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Short article

The detection of temporally defined objects does not require focused attention

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Perceptual grouping is crucial to distinguish objects from their background. Recent studies have shown that observers can detect an object that does not have any unique qualities other than unique temporal properties. A crucial question is whether focused attention is needed for this type of grouping. In two visual search experiments, we show that searching for an object defined by temporal grouping can occur in parallel. These findings suggest that focused attention is not needed for temporal grouping to occur. It is proposed that temporal grouping may occur because the neurons representing the changing object elements adopt firing frequencies that cause the visual system to bind these elements together without the need for focused attention.

Keywords: Temporal grouping; Attention; Visual search.

Distinguishing objects from the background is one of the basic capabilities of the visual system and has been a focus of research since the start of psychophysical science. Dynamic properties allow for particularly strong grouping. An example of a dynamic grouping principle is the Gestalt principle of common fate, which states that items that move together are seen as one object (Wertheimer, 1923). Other, later proposed, examples are grouping by common onset, in which items that appear together are treated as a single object, set, or surface (Jiang, Chun, & Marks, 2002), and grouping by common luminance change, in which items that change luminance together in the same direction are clustered (Sekuler & Bennett, 2001).

Interestingly, it has been suggested that elements do not need to change in the same direction in order to be grouped. They may not even have to undergo the same type of change. They may group as long as they change together, at the same moment in time. This has been called *temporal grouping*. It occurs not on the basis of a common change (as in common fate, common onset, or common luminance change), but on the basis of a common *moment* of change.

For example, Fahle (1993) found that a group of dots changing luminance out of phase with the surrounding dots could be detected with phase shifts as short as 10 ms (depending on the frequency of the luminance change) between target dots and background. He concluded that participants can segregate an object from the background purely based on temporal cues. However, his results might also be explained by common

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onset grouping, since the target dots all appeared at the same moment, at a time when all the background dots were switched off.

Lee and Blake (1999b) continued to investigate grouping solely based on temporal information, by presenting participants with a field of Gabor patches, each of which contained a randomly oriented grating moving in a direction perpendicular to this orientation. At random moments in time, each Gabor patch could change motion direction (by 180°). In the background these motion flips were uncorrelated, but for a central rectangular region the patches changed motion direction in synchrony. Thus, in the target rectangle the motion direction of the Gabor patches was uncorrelated, and only the moment that the motion direction changed was synchronized. Participants had to determine the overall orientation of the target rectangle (horizontal or vertical) and could do so almost without errors. Lee and Blake (1999b) concluded that temporal information alone is sufficient to segment spatial regions from their background (see also Aslin, Blake, & Chun, 2002; Guttman, Gilroy, & Blake, 2005).

An important question is whether focused attention is needed for temporal grouping to occur. In other words, does attention need to focus on the changing items or regions in order for them to be grouped, or does grouping occur in parallel across the visual scene?

Intuitively, it seems that most grouping takes place without focused attention. It appeals to common sense to assume that the visual scene is preattentively parsed according to basic grouping principles, after which focused attention is directed to items or regions of interest to extract further information. However, at presence, the picture regarding the need for focused attention in grouping mechanisms is mixed. For instance, it has been shown that focused attention is needed to detect bilateral symmetry in visual search, despite symmetry being a prime example of strong Gestalt grouping (Olivers & van der Helm, 1998). On the other hand, Moore and Egeth (1997) found a line judgment task to be affected by irrelevant dots in the background, which, when grouped by proximity, formed displays similar to the Ponzo illusion or the Müller–Lyer illusion—despite the fact that participants could not accurately report what the background patterns were. This implies that this type of grouping may occur without focused attention. Furthermore, both common motion and common onset grouping appear to occur in parallel, without the need for focused attention, even when the to-be-grouped items are interspersed with irrelevant distractors (McLeod, Driver, & Crisp, 1988). Therefore, it seems that neither form of dynamic grouping requires focused attention.

In the present research we conduct two experiments to investigate whether focused attention is needed to detect objects solely defined by temporal cues.

EXPERIMENT

We presented participants with displays comparable to those of Lee and Blake (1999b). However, instead of presenting one temporally defined target bar on each trial, the number of temporally defined bars was varied from trial to trial (between 2 and 8, see Figure 1 for an example). We ran two versions of the task. In the detection version, on half the trials all bars were vertically oriented, and on the other half one of the vertical bars was replaced by a bar tilted to the left. Participants performed a detection task in which they indicated whether the tilted bar was present or absent. In the discrimination version, a tilted bar was always present, and observers indicated whether it was tilted left or right.

If focused attention is needed for the temporal grouping of elements into an object that can be distinguished from the background, then search reaction times (RTs) are expected to increase with the number of such temporally defined objects (the *set size*). Furthermore, the slope of the search function on target absent trials should be twice the slope on target present trials, since for a correct target absent decision all the bars need to be attended whereas on target present trials, on average,

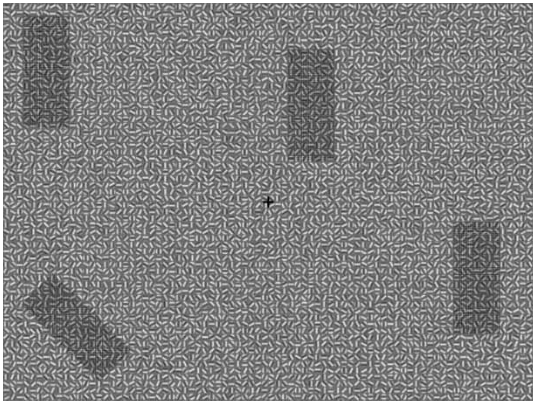

Figure 1. *Example display of the visual search tasks used. The darker areas represent rectangles that were defined by their unique temporal properties. In the actual displays these areas were not darkened. All sinusoid patches had a randomly varying luminance (between 56 cd/m^2 and 64 cd/m^2) and a randomly varying contrast (between 0.7 and 1). In the detection version, the task of the participants was to indicate whether a left-tilted rectangle was present or absent. In the discrimination version, a tilted target was always present, and participants indicated whether it was left- or right-tilted.*

only half of the bars need to be checked. If focused attention is not required for the detection of a temporally defined object, then RTs should be roughly the same for target present and target absent trials and should not increase with set size. Note that although set size effects are often interpreted as reflecting attentional effects (be it either serial or limited-capacity parallel), alternative interpretations are possible (e.g., Carrasco, Evert, Chang, & Katz, 1995; Eckstein, Thomas, Palmer, & Shimozaki, 2000). However, to foreshadow the results, here we report the absence of set size effects and hence argue for the absence of the need for focused attention, as it is difficult to argue that the need for highly selective, focused attention results in parallel search.

Method

Participants

A total of 11 paid volunteers, ranging in age from 18 to 27 years, average 22.6 years, participated in the detection version of the task. A total of 10 paid volunteers, ranging in age from 19 to 35 years, average 26.8 years, participated in the discrimination version. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. A total of 5 volunteers were a priori excluded from the study because they failed to see any object at all during the practice session. A total of 3 participants were excluded a posteriori; 2 of them had overall error rates exceeding 25%, and the other showed a considerable speed–accuracy trade-off (a 360-ms drop in RTs combined with a 12% drop in accuracy between set sizes 2 and 8).

Apparatus and stimuli

The experiment was conducted on a computer with a Pentium IV processor, a 17-inch monitor and a standard QWERTY keyboard. The software package E-Prime was used for the layout and timing of the experimental trials. See Figure 1 for an example display. The stimulus field consisted of a 80 × 60 matrix (17.7° × 13.3° visual angle). Each cell contained a circular patch (0.22° diameter) consisting of a greyscale sinusoid grating comprising 1 1/2 periods. Contrast and luminance were randomly modulated during each trial on a frame-by-frame basis with a mean contrast of 0.85 and an amplitude of 0.15. The maximum luminance varied between 56 cd/m^2 and 64 cd/m^2 (as measured with a Tektronix photometer). Each element's sinusoidal grating was phase shifted by $2\pi/6$ radians per frame, a spatial displacement sufficient to produce smooth apparent motion of the grating within the circular aperture, with the direction of motion being in either of the two directions orthogonal to the grating's orientation (both directions were equally likely, and there were eight possible orientations). The direction of the phase shift in each frame was constrained so that no four consecutive frames contained either alternations between positive and negative phase shifts or continuous phase shifts in a single direction. This constraint, as well as the randomization of contrast and luminance among elements, was implemented to minimize potential luminance, contrast, or motion artefacts that may contribute to the object perception in temporal grouping displays (Adelson & Farid, 1999; Lee & Blake, 1999a; Morgan & Castet, 2002), even though it is arguable whether these potential cues are actually realized by the visual system (Lee & Blake, 1999a). In any case, the method we used here was similar to the method employed by Aslin et al. (2002). The matrix was divided in eight 20 × 30 rectangular areas. Each area could contain a temporally defined vertical bar, comprising 7 × 17 cells (1.56° × 3.79° visual angle). In the detection version of the task, on half of the trials one temporally defined bar was tilted to the left, diagonally spanning 5 × 12 (1.57° × 3.78° visual angle) cells. The bar could appear anywhere within the rectangular area, as long as it was at least two cells away from the borders. In the discrimination version, the same bar could also be tilted to the right. The orientation of each grating was randomly determined from a set of 8 (between 0° and 157.5° with 22.5° intervals), with the restriction that two horizontally, vertically, or diagonally neighbouring gratings could not have the same orientation. Every 8 ms a new frame was presented; hence the average frequency of motion change was 62.5 Hz. Within each bar, but also within the background, the change of motion direction was synchronized (between the gratings). However, the moment of motion direction change between objects and background, and between objects themselves, was uncorrelated. Trials started with the presentation of the dynamic background. After 360 ms a black fixation cross appeared in the middle of the screen (0.341° × 0.341°), and after 1,160 ms all temporally defined objects appeared. The display disappeared after response or after 25.5 s (whichever came first).

Design and procedure

Participants sat at approximately 90 cm from the monitor, with their index fingers resting on the z- and m-keys, which were used as the response buttons. The experiment consisted of 10 blocks, each containing 30 trials. On each trial two, four, or eight bars were presented. In the detection task, on half of the trials all of the bars were oriented vertically (target absent condition); on the other half of the trials one of the bars was tilted to the left (target present condition). These conditions were randomly mixed within blocks. The task was to determine whether a bar tilted to the left was present (by pressing "z") or absent (by pressing "m"). In the discrimination task, a target bar was always present and could be tilted left (press "z") or right (press "m"). Participants were instructed to keep the eyes fixated at the cross in the centre of the screen and to keep in mind that both speed and accuracy were important. The first 5 blocks were practice blocks; the other 5 were included in the analysis. The experiment took approximately 45 minutes, with breaks between the blocks.

Results

Trials on which RTs were 3 standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 2.5% of the trials in the detection task and 3% in the discrimination task. See Table 1 for an overview of the error percentages. A two-way analysis of variance (ANOVA) on mean accuracy for each participant with condition (target absent or target present) and set size (2, 4, or 8) as factors revealed a main effect of condition. $F(1,\ 10) = 5.84$, $MSE = 0.011$, $p < .05$, in the detection task. Participants made more errors when the target was present than when it was absent. No other effects in any of the versions approached significance, $Fs < 1.6$, $ps > .25$.

Table 1. *Average error percentages in both the detection and the discrimination tasks of the experiment*

	Set size		
Task	*2*	*4*	*8*
Detection			
Target absent	6.16	5.80	5.24
Target present	11.82	10.25	13.97
Discrimination	6.07	6.07	5.52

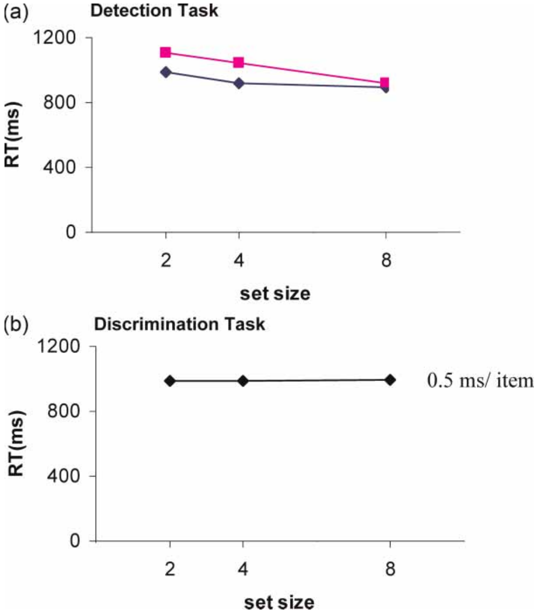

Figure 2. *(a) Mean reaction time for target absent and target present conditions of the detection task, as a function of set size. (b) Mean reaction time as a function of set size in the discrimination version. The legend includes the mean search slopes.*

Figure 2a depicts the RT results for the detection task. A two-way ANOVA on mean RT for each participant in the detection task, with condition (target absent or target present) and set size (2, 4, or 8) as factors revealed that RTs were significantly elevated when the target was absent, $F(1, 10) = 9.50$, $MSE = 13{,}475.06$, $p = .01$, and that RTs significantly decreased with set size, $F(2, 20) = 11.27$, $MSE = 9{,}276.37$, $p = .001$. There was a trend towards a more negative search slope when the target was absent than when it was present: Condition × Set Size interaction, $F(2, 20) = 3.45$, $MSE = 4{,}856.97$, $p = .052$.

Figure 2b depicts the RT results for the discrimination task. A one-way ANOVA on mean RT for each participant with set size (2, 4, or 8) as a factor revealed no significant effects ($F = 0.01$, $p = .99$). At first sight then, unlike in the detection task, in the discrimination task search slopes were not negative. However, an examination of the RT data per participant (see Table 2) reveals that this was mainly due to one participant with a rather high positive search slope (61 ms/item).Without this participant, the average slope was −6 ms/item. In any case, across participants, both RTs and error rates did not significantly increase with set size.

Table 2. *Reaction times as a function of set size per participant in the discrimination task*

	Set size			
Participant	*2*	*4*	*8*	*Slope*[a]
1	1,009	1,034	949	−12
2	1,295	1,310	1638	61
3	821	872	807	−4
4	1,062	966	984	−11
5	881	954	891	−1
6	1,004	1,006	889	−21
7	809	852	863	8
8	1,038	1,036	978	−11
9	992	917	938	−7
10	984	929	987	2

[a] In ms/item.

Finally, to assess the effect of training, we compared performance in the first half to performance in the second half of the experiment. For both tasks, accuracy was higher, and average RTs were lower in the second half of the experiment (all *p*s < .01). However, in both tasks, search slopes did not differ significantly between halves (all *p*s > .45). This suggests that only factors unrelated to selection were affected by training.

Discussion

There were no signs that focused attention is required to distinguish objects defined by temporal grouping. RTs did not increase with set size (instead they decreased for by far the largest proportion of participants). Furthermore, in the detection version of the task, RTs did not diverge between present and absent trials with increasing set size. The results therefore point towards parallel search.

One objection against parallel search could be that perhaps participants systematically scanned each area of the display, regardless of whether or not this area contained an object. Such a strategy would also predict RTs that do not increase with set size. However there are two arguments against such a conjecture. First, if participants indeed inspected the display area by area, then it is expected that on target present trials, on average, they found the target after scanning half of the areas, whereas on target absent trials they needed to scan all areas before they could decide that the target was not present. RTs on target absent trials were indeed slightly higher than those on target present trials (88 ms on a total of approximately 1 s). However, this finding can also be explained by some participants adopting a more conservative search strategy. With such a strategy participants are inclined to double-check when they do not see a target, to make sure they did not miss it, which also predicts elevated RTs in the target absent condition. To determine whether the slower RTs in the target absent condition were due to a conservative strategy employed by some participants, or the need to focally attend each region in all cases, we looked at the fastest half of participants, since they presumably adopt a less conservative strategy. Indeed, consistent with the strategy idea, this group showed no reliable difference in RT between target absent and target present conditions (33 ms, $F < 1$, $p > .4$).

Second, search slopes were found to be overall negative. Such negative search slopes are indicative of increasing contrast between the target and distractors, with higher set sizes, resulting in relatively higher salience of the target (Sagi & Julesz, 1987). As argued by Sagi and Julesz, finding a negative slope indicates that target and distractors are processed in parallel, so that display-wide target–distractor comparisons can be made. The negative search slopes also argue against the possibility of observers making use of the residual contrast and/or motion artefacts that could occasionally occur despite the precautions described in the Method section.[1] Such artefacts might randomly make one or two of the items visible at a time, and although this might explain relatively efficient search, it does not explain the negative search slopes found here, for which items need to be continuously present (as would be the case if temporal grouping creates the items). All in all then, the results indicate that the segmentation of an object from its surroundings purely based on temporal cues takes place largely in parallel across the visual display, without the need for focused attention.

The validity of visual search tasks for investigating focused attention

Note that we do not wish to argue that no attention at all is needed to perceive these displays. Parallel search does not mean preattentive search, nor does it mean that it is completely unlimited in capacity. The fact that about 25% of participants have trouble discerning these temporally defined objects puts obvious limits on conclusions regarding the automaticity, early level, or hard-wired nature of such grouping processes. Instead, it is likely that some distributed attention is necessary across the displays. What we argue here is that such distributed attention is sufficient for temporal grouping to occur: There is no need for focused attending (be it serial or limited-capacity parallel) to construct each individual temporal group, as there is, for instance, for the construction of other groups such as mirror

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[1] For each grating element, we varied both luminance and contrast randomly from frame to frame. Furthermore, no more than four consecutive phase shifts in the same direction or four consecutive changes in motion direction were allowed. In general this makes it difficult for a contrast or luminance filter to pick up on an object defined by temporal grouping. However, when the object elements undergo four consecutive shifts in the same direction, and the background elements undergo four consecutive changes in motion direction (or vice versa), then a perfect contrast filter (averaging over exactly the correct five frames) could detect the object, allowing for the relatively rare and brief emerging of an individual object (on average 16 ms per 256 ms). However, our participants reported to perceive all items continuously being there, rather than individual objects popping into visibility one at a time. Together with the negative search slopes this makes it unlikely that the perception of temporally defined objects is entirely due to a contrast filter.

symmetries (Olivers & Van der Helm, 1998). Also, by referring to focused attention, we refer to selection of the target and not access to the target once it is selected. Thus, the results here suggest that for detecting a temporal group focused attention is not required. However, it may be that after the temporal group has been selected, focused attention is shifted towards the target for further access (e.g., in order to determine the response).

We emphasize again that positive search slopes can have causes other than attentional shifts. Therefore, one should be cautious with conclusions about the need for focused attention in selecting the target if a positive search slope is found. However, the reverse case (that no focused attention is needed in selecting a target if there is no positive search slope) seems less contaminated (e.g., Townsend, 1972). There are several possible reasons for positive search slopes, yet it is hard to imagine how focused attention can serially shift from object to object without RTs increasing with the number of items in the display. Although there is no evidence that search slopes can be flat when focused attention is required for selection, it has been shown that focused attention can be directed to the target after an effortless search (Kim & Cave, 1995). Again, we see this as a case of accessing the object for response purposes only after the object is detected. Kim and Cave's (1995) study does not show that the detection itself requires attention to be focused on the object. In any case, our current research does not show that focused attention is never directed towards the target; it shows that focused attention is not needed for detecting a temporal group. Importantly, this implies that focused attention is not required to separate temporal groups from the background.

Temporal grouping: Sufficient but not necessary for object perception

The present results reveal that temporal synchrony is sufficient for object perception. However, this does not imply that synchrony is necessary. In this light, it is interesting to regard the work of Fahle and Koch (1995). They presented participants with bistable displays consisting of six pacmans from which two overlapping Kanizsa triangles could be formed. However, if participants had a percept of one of the triangles the other percept disappeared. Normally participants flipped back and forth between the two triangles. Fahle and Koch (1995) investigated whether temporal synchrony played an important role in determining which of the percepts became dominant. They presented five of the six pacmans simultaneously and one up to 50 ms later. They hypothesized that if temporal synchrony is important, the simultaneously presented triangle would be dominant over the asynchronously presented triangle. However, they found that the temporal asynchrony did not affect the relative dominance of either of the triangles. Fahle and Koch (1995) concluded that temporal synchrony is not necessary for object perception. Thus, on the one hand the breaking of temporal synchrony does not break the grouping of elements within an object, whereas on the other hand, as shown here, the presence of temporal synchrony does create grouping. In other words, temporal synchrony appears to be a sufficient, but not a necessary, condition for object perception.

How are temporal groups detected?

A possible explanation to how the visual system is able to perceive temporal groups without focused attention may involve the existence of a class of low-level detectors that do not respond to motion or motion change per se, but that respond to motion change in relation to the surroundings. That is, these low-level detectors only become active when the item changes motion at the same time that its neighbours do (see also Kandil & Fahle, 2004, for a similar idea). Future research, for instance employing single-cell recordings, should be conducted to test whether these low-level detectors really exist.

A second explanation might be that patches changing in synchrony constitute a surface medium in which features can appear. Cavanagh, Arguin, and Treisman (1990) found that size and orientation features, such as a tilted bar among vertical bars, were detected in parallel in most surface media that defined these features. This result held for the surface media defined by luminance, colour, texture, or motion (e.g., such displays could consist of green bars against a red background, or bright bars against a dim background). The current results might fit into this larger picture, and synchronous change should perhaps be considered as a surface medium within which objects can be defined (whereby the bars consist of synchronously changing elements against a background of nonsynchronously or different synchronously changing elements).

Another tentative but interesting possibility is that temporal binding plays a role in the perception of temporal groups. The temporal binding hypothesis suggests that neuronal synchrony underlies object perception. According to this hypothesis, neurons that represent features belonging to the same object start firing at the same frequency (Singer & Gray, 1995). According to this theory, the typical frequency range in which the temporal binding is most effective is the gamma range, between 30 and 80 Hz. In our experiments motion direction reversed on average every 16 ms, which is 62.5 Hz. It could be argued that our fast-changing displays caused the neurons that represent the reversals in motion direction of the temporally defined rectangles to adopt firing frequencies of approximately 60 Hz. This behaviour of the neurons may lead the visual system to automatically bind the underlying features (the fast-changing patches) into one object (see also Alais, Blake, & Lee, 1998). However, the temporal binding hypothesis is not undisputed (Shadlen & Movshon, 1999). Interesting in this respect is that the visual system also appears able to group nonsynchronous elements. The work by Fahle and Koch (1995) has already been mentioned. More recently, Pinto, Olivers, and Theeuwes (2006) presented participants with a search task in which participants had to detect a static target among randomly (i.e., nonsynchronously) blinking or moving distractors. Participants could do so efficiently, which may imply that the nonsynchronous elements were rejected together.

Summing up, we conclude that temporal grouping is applied in parallel across the visual field, independent of focused attention. This ability might be based on the synchronous firing of neurons or on low-level synchrony detectors.

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