects of location and feature repetition seem to be (partially) independent. Riggio, Patteri and Umilta (2004) proposed that location and feature based IOR can work in an additive fashion. Our study used a detection task, where cues/distractors and target shared location as well as shape. Therefore both inhibitory effects might explain our strong results.

Hu and Samuel (2011) found that IOR manifests faster in detection tasks, as compared to discrimination tasks. This is in line with studies from Lupiáñez, Milan, Tornay, Madrid and Tudela (1997). They compared the time-course of IOR in detection and discrimination, and found a delayed onset of IOR in the latter task. They attributed their resutls to the more demanding task properties. Discrimination relys on an object-based representation of the cue, wheras for detection, a simple location-based representation is suffcient. In other words, for preceptually more difficult tasks, IOR develops later. After the publishing of the influential and highly cited paper by Lupiáñez et al. (1997), task difficulty became an important and vigorously discussed research topic in IOR. For example, it was objected that not the mere task difficulty, but the task-type itself (detection, discrimination), along with the number of non-targets (distractors) and the number of possible target locations, determine the time-course of IOR (Cheal & Chastain, 2002). Birmingham, Visser, Snyder and Kingstone (2007) outlined IOR as a capacity-limited process whose effect declines as the number of possible target locations increases. This is particularly astonishing, because in situations with many target locations, an efficient mechanism for guided visual search would be most helpful.

In any case, it was assessed whether task demands can influence target detection as well. Castel, Pratt, Chasteen and Scialfa (2005) used perceptually degraded targets in detection tasks, and found a later onset of IOR. Two different explainations were offered. First, for harder-to-percieve-targets, more attention has to be allocated at the cue's position. This can be also interpreted as a stronger attentional control setting for difficult target detection (Klein, 2000). A stronger top-down influence is necessary which requires more time. Secondly, with more attention at the cued location, the cueing effect could be enhanced. Thus, the amount of faciltation is increased and maskes subsequent inhibition.

Converly, we could argue that for easier detection tasks, IOR appears sooner. In our experiment salient colour singletons were presented at four possible locations against a black background. Due to these easily percievable stimuli, inhibition might have developed more quickly.

Facilitation in bin 1

In bin 1, valid cues evoked a reaction-time benefit. This facilitation was found in many other IOR-studies, but its implications continue to be discussed extensively. In the introduction, we already pointed out that facilitation occurs only under specific circumstances and is not necessarily coupled with inhibition. For example, Tassinari and Berlucchi (1995) found no facilitation in cue-target experiments with very short SOAs (e.g. 200 msec, compare their figures 1 and 2) and propose that facilitation might be a separate process that runs parallel to inhibition. Among others, Maruff, Yucel, Danckert, Stuart and Currie (1999) argue that, in addition to a sort SOA (< 150 msec), a temporal overlap between cue and target is necessary to induce facilitation. However, this overlap might not be as mandatory as claimed, because there are plenty of studies where facilitation was shown without temporal overlap (e.g. Lupiáñez et al., 1997; Briand, Larrison, & Sereno, 2000; Hu and Samuel, 2011). Danziger and Kingstone (1999) claimed that inhibition is triggered by the offset of the cue. This inhibition is initially masked by the facilitatory effects of cues (i.e. cues capture attention, which subsequently lingers at the cues location for a brief period of time). This points to the assumption that the SOA is not the only crucial factor that influences the occurrence of IOR and facilitation respectively. The ISI (inter-stimulus-interval, i.e. the duration between cue offset and target onset), as well as the duration of the cue, may also have an influence. Maintaining the eyes on the fixation-cross, while covertly attending to a peripheral location, requires the suppression of a saccade, which results into a motor bias towards the attended location (Tassinari, et al., 1994). However, the findings of Collie, Maruff, Yucel, Danckert and Currie (2000) point out that "the motor bias takes longer than 150 ms[ec] to arise" (p. 1744) and therefore a respectively short ISI can induce facilitation or reduce inhibition. This explains why Maruff et al. (1999) found facilitation with a temporal overlap of cue and target (i.e. no ISI), as well as the reason why facilitation is found in some experiments and not in others, although a similar SOA is used.

But not only temporal factors have an influence. There is evidence indicating that facilitation at short SOAs is dependent on whether or not cue and target spatially overlap. In order to induce facilitation, along with a sort SOA, cues and targets ought not to overlap. Pratt and colleagues (Pratt, Hillis, & Gold, 2001) found neither facilitation nor inhibition for spatially overlapping cues at short SOAs. The relation of combined temporal and spatial overlap was further investigated by McAuliffe and Pratt (2005). They conclude that there are different patterns for facilitation and inhibition. There was only inhibition at ISIs of at least 100 msec and never facilitation if cues and targets overlapped spatially, even when the SOA was short.

As we can see, inducing facilitation is not as easy as inducing inhibition. Lupiáñez (2010) summarises in his paper a few studies about facilitation in IOR and concludes:

> the optimal conditions for obtaining facilitation at short SOAs in spatial cuing detection tasks appear to involve: a paradigm with a short enough SOA (around 100ms), in which the cue and target are spatially easy to discriminate, target onset is easy to discriminate, participants are not practised, and the experiment is as short as possible. (p. 23)

Given this argumentation, it seems unlikely that our results are explained by "classic" facilitation. We used a SOA of 300 msec, participants were trained (65 training trials), and cues/distractors and targets shared the exact same location in valid trials. But if our results are not explained by facilitation, by what are they then? It has been proposed that fast saccades are more bottom-up driven than slower saccades (Mulckhuyse, van Zoest, & Theeuwes, 2008) and may therefore be more influenced by stimulus properties than by the experimental manipulations. Furthermore, bin 1 may contain some anticipatory saccades, which slightly exceed the lower boundary of 100 msec for valid saccadic latencies.

The influence of the task

In bins 4 and 5, we see that cues evoke slower reactions than distractors (significant main effect of task in both bins). We argue that participants disengaged their attention from cues only slowly, although they were uninformative. A cued location had to be remembered. Therefore, it had to be actively held in working memory and received most likely a sounder processing than distractors. Assuming this is the case, why do we find slower reaction for cues, especially for valid ones? Belopolsky and Theeuwes (2009) let their participants perform a series of detection tasks, where the location of a cue had to be held in spatial working memory (SPWM). They found that saccades in memory conditions were significantly slower than in no memory conditions. Furthermore, these results seemed to be independent from the number of possible cue locations (see experiment 3A), and they also provided evidence that attention was maintained at to-be-remembered locations and was not disengaged (see experiment 3B).

The coincidence of cue location and memorised location appears to be critical, because studies where the memorised location was only near the cue, failed to affect the magnitude of IOR (Theeuwes, Van der Stigchel, & Olivers, 2006), though it was found that saccadic trajectories

deviated away from cued locations. In addition, Zhang and Zhang (2011) recently argued that saccadic IOR is not diminished if the SPWM is occupied by up to four items, whereas memorised and cued locations never coincided. This suggests that keeping a location in SPWM does not result in facilitated reactions. For our data, this would mean that memorised locations do not promote target detection.

Furthermore, Berlucchi, Chelazzi, and Tassinari (2000) proposed that "benefits and costs from intentional covert orienting were additive with cue-induced effects, regardless of whether the cues were valid or invalid" (p. 658). They used a cuing paradigm with a neutral condition, where all four possible lateral target locations should be attended to without removing the eyes from fixation. This notion can also explain why cues yield slower reactions in comparison to distractors of the same validity.

Speed-accuracy trade-offs

As Figure 4 (p. 34) shows, saccadic accuracy was affected by the validity but not by the task. Thus, the load of SPWM or the additional discrimination task had no influence on accuracy in our experiment. Responses to valid trials were more accurate. This may be accounted for by simple speed-accuracy trade-offs, because reactions in invalid trails were faster than in valid ones. On the other hand, one can argue that covert shifts improve saccadic accuracy (Deubel & Schneider, 1996), because attention was allocated there and a saccade could be planned in advance. However, the fact that valid distractors also provoked more accurate responses indicates that distractors captured attention as well.

6   Touch-Experiment

To elucidate the effects of covert deployment of attention outside the domain of eye movements, we adapted the design of the saccade-experiment, and used manual finger-pointing as reaction modality. The eyes were not tracked. Stimuli and procedure were not changed. Thus, the following sections focus primarily on the differences to the saccade-experiment.

Participants

Twenty-one undergraduate students (seven male) from the Faculty of Psychology of the University of Vienna were tested. Their acuity of vision was reported as normal or corrected. Ages of participants ranged from 18 to 28 years (Mean age = 21.38, standard deviation = 2.67) and seven were left-handed. Participants were naive to the purpose of the experiment and its hypotheses, and had no prior experience with the design or the used stimuli. It was particularly accounted for that they had not participated in any other study using a similar paradigm. Participants were tested individually in a one hour session and received partial course credit in compensation.

Apparatus

We used the same computer (AMD Athlon Dual Core 5000B) and software as in the previous experiment. For the stimulus' presentation, the registration of the participants' manual reactions, and the registration of the participants' answers in the discrimination task, a 19'' Ilyama ProLite T1931SR touchscreen was used. The screen had a native resolution of 1280 x 1024 pixels, 32 bit and a refresh rate of 75 Hz. The experiment was run with a resolution of 1024 x 768 pixels.

Participants had to stay in front of the screen, looking down at it. The screen was placed on a table with the height of 72.2 cm above the floor, and was inclined at an angle comfortable to the participants. They were able to clearly see the screen, without any disturbing effects like reflections present. Due to this individual inclination, the distance between participant and screen could not be held constant. However, this is not considered to have a debilitating impact on the value of our results. The touchscreen was calibrated in advance, using a four-point-calibration. Its sensitivity was set to the maximum, its delay to the minimum.

For the registration of the participants' data at the beginning of the experiment a standard QWERTZ-Keyboard (German language setting) was used.

Stimuli and procedure

First, the data about the participants' age, gender, handedness and whether or not they used of glasses or corrective lenses were collected. For this task the keyboard was used. Afterwards, the participants read the instruction on the screen and received a training phase.

The illuminances of the IIyama Touchscreen were slightly different from the screen we used in the previous experiment. Again, stimuli were presented against a black background (< 0,2 cd/m²). For starting a trail, participants had to press the index finger of their dominant hand on the central grey fixation-cross (~[9] 0.7 x 0.7; CIE: 6.9, 16.8; 36 cd/m²). They were not allowed to change hands or fingers during the experiment. Only if they applied constant pressure on the cross, the trial started. Participants were also instructed to constantly fixate their index finger with their eyes.

Screen 1 (refer to Figure 1, p. 28) showed the central fixation, seven grey placeholders (~1.7° x 1.0°, outline 0.3°) and equiprobably either one blue cue (~1.7° x 1.0°, outline 0.3°; CIE: 46.9, -89.0; 29 cd/m²), or one green distractor (~1.7° x 1.0°, outline 0.3°; CIE: -30.2, 24.9; 33 cd/m²). Colour singletons could only appear at one randomly chosen lateral position (counterbalanced across all trials) with equal probability. The display duration was 50 msec.

After the offset of the colour singleton, the screen remained black for 300 msec, and only the fixation-cross was visible. Note that from the beginning of the trail until the presentation of screen 2, participants had to apply constant pressure on the central cross. If they relieved their finger at any earlier point, the trial was aborted and discarded from the statistical analysis.

Screen 2 showed seven placeholders in the same array as in screen 1, and one red pointing target (~1.7° x 1.0°, outline 0.3°; CIE: 47.6, 41.1; 35 cd/m²). As in the saccade-experiment, cues and distractors were uninformative (75 % of all trials were invalid, 25 % valid). For invalid trials the position of the target was chosen randomly (counterbalanced across all trials) among the remaining three lateral positions. Only after target onset participants were allowed to relieve their finger from the central cross, and to tab the red singleton as fast as possible. If participants should have reacted too slow (> 1000 msec) or too fast (< 100 msec) they received an on-screen feedback, and the corresponding trial was excluded from the analysis. Every tab on the target or within 1.5° around its outline was counted as a correct reaction.

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[9] as mentioned, the distance between screen and participant was not constant. Therefore, the approximate sizes of the stimuli are reported here.

If screen 1 contained a cue, a discrimination task was demanded. After participants tabbed the target, all placeholders and the target switched to the grey characters E or Ǝ (~1.7° x 1.0°, outline 0.3°). Participants were asked about the identity of the character on the former location of the cue. Two new symbols for the registration of the answer were now displayed, the character E (~3.4° x 2.0°, outline 0.6°) in the lower left corner of the screen, the character Ǝ in the lower right corner (both about 2° away from screen borders). To answer, participants had to tab one of these characters, without time-limit. After the answer, the central fixation-cross was shown again in order to start the start the next trail.

The design, as well as the four experimental conditions, were analogous to the saccade-experiment.

6.1   Results

Table 2: Reaction-times for manual responses

Means (M) and standard deviations (SD) of finger lifted (upper panel) and finger landed (lower panel) for all bins (rows) and all four experimental conditions (columns). The reaction-times are measured in msec after target onset.

		valid cue		invalid cue		valid distractor		invalid distractor	
		M	SD	M	SD	M	SD	M	SD
finger-lifted	Bin 1	153,13	24,55	158,49	28,81	147,83	16,93	153,81	26,62
	Bin 2	189,49	38,02	190,42	42,32	179,05	26,33	181,97	33,23
	Bin 3	227,45	50,82	222,54	46,66	214,48	36,32	213,65	39,11
	Bin 4	281,42	57,69	271,55	45,26	259,50	43,18	256,09	40,07
	Bin 5	389,84	82,42	378,05	109,72	357,14	84,55	331,41	79,10
finger-landed	Bin 1	538,84	69,73	519,50	74,15	545,61	61,52	532,13	66,88
	Bin 2	602,34	80,17	573,73	79,17	601,00	69,96	580,67	72,25
	Bin 3	647,66	88,18	614,65	81,51	643,89	78,41	617,05	78,25
	Bin 4	712,44	103,29	665,57	94,03	704,08	89,40	659,98	86,56
	Bin 5	826,51	115,66	754,30	101,82	814,72	89,02	748,80	96,06

All trials with too slow or too fast responses, as well as trials were the finger was lifted before the occurrence of the target, and trials were an incorrect answer in the discrimination task was given, were excluded. This applied to 7.40 % of all trials. As mentioned, the first block was used for practice and therefore discarded from the analysis.

Analogous to the saccade experiment we divided the responses of all participants into five bins. Two different time-measurements were taken. Finger-lifted describes the time it took to initiate the reaction and was collected as the interval between target onset and disengagement of the finger from the fixation-cross. Finger-landed illustrates the time the finger took to land on the target and was measured as the interval between target onset and the time the participant tabbed the target. To account for differential results, these two times were analysed separately. Furthermore, the accuracy of reactions was analysed to account for trade-off effects.

Finger-lifted

The upper panel of Table 2 summarizes the means and standard deviations for all bins and conditions. We conducted a repeated-measurements ANOVA with the factors bin (5 levels), validity (2 levels) and task (2 levels). The overall ANOVA displayed a significant main effect of validity, $F(1,20) = 8.42$, $p = 0.009$, as well as the significant interactions task*bin, $F(4,80) = 3.23$, $p = 0.017$, and validity*bin, $F(4,80) = 4.54$, $p = 0.002$. The factor task and all other interactions remained statistical insignificant (all Fs < 1.70, all ps > 0.207). It seems that task and validity have differential effects on individual bins. Therefore, they were analysed separately and pairwise comparisons were computed.

Bin 1 showed a significant main effect of validity, $F(1,20) = 5.49$, $p = 0.030$. This was accounted for by slower reactions of valid distractors, compared to invalid distractors ($t(20) = 2.14$, $p = 0.045$) and invalid cues ($t(20) = 2.39$, $p = 0.026$). The effect of task neared significance, but did not exceed it, while the interaction yielded no relevant results (all Fs < 3.25, all ps > 0.087).

The factor validity was also significant in bin 2, $F(1,20) = 6.52$, $p = 0.019$. This is accounted for by faster reactions following invalid cues, compared to valid cues ($t(20) = -2.33$, $p = 0.030$). Furthermore, invalid distractors were responded to faster, than both valid cues, $t(20) = -2.08$, $p = 0.050$, and valid distractors, $t(20) = -2.39$, $p = 0.027$. No other effects were found (all Fs < 0.38, all ps > 0.544).

In Bin 3, no significant results were found (all Fs < 0.55, all ps > 0.466), although the factor validity came close ($F = 3.92$, $p = 0.062$). In any case, one can conclude that the trend of invalid trials being faster than valid trials continues. This was confirmed by a slightly significant comparison between the condition invalid distractor and valid cue, $t(20) = -2.12$, $p = 0.047$.
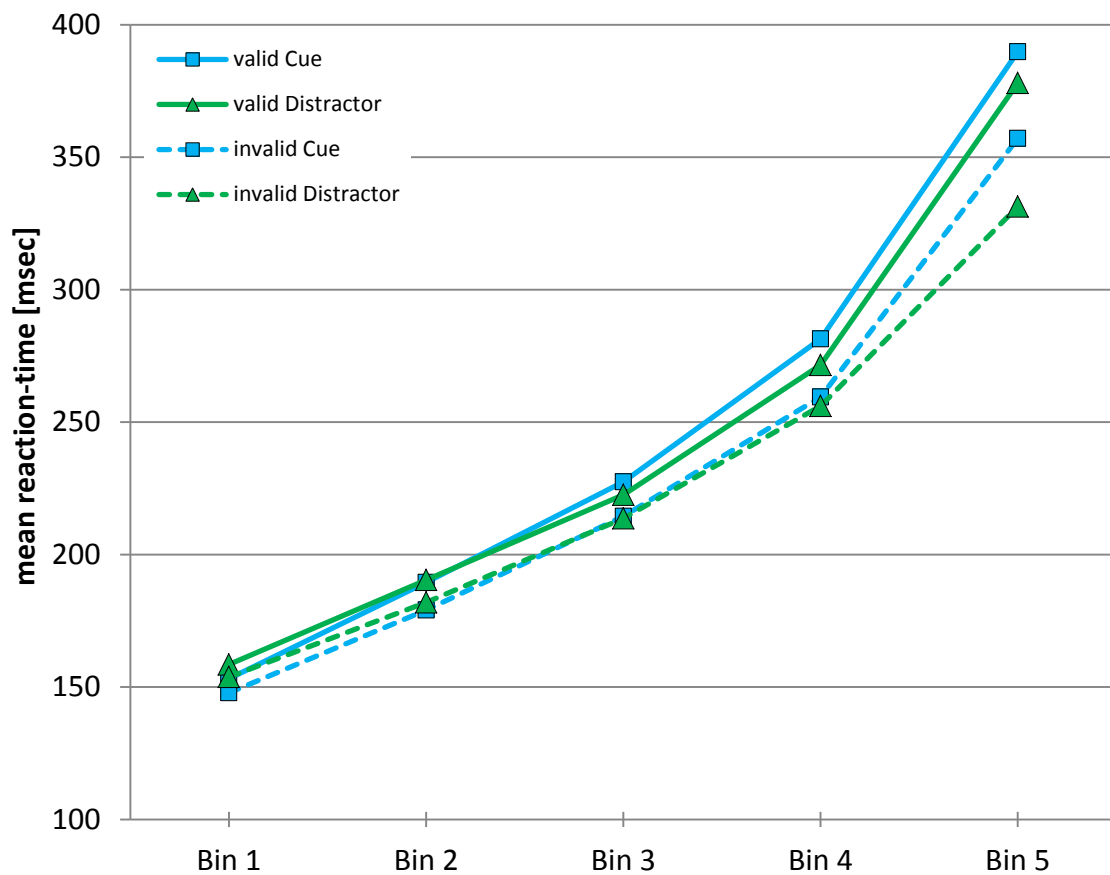
Figure 5: Reaction-times for finger-lifted

Mean time it took participants to lift their finger (ordinate), as a function of bin (abscissa), and experimental condition (separate lines). Blue lines indicate trials with cue, green lines trials with distractor. Solid lines signify valid trials, dashed lines invalid trials. For exact data and standard deviations refer to Table 2, upper panel. Reaction-times were measured in msec after target onset.

Bin 4 continued the pattern of the last bins, with an effect of validity, $F(1,20) = 10.23$, $p = 0.005$, but no effect for task or the interaction (all Fs < 2.59, all ps > 0.123). Also the pairwise comparisons outlined the same pattern as before, with invalid distractors being faster than valid distractors, $t(20) = -2.86$, $p = 0.010$, and valid cues, $t(20) = -3.46$, $p = 0.002$, as well as invalid cues being faster than valid cues, $t(20) = -2.67$, $p = 0.015$.

In bin 5, we found a main effect of validity, $F(1,20) = 6.30$, $p = 0.021$, but no interaction ($F = 0.32$, $p = 0.577$). Invalid distractors again provoked significantly faster reactions, compared to valid cues, $t(20) = -4.21$, $p < 0.001$, and invalid cues, $t(20) = -3.10$, $p = 0.006$. The latter result also accounts for the almost significant main effect of task ($F = 3.29$, $p = 0.085$).

We can conclude that the results are quite consistent across the bins. In the omnibus ANOVA we found a significant interaction of task*bin. This is solely explained by the two almost significant effects of task in bins 1 and 5. Figure 5 (p. 44) illustrates the results reported above. From the close arrangement off all lines, we can conclude that IOR-effects occurred at a minimum.
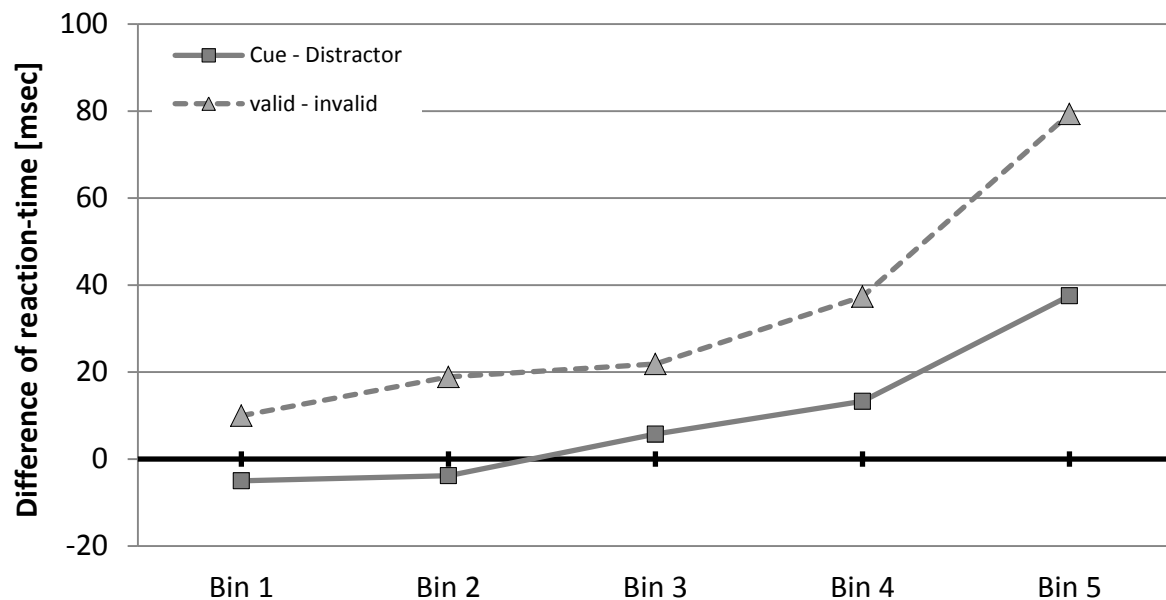

Figure 6: Differences of reaction-times for finger-lifted

Solid lines show the differences between cues and distractors. Reaction-times for distractors were subtracted from cues. Positive values represent slower reactions for trials with cue. Dashed lines show differences between valid and invalid trials. Reaction-times for invalid trials were subtracted from valid trials. Positive values represent slower reactions for valid trials.

As for the saccades, the differences of the reaction-times between the factors were plotted (Figure 6). As can be easily seen, valid trials always lead to inhibition. Besides, this graph further illustrates the absence of the main effect of task or an interaction. No significant differences between cues and distractors were found, whereupon in bin 5, a trend towards slower reactions for cues is visible.

Finger landed

In the saccade-experiment, we found that saccade-landing yielded the same results as saccade-start. However, the comparison of the onset of the manual response and the time the finger has landed, show diverging results. The lower panel of Table 2 (p. 42) summarizes the means and standard deviations of all bins and conditions for finger-landed.

A repeated-measurements ANOVA showed a strong main effect for task, $F(1,20) = 43.77$, $p < 0.001$, as well as an interaction between task and bin, $F(4,80) = 25.95$, $p < 0.001$. The factor validity*bin neared significance ($F = 2.38$, $p = 0.059$). No other effects were noticeable (all Fs < 0.61, all ps > 0.443). Once more we seem to have differential effects across the different bins.
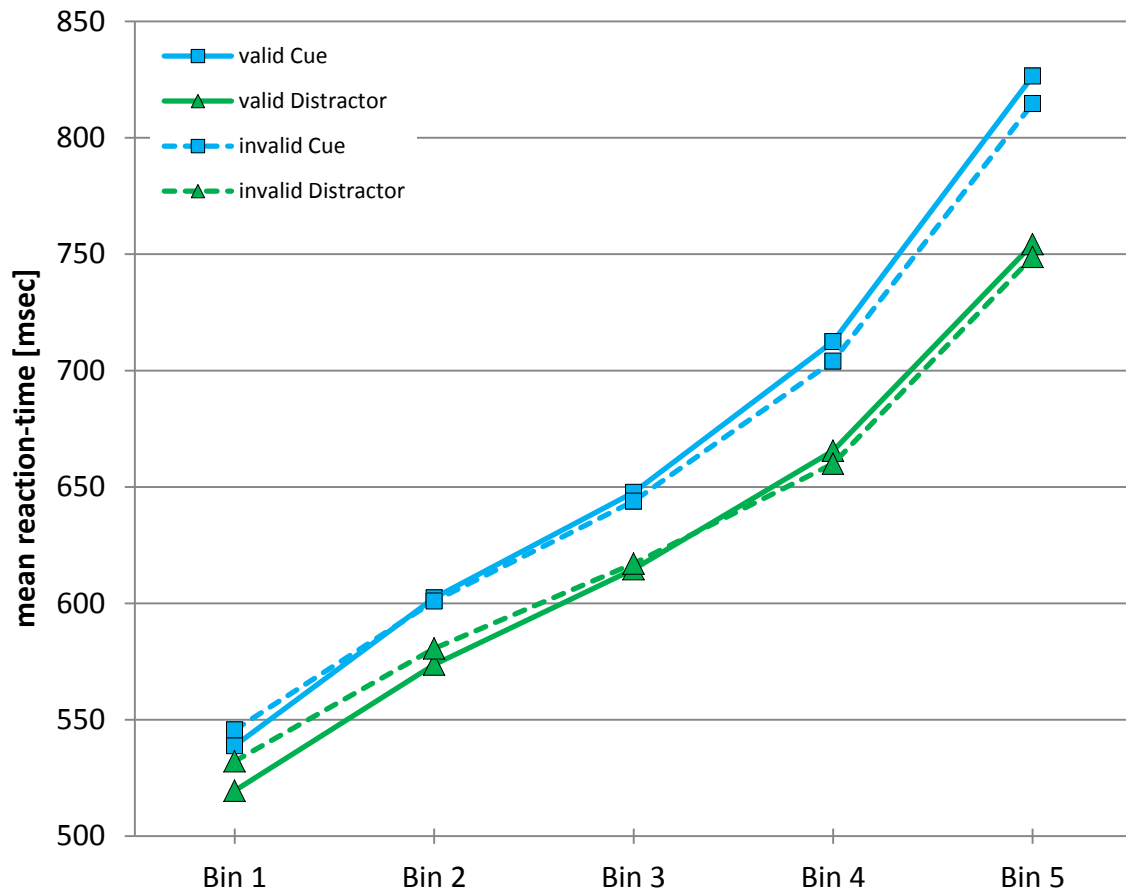

Figure 7: Reaction-times for finger-landed

Mean times when the manual response landed (ordinate), as a function of bin (abscissa), and experimental condition (separate lines). Blue lines indicate trials with cue, green lines trials with distractor. Solid lines signify valid trials, dashed lines invalid trials. For exact data and standard deviations refer to Table 2, lower panel. All reaction-times are measured in msec after target onset.

A differential analysis revealed that the main effect of task starts in bin 1 at $F(1,20) = 11.04$, $p = 0.003$. All pairwise comparisons between cues and distractors were significant (all ts > ±2.68, all ps < 0.014), except for the difference between valid cues and invalid distractors (t = 0.82, $p = 0.421$). We also found no effect for validity (F = 0.95, p = 0.150). Comparing invalid cues with valid ones yielded no effect (t = -0.91, $p = 0.373$), valid versus invalid distractors however, showed a tendency towards significance (t = 1.84, $p = 0.080$).

The main effect of task became stronger throughout bins 2, 3 and 4 and finally reached its maximum in bin 5 (all Fs > 26.64, all ps < 0.001). Neither validity nor validity*task came anywhere near significance (all Fs < 0.94, all ps > 0.345).

Hence, the interaction task*bin of the omnibus ANOVA is explained by the varying strength of the effect of task, throughout the bins. The almost significant interaction validity*bin, results from the almost significant effect of validity in bin 1.

As these data show and Figure 7 illustrates, the reaction-times are only influenced by the task and not by the validity. Figure 8 further clarifies these results. The reaction-time differences between valid and invalid trials, all settle around zero. Cues however, show slower reactions as distractors, with a strengthening of the effects for later bins.
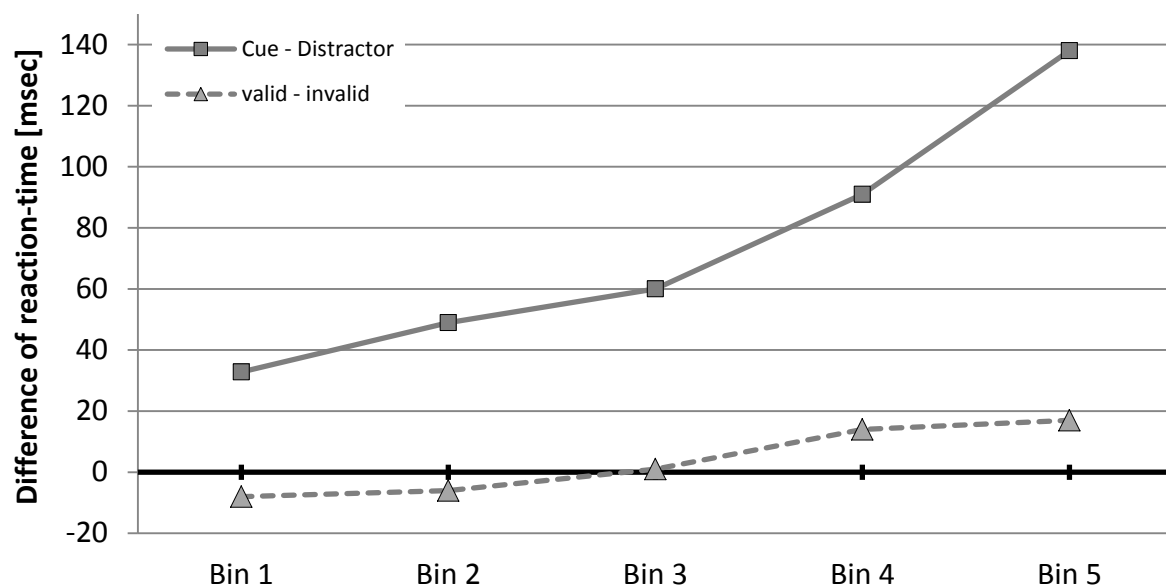

Figure 8: Differences of reaction-times for finger-landed

Solid lines show the differences between cues and distractors. Reaction-times for distractors were subtracted from cues. Positive values represent slower reactions for trials with cue. Dashed lines show differences between valid and invalid trials. Reaction-times for invalid trials were subtracted from valid trials. Positive values represent slower reactions for valid trials.

Accuracy of pointing

To control for trade-off effects, we analysed the accuracy with which reactions were made. An ANOVA with repeated-measures yielded no significant results. Hence, we can conclude that in each condition and for each bin the answers occurred with equal accuracy.

6.2   Discussion

Analogues to the saccade-experiment, this discussion focuses primarily on the results of the pointing-experiment. For comparisons of the two experiments and the discussion of the main hypotheses, refer to the general discussion (chapter 7, p. 52)

The most striking finding is the clear difference between finger-lifted (main effect of validity) and finger landed (main effect of task). This points out a clear dissociation between the start and the landing of the pointing movement. We can follow that the participants' reaction was subdivided in at least two different parts. The first task was to lift the finger off the fixation-cross as fast as possible. Possibly not until then was the target chosen. The choosing of the target location was influenced only by the task to be performed. These two results will be discussed separately.

Main effect of validity

For the moment when the finger was lifted, we find classical IOR results. Previous studies could also show IOR with manual responses. Yet, the number of studies using manual pointing as reaction modality is quite small. Even smaller is the number of papers that used an experimental design similar to ours (distractors, memory task and discrimination task).

Briand et al. (2000) compared saccadic to manual responses (key-presses and mouse movements), and found that manual IOR takes more time to develop. They found that facilitation declined sooner and inhibition developed faster for saccades, than for both types of manual responses. However, the magnitude of facilitation and IOR did not differ[10]. These results are interpreted in terms of a PMT of attention (Rizzolatti, et al., 1987; Rizzolatti, et al., 1994). Each motor modality is thought to have its own sub-system that codes space. Because manual responses are more complex than saccades, their coding speed is slower.

However, a manual pointing reaction differs from the movement of a mouse or a key-press, because pointing is a directional movement that needs more spatial information. Werner (1993)

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[10] Note that the net-IOR-effect at a SOA of 1000 msec was similar for all three response-types (saccades: -26 msec, mouse-movements: -19 msec and key-presses: -25/-33 msec), and no statistical comparisons were reported.

found, during aimed limb movements, neuronal discharges in the superior colliculus (SC). This could mean that the SC plays a more general role in the orienting of movements, and its role is not restricted solely to the oculomotor system. Indeed, Bekkering, Pratt and Abrams (1996) were able to demonstrate that the gap-effect is present in guided limb movements, but not in simple key-presses (without spatial discrimination). The gap-effect describes faster reactions (especially of saccades) to targets, if after cue-offset the central fixation vanishes (Saslow, 1967). The source of this effect is highly debated. Amongst others, Kingstone and Klein (1993) argue that the gap-effect can be attributed to a general warning effect, as well as to a specific readiness within the oculomotor system. Because of the short latency saccades the gap-effect evokes, the SC is thought to play an important role (Munoz & Wurtz, 1992). Stuphorn, Hoffmann and Miller (1999) further found neurophysiological evidence indicating that the SC innervates the proximal musculature of limbs. Taken together, one can suggest, that pointing is more similar to saccades than key-presses or mouse-movements. Therefore, the IOR- time-course for pointing might be different.

To investigate the latter point, Khatoon, Briand and Sereno (2002) conducted a follow-up-study of Briand et al. (2000). They used the same experimental design and compared saccades to mouse-movements and pointing movements. Indeed, they obtained a similar time-course for saccadic reactions and pointing. Inhibition tended to begin at a SOA of 200 msec. They also reported facilitation up to a SOA of 94 msec (see Khatoon et al., 2002, figure 3). Khatoon et al. (2002) explained their results by a more direct stimulus-response (S-R) mapping for saccades and pointing. Attending to a visual stimulus with the eyes is thought to be very natural response (direct S-R mapping), whereas pressing a key on target onset, or moving a mouse towards it, is considered to be a more artificial type of response (indirect S-R mapping). Because indirect S-R mappings are more difficult and elaborated, areas of the prefrontal cortex (PFC) become more active. These areas cause facilitation to last longer, as well as delaying inhibitory effects. These assumptions are consistent with neuroscientific results that propose an inhibitory effect of the PFC on subcortical areas (Koval, Lomber, & Everling, 2011; see also chapter 3.2, p. 17). These differences in S-R mapping are able to explain why IOR is stronger in saccades (mean = 40 msec) as in finger-lifted (mean = 17 msec). Pointing still needs visual input in order to program the motor reaction and might therefore be still more indirect as a saccade.

The fingers' disengagement from the fixation-cross was faster, if the target appeared at a location other than the cue/distractor. This could be due to a motor-bias of the movement or an attentional bias.

Taylor and Klein (1998, 2000) proposed that, for saccades IOR is primarily a motor bias, which is restricted to the oculomotor system. Among others, Hunt and Kingstone (2003) proposed that in saccadic tasks, IOR occurs due to a motor bias. In manual tasks however, IOR is thought to be an attentional mechanism. Sumner (2006) used in his experiments special stimuli to distinguish different cortical mechanisms of IOR. S-cone-stimuli are colour changes that are only visible to short-wave sensitive retinal receptors. There are no known projections between these receptors and the SC. Therefore, S-cone-stimuli should be processed mostly via the cortical visual pathway, while almost completely ignoring the retino-tectal pathway. Sumner, Nachev, Vora, Husain and Kennard (2006) found that S-cone-stimuli elicited IOR with manual responses, but not with saccades. Therefore, they proposed at least two separate IOR mechanisms, one attentional and one motor-driven, that have differential effects on different motor modalities. This can also explain the results of studies where a supramodal nature of IOR is proposed (Spence, Lloyd, McGlone, Nicholls, & Driver, 2000).

But given the aforementioned notion that saccades and aimed limb movements rely on the SC, can we argue that the motor bias extends to pointing? A literature review however, provides evidence in favour of an attentional mechanism.

Fischer, Pratt and Neggers (2003) used different types of targets (peripheral and central). Central targets (i.e. a central arrow pointing to one of two peripheral boxes) should only inhibit saccades, because manual key-presses are provided with all necessary spatial information by the central arrow. Eye movements need specific spatial information from cued locations in order to be executed. If pointing (which needs also spatial information) shows also inhibition with central targets, this would indicate that motor IOR is not solely restricted to oculomotor system. Indeed, Fischer et al. (2003) failed to show pointing-IOR with central targets.

Pratt and Neggers (2008) compared IOR in key-presses and pointing, with and without a conjoined saccade. Overall, they found lesser IOR for saccades, which were executed together with a pointing movement to the same target, than for saccades alone. Importantly, when key-presses and saccades occurred simultaneously, no significant influence on IOR was discovered. This supports the notion that IOR for saccades has a specific oculomotor component. Note however, that this interdependence does not go both ways. Both, pointing and key-presses were not

affected by a conjoined saccade. This poses evidence that the dissociation between oculomotor and skeletal-motor IOR is not absolute.

Main effect of task

For the moment when the finger landed, we see no influence of validity, but only an effect of task. Cues were overall responded to slower. Could it be that the memory task has impacted reaction-times?

Zhang and Zhang (2011) recently showed that spatial working memory load can diminish IOR in manual key-press-responses. This suggests that manual reactions rely, at least in part, on available resources of the spatial working memory (SPWM). The saccadic system on the other hand, seems to have a different way (e.g. implicit memory) to hold an inhibitory tagging upright. In line with the previous argumentation, this strengthens the notion that manual and saccadic IOR differ from each other in several respects.

IOR in manual responses was only diminished, when participants kept four locations in mind. When only one location was to be remembered, IOR was present. Note that to-be-remembered stimuli were presented before the peripheral cue and that they were always on different locations. It remains unclear whether these results would have been different if to-be-remembered and peripheral cues coincided (e.g. like in Belopolsky & Theeuwes, 2009).

It is unlikely that our effect of task is owed to SPWM-load. More likely the different tasks created different top-down sets, which influence the time-course of target detection (see next chapter).

Above, we discussed a possible involvement of the SC in pointing movements. By including the findings of White, Boehnke, Marino, Itti and Munoz (2009), another very interesting perspective develops. White and colleagues found that neurons in the intermediate layers of the SC respond to colour signals. These reactions are not attributable to simple luminance changes, because they occurred around 30-35 msec after the luminance changed. This indicates that colour signals reach the SC across a distinct pathway. The SC has a strong sensitivity for colour signals, but cannot discriminate between them. In plain words, the SC can detect colour, but is not able to identify it. These results support the important role of colour (along with luminance) for saccade-target selection (Hansen & Gegenfurtner, 2009) Given that the SC also plays an important role in pointing movements, the question arises whether these movements can make use of the colour information. Especially the results of finger-landed in our experiment show a strong influence of colour, while location does not play an important role. Possibly, the programming of manual

pointing has access to information of the SC. This would strengthen the notion that pointing is a special manual response that shares some characteristics with saccades.

7   General discussion

We find most of our hypotheses confirmed. We found IOR in saccades, as well as in manual pointing, but to a lesser degree. This indicates that saccades are especially prone to IOR.

Contingent capture versus differential disengagement

As mentioned in the introduction, there is an on-going debate as to whether attention is subject to bottom-up or top-down control (Connor, Egeth, & Yantis, 2004). Resolving this question is far beyond the scope of our experiment. In fact, our results can be explained by both accounts.

The results of the saccade-experiment (especially bins 4 and 5) and those of finger-landed are in line with the differential disengagement hypothesis (Born, et al., 2011) and argue against contingent capture (Folk, et al., 1992). Cues and distractors captured attention in an automatic, bottom-up manner. Afterwards, attention was immediately withdrawn from distractors (due to the top-down set "ignore"), but lingered on cues (due to the memory task). This explains why distractors showed faster reactions than cues.

Additionally, the stimulus properties might have provoked bottom-up capture. It has been shown that onset target capture attention, regardless of top-down sets (Belopolsky, et al., 2010; Schreij, et al., 2010). This might have evolutionary reasons, because sudden onsets could pose a potential threat that needs to be evaluated. In our design, all figures (placeholders as well as singletons) were onset stimuli. Probably, because all onsets happened at the same time, the effects cancelled each other out and only colour remained as critical capture-factor. But what if the effects of onset were additive to the effects of colour? Then attention would have been captured automatically by cues and distractors due to their salience. To cancel out any effects of onset, we would have to introduce a new screen with eight placeholders at the start of every trial. Only after an initial presentation of all placeholders, one changes into a singleton. This would help to diminish any moderating bottom-up capture influences.

On the other hand, there are quite a few arguments in favour of the top-down account. First of all, in the case of easy tasks, it is known that participants may adopt a singleton-search mode, rather

than a feature-search[11] mode. Singleton search describes a strategy, where every salient stimulus is sought, although the specific features are known. This mode is especially attractive in simple search task, i.e. task-relevant stimuli are the only salient stimuli in a visual array. All of these salient stimuli capture attention, not due to bottom-up mechanisms, but because of the broadness of the attentional top-down set. Bacon and Egeth (1994) replicated the experiment of Theeuwes (1992), and showed how singleton-search and feature-search can lead to different results (see also Ruz and Lupiáñez, 2002, for a review).

We could argue that according to contingent capture (Folk, et al., 1992), only stimuli that matched a task-relevant top-down set (i.e. cues) attracted attention. Distractors were irrelevant and did not attract attention at all, or only very minimal. One can hypothesize that the distractor condition represents a baseline for reaction-times, comparable to catch-trials, where only the target is shown, without a precedent cue or distractor.

However, if distractors constitute a baseline of reaction-times, it remains illogical why we have an effect of validity for distractors in both reaction modalities. If distractors were ignored completely, why should their location influence reaction-times? However, distractor-stimuli did match a top-down set. Therefore they were not irrelevant as with classical contingent capture studies. In other words, distractors did not so much passively capture attention as that they were selected actively for processing. In order to actively ignore something, it has to be recognised first. After the processing of distractors, attention was immediately removed, as opposed to cues where attention was held (memory task).

Furthermore, the distractors shared relevant features with cues (i.e. the shape). Eimer and Kiss (2008) found that even irrelevant stimuli, that share features with relevant stimuli, elicit an attentional ERP[12]-component. This component is called N2pc and describes a posterior negativity that occurs 200 msec poststimulus, contralateral to the stimulus' location. The N2pc is thought to resemble attentional engagement to a stimulus on a given screen (Eimer, 1996). Therefore, attentional engagement on distractors is reconcilable with studies that propose a dominant top-down control of early visual attention (Ansorge, et al., 2011).

To resolve the question of whether or not distractors captured attention, an ERP-experiment would be quite useful. Of course, we first would have to change the shape of target, so that the target differs from the distractor. If distractors elicit an N2pc component, we would have strong evidence in support of attentional engagement. Furthermore, by including recent results of

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[11] The observer searches the display for specific features of shape and/or colour, directed by a top-down set.
[12] event-related brain-potential

Toffanin, de Jong and Johnson (2011), we could take a closer look at attentional disengagement. In two experiments they proposed an ERP-component for attentional disengagement, temporally and spatially close to the N2pc but with opposite polarity. This component was dubbed P4pc (a posterior contralateral positivity, 400 msec poststimulus).

By using the P4pc as an electrophysiological marker, we could assess our results more closely. Given that this component also reflects the time course of disengagement, we could analyse how long the dwell times on cues and distractors are and whether or not they differ.

The coupling between covert shifts and motor preparation – revisited

Deubel and Schneider (1996) stated that attentional processing is best at the location of the covert shift. This means that attentional processing is already finished by the time the motor response occurs. Most importantly, Deubel, Schneider and Paprotta (1998) showed that their previous findings expand to manual reaching movements as well. An obligatory coupling between motor preparation and attention supports a premotor theory of attention (Rizzolatti, et al., 1987; Rizzolatti, et al., 1994).

Fagioli, Hommel and Schubotz (2007) found that preparing for an action, biases attention towards perceptual dimensions important for the motor action. For example, preparing for a reaching movement improves spatial attention. Wykowska, Schubö and Hommel (2009) extended these findings and implied that this intentional weighting (Hommel, Musseler, Aschersleben, & Prinz, 2001) of stimulus dimensions, affects already early stages of visual attention. This also points to a strong link between preparing of an action and attentional processing.

Our results support this notion. There seems to be an attentional component that selects targets prior to the motor response. We can see this in saccades and especially clear in finger-lifted, where there is an effect of validity prior to target selection.

Nevertheless, we cannot confirm that the location of the covert shift receives preferential attentional processing. On the contrary, reactions were faster when the target appeared not at the location of the covert shift. Ro, Pratt and Rafal (2000) concluded that programming a saccade to a cued location can generate IOR. This is in line with the PMT, although Ro el al. (2000) state that the exact relationship remains unclear. To merge our results with the PMT, one must allow a modification. If a motor response is necessarily programmed to the location of the covert shift, it could be that this motor program can be deleted under top-down control. Due to the uninformative singletons in screen 1 of our experiment, participants had strong incentive to

disengage attention. If the motor program is therefore immediately cancelled, cost may arise if a reaction to the same locations has to be reprogrammed (see valid trials).

Further evidence for our hypotheses, comes from a literature review. Not in all cases, attention seems to be locked on the location of the motor response. Montagnini and Castet (2007) systematically manipulated the likelihood with which the discrimination-target appeared at the goal of the saccade. Participants were informed in advance about the probability that target and covert shift coincided (either 75 %, 50 % or 25 %). If attention is obligatory fixated at the location of the covert shift, the change of probabilities should not influence the results. Actually, they found a strong effect of the probability condition on the performance in the discrimination task. Montagnini and Castet concluded that there is an attentional component that can be deployed voluntarily, independent of the saccade goal.

Doré-Mazars, Pouget and Beauvillain (2004) found that a change in a letter string was best detected when it happened close to the saccadic landing position. That points towards a coupling of saccade preparation and attentional processing. However, they also found that during early saccade preparation, distractor stimuli can shift attention away from the saccade-target. Additionally, there is evidence that the acuity of saccades builds up over time and reaches its maximum after 150-200 msec (Castet, Jeanjean, Montagnini, Laugier, & Masson, 2006).

Taken together, it seems that the link between covert shift and motor preparation is only strong at particular time after cue onset and that there is an attentional component, independently deployable from the target. This notion is also able to explain our results. Under top-down control, it seems possible to separate attention from the target location.

In conclusion, we can summarize three key facts about our results:

- The link between covert shifts and motor preparation extends to modalities other than saccades.
- We found IOR at the location of the covert shift. By using the PMT as a framework, we are able to explain these results. This does not mean that Deubel and Schneider are falsified. It only means their hypothesis has to be broadened. Although there is a close link between motor preparation and covert shifts, attention seems not to be locked on the location of the motor response.
- Although distractors did presumably capture attention, this does not rule out a top-down control of early visual attention. We named various factors that could account for this

assumption. It remains the possibility that contingent capture and differential disengagement rely on stimulus properties or experimental conditions.

8   Outlook

Visual research is exceptionally complex. Even such a seemingly intuitive and simple concept as IOR, reveals an unimaginable depth. Therefore, designing experiments requires much care and caution. As the literature review shows, researching IOR resembles a clock-work. As soon as one changes a little detail such as the SOA or the cue-duration, all other cogwheels turn as well.

One has further to keep in mind that our experiments, as well as most of the experiments cited in this thesis, used an extremely simple visual display for research. The mechanisms of real dynamic, environmental scenes, as well as social and emotional factors that may influence top-down sets, were not even touched upon here. Additionally, visual attention and effectiveness of visual search seem to have an individual component (Fukuda & Vogel, 2011), and seem to be dependent on experience and practice with visual tasks (Castel, Pratt, & Drummond, 2005).

The increasing interdisciplinary in this field of research holds promising possibilities. Not only can psychological findings and theories be assessed neuroscientificly via fMRI (de Haan, et al., 2008) or single-neuron recordings (Koval, et al., 2011), but can also be exported to the computer sciences, in attempt to develop artificial intelligences able to efficiently scan visual scenes (de Campos, Csurka, & Perronnin, 2012).

The necessity of researching visual attention exceeds the pure quest for knowledge. From this understanding, new perspectives for sensors and robotics emerge. Complex work environments can be designed more ergonomically, therefore minimizing human mistakes. But to achieve such ambitious goals, one has first to understand the basics of vision thoroughly and exhaustively. The present study provides some insight into top-down and bottom-up processes and can help to design further studies, as well as to resolve inconsistencies in the literature.

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Curriculum Vitae

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Interships, project studies

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10/2010 – 06/2011   **Project study: Evaluation of "neue Wiener HAK"**

Institute for Evaluation, University of Vienna, Austria

03/2011 – 06/2011   **Research internship: Event correlated potentials of social feedback**

Social, Cognitive and Affective Neuroscience Unit, Vienna, Austria

08/2010 – 09/2010   **Internship: Austro Control, Vienna, Austria**

Austrian Association for civilian aviation and air traffic control

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10/2005 – 06/2006	**Civil Service: School of therapeutic pedagogy, Offenstetten, Germany**
08/1996 – 06/2005	**Musikgymnasium der Regensburger Domspatzen, Regensburg, Germany**

Languages

German:	native language
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Computer

Office:	Word, Excel, Powerpoint, Access, Outlook, Adobe Acrobat
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