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Crowding, Attention and Consciousness: In support of the Inference Hypothesis.

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Abstract.

One of the most important topics in current work on consciousness is what relationship it has to attention. Recently, one of the focuses of this debate has been on the phenomenon of identity crowding. Ned Block has claimed that identity crowding involves consciously perceiving an object that we are *unable* to pay attention to. Others have offered different interpretations, emphasising the role of cognitive inference over conscious perception. In this paper, we draw upon a range of empirical findings to argue against Block's interpretation of the data. We also argue that current empirical evidence strongly supports one particular version of the inference hypothesis. Finally, we consider the additional evidence Block gives in favour of his view, and argue that it fails to establish his position.

1. Identity Crowding

One of the most hotly debated questions in contemporary philosophy of mind and cognitive science is the relationship between attention and consciousness.[1] One of the focal points of this debate is the phenomenon of 'identity crowding'. Ned Block has argued that identity

[1] See Carrasco (2011), Van Boxtel et al. (2010) and Kentridge (2011) for surveys of work in cognitive science. See Watzl (2011) and Wu (2014), for philosophical surveys.

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crowding provides an example of an object that is consciously seen but which we are *unable* to pay attention to. If Block is correct, this will be a decisive blow to many theorists (such as Mack and Rock 1998, Prinz 2012, Montemayor and Haladjian 2014 and Cohen et al. 2012) who argue that attention is necessary for consciousness, and it would confirm the view of other thinkers (e.g. Mole 2008, Jennings 2015, Li et al. 2002 and Koch and Tsuchiya 2007) who argue that consciousness is possible in the *absence* of attention. Furthermore, Block argues that we can have *de re* thoughts about an object that we are unable to attend to.[2] This runs counter to the majority view in philosophical discussion of *de re* thought (e.g. Campbell 2002, Levine 2010 and Tye 2009a, 2009b, 2010). For this reason, our assessment of identity crowding has important consequences throughout cognitive science, as well as philosophy of mind and language.

In this paper, we offer an analysis of this debate. We firstly examine the phenomenon of identity crowding and the different interpretations of it that have been given (§1). Next, we draw upon a large body of empirical evidence to argue against Block's interpretation of identity crowding (§2) and put forward a rival interpretation (§3). Finally, we consider additional arguments put forward in favour of Block's view, and argue that they fail to establish Block's conclusion (§4).

[2] By '*de re* thoughts' we mean demonstrative thoughts, thoughts that 'mentally point' to objects.

Figure 1: An example of identity crowding. In the first row, an unflanked target is shown. The second row shows a 'normal' case of crowding and the third row the 'identity' crowded target (details see text).

Identity crowding is a particular variety of visual crowding (fig.1). When you fixate your gaze on the upper '+' in fig.1, you will probably find that you are able to identify the letter to the right of it. This is a normal instance of non-crowded peripheral vision. 'Crowding' is an effect that occurs when target items are 'flanked' by other items. For example, when you fixate on the middle '+' in fig. 1, you will most likely be unable to identify the middle letter in the array to the right of that '+'. This is a case of normal crowding. It occurs because the presence of the flanking letters disrupts the perception of the target letter (see Levi, 2008 for a survey). Crowding is not constrained to letters but occurs with a large range of other stimuli. [3]

There are various proposed explanations of crowding, and a large empirical literature dedicated to it (e.g. Herzog et al. (2015), Levi (2008), Pelli et al. (2004), Parkes et al. (2001), and Strasburger (2005)). Ned Block follows the view that crowding is due to 'excessive feature integration', where the visual system is unable to differentiate which properties belong to the target, and which belong to the flankers, and the result is that in cases of normal crowding, one only sees a 'messy' texture (Block, 2013a, pp.171-2). The

[3] Following convention, we refer to the middle letter as the 'target' and the outer two letters as 'flankers'.

purpose of the present paper is not to contest this general approach to crowding, but to focus on a particular kind of crowding: identity crowding.

The crucial case for our purposes is the bottom row in fig.1. When fixating the bottom '+', most observers find that they are able to identify the target letter. We follow Block (2013a) in referring to this phenomenon as 'identity crowding'. It occurs when the target is physically identical to the flankers. In this paper, our focus will be on the recent and highly controversial claim that identity crowding is a case where subjects are *unable* to direct attention to a target item, but can still consciously *see* that item (the item in question being the middle letter). We call this view the 'conscious perception' view.

Block (2013a, 2013b and 2014) defends this view.[4] Block's case can be divided into two main points (each of which will be more thoroughly explained later in the paper). Firstly, he notes that subjects are usually able to detect identity crowded targets, discriminate them from the background (and from the flankers), identify them, and have *de re* thoughts about them. Block concludes from this that 'it is difficult to see a rationale for denying that one can consciously see [the target]' (2013a, p.175). Secondly, Block draws upon work based upon summary statistics, binding and 'singular elements' to argue that identity crowding is 'sufficiently perceptual to involve consciously seeing identity-crowded objects' (2013b, p.31).

Views that oppose the conscious perception hypothesis offer a rival interpretation of identity crowding. These views all deny that subjects have a conscious experience of the middle item in identity crowding, and they explain subjects' abilities in terms of some kind of cognitive inference, rather than conscious perception without attention. Such

[4] Though Block grants that there may be *spatial* (as opposed to object-based) attention to it (2013a, p.173).

interpretations fit into a family that we call 'inference views', but this is only a loose label, as different versions of the view emphasise inference to very different extents. Bradley Richards (2013) claims that subjects *unconsciously* perceive the middle letter, but this unconscious perception is accompanied by a conscious *judgement* to the effect that there is an 'A' (see fig.1), present. Henry Taylor (2013) suggests that the experience of the group of letters as a whole lacks the detail to represent the middle letter specifically, but that subjects are able to identify one of the flankers, and also identify that the group of letters as a whole is congruous and uniform. Taylor claims that subjects can use this information to infer that the target is the same as the flankers, and thus identify the target. Michael Tye (2014) claims that in the case of identity crowding, we *only* see the two flanking letters: '[w]hat your experience erroneously tells you is that there are two [letters] on the right, not three' (2014 p.156). Then, when asked what the 'middle' letter is, subjects infer (based on the fact that they can only see two similar letters) that any letter there must be the same.

Inference theorists and conscious perception theorists also differ on their interpretation of cases similar to identity crowding (e.g. fig. 2).

Figure 2: Identity crowded lines. Adapted from Intriligator and Cavanagh (2001). (Details see text).

When subjects fix their gaze on the cross in fig.2, they typically find it difficult to direct attention toward each of the bars individually (Intriligator & Cavanagh, 2001). Block (2013a, p.175) claims that each individual bar is consciously seen. Inference theorists reject

this. Tye (2009a, 2009b and 2014) claims that one sees the collection of bars as a whole, without seeing each individual bar, and this experience allows subjects to infer properties of each individual bar. Taylor (2013) offers a similar view to Tye, though he emphasises the role of properties of the group such as congruity and uniformity in allowing subjects to infer properties of individual bars. Richards' (2013) view is again similar, though he emphasises the role of unconscious perception.

Importantly, Block agrees with these opponents that perception *and* inference play at least *some* role in identity crowding (Block, 2013b, p.31). The difference is that Block (unlike his opponents) thinks that there is *conscious* perception of the target in the absence of attention in cases of identity crowding and in cases like fig.2. Block puts forth this claim with different strengths in different places, occasionally he seems to say that the target letter in identity crowding cases is always consciously seen, though it escapes attention (2013a, p.175), whilst at other times he claims that it is consciously seen 'at least in some cases' (2013b, p.31). Each version of the view raises its own distinctive questions. For example, if the claim is that the middle letter is only seen *sometimes*, then we require an account of what is going on in the cases where it is not seen; whilst no such need arises when the claim is that the letter is *always* seen. In any case, in this paper, we will argue that Block's arguments fall short of showing that the target is consciously seen, and that all of the data can be accommodated without needing to make this claim. We further claim that in cases of identity crowding, we have good reason to deny that the target is ever consciously seen.

2. Evidence Against Conscious Seeing in Identity Crowding.

One core part of Block's case against both Tye and Taylor is that they do not support their views with empirical evidence (Block, 2013b, pp.36-37 and 2014). These complaints are fair, Block's opponents have by and large relied on intuition and introspection. In this section and the next, we remedy this: we review evidence related to the phenomenon of 'grouping' in crowding, and the relation of conscious target perception to the abilities to direct attention to the target. We argue that both kinds of evidence oppose Block's 'conscious perception' view.

2.1 Similarity and grouping in crowding

To Block, the conscious perception of the target in identity crowding is what explains subjects' abilities to identify, discriminate etc. the target. Of course, Block does not base his case on *normal* crowding (e.g. the middle row of fig.1) because in these cases subjects are not able to identify, discriminate etc. the target (again, given that crowding is sufficiently strong), so there is no positive reason to claim that the target is consciously seen. In this section, we draw upon work on grouping to argue that we have *more* reason to doubt that the target is consciously perceived in the case of *identity* crowding than in the case of normal crowding! Given these findings, we have reason to doubt Block's view.

The main feature of (normal) crowding is that it becomes harder to identify the target in the presence of flankers compared to unflanked targets (for reviews, see e.g., Herzog et al. 2015, Levi, 2008; Whitney et al., 2011). One of the important factors determining the strength of this crowding effect is whether the target is 'grouped' with the flankers. Visual grouping occurs when certain distinct elements in the visual field are perceived as in some way 'connected' and belonging together (e.g., Köhler, 1947; Koffka, 1935; Wertheimer, 1955). An

example is shown in fig.3.

Figure 3: an example of grouping. On the left, the central A strongly 'groups' with the two close-by letters to the left and right but not with the two distant (vertically arranged) letters. Changing the shape and colour of the close-by letters changes grouping. On the right, the three vertically arranged As appear more grouped than on the left.

Numerous studies have shown that the more the target groups with the flankers, the stronger is the effect of crowding, i.e. the more difficult it becomes to identify the target (for a review see, Herzog, Sayim, Chicherov, Manassi, 2015). Grouping strength between the target and its (directly neighbouring) flankers is often determined by how similar/dissimilar their properties are. For example, a black target groups more strongly with black than with white flankers, and is harder to identify when it is surrounded by black flankers than by white flankers (Kooi, Toet, Tripathy, & Levi, 1994; Sayim, Westheimer, & Herzog, 2008). This similarity effect has been shown for a variety of features (e.g., colour: Kooi, Toet, Tripathy, & Levi, 1994; Sayim, Westheimer, & Herzog, 2008; Manassi, Sayim, & Herzog, 2012; shape: Nazir, 1992; depth: Sayim et al., 2008; Astle, McGovern, & McGraw, 2014). Importantly, target-flanker similarity was also correlated with the error rate in crowded letter discrimination. The upshot of these results is that the more the target and flanking letters were similar, the harder it was to identify the target, i.e., the *higher* was the error rate (Bernard & Chung, 2011).

It is reasonable to take the increased difficulty of identifying targets as grouping strength increases to indicate increased disruption in the perception of the target. This is because crowding itself is due to a perceptual disruption of the target of one kind or another, so it is reasonable to assume that an increase in the effects of crowding indicate an increase in this disruption. Note that this need not commit us to any one particular theory of the mechanisms involved in crowding, we need only claim that the effect is perceptual in at least some way.

It might be argued that grouping changes the decision criterion, for example, by introducing a bias by the flankers. Systematic flanker bias has to be considered when the flankers contain features that are relevant for observers' responses. For example, in letter identification, flankers that strongly group with the target because of shape similarity could bias observers independent of perceptual changes of the target. In such cases, it is advisable to distinguish between disruption in the perception of the target and other factors, such as flanker bias, for example, by using signal detection theory (see, for example, Sayim & Cavanagh, 2013).

Additionally, there is reason to think that decrease in performance as grouping strength increases is mirrored in the phenomenology of the experience, as subjective estimates of how much the target 'stood out' (i.e., "ungrouped" from the flankers) are positively correlated with performance (e.g., Saarela et al., 2009). Furthermore, consider an alternative (non-perceptual) explanation of why subjects' abilities deteriorate as grouping increases. Such a view would have to claim that perception of the target remains approximately the same as grouping increases, but that subjects' judgements become steadily worse. Such a view is empirically unmotivated and inexplicable on current theories

of crowding.

What's more, these effects are unsurprising on the view (that Block endorses) that crowding is due to 'excessive feature integration'. On this view, crowding is due to the visual system being unable to differentiate between the properties of the target and those of the flankers in peripheral vision, which leads to disruption in the conscious perception of the target. Given this, it is natural to suppose that the more similar the properties of the target and the flankers are, the harder it is for the visual system to differentiate them, and thus the more there will be excessive feature integration, and the more conscious perception of the target will be disrupted (note, however, that global grouping can trump effects of local similarity; e.g., Sayim et al., 2008; Manassi et al., 2012).

The role of grouping in crowding is highly relevant for the discussion of identity crowding. In the standard case of identity crowding - one target letter with two flanking letters - target-flanker similarity is maximal (because, of course, the targets and the flankers look exactly the same). As a result, target-flanker grouping is extremely strong. Hence (since grouping is linked with disruption in the perception of the target) one would assume that conscious perception of the target will be maximally disrupted. By contrast, Block's claim (that of conscious seeing without attention) suggests that (in cases of identity crowding) perception of the target is *superior* compared to normal crowding.

So, assuming that Block accepts that an increase in the strength of target-flanker grouping increases the effects of crowding, and thus increases disruption of the conscious perception of the target (and given the evidence explained above, it is very difficult to see how he could deny this), Block would have to claim that even though perception of the target is disrupted more as the target and the flankers get more and more similar, the exact

reverse happens when they are identical: the disruptive effects of crowding in the visual system become weak, and the target can be consciously perceived and identified. Such a reversal of grouping and similarity effects in crowding at physical identity is highly implausible and not supported by empirical evidence. To the contrary, an accumulating body of studies shows that the relationship between grouping/similarity and crowding strength holds for a large range of stimuli, including almost identical targets and flankers close to physical similarity. We take these results to count strongly against Block's claim that the identity-crowded target is consciously perceived.

2.2 Attention in Crowding

Another difficulty for Block's general view is as follows: Block claims that in cases of identity crowding, subjects can consciously see and identify items that they are *unable* to attend to. But this is at odds with evidence suggesting that conscious perception and ease of identification of a target in crowding is correlated with how easy it is to pay attention to that target. To see this, consider that as grouping becomes stronger, the item in question 'blends in' more with its surroundings, whilst when grouping is weak, the item 'stands out' more. The more that an item stands out, the easier it is to direct attention to that item, this is a well known phenomenon in visual search (e.g., Nothdurft, 2000; Treisman & Gelade, 1980). Several studies showed that discrimination performance of a crowded target goes hand in hand with how much the target stands out (or "ungroups") from the flankers. This was shown with objective measures such as reaction time in visual search (e.g., Sayim, Westheimer, & Herzog, 2011; Gheri, Morgan, & Solomon, 2007; but see Felisberti, Solomon, & Morgan, 2005) and subjective measures (e.g., Saarela et al., 2009; Manassi et. al, 2012). For

example, when the target stood out, i.e., was easily attended and efficiently searched, the disruptive effects of crowding were reduced compared to when the target did not stand out – the success of subjects at the discrimination task and directing attention to the target went hand in hand (e.g., Sayim et al., 2011).

Since Block claims that conscious seeing is possible without attention in crowding, he has difficulty explaining why performance is linked so closely to how easy it is to direct attention towards crowded items. Block's opponents have no such problems: they accept that there is an explanatory link between conscious seeing and attention, so their view would *predict* that there would be a link between how well subjects perform at these tasks and how easy it is to attend to the target, which is precisely what we see.

3. Evidence in Favour of the Inference View.

We have argued that grouping and attention effects in crowding tell against Block's interpretation. However, there is still something that remains to be explained: if in identity crowding, the target is not consciously seen, how is it that subjects can identify, discriminate and differentiate the target, as well as have *de re* thoughts about it? In this section, we turn to this question. We argue that subjects' (seeming) success can be explained in terms of grouping and congruity effects, flanker biases, and prior knowledge. Again, we supply evidence for these claims. We argue that the evidence supports Taylor's version of the inference view, and also supports *some* aspects of Tye's view.[5]

3.1 Grouping and Congruity

[5] For reasons of space, we will not be able to discuss Richards' view much more, nor will we have the space to dispute Block's criticisms of Richards (Block, 2013b, p. 31). Of course, the fact that the evidence we supply does not support Richards' view does not imply that his view is *wrong.*

As we mentioned in §1, Taylor's view is that subjects identify a flanker, then infer (based on the fact that the group of letters as a whole appears congruous, i.e., no item "stands out") that the target is the same as the flankers. Taylor's claim that subjects can detect properties of the group such as 'congruity' neatly fits with our discussion of grouping above. As we pointed out, subjects are able to make accurate judgements about how much a target 'blends in' (i.e. groups) with its flankers. These judgements of how much a target 'blends in' with the group seem very similar to the kinds of judgements about 'congruity' that Taylor claims subjects can make. Since we know that subjects are capable of making these judgements, it is reasonable to assume that they feature in the inferences that allow them to correctly identify the crowded item. This will especially be the case when the targets are identical with the flankers, as grouping will be maximal, and the group of items will appear maximally congruous. Correlations between identification performance and grouping/ congruity support this view.

3.2 Errors and biases in crowding

In this section we argue that biases and errors to report the identity of the flankers are important factors in explaining subjects' performance in identity crowding.[6] Identity crowding is a special case of crowding because reporting a flanker is a correct response. Therefore, it is essential to differentiate between responses to the flankers and responses to the target. This is particularly important because a common error in crowding is target-flanker substitution, i.e., reporting a flanker instead of the target (e.g., Strasburger, 2005). Substitution errors may account for about 30% of the total error rate in crowding (e.g., Strasburger, 2005; Bernard & Chung, 2011).

[6] Again, though Taylor and Tye both suggest possibilities similar to these, they do not discuss any evidence related to them, as we do here.

When target and flankers are different, substitution errors are noticed because observers do not correctly report the target. However, this is not the case in identity crowding where the target response is 'correct' even if the observer identified a flanker. What's more, substitution errors in letter identification were shown to *increase* as targets and flankers get more similar (Bernard & Chung, 2011). Since the targets are identical in appearance to the flankers in cases of identity crowding, we would expect substitution errors to be rather high. This suggests that the (seemingly) correct identification of the target in identity crowding may be partly due to substitution errors, which go unnoticed because mistaking a flanker for the target still delivers the 'correct' answer. If this were so, it would tell against Block's interpretation that subjects' reports were due to conscious perception of the target.

In a recent study, Sayim and Cavanagh (2013) used stimuli highly similar to the standard identity crowding stimulus and showed that subjects have a tendency to report the identity of (grouped) flankers. In these experiments, the stimuli were letters, just as they are in Block's central case. In the first experiment, a target letter T was presented in one of four orientations (Figure 4; Sayim & Cavanagh, 2013). Observers indicated the orientation of the target. The target was flanked by two sets of flankers. One pair (the horizontal flankers) was presented to the sides of the target and always had different orientations from each other and the target. The other pair (the vertical flankers) was presented above and below the target, and always had the same orientation as each other (see Fig. 4A).

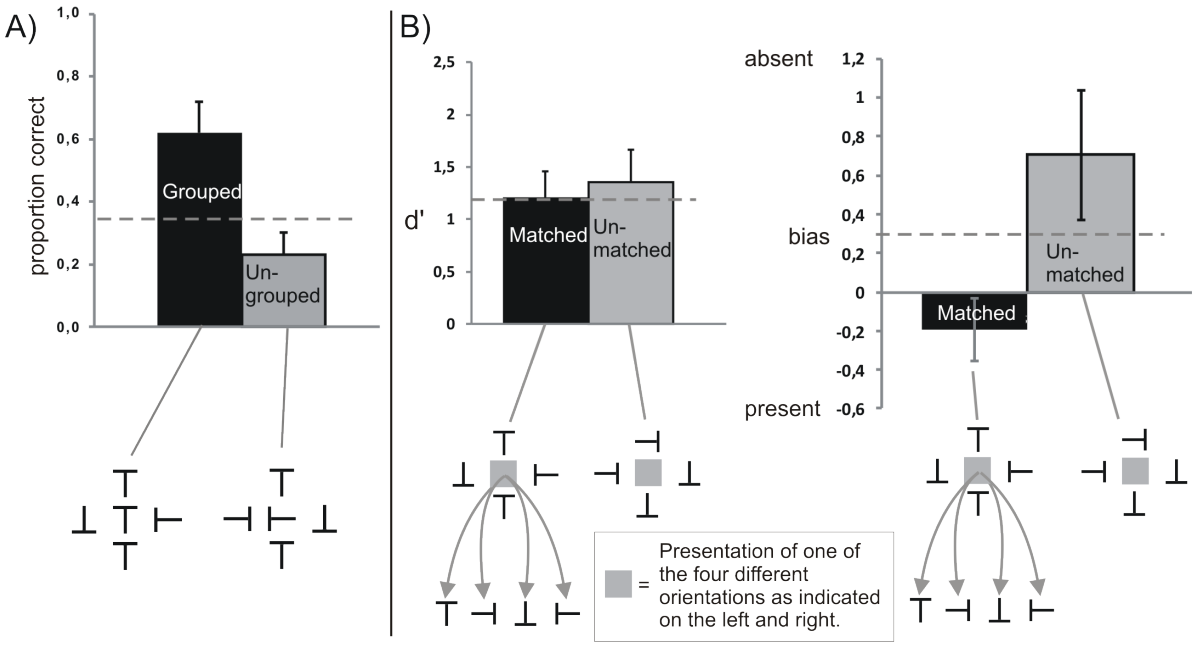

Figure 4: A) Observers indicated the orientation of the target T in the centre. When the target had the same orientation as the vertical flankers (Grouped condition), performance was better than when the target had a different orientation than the vertical flankers (Ungrouped condition). This result is expected if target discrimination is superior in identity crowding than in normal crowding. B) Observers indicated if the predefined response orientation was presented at the target location ("upright" in the depicted example). Sensitivity did not differ between the Matched and Unmatched condition (left panel). However, bias differed between the conditions (right panel). Observers indicated that the predefined orientation was present when it was not presented more frequently in the Matched than in the Unmatched condition (adapted from Sayim & Cavanagh, 2013). Dashed lines indicate results with only Horizontal flankers.

When the target had the same orientation as the vertical flankers, the three letters were the same as in the standard case of identity crowding – three identical letters of the same orientation in a row (but vertically rather than horizontally arranged). The results showed that the proportion of correct responses was higher when the vertical flankers and the target had the same orientation, i.e., when they were identical. This is exactly what would be expected if target discrimination is better in identity crowding than in normal crowding, and it may initially seem to support Block's view. However, the experiment did

not distinguish between responses to the *flankers* and responses to the *target*. For example, if observers always indicated the orientation of the vertical flankers, they would be 100% correct in the condition where the flankers and the target were the same and 0% correct in the condition where they were different. Similarly, in standard identity crowding – reporting a flanker is always correctly reporting the target.

To investigate if a bias to report the flanker orientation underlies the (seemingly) better performance when the vertical flankers and the target were identical, in the second experiment signal detection theory (Macmillan & Creelman, 2005) was used to separate sensitivity (perceiving the target *better*) and bias (responses driven by non-target sources, e.g., the flankers). Observers indicated if the 'T' at the target location had an orientation that matched the orientation of a 'T' they were shown beforehand, the 'predefined orientation' (e.g., upright in Fig. 4B). If it did, they were instructed to respond 'present' and if it did not, subjects were to respond 'absent', so this is a straightforward Yes/No task. In half of the trials, the vertical flankers were of the same orientation as the predefined target orientation (the matched condition), in the other half not (the unmatched condition; for more details see Sayim and Cavanagh, 2013).

The important point is this: unlike in the previous experiment (and unlike the examples of identity crowding that Block cites) a bias to respond in line with the flankers *does not* improve performance in this case (in the matched condition compared to the unmatched condition), so if (contra Block) subjects tend to report "target present" when actually only the vertical flankers had the predefined orientation, this experiment would reveal that subjects were biased to report the orientation of the vertical flankers. Indeed, that is what was found. In the matched compared to the unmatched condition (see fig. 4B, bias

results), observers frequently reported that the target was present even though it was not. In other words, when the vertical flankers had the same orientation as the predefined one, observers *falsely* reported that the target was of that same orientation. Hence, observers were biased to respond in line with the vertical flankers. The vital point is this: the results showed that identical flankers *did not improve target perception, they merely made subjects more likely to report that the target was of the same orientation as the flankers.*

The result of these two experiments are of major importance for the identity crowding debate. Block's view (conscious seeing without attention) depends on the claim that subjects' reports in identity crowding cases are based upon consciously "seeing" the target. This was not the case. Instead, the results showed that targets which are not the same as the flankers are often mistakenly seen to be the same as the flankers. So it is clear that subjects manifested a tendency to report the orientation of the flankers. Hence, (apparent) superior performance in identity crowding compared to normal crowding is likely due to this bias imposed by the flankers when they have the same orientation (as well as other factors, see below).

This is bad news for Block, but what about his opponents' views? Firstly, return to Taylor's view. Taylor claims that subjects identify a flanker, and then infer (based on the fact that the group appears congruous) that the identity of the target is the same as that of the flanker. If this is so, we would expect subjects to be *more* likely to report the identity of a *flanker* the more congruous the group of letters is. Strikingly, this is precisely what was found. Sayim & Cavanagh (2013, p.9) performed a further experiment, which showed that the bias to report the flanker was *not* maintained when the vertical flankers were not aligned with the target (but with the innermost flanker). This suggests that subjects are only biased

to report the identity of a flanker when the group of letters are better aligned, and thus are more congruous with the target in the centre. This strongly supports Taylor's view that congruity is a powerful factor in making subjects believe that the target letter is the same as the flanker letters. Importantly, it also shows that the effect is not a mere response bias, i.e., reporting the presence of a particular target orientation simply because that orientation is frequent in the entire stimulus.

Now, compare this with Tye's view. We do not endorse Tye's claim that in *all* cases of identity crowding, subjects do only see two letters.[7] Tye's account is at odds with the fact that in crowding, subjects are typically able to tell whether a target is absent or not, which is difficult to explain if all subjects saw was two letters (Levi, Hariharan, & Klein, 2002; Livne & Sagi, 2007; Pelli, Palomares, & Majaj, 2004).[8] On Taylor's interpretation, there is no such problem, since Taylor allows that subjects have a conscious representation of a *group* of letters, subjects would be able to use information about the size and shape of this group to determine whether there were three items there or two, and thus detect the presence or absence of a target (cf. Taylor 2013, p.22)[9]. For this reason, we prefer Taylor's view to Tye's. Tye is nonetheless correct that bias to report a flanker is an important factor.

Block (2013a, p.175 and 2014, p.162) argues that the identity crowding results cannot be explained in terms of subjects simply identifying the flankers and reporting them. He cites an experiment (Petrov and Popple, 2007) where three Gabor patches were presented

[7] However, we will not debate the claim that subjects *sometimes* only perceive two letters, we only claim that this view has difficulty applying across the board and (as we shall show) advocates of the inference thesis do not need to make the extreme claim that Tye does, as the data can be accommodated for in other ways.

[8] Block (2014, p.164) claims that Tye's view is also phenomenologically implausible. However, as such disputes are notoriously difficult to adjudicate, and because we do not need to take a stand on this, we will discuss it no further here.

[9] Note that knowledge about the stimulus may strongly shape the outcome of an identity crowding experiment (see also 3.3.). For example, comparing the relative size of two stimuli when knowing that there are either two or three elements, is easier than indicating the absolute number of items without any comparisons.

peripherally, with each Gabor slanted left or right. Block notes that subjects performed with 96% accuracy when the Gabors were uniformly slanted (///) but only 53% accurately when the middle Gabor was differently slanted left (/\/). Block takes this to show that results in identity crowding cannot simply be based on subjects' identification of the flankers (2013a). Furthermore, Block notes that other asymmetries, such as 72% correct responses in the (\/\) case vs only 53% correct responses in the (/\/) case in normal crowding 'can only be explained perceptually' (2013b, p.31).

Start with the asymmetry between the (///) case and the case when the central Gabor is tilted to a different orientation from its flankers, such as (/\/). This is clearly the asymmetry that is more directly relevant to identity crowding, as in this case one of the sets of stimuli are identity crowded. Subjects' (apparently) superior performance in the (///) case can easily be explained in terms of the mechanisms we have already outlined. In the (///) case, subjects' accidentally reporting the orientation of one of the flankers ('flanker substitution') would go unnoticed, and be recorded as a 'correct' judgement, but this would not go unnoticed in the (/\/) case, so this will contribute to the apparently higher performance in the (///) case. Similarly, it is often assumed that in crowding, subjects can detect the presence of features of the stimuli, but cannot detect the location at which the features appear, which would again result in uncertainty about the orientation of the target and the flankers in the (/\/) case but not in the (///) case. Finally, we have already pointed out that subjects are more likely to report the identity of a *flanker* when the group appears congruous (as predicted by Taylor, see also Sayim and Cavanagh 2013, p.9). Since congruity is maximal in the (///) case, we would expect subjects to be most likely to report the identity of flankers in this case. These factors can easily account for subjects' apparently superior

performance in the (///) case, as opposed to the (/\/) case.

Turn now to the other asymmetry: subjects give 72% correct responses in the (\/\) case as opposed to 53% in the (/\/) case. Neither of these are cases of identity crowding, so it is difficult to see why this asymmetry should support Block's case that the middle item is consciously seen in the case of identity crowding. Block does not connect this case with identity crowding specifically, rather he seems to use it only to establish a more modest claim, which is that crowding effects in general can only be explained in terms of perception (2013b, p.31). Furthermore, in response to Taylor, Block concedes that 'Taylor is right that these asymmetries show only that the abilities I appealed to must be *at least partially* perceptual' (2013b, p.31. Our emphasis. See also his 2014 p.162).

Block's claim that these asymmetries are to be explained partly perceptually is quite modest, and we can agree with it. After all, our explanation of the asymmetries between identity crowding and normal crowding rely explicitly on subjects' conscious perception of the group of letters as a whole, and perceptual experience of the flankers, as well as congruity and uniformity properties. Furthermore, these conscious perceptual experiences will of course be underwritten by some unconscious perceptual processes.[10] So, we are happy to agree that the asymmetry between these two cases of normal crowding can be explained partially perceptually as well.

As Block notes, the mechanism underlying the (\/\) vs (/\/) asymmetry is not well understood (2013b, p.31) so we will not take a stand on this issue here. However, our view is compatible with a wide range of proposed explanations of this phenomenon. For example, Petrov and Popple speculate that we may be able to explain the asymmetry in terms of optic

[10] We will expand on this point about unconscious perception in §4.

flow and saccadic eye movements (2007, p.5). Block himself notes this as a possible explanation (2013b, p.31). We do not commit to this view here, but nothing we have said is inconsistent with it.

3.3 Effects of knowledge

In identity crowding illustrations, observers know that they are looking at an example of identity crowding. Hence, they know in advance that, for example, three letters are presented. Without gaze contingent presentation, (presentation of the stimulus only when the observer keeps fixation at a particular point *away* from the stimulus), or very short presentation times, it is difficult to prevent observers from directly looking at the stimulus. Hence, prior knowledge either about the entire stimulus or the flanker identity is likely to occur and have an effect in identity crowding.

This has been shown in a variety of experiments. Zhang et al. (2009) showed that if subjects have prior knowledge of the set of items the target and flankers were drawn from, then superior performance was observed compared to conditions in which the set was not known before the experiment. Similarly, if subjects are cued with an item in the fovea, and then are made to scrutinize a crowded target for that item, success increased when the cued item was the same as the target (Sayim et al., 2014)[11]. This effect of prior knowledge even occurs with extremely complex crowded stimuli, such as abstract paintings (Sayim, Myin, & Van Uytven, 2015).

It is likely that subjects can reach conclusions about the identity crowded stimuli based upon these knowledge effects. As observers know the target in identity crowding

[11] Note that simultaneous presentation of the foveal item and the stimulus showed a stronger effect than presenting the foveal item before the stimulus, indicating that the effect of target-flanker grouping was stronger than cueing.

because they can directly look at them, conclusions about the identity of the target are influenced by this prior knowledge. Having prior knowledge will obviously make the question of what the target letter is very easy. Again, this suggests another explanation of subjects' abilities, other than conscious perception of the target

3.4 Subjects' abilities: conclusions.

We have discussed empirical results which indicate that the (seemingly) better performance in identity crowding can be attributed to several factors without invoking the conscious perception view. These factors include the regularity of the group of letters, i.e., the lack of "standing out" of the target (leading subjects to make inferences based upon 'congruity' properties of the group), in conjunction with identification of a flanker, biases to report the identity of the flankers and knowledge of the stimulus. We claim that it is some variety of these factors that accounts for subjects' performance in identity crowding. What's more, unlike Block's other opponents, we have supported this claim with a large range of empirical evidence.

4. Summary statistics and the phenomenology of crowding.

In this section we consider some additional arguments that Block uses to support the conscious perception hypothesis. Block (2013b, pp.32-36) refers to an experiment that applied a texture synthesis algorithm to images to produce new 'scrambled' images which should be indiscernible from the original, when both images are viewed in peripheral vision (Balas et al. 2009).[12] These scrambled images are called 'mongrels'.

[12] See Portilla and Simoncelli (2000), Simoncelli and Portilla (1998) and Freeman and Simoncelli (2011) for more on these algorithms.

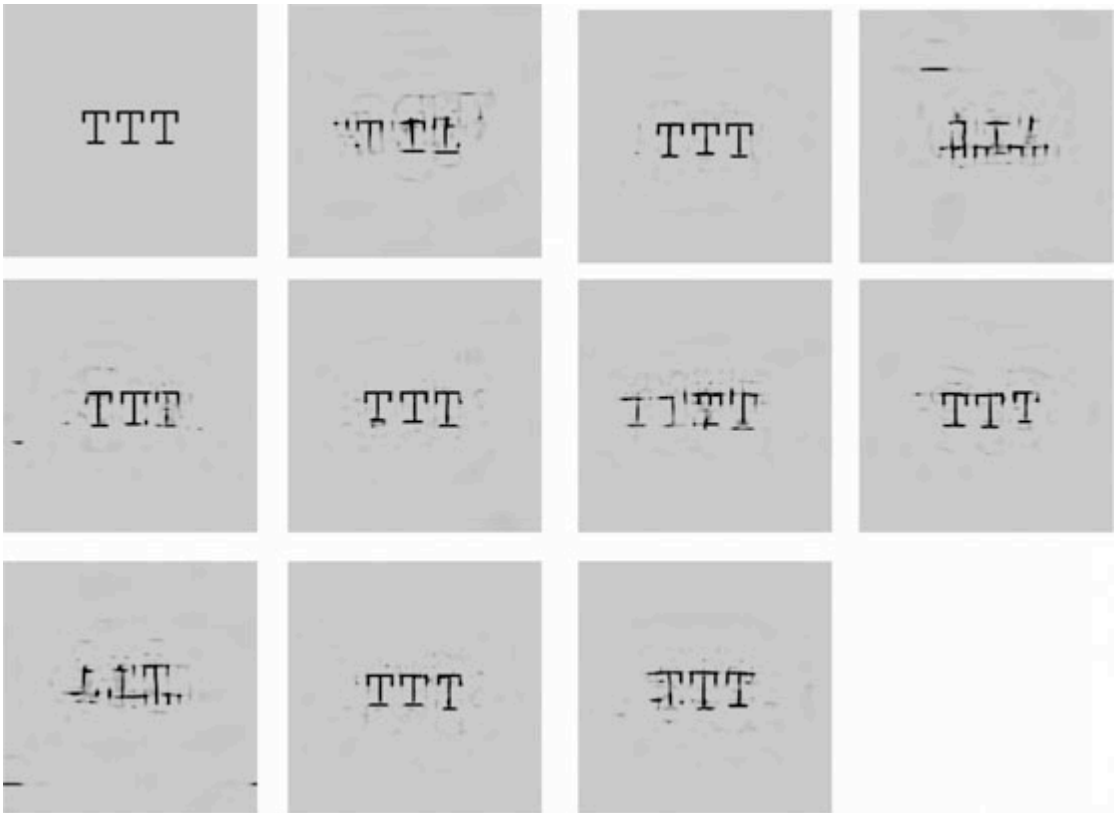

Figure 5: From Block (2013b, p.35): John Wiley and Sons, Inc. Reproduced with Permission. Block credits Ruth Rosenholtz with creation of the image.

Fig.5 shows the results of applying the mongrelisation algorithm to stimuli used in identity crowding: the original image is shown in the top left, and each of the other images is a different result of the application of the mongrelisation algorithm to the original image. Balas et al. suggest (albeit tentatively) that the perceptual system may represent stimuli viewed in the periphery using a process similar to this mongrelisation algorithm (2009, pp.11-14).

When discussing the summary statistics data, it is important to separate the different points that Block makes. The first is to do with binding. Block notes that in many of the mongrels, the middle letter is recognizable as an upright 'T'. He then concludes that:

'[t]hese figures suggest that the visual system can sometimes bind features to some objects in peripheral vision so long as the objects are all the same' (2013b, pp.35-36).

We are happy to accept that the visual system can bind features in peripheral vision. However, it is well known that perceptual binding can occur in the absence of consciousness (Dehaene et al. 2004), so the presence of binding does not tell us whether perception of the object is *conscious.* In crowding generally, the view that crowded targets which cannot be discerned are nevertheless processed by the visual system and affect perception and behavior, is well supported by empirical results (He et al., 1996, Yeh, He, & Cavanagh, 2012, Kouider, Berthet, & Faivre, 2011, Faivre & Kouider, 2011). Though these studies did not concern *identity* crowding, they do show that unconscious perception of crowded items occurs, and so we see no reason to resist the claim that it may occur in the case of identity crowding. Similar things go for Block's claim (based on Burge, 2010) that unconscious seeing and conscious seeing form a natural kind (2013a, p.180 and 2014, p.161).[13] We are happy to accept all of these points, we simply deny that the target is consciously perceived.[14]

Crucially for our purposes, Block extends this discussion in an attempt to demonstrate that the middle letter is *consciously* represented, at least sometimes. Block argues that we have good reason to think that the *phenomenology* of seeing the 'TTT' stimulus in peripheral vision is accurately represented by the different mongrels in fig.2, saying that:

[13] Block further claims that in identity crowding, our perception of the target involves a 'singular element' (2013b, p.36). A singular element is part of the content of a perceptual episode that represents the individuality of the percept, the fact that the percept is a particular (Burge 2009, p.287). Again, we are happy to accept this, but we claim that singular elements are unconscious in the identity crowding case. Burge himself agrees that singular elements can be present in unconscious perceptual episodes (2010).

[14] This point also applies to an argument for a similar conclusion that Block bases on Freeman and Pelli (2007), where subjects were just as good in performance at a change-detection task when the cued items were crowded letters, as when they were uncrowded ones. Block takes this to imply that perception in crowding is object-perception (2013b, p.36) and that a Burgean 'singular element' is present in crowded perception (2014, p.161. See also Block 2013a, pp.178-182). As above, we will not dispute these claims, we simply claim that all of this is *unconscious* perception.

> 'the mongrelisation algorithms are designed to reproduce the conscious qualities of peripheral vision… there is reason to think that the mongrelisation process is telling us about conscious vision' (2013b, p.37. Cf. 2014, p.162). [15]

If we accept Block's claim that the phenomenology of identity crowding is accurately captured by the mongrels, then (since some of the mongrels contain a clear middle letter 'T') we have good reason to accept that the middle 'T' is represented in consciousness, at least sometimes.

This argument hinges on accepting that the mongrels accurately represent the phenomenology of peripheral vision. However, we do not think that Block is warranted in drawing this conclusion from the Balas et al. data, for two reasons: firstly, the claim that mongrels are a good representation of what the original would look like when viewed peripherally is based on an experiment that involved exposing two different groups of subjects to different stimuli, and asking them to identify the stimuli. One group viewed the *original* images in peripheral vision, whilst the other viewed *mongrels* in foveal vision. The correlation of performance between the tasks was taken as the indication that the mongrel accurately 'matched' what the original would look like in peripheral vision. However, it simply doesn't follow from the fact that performance at an identification task was the same in both cases that the phenomenology of the original in peripheral vision is the same as that of the mongrel in foveal vision. More generally, the experiment that Block describes is put forward extremely tentatively by Rosenholtz and her colleagues, as is the method outlined above for 'matching' mongrels with original images. We would require far more converging evidence before we accepted that mongrels are an accurate portrayal of the phenomenology

[15] Simoncelli and Portilla themselves note that whether the algorithm is reproducing the phenomenology of conscious vision is in need of experimental verification using 'subjective measurements' (1998, p.4).

of peripheral vision. Balas et al. themselves typically claim that the mongrels accurately capture 'the information available to the visual system under conditions of crowding' (2009, p.10), so it is unclear whether they are making a claim about *phenomenology*, as Block does.

Secondly, (and, we think, devastatingly) for any one original image, there are infinite possible mongrels. As you can see from fig.5, some of them involve a central letter, and others do not. So even if we do assume that some of the mongrels accurately represent how the original image appears in peripheral vision, we have no reason to think that this includes the mongrels that contain the middle letter. Block could argue that a high proportion of the set of possible mongrels include a middle letter. However, the problem is that whether or not this is true, there is still nothing forcing Block's opponents into accepting that the phenomenology of identity crowding resembles *any* of these particular mongrels (or even any mongrels at all). Moreover, it is not sufficient to claim that a high proportion of the stimuli contain the (correct) middle letter because the important aspect is that the proportion should be higher than that for "normally" crowded targets under similar conditions.

Drawing on suggestions by Balas et al. (2009, p.5), Block (2013b, p.35) notes that when we view items in conditions of crowding, our perception of crowded items may shift between the different possible mongrels in figure 5. He agrees with Balas et al. when they say:

> 'this may be the explanation for the shifting and dynamic percept many observers experience when attending to their peripheral vision' (2009, p.5).

However, this point cannot establish that the mongrels accurately represent the phenomenology of crowding. Firstly, it is unclear whether the phenomenology of crowding

really is 'shifting and dynamic'. If we know anything about crowding, it is that its phenomenology is extremely hard to put one's finger on. Secondly, even if we accept this description of the phenomenology, we need not accept that it is due to changes which correlate with different images akin to the different mongrels. Such 'dynamic' phenomenology may be as a result of subtle shifts in attention to the group of items: it is well known that attention to items can change their perceived appearance (e.g. Carrasco et al. 2004 and Tse, 2005).

We must now discuss a pilot study that Block mentions (2013b, pp.35-36). Some applications of the algorithm result in crowded stimuli that contain letters that are inverted relative to the original image. Block notes that if we take seriously the claim that the mongrelization algorithms accurately represent what is happening in cases of crowding then this will predict that subjects should find it difficult to discern mongrel stimuli with inverted letters from original stimuli without such inversions. Balas et al. performed a pilot experiment which shows that subjects have difficulty telling apart a set of stimuli containing upright A's from one containing an inverted A under crowding (2009, p.11).

However, the pilot study cannot support any substantial claims about whether the mongrels accurately represent the phenomenology of peripheral vision.[17] The first important point is that the study was only a pilot study. For example, there were no baseline measurements, no control conditions, and it was a null finding (chance performance). To our knowledge, a full version of this experiment has not been performed, so we cannot draw any firm conclusions from it.

[17] Importantly, Balas et al. themselves do not claim that it does.

In any case, this is only a *discrimination* task, and as a result is subject to certain limitations. Even if a full experiment were carried out, the most we could conclude from a discrimination task such as this would be that (whatever the phenomenology of the experience of the original and the experience of the mongrel were like) it was hard for subjects to tell them apart. This is, of course, what would be expected if the mongrelisation algorithm was working properly. However, the inability of subjects to discern a set of upright 'A's from a set containing an inverted one can only tell you that subjects find the two sets of stimuli difficult to discern. We cannot draw from this any conclusions about what the phenomenology of *either* set of stimuli actually *was like*. It tells us nothing about what the phenomenological appearance of each one was to the subject. So we are not entitled to draw any firm conclusions about the phenomenal appearance of either set of letters, which is what would be required for Block's argument to hold up. Of course, we are not expressing scepticism about the general possibility of using introspective measures to establish the phenomenology of crowding,[18] we are simply pointing out the limitations of discrimination tasks such as this one.

5. Conclusion

Before drawing any firm conclusions about identity crowding, it is important to examine all of the available evidence. In this paper, we have argued that Block's interpretation of the crowding data is untenable. Though we have disagreed with Block's view, we are in complete agreement with him that crowding generally (and identity crowding particularly) provides a rich source of insights about attention and its relationship to consciousness, and

[18] For example, Sayim and Wagemans (2013) use a paradigm on which subjects are asked to *draw* the crowded items (see also Coates, Wagemans, & Sayim, in press). There is good reason to think that this gives us a better insight into the phenomenology of crowding than simple discrimination tasks.

we are confident that much that is philosophically and scientifically interesting remains to be learned from interdisciplinary discussion of these issues.[19]

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