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Competition for feature selection

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Chapter 3

Visual Selection is Modulated by Action Intention

Action-Related Biased Competition in Feature Search

Abstract

Recent psychophysical findings have been interpreted to indicate that the attentional selection of behaviorally relevant visual feature dimension can be selectively enhanced depending on the intention to undertake a motor action. The potential effects of action intention on the behaviorally less relevant visual dimensions are largely ignored. The purpose of this study was to investigate the potential decline in the processing of behaviorally neutral visual feature as a function of manual task demands. We used visual search paradigm to investigate the mechanisms of action-induced perceptual effects on visual selection. Fifteen participants conducted color search tasks and orientation search tasks with the intention to find the target as fast and as accurately as possible, and to point to it on the screen or to imitate a grasping movement on the screen. Visual search performance was measured by feature discrimination accuracy of the initial saccade.

Results indicated that in a grasping condition where orientation was expected to be behaviorally more relevant, color discrimination accuracy decreased relative to pointing condition. In contrast, orientation discrimination accuracy was approximately equal in both pointing and grasping condition. This finding demonstrates that action induced effects are not based on mere facilitation of behaviorally relevant visual feature. We conclude suggesting a biased competition between different visual features bound to the searched objects.

3.1 Introduction

One of the central interests in the research of visual cognition and its underlying processes concerns the operational mechanisms of selective attention. Due to the structural and functional limitations of the attentional system, only a relatively small amount of available visual information can be efficiently processed. Therefore, successful selective allocation of the limited processing resources is required based on current behavioral intentions. There is now convincing amount of evidence that relations between sensory input from visual environment and behavioral output from motor system are not unidirectional from perception to action but reveal a complex interplay between attentional processes and goal-directed behavior (for reviews, see Perry et al., 2016; Pratt et al., 2015; Ridderinkhof, 2014; Schenk, 2010). The effect of behavioral intentions on the allocation of visual processing resources is a question of great interest in the field of visual attention. Apparently, our motor behavior hinges on the accuracy of visual processing. In accordance with the selection-for-action approach (Allport, 1987, 1989) and related theories (Gibson, 1979; Hommel et al., 2001; Rizzolatti, Riggio, & Sheliga, 1994), we argue that visual search is rather a servant of our goal-directed behavior and not the thing in itself. While there has been much interest in describing the neural and psychological mechanisms underlying visual search, the majority of the studies have considered visual selection on the basis of increments in the processing of behaviorally relevant visual features. In this chapter, we describe a simple approach designed to investigate the potential decline in the processing of behaviorally neutral visual feature as a function of different task demands. Specifically, we were interested in how behavioral intention modulates the discrimination accuracy of behaviorally relevant and neutral visual features[a].

A growing body of research recognizes action-related attentional mechanisms regulating the selection and processing of action-relevant visual information. Experiments designed to evaluate the effect of action planning on visual cognition have used a variety functional outcomes such as response times to stimulus detection (Craighero, Mele, & Zorzi, 2015; Fagioli, Ferlazzo, & Hommel, 2007; Reed, Betz, Garza, & Roberts, 2010; Wykowska, Schubo, & Hommel, 2009), response rates (Fagioli, Hommel, & Schubotz, 2007; Wykowska et al., 2009), different measures of brain activity (Craighero et al., 2015; Gutteling, Park, Kenemans, & Neggers, 2013; Gutteling et al., 2015; Kiefer, Sim, Helbig, & Graf, 2011; Perry, Sergio, Crawford, & Fallah, 2015; Symes, Tucker, Ellis, Vainio, & Ottoboni, 2008; Wykowska & Schubö, 2012), and eye movement

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[a] Here we prefer not to adopt the term „irrelevant feature" frequently used in similar studies. For instance, in our color singleton search task the color is still a relevant characteristic defining the task, but it is neutral in terms of the manual behavioral task. Therefore we prefer the "behaviorally neutral feature".

recording (Bekkering & Neggers, 2002; Hannus, Cornelissen, Lindemann, & Bekkering, 2005; Symes et al., 2008). On the basis of these and related studies, the consensus has been reached that planning an action selectively facilitates visual processing of the action-relevant object features. Indeed, convincing explanations for this kind of phenomena are provided by several theoretical models. For instance, both the hypothesis of selection-for-action and the closely linked theory of event coding (TEC; Hommel, 2009) can explain facilitated visual processing as a result of the action preparation. The TEC suggests that action-related representational functions (e.g., planning a hand movement) share the perceptual representations of events (perceiving visual objects) and therefore activating an action system may prime the processing of stimuli characterized by perceptual dimensions related to those actions. In other words, the intention to grasp an object primes orientation dimension and therefore facilitates orientation processing. The mere activation of an action plan could stimulate certain intentional weighting mechanisms and thereby increase the weights of those feature dimensions that allow for the specification of action parameters (Hommel, 2010). Recently, a few psychophysical studies have estimated the effect of the action plan on the selective processing of action-relevant visual features or feature dimensions. A common underlying assumption utilized in this specific line of research is the agreement that efficient orientation discrimination is required for precise grasping, and therefore the orientation of objects is behaviorally relevant in grasping conditions. Differently, since prehension of the hand to fit the orientation of the object is not needed when pointing toward an object, pointing tasks are not expected to presume refined orientation discrimination. Thereby, Gutteling and colleagues estimated participants' sensitivity to detect a change in stimulus orientation dependent on whether they prepared to grasp the stimulus or to point toward it (Gutteling, Kenemans, & Neggers, 2011). They showed an increased change detection resulting from grasping preparation as compared with the pointing preparation. Also, Wykowska and colleagues (2009) systematically tested the potential of action plans to bias target detection toward action-relevant visual dimension. Using a singleton search design, they were able to demonstrate that planning a grasping or a pointing movement facilitated the detection of targets and rejection of action-irrelevant singletons. Similarly, in two studies Fagioli with colleagues has required preparation of pointing or grasping but performing a visual discrimination task before hand movement execution (Fagioli, Ferlazzo, et al., 2007; Fagioli, Hommel, et al., 2007). Their findings suggest that action plans induce an intentional weighting process and thereby bias perceptual systems toward the entire action-relevant perceptual dimensions (e.g., size) instead of simple facilitation of the processing action-congruent feature values (e.g., small or large). Hence, a few studies have been designed to understand the selective gain in the processing of action-relevant visual objects or feature dimensions.

At the same time, surprisingly little interest has been devoted on to potential interactions or even interferences between the features that make up the visual representation of an action-related object. We believe that such an idea is not entirely far-fetched, particularly when the limitations in processing resources are presumed. Given the outstanding issues, the goal of the current study was to validate the hypothesized interactions between concurrent visual features.

One of the most plausible and powerful models accounting for interactions between concurrent stimuli is the biased competition theory (Desimone, 1998; Duncan, 1996). Specifically, the theory explicitly demonstrates how simultaneously accessible visual objects interact and compete for neural representation in the visual cortex. Alongside to continuous stimulus-driven bottom-up biased competition, the various top-down mechanisms can bias processing toward a spatial location or visual feature based on the cognitive demands of the current task (for review, see Beck & Kastner, 2009). However, the biased competition model describes suppression of representations of the action-irrelevant visual objects and excludes competition between individual features (Duncan, 1996; Duncan et al., 1997). Still, contrary to this view, some findings suggest that the suppressive competition could take place not only among nearby objects but at the level of individual features also independently of the spatial location (Beuth & Hamker, 2015; Haenny & Schiller, 1988; Hannus et al., 2005; Martinez-Trujillo & Treue, 2004; Motter, 1994; Polk et al., 2008). One potential source of top-down biased competition might be the current behavioral goal (Bekkering & Neggers, 2002; Hannus et al., 2005; Symes et al., 2008; Symes, Tucker, & Ottoboni, 2010). Similarly, in a series of three fMRI experiments Xu (2010) demonstrated that processing of the task-irrelevant component feature of visual conjunctions is dynamically modulated by the processing load of the task-relevant feature. The study of Hannus and colleagues (2005, presented in Chapter 2), which bears a particular relevance to the current study to be reported below, demonstrated that processing of a behaviorally relevant visual feature could be selectively enhanced depending on the intention to undertake a specific manual action. This study showed that if there is an intention to grasp an object with a particular color and a particular orientation, the orientation discrimination performance is enhanced as compared to the situation where the task is to point at the same object. Differently, the discrimination accuracy of the color as a behaviorally neutral feature (equally relevant for both grasping and pointing) was independent of the motor task. However, as the magnitude of the action intention effect was contingent on the salience of the behaviorally neutral feature, the authors suggested that action intention does not selectively enhance the behaviorally relevant feature, but rather biases the competition between behaviorally relevant and behaviorally neutral feature toward the relevant one.

3.1.1 Experimental questions addressed in this study

In the present study, we applied the visual search paradigm to further investigate action-induced effects on the feature-based attention. We adopted a novel approach for disentangling enhanced action-dependent visual processing. Therefore, we tested if the processing of stimuli defined on perceptual dimension related to a certain manual action can interfere with a dimension not related to the action. Like Wykowska, Schubö, and Hommel (2009), we designed simple feature search tasks. Specifically, participants performed either a color search task or an orientation search task while reaching and pointing at or grasping the target. A critical aspect of our experimental design was the color search task where the orientation of the stimulus objects was still important for grasping. To execute the correct grasping response, one has to process even the uniform constant orientation of color-defined objects, whereas pointing to the color singleton does not require any orientation processing. This latter assumption is based on the findings that pointing is directed to the centre of the object and can be planned independently of orientation (Smeets & Brenner, 1999). Consequently, a higher demand for orientation processing is expected in the grasping condition compared to the pointing condition and therefore color discrimination performance might suffer. In the orientation search task, on the other hand, the only relevant feature for guiding visual search is the orientation, as it is defining the search for the target as well the execution of the action in both grasping and pointing conditions. Therefore, approximately equal visual search accuracy in both pointing and grasping in orientation search was expected. In other words, the rationale behind the present experiment is to test if action intentions deteriorate processing of behaviorally neutral visual feature dimension.

Importantly, we first equalized color and orientation discriminability at an individual participant level to balance stimulus discriminability over conditions. After that, we measured the accuracy of the initial saccade in two singleton feature search tasks under both pointing and grasping conditions. We assumed that gaze behavior reflects the deployment of visual attention. There were two predictions. First, if there is indeed a biased competition between the visual features, then we would expect to see decreased color discrimination performance in the grasping condition of the color search task as compared to the pointing condition. We propose that the reason for such an effect would be the higher demand for processing the orientation of stimuli in grasping condition. Alternatively, if there is a biased competition between the objects, then we would expect to see even increased color discrimination performance in the grasping condition of the color search task as compared to the pointing condition. The reason for such an effect would be the bottom-up bias in favour of the color singleton target combined with the bias by virtue of greater behavioural relevance of orientation discrimination from top-down feedback in grasping

condition (e.g., Beck & Kastner, 2009; Desimone, 1998).

3.2 Experiment

3.2.1 Method

Participants

Fifteen volunteers (aged 19-30 years) participated in the experiment in return for payment. All participants were naïve as to the purpose of the experiment and had normal or corrected to normal vision. The study conformed to the research ethics guidelines of the Psychology Department of the University of Groningen.

Apparatus and stimuli

The XGA mobile DLP projector (PG-M20X; Sharp Corporation, Japan) presented the computer-generated stimuli on a translucent screen, positioned on the table in front of the participant, with dimensions of 94 × 94 cm, and a background luminance of 55 cd/m². The viewing distance was 45 cm. It is important to note that the objects were 2D images projected on a screen, similar to Chapter 2 (Hannus et al., 2005).

At the beginning of each trial, the participant had to fixate at the central fixation cross (1.2° visual angle, Figure 3.1). Next, a target cue with a particular color or orientation appeared in the centre of the screen for 500 ms. After that, 16 equally spaced stimuli appeared along the circumference of the circle with a radius of 11.5° and centered on the fixation cross. Every stimulus had the shape of a bar (0.6° × 2.3°), and one of them was the uniquely defined target stimulus. In the color search task, the target was a green or red 45° tilted bar with a 40% luminance contrast relative to the background. In the orientation search task the target was an achromatic clockwise or anti-clockwise tilted bar relative to baseline orientation of 45° (similarly, 40% luminance contrast relative to the background). We first determined the individual color and orientation contrasts needed to obtain 50% discrimination accuracy in the pre-experiment, see below. On the basis of those 50% discrimination thresholds, individualized stimuli were prepared for each participant. Next, we will describe this procedure in more detail. However, in all task conditions, search stimuli were presented for 1500 ms. After the disappearance of the search array, the next trial started.

Pre-experiment: Threshold determination

When we aim to compare the feature discrimination performance of individual features, we should make sure that the difficulty of each task is at least approximately comparable. Discrimination of one feature (e.g., clockwise tilt vs. counterclockwise tilt) could be more difficult for the visual system than discrim-

ination of another feature (green vs. red). Therefore, we first determined 50% discrimination thresholds in orientation and color singleton search tasks for each individual participant in displays employing 16 items. These values were then used to set the feature contrasts in the experimental search tasks.

In color threshold discrimination, color contrast between target and non-targets was 1.5, 2.2, 3.3, 5.0, 7.5, 11.3, 16.9, 25.3, or 38.0% (40% luminance contrast

A. Color Search Task
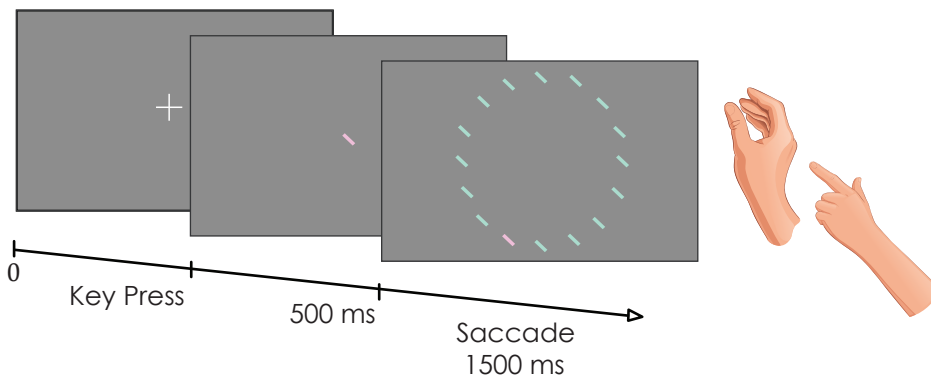
B. Orientation Search Task
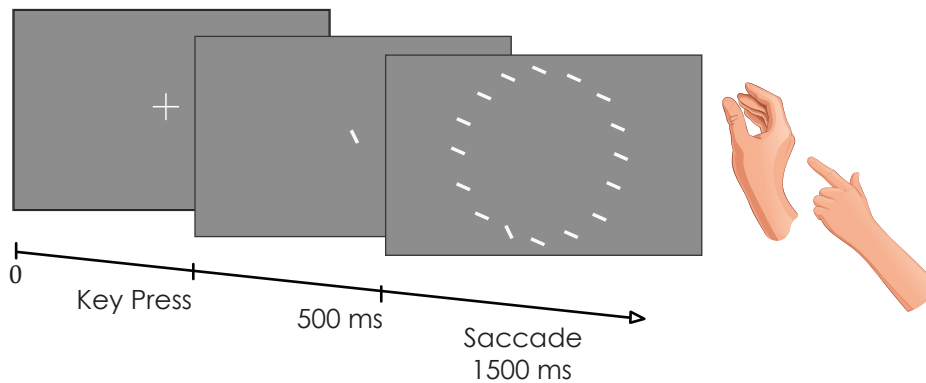
Figure 3.1: Schematic of the experimental paradigm. At 16 possible positions, objects were presented. A. Sample display from color search task with uniformly orientated stimuli; orientation is irrelevant for target discrimination. In this example, the singleton is the red bar. B. Sample display from orientation search task with uniformly colored stimuli; orientation is relevant for target discrimination irrespectively of the manual task. In this example, the singleton is the more clockwise oriented bar. After the target was found, participant eiher reached and pointed to the target or imitated a grasping movement on it. Note that in the actual experiment color and orientation contrasts varied as they were products of individual 50% discrimination thresholds determined prior to the main experiment.

in relation to the background). The nontargets always had the opposite contrast of the target. Participants were required to find the target as quickly as possible. Orientation threshold determination was designed similarly. To prevent a potential use of the internal representation of verticality, the reference value for manipulating the orientation was a 45° clockwise tilt. Thus, the target was a gray bar (40% luminance contrast in relation to the background) orientation contrast between target and nontargets was created by both increasing and subtracting 1.5, 2.2, 3.3, 5.0, 7.5, 11.3, 16.9, 25.3, or 38.0% from the reference 45°. Nontargets had the opposite tilt of the target. In both tasks, participants performed 144 trials (nine contrast levels × one positive and one negative contrast).

Procedure of the main experiment

After the 50% discrimination thresholds had been determined, each participant performed feature search tasks requiring pointing to the target or imitating a precise grasping movement on it both for color and orientation singletons at individual threshold levels. Each search trial started with the presentation of a white fixation cross of 1.2° of visual angle, in the centre of the screen until fixation was stable for 500 ms. After that, the target cue was presented in the centre of the screen for 500 ms. The target was a tilted bar (0.6°× 2.3° with the luminance contrast set 40% higher than the background). In color search tasks, the target was either isoluminant green or red, the color contrast being adjusted to the individual 50% discrimination threshold for each participant. In the orientation search tasks, the target was either more or less clockwise tilted, the orientation contrast adjusted to the individual 50% discrimination threshold for each participant. The experimental procedure is schematically illustrated in Figure 3.1. After the disappearance of the target cue, the search display was presented for 1500 ms. The target was presented in each trial.

Participants obtained detailed written instructions and performed learning trials before the experiment began. They were instructed to find the target as fast and as accurately as possible and to point at it on the screen or to mimic a grasping movement on the screen with the index finger and thumb along the linear axis of the target. Note that the study presented in Chapter 2 has shown that imitation of manual actions is sufficient for elicitation of action-related facilitation effects of visual selection. The same conclusion has been reached by Gutteling and colleagues (2011). Our participants were instructed to complete four block-wise visual search tasks: color search and orientation search, pointing and grasping in a single session, with block order counterbalanced across participants. One block consisted of 80 trials. The search performance was assessed as the accuracy and latency of the first saccadic eye movement that was initiated after the appearance of the search display. An eye movement was considered a saccade when the velocity of the eye was at least 25°/s with an acceler-

ation of 9500°/s². A saccadic response was defined as the initial eye movement landing on a stimulus or within 1° of its borders.

Analysis and statistics

In the saccadic accuracy and latency analyses, trials were rejected if (a) the initial saccade did not land within 1° around a stimulus (5.4%), (b) the saccadic latency was shorter than 100 ms (0.6%), or (c) the saccadic latency was longer than 500 ms (0.4%). Responses were classified into two categories: (a) hit—initial saccade directed to the target; (b) error—initial saccade directed to a nontarget. For the analysis of feature discrimination accuracy, we calculated the feature hits as percentages of the total number of trials.

   To examine whether there was a biased competition evident in the feature discrimination accuracy the individual hit scores (%) for all four conditions were determined. Then, repeated measures analysis of variance (ANOVAs) and planned comparisons of the last square means were performed for two within-subject factors: (a) manual task (two levels: pointing; grasping), (b) visual search task (two levels: color search; orientation search). A significance level of α = .05 was considered for all statistical tests.

3.2.2 Results

At the outset, we aimed to verify that any potential differences between feature discrimination accuracies across two manual tasks were not caused by speed-accuracy trade-off. Therefore, we analyzed the mean saccadic latencies of hits. We performed a 2 × 2 repeated measures ANOVA with two factors (manual task, visual search task). Although in general the correct orientation discrimination
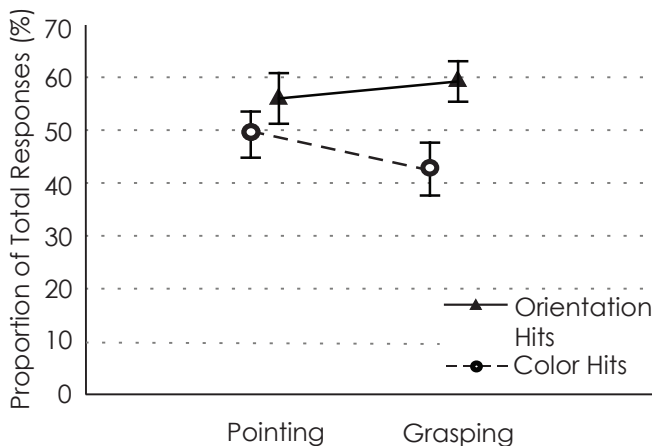
Figure 3.2: Saccadic hit distribution as a function of the manual task. The color hits occured significantly less frequently when participants grasped the target object compared with saccades towards color target preceding a pointing movement. Mean values and standard errors are presented.

was performed somewhat slower ($M = 260$, $SD = 7$ ms) than color discrimination ($M = 254$, $SD = 5$ ms), this main effect of the visual search task was not significant, $F(1,15) = 3.49$, $p = .081$, $\eta_p^2 = .189$. Both the main effect of manual task and interaction between the factors were small, F's < 1.

Next, we analyzed in which percentage of trials in the pointing and the grasping condition the initial saccade was directed toward the color target and to the orientation target (Figure 3.2). The 2 × 2 repeated measures ANOVA showed a small significant interaction between the manual task and visual search task, $F(1, 14) = 4.65$, $p = .049$, $\eta_p^2 = .249$. However, this effect was not strong enough to reveal any significant main effects. Although in general the orientation discrimination performance was slightly higher than color discrimination performance, this main effect of visual search task was weak, $F(1,14) = 3.92$, $p = .068$, $\eta_p^2 = .218$. The main effect of manual task was also small, $F < 1$. Importantly, though, the hypothesized prediction was tested by following planned comparisons between manual task conditions across the two target-defining feature dimensions. Comparisons indicated that the manual task had an effect on feature discrimination performance in color search and not in orientation search. Specifically, as predicted by our hypothesis of a selective effect of manual task on feature discrimination accuracy in color search, the percentage of the initial saccades to target stimulus was significantly lower in the grasping condition compared to the pointing condition, $t(14) = 2.54$, $p = .024$, suggesting a decreased feature discrimination performance in grasping condition as compared with pointing condition. In contrast, the percentage of the initial saccades to target stimuli did not significantly differ between grasping and pointing conditions, $t(14) = 0.73$, $p = .479$, suggesting approximately equal orientation discrimination independent of the manual task.

3.3 Discussion

Most theories of action-related attentional mechanisms assume that action plans selectively facilitate processing of action-relevant visual objects or features. Although there is clear evidence that action intentions modulate perceptual processing (e.g., Engbert & Wohlschlager, 2007; Fagioli, Ferlazzo, et al., 2007; Lindemann, Stenneken, van Schie, & Bekkering, 2006; Müsseler, Wühr, Danielmeier, & Zysset, 2005; Symes et al., 2008; Witt & Proffitt, 2008), the underlying neurocognitive mechanisms of this modulation are still unclear. The results of the present experiment demonstrate that action-related perceptual facilitation is not necessarily an independent gain in the processing of behaviorally more relevant visual feature. We compared visual search performance in two singleton search tasks while varying manual tasks planned toward the objects to be searched. Our findings demonstrate a discrimination-efficiency trade-off in feature-based selection for action. We found that the planned

manual task selectively interferes with discrimination of behaviorally neutral feature: color discrimination accuracy decreased when grasping was required in comparison to the pointing task. We also observed that grasping did not increase orientation discrimination accuracy as compared with pointing. This latter finding suggests that when the behaviorally relevant visual feature is the only feature defining the visual search task, there may not be any room for an impact of the top-down action preparation. We suggest here that the explicit decrease in color discrimination accuracy in grasping condition is due to biased competition between objects' features. In the following sections, we will attempt to elaborate upon aspects of selection-for-action, as we see it, implicated in conceptualizations of intentional weighting and biased competition.

3.3.1. Selection-for-action

The present study aims to make a basic contribution to the growing body of literature on the deeply ingrained relationship between perceptual and motor systems. According to the hypothesis of selection-for-action (Allport, 1987, 1989), action-related attentional mechanisms determine the early selection and processing of action-relevant visual information. Allport (1987) suggested that attentional selection is not needed for coping with central limited capacities of cognitive processing but rather for operating the strictly limited effector system. The rules that are proposed to govern this early selection derive from the necessity to select particular attributes from the environment that are relevant to the action at hand. This, in turn, requires action-irrelevant information to be ignored. Therefore, the attentional processes are viewed as the selection of action-relevant events or stimuli relying on particular action plans. The present study, however, was designed to unravel the process of ignoring behaviorally neutral visual information.

Psychophysical findings from stimulus discrimination tasks as well as detection tasks have found early effects of action intentions on the visual selection of action-congruent information. Specifically, when observers prepare a grasping movement, they tend to direct overt visual attention to the target orientation more frequently than during pointing preparation (Bekkering & Neggers, 2002; Hannus et al., 2005, presented in Chapter 2). Psychophysiological evidence for this kind of early selection adjacent to action intentions suggests that action preparation activates visual processing resources in the occipital areas (van Elk, van Schie, Neggers, & Bekkering, 2010) and this can occur as early as the V1 (Gutteling et al., 2011). Moreover, the action-related priming effect is not limited to the specific feature values representing target properties of the compatible behavioral actions but selectively increases the weight of entire task-relevant feature dimension (Fagioli, Hommel, et al., 2007; Wykowska et al., 2009) and its psychophysiological correlates can be traced to the early stages of processing

(Kiefer et al., 2011; Wykowska & Schubö, 2012). The current results suggest that the increased tendency to shift the initial gaze toward the behaviorally relevant visual feature that has been revealed in previous studies presented in Chapter 2 cannot be merely due to selectively privileged processing of (or more intentional weight assigned to) the feature dimension that is more relevant in terms of the planned motor action. Our findings indicate that action intention modulates even the activation of the feature dimension neutral for the manual task.

3.3.2. Intentional weighting as biased competition

Our observations converge with support for the TEC (Hommel, 2009) and offer nuanced considerations of the functional underpinnings of the effect of action intention on visual selection. The TEC suggests that perceiving and acting are identical processes, i.e., perceptual events and action plans are represented in a common format of assembled feature codes (Hommel, 2009). According to the TEC, it is possible to increase the weights of a particular feature to facilitate the coding of that particular feature, and this is based on top-down anticipation of the behaviorally relevant feature. As mentioned above, Faggioli and colleagues (2007) have demonstrated that action preparation primes compatible feature dimensions in general, not merely specific feature values of those dimensions. Given the results of the present study, we suggest that intentional weighting might be achieved by biased competition between behaviorally relevant and behaviorally neutral visual features.

Biased competition in visual selection is manifested in suppressive interactions between stimuli. Exposure to concurrent visual stimuli yields competition for neural representation in visual cortex. This is an automatic continuous process employing both automatic and deliberate direction of attention. Suppression of concurrently presented stimuli is achieved by enhanced amplitude and duration of responses to some other objects. The model of biased competition holds that top-down biases can be based on spatial locations (Bles, Schwarzbach, De Weerd, Goebel, & Jansma, 2006; Luck, Chelazzi, Hillyard, & Desimone, 1997) or particular features across the visual field (Bichot, Rossi, & Desimone, 2005; Haenny & Schiller, 1988; Motter, 1994), and achieved by contrast gain, response gain, or baseline shift (see Beck & Kastner, 2009; Boynton, 2009). Accordingly, encouraged by TEC, Wykowska and colleagues (2009) demonstrated a selective bias toward action-relevant feature dimension and inhibition of the irrelevant feature. Specifically, they showed that planning a pointing or grasping movement facilitates detection of targets and rejection of irrelevant singletons on action-congruent feature dimensions even when visual search targets and manual execution stimuli are spatially disentangled. Recording of initial saccades during singleton search tasks in the current study provides direct evidence for an action-related decrease in the processing of the behaviorally neutral visual

feature. Specifically, although participants performed two separate singleton search tasks, we argue that in our experimental design only orientation search task represented a perfect simple feature search condition, where achromatic stimuli varied in orientation dimension. In the case of the color search task, orientation dimension was homogenous at the feature level but the top-down instruction to grasp the target induced the need to process also the orientation of the uniformly oriented stimuli. Therefore we suggest the emergence of semi-conjunction stimuli, where bottom-up color information was combined with the top-down necessity to process orientation information. Put simply, the top-down grasping intention generated a condition where a stimulus-driven color singleton search acquired the characteristics of a color and orientation conjunction search task. This condition allows us to draw conclusions about the allocation of attentional resources in favor of behaviorally relevant feature. Accordingly, by comparing color discrimination accuracy between pointing and grasping, we were able to demonstrate color performance decrease in orientation-dependent grasping tasks. Therefore we suggest a biased competition to take place whereby higher intentional weighting of the behaviourally relevant feature (orientation) occurs at costs of the behaviorally neutral feature (color).

Contrary to color search, in the orientation search task, the only task-relevant visual dimension was the orientation, as it was defining the search for the target as well the execution of the action in both grasping and pointing conditions. As predicted, orientation discrimination performance was approximately equal in both the pointing and grasping condition. However, this result has not previously been described. For instance, Gutteling and colleagues (2011) compared orientation discrimination performance across pointing and grasping tasks and compared this with corresponding luminance discrimination tasks. They showed an increased orientation discrimination performance in grasping as compared with pointing. More recently, authors from the same research group confirmed this finding and showed that the orientation-reliant grasping preparation modulates orientation sensitivity in the anterior intraparietal sulcus (aIPS; Gutteling et al., 2013) which is a part of the dorsal visual stream and thereby connected to the visual cortex (Grefkes & Fink, 2005). This inconsistency in the results may relate to methodological differences between the studies. In both studies, Gutteling and colleagues have used change detection tasks where only one stimulus was presented (Gutteling et al., 2011; 2013). Differently, in the current study, we used singleon search tasks where the bottom-up contrast between target and distractors could also be used in pointing condition.

3.3.3 Selection-for-action in ventral stream

Our findings raise an interesting question regarding the impact of selec-

tion-for-action on visual processing of the color which is usually regarded as a feature processed in the ventral stream. However, despite the well-established functional distinction between differentiated visual processing of object-based information ("what") in the ventral visual stream and visuospatial information ("where") in the dorsal visual stream (Ungerleider & Haxby, 1994; Ungerleider & Mishkin, 1982), the two visual systems have connections at several levels (Hutchison & Gallivan, 2016; Pisella et al., 2006; Zanon, Busan, Monti, Pizzolato, & Battaglini, 2010; Takemura et al., 2016; van Polanen & Davare, 2015). Given that the aIPS connects the ventral and dorsal streams with premotor and prefrontal areas (Borra et al., 2008) and modulates contributions from ventral stream to visuomotor processes as a function of task characteristics (Verhagen, Dijkerman, Grol, & Toni, 2008), our findings are not surprising. The apparently biased competition between features could, thereby, rely on differential recruitment of ventral areas in service of grasping as suggested by van Polanen and Davare (2015). A related explanation has been given by Ganel and Goodale (2003) showing that perceptual judgments of objects require holistic perception without the possibility to filter out irrelevant features, while during grasping the irrelevant feature was completely ignored.

Our experiment also adds to previous work on a conditional selection of task-irrelevant object features (Xu, 2010) which demonstrates that processing of task-irrelevant features depends on the encoding demands of the task-relevant feature. Given that our visual search tasks at the 50% threshold levels were rather ambitious tasks, our findings could well be construed as complementary support for suppression of task-irrelevant feature dimension in complicated tasks.

Whereas most of the previous studies have been designed for detection tasks of highly salient stimuli and conclusions about visual selection have been based on manual reaction times (Fagioli, Ferlazzo, et al., 2007; Fagioli, Hommel, et al., 2007; Wykowska et al., 2009), only a few studies have applied eye tracking (Bekkering & Neggers, 2002; Gutteling et al., 2011) and controlled the bottom-up saliency along with manipulation of top-down action preparation (Hannus et al., 2005, presented in Chapter 2). Here, by making use of the advantages of eye movement recording (Kowler, 2011; Liversedge & Findlay, 2000), we were able to describe the direction of overt visual attention and carefully disentangle discrimination accuracy of different but perceptually equated features. Specifically, our design allowed us to selectively bias visual discrimination performance away from behaviorally neutral color discrimination task. Taken that detection and discrimination are different types of tasks (Sagi & Julesz, 1984) that may even relay on distinctive neuronal functions (e.g., Dupont et al., 1993; Hol & Treue, 2001), the findings of this study can be interpreted as a novel evidence for the interdependent competition between object features.

Finally, further studies with more focus on ecological validity are suggested. A better understanding of the mechanisms underlying action-related competition between visual features will clearly require additional support from more natural visual search tasks and psychophysiological studies. However, the presented finding establish that task demands related to object manipulation modulate interactions between object features.