Visuospatial Perception

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4. Eyes on crowding: crowding similarly affects identity and position accuracy

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Abstract

Peripheral vision guides recognition and selection of targets for eye movements. Crowding – a decline in recognition performance that occurs when a potential target is surrounded by other –similar– objects influences peripheral object recognition. A recent model study suggests that crowding may be due to increased uncertainty about both the identity and the location of peripheral target objects. Given that in the previous chapter (chapter 3) we found that crowding magnitude is preserved while responding by eye, we can now proceed to study position ambiguity in crowding. In our experiment, observers made eye movements to the location of a tilted Gabor target while we varied flanker tilt to manipulate target-flanker-similarity. The results indicate that this similarly affected the accuracy of peripheral recognition and saccadic target localization. Our results inform about the importance of both location and identity uncertainty in crowding.

4.1. Introduction

In crowding, recognition of an object is impaired when it is surrounded by other –similar– objects. The current main theories explain crowding either in terms of excessive feature pooling (e.g Greenwood, Bex, & Dakin, 2010; Pelli & Tillman, 2008; van den Berg, Roerdink, & Cornelissen, 2010) or as due to a loss of positional information (source confusion) resulting in reporting a flanking object as the target (e.g. Dakin, Cass, Greenwood, & Bex, 2010; J. a Greenwood, Bex, & Dakin, 2009; Strasburger, Harvey, & Rentschler, 1991; Strasburger & Malania, 2013). A recent model integrates both of these accounts by assuming that uncertainty (i.e., the width of the internal noise distribution) about both stimulus positions and identities depends on flanker proximity (van den Berg, Johnson, Martinez Anton, Schepers, & Cornelissen, 2012). To further test this idea, crowding studies would ideally assess target position and identity in tandem, but to our knowledge hardly any studies have done so thus far (a study by Greenwood, Bex, & Dakin (2012) forms a notable exception and we will discuss it later). In this chapter, we will do so, using eye movements.

4.1.1. Measuring perceived target identity and location using eye movements

In chapter 3, we have shown that crowding is preserved for eye responses, so we now can use eye-tracking to simultaneously quantify errors in identity and perceived location caused by crowding. It is not a priori certain that both aspects would be affected – let alone similarly affected – by crowding. "What" and "where" information are considered to be processed in different streams in the visual cortex (Goodale & Milner, 1992). A number of studies locate crowding effects beyond the early visual areas (Dakin et al., 2011; Liu, Jiang, Sun, & He, 2009) increasing the likelihood that position and identity information are differentially affected by crowding. Psychophysical support for separate coding of the what and where aspects in crowded conditions has also been reported (Strasburger, 2005).

Another reason that might result in differences in identification and localization performance is the following. A number of studies have indicated the importance of perceived target position in crowding (Dakin et al., 2011; Maus, Fischer, & Whitney, 2011). However, as recently demonstrated using a motion illusion, (saccade) localization need not necessary follow perceived position (Lisi & Cavanagh, 2014 but see chapter 2). Greenwood et al. (2009) suggested that "*crowding is a preattentive process that uses averaging to regularize the noisy representation of position in the periphery*". Based on this –if anything– one would expect that crowding would tend to minimize localization errors and consequently, identity and position errors would perhaps even be anti-correlated.

On the other hand, a recent crowding model proposed that flanker proximity affects uncertainty about both stimulus positions and identities (van den Berg et al., 2012). This model therefore predicts that both aspects would be affected by crowding, and most likely to a similar extend. Moreover, a study by Greenwood et al. (2012) investigated the binding of feature and relative position information in crowding. In one of their experiments, observers were asked to indicate both the target identity and perceived location. The authors concluded that "…., *crowding is a singular process that affects bound position and orientation values in an all-or-none fashion*". Based on this finding recognition and localization errors would also be expected to be largely correlated.

To assess how identity and position uncertainty are affected by crowding, we used eye-tracking to measure the influence of target-flanker-similarity on both recognition and saccadic localization performance. Based primarily on our model (van den Berg et al., 2012) our hypothesis is that increasing target-flanker similarity will lead to both increased recognition and localization errors.

4.2. Methods

4.2.1. Overview

We quantified the errors in recognition performance and saccadic landing position of a crowded target. The target was defined by tilt: the observer's task was to choose the most right or left tilted target respectively, by making a saccade to the target.

4.2.2. Observers

Six different observers (age range 23-27; all males) participated in the experiment. All of the observers were naïve as to the purpose of the experiment. All observers had normal or corrected to normal vision. One observer was excluded because of poor attention resulting in poor performance, leaving five observers for the results reported.

4.2.3. Materials

Observers viewed stimuli on a 22-inch CRT RGB monitor with a frame rate of 75 Hz (LaCie) from a distance of 59 cm. Stimulus presentation, eye movement recording, and response collection were programmed in Matlab (MathWorks) using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) and EyeLink Toolbox extensions (Cornelissen, Peters, & Palmer, 2002). Eye movements were recorded at 250 Hz with an EyeLink 1000 (SR Research, Kanata, Ontario, Canada) infrared eye tracker. We used the EyeLink's built-in 9-point calibration procedure. Background luminance during the experiment was 35 cd/m^2. We used a chin rest and a forehead rest to stabilize the observer's head position.

4.2.4. Stimuli and procedure

Prior to the start of a trial, a white fixation cross (0.2 deg) was presented at the center of the display. The observer initiated a trial by fixating on this fixation cross. If the fixation was stable for at least 250 ms, the trial commenced by presentation of the stimulus. It was presented until the observer made an eye response. If there was no response given within 3000 ms, the trial was marked as invalid. An example stimulus is shown in Figure 1. The stimulus consisted of a target and reference that were presented left and right of fixation, both either at 8 or at 10 deg of eccentricity, and either in isolation or surrounded by flankers. The side at which the target appeared was determined randomly. Target, reference and flankers were gabor patches (width = 1.0 deg, spatial frequency 3.0 cycles/deg).

In 10% of the trials, target and reference were presented in isolation. In the remaining 90% of the trials, flankers were present and these were positioned at the four corners of an invisible square with the target or reference at the center. Center to center distance of the target and flankers was 0.15 times the target eccentricity. All four flankers always had the same tilt, which was randomly chosen to be one of 12 different values in the interval –75° to 90° (step size 15°). Flankers were always presented at 25% contrast. Target and reference were presented at 5% contrast.

In alternating blocks of trials, the base target and reference tilt was set to either 45° or -45° from vertical. To distinguish the target from the reference, targets varied either 5° or 10° from this base tilt, always mirrored for the reference Gabor. So, the target and the reference differed in orientation by either 10° or 20° degrees. The observer's task varied depending on the base tilt. In blocks in which base tilt was 45° (-45°), the observer's task was to choose the target by making a saccade to the most rightward (leftward) tilted Gabor[1]. After the response, the fixation point turned either red (error) or green (correct) to provide feedback to the observer. During manual responding, observers were required to maintain steady fixation throughout the trials and their gaze was monitored. A single block of trails consisted of 300 trials.

In each of 6 sessions, observers completed two blocks of 300 trials each. For each session, the base tilt for the first of the two blocks was determined randomly. The other base tilt was used in the second block. Observers were offered a short break in between the two blocks of trials to minimize fatigue. All 6 observers thus completed 12 blocks of trials for a total of 3600 trials per observer. Prior to the actual experiment, observers completed 2 training blocks of trials, one for each base tilt and task combination. These trials were used to verify that the observer's performance for isolated targets was in the range 70%-90%. The training trials were not used in the further analysis.

Figure 1. An example stimulus for the second experiment. In different blocks of trials, observers were instructed to indicate either the most rightward-tilted target (central object) or the most leftward-tilted target by making a saccade.

4.2.5. Eye movement analysis

Saccades were determined using the EyeLink's built-in analyses routines. Prior to the statistical analysis, eye movement responses were filtered based on saccadic amplitude, saccade latency and saccadic direction. Trials were removed in which saccades were either: i) made within 150 ms following the start of the stimulus presentation, or ii) in which saccadic direction differed more than ±15 deg from horizontal (the direction of the target or reference), or iii) in which saccadic amplitude was less than 2/3 of the target or reference eccentricity. On average, this excluded 13% of the eye-response trials.

Analysis of recognition performance (crowding magnitude)

The first part of the analysis was done separately for each observer. First, we determined the average recognition performance in the "no-flanker" condition – separately for each eccentricity and base tilt. To obtain crowding magnitude, this value was subtracted from performance in each of the flanker conditions – again separately for each eccentricity and base tilt. For the final analysis, the results were averaged over observers.

4.2.6. Analysis of localization errors

To determine the occurrence of changes in localization performance, we included the saccades made during both erroneous and correct recognition responses. Our reasoning behind also using the recognition errors is that in those cases, the observer apparently considered the reference to be the target. Therefore, for determining localization performance, an error is as informative as a correct response.

First, saccadic landing positions to the left of fixation were mirrored in the origin. Next, we determined the average saccadic landing position for isolated target/reference trials (i.e. no flanker presented). This was done separately for each eccentricity and base tilt. Next, for each trial, we calculated the absolute distance between the saccadic landing position in that particular trial and the average saccadic landing position in the no flanker condition – for the corresponding eccentricity and base-tilt. Note that this removes any bias (e.g. due to saccadic undershoot) a participant may have had. We refer to this value as the localization error.

Next, average localization errors were calculated for each flanker orientation. Subsequently, the average localization error in the no-flanker condition was subtracted from the average localization error in each of the flanker conditions – separately for each eccentricity and base tilt. Note that this measure is therefore analogous to the calculation of crowding magnitude, in that it indicates the extent to which the localization error changed in magnitude as a result of the presence of flankers.

Finally, to compare the changes in recognition performance and localization error induced by the presence of flankers, each measure was also converted into a "z-score", by subtracting the average value, and dividing by the standard deviation (over flanker orientation). These z-scores were calculated first for each individual observer – separately for each base tilt and eccentricity.

4.3. Results

Repeated measures ANOVA results revealed that eccentricity and base tilt of the target had no significant effect on neither recognition performance ($F(1, 64) = 0.67$, $p>.05$) nor on localization error ($F(1, 64) = 0.187$, $p>.05$). Hence, for the remainder of the results, we report data averaged over eccentricity and target base tilt.

We examined performance as a function of target-flanker similarity. Results are shown in figure 2. As expected, target-flanker similarity had a substantial effect on crowding magnitude and a clear peak in crowding magnitude can be observed at 0° difference, i.e. when target and flanker are most similar. Since crowding was predicted to be strongest at 0° tilt difference, we used a paired t-test to compare crowding magnitude at tilt level 0° to the average crowding magnitude in the other conditions ($p<.001$). This indicates that crowding magnitude at 0° was increased compared to crowding magnitude in the other tilt conditions.

In an analogous fashion, for the analysis of localization error, we examined performance as a function of target-flanker similarity. Results are shown in figure 3. Similar as for crowding magnitude for recognition performance, target-flanker similarity had a substantial effect on localization error and a clear peak can be observed near 0° difference. A paired t-test comparing localization error at tilt level 0° to the average error in the other conditions ($p=.06$) indicated that localization error at 0° was increased compared to the average error in the other tilt conditions.

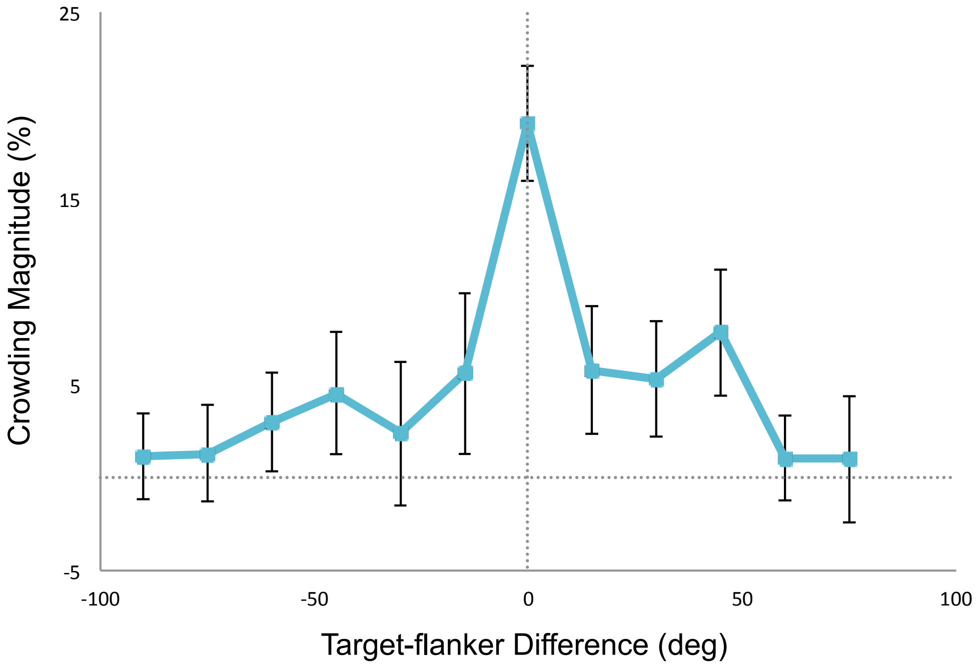

Figure 2. Crowding magnitude plotted as a function of the difference in tilt between target and flankers. Bars indicate ±1 s.e.m. over observers.

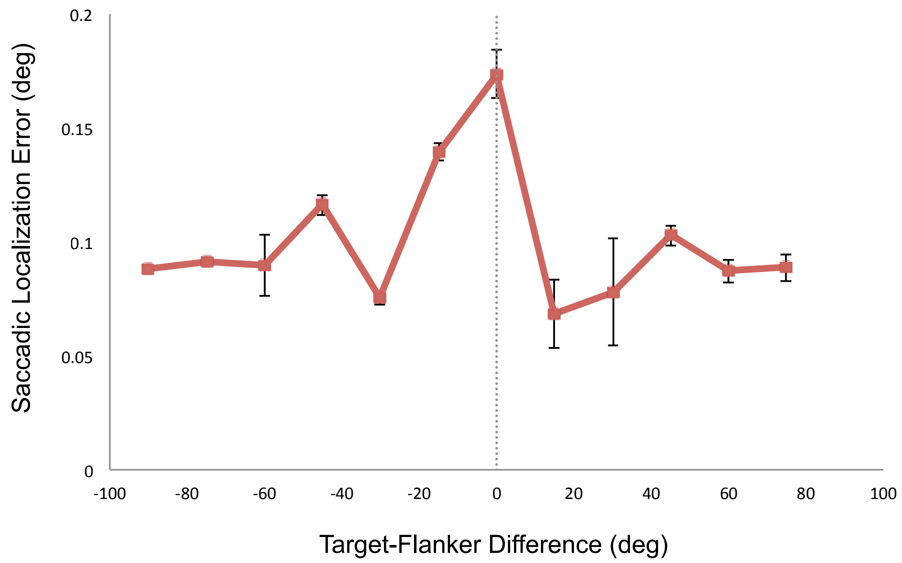

Figure 3. Saccadic Localization Error plotted as a function of the difference in tilt between target and flankers. Bars (where visible) indicate ±1 s.e.m. over observers.

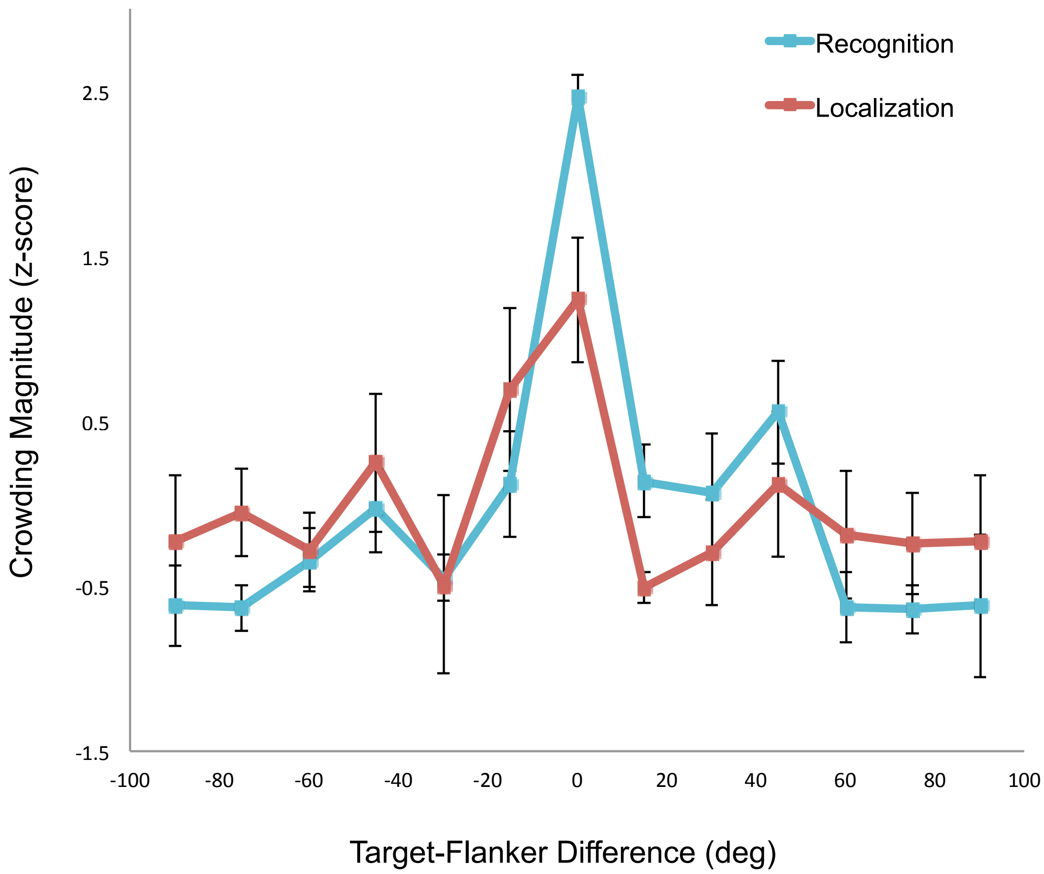

Figure 4: Comparison of average crowding magnitude (blue) and localization error (red) expressed in terms of a z-score and plotted as a function of target-flanker similarity. Bars indicate ±1 s.e.m. over observers.

To enable comparison of the changes in recognition performance and localization error caused by crowding, results for each observer were converted into a *z-score*. The results are shown in figure 4. Coinciding peaks in recognition (crowding magnitude) and localization performance (localization error) can be observed at 0° difference, i.e. when target and flanker are most similar. A repeated-measures ANOVA on the z-scores of recognition and localization performance revealed no significant interaction between similarity level and parameter $F(11, 44)=1.15$, $p=.345$) indicating that – when expressed in terms of a z-score – the crowding magnitudes for recognition and localization are not different.

4.4. Discussion

The main finding of our experiment is that flanking objects affect both recognition and localization performance and that crowding magnitude in both domains is approximately equal. As anticipated based on previous studies, we observed that crowding magnitude (recognition) was largest for identical target and flankers and decreased with increasing target-flanker difference (Figure 2). The localization error showed a very similar dependence on target-flanker difference (figure 3). Moreover, when expressed as a z-score (figure 4), crowding magnitudes for recognition performance and for localization error turned out to be approximately equal. In turn, this suggests that identity and position uncertainty are similarly affected by target-flanker differences.

These results are consistent with the predictions based on the model study of van den Berg et al. (2012). They are also consistent with a report by Greenwood et al. (2012) who concluded that bound position and orientation are affected by crowding in an all-or-none fashion. Our results – although measured in an entirely different manner – are congruent with this finding.

In our study, saccadic localization error showed a similar pattern of results as present in identification performance therefore suggesting that the perceived position of the target was affected by target-flanker similarity. Our results therefore imply that in this kind of task, saccadic localization follows the perceived rather than the physical location of the target.

Our finding that crowding affects saccadic localization performance is also relevant for understanding the potential role of reduced crowding around saccade initiation (Harrison, et al., 2013a,b). Although –as in our first experiment– orientation-based target selection would have occurred in advance of saccadic planning, target localization should definitely take place just prior to this process. Our finding that target discrimination and localization are similarly influenced by crowding argues against the notion that any modified crowding around saccade initiation might affect performance. As we noted previously, it simply appears to occur too late in the process.

The pattern of results (Figure 2-4) suggests that the relationship between target-flanker similarity on the one hand and crowding magnitude and saccadic localization error on the other hand does not follow a monotonically increasing and decreasing function. The reason for the deviations from monotonicity could be the "tilt illusion", which causes exaggeration of perceived target-flanker tilt differences. For crowding in the identity domain, the relation with the tilt illusion has previously been described (Solomon, Felisberti, & Morgan, 2004). Our present results indicate deviations from a smooth function also for saccadic localization, suggesting that this process is similarly affected by the tilt illusion.

A limitation of the present experiment is that we used a fixed target contrast instead of basing it on individual contrast thresholds. Also, our present experiment may underestimate the actual localization errors due to crowding because of the very presence of the flankers. Although distant from the target, flankers were presented in a regular array. Therefore, participants might have used the flanker position for planning saccades to the target, thereby diminishing the influence of perceived target position. Using flankers with a randomized position around the target might diminish this possibility. Another reason for underestimation could be that participants habituate to making saccades to the limited number of four positions (±8 and ±10 deg of eccentricity) thereby potentially limiting the magnitude of the saccadic localization error. A final limitation of the present experiment relates to the fact that observers had to choose between two objects only. This is a very limited choice compared to the demand usually posed by natural scenes, which tend to provide much more complex sceneries and choices. Future experiments should therefore consider using more variegated visual stimuli and response requirements.

4.5. References

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