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1                   **Kanizsa-figure object completion gates selection**  
2                                   **in the attentional blink**

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20

**Abstract**

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Previous work has demonstrated that perceptual grouping modulates the selectivity of attention across space. By contrast, how grouping influences the allocation of attention over time is much less clear. The current study investigated this issue, using an attentional blink (AB) paradigm to test how grouping influences the initial selection and the subsequent short-term memory consolidation of a target. On a given trial, two red Kanizsa-type targets (T1, T2) with varying grouping strength were embedded in a rapid serial visual presentation stream of irrelevant distractors. Our results showed the typical AB finding: impaired identification of T2 when presented close in time following T1. Moreover, the AB was modulated by the T2 grouping – independently of the T1 structure – with stronger grouping leading to a decreased AB and overall higher performance. Conversely, a reversed pattern, namely an increased AB with increasing grouping strength was observed when the Kanizsa figure was not task-relevant. Together, these findings suggest that the grouping benefit emerges at early perceptual stages, automatically drawing attentional resources, thereby leading to either sustained benefits or transient costs – depending on the task-relevance of the grouped object. This indicates that grouping modulates processing of objects in time.

Keywords: attentional blink, rapid serial visual presentation, perceptual grouping, Kanizsa figure.

## 40 **Introduction**

41           The organization of fragments and parts into coherent wholes is a central  
42 problem for visual perception. For instance, Kanizsa subjective figures (Figure 1A,  
43 complete; Kanizsa, 1955) give rise to a well-known visual illusion: the percept of an  
44 object with sharp contours and a brighter-than-background surface even though there  
45 is no actual luminance discontinuity in the physical stimulus. Kanizsa figures thus  
46 illustrate that the visual system can bind together separate parts (such as the “pacman”  
47 inducers in a Kanizsa figure) to produce a vivid impression of an integrated and  
48 coherent object. In this particular case, the association of distinct elements into a  
49 coherent whole has been shown to be governed by a set of Gestalt principles, such as  
50 collinearity and closure (Koffka, 1935; Wertheimer, 1923; see Brooks, 2015, for a  
51 recent review).

52           Visual search studies have consistently shown that component parts may be  
53 grouped prior to the engagement of attention (e.g., Moore & Egeth, 1997; Rensink &  
54 Enns, 1995). The critical measure in a visual search task is usually the time required  
55 to detect a particular target among a variable number of distractors. If the target is  
56 distinguished by a property that can be efficiently coded in parallel across the visual  
57 field, then it should “pop out”, that is: search performance should not be affected by  
58 the number of distractors in the display. For instance, the search time for a target  
59 Kanizsa figure (Figure 1A, complete) is little affected by the number of distractor  
60 configurations (Figure 1A, ungrouped) that are composed of the same pacmen but do  
61 not induce an illusory figure (Conci, Müller, & Elliott, 2007a, 2009; Davis & Driver,  
62 1994; Senkowski, Röttger, Grimm, Foxe, & Herrmann, 2005). Moreover, search for a  
63 Kanizsa target figure is far more efficient than search for a comparable “ungrouped”  
64 target configuration that does not render an illusory object, even though in both  
65 variants of the search task, the same distractor configurations were used, which were  
66 equally similar to both types of target (Conci et al., 2007a; Conci, Töllner,  
67 Leszczynski, & Müller, 2011). Together, these findings suggest that efficient search  
68 for Kanizsa figures is guided by grouping principles (i.e., collinearity and closure)

69 that operate at early stages of visual processing, that is, prior to the engagement of  
70 attention (Conci, Müller, & Elliott, 2007b; Nie, Maurer, Müller, & Conci, 2016).

71 Integrated object configurations such as the Kanizsa figure have also been  
72 shown to automatically capture spatial attention. For example, search for a target disk  
73 in an array of randomly oriented (pacmen) distractor disks is substantially slowed  
74 when an illusory square is present (vs. absent) in the display (Rauschenberger &  
75 Yantis, 2001). Other experiments used search arrays containing a Kanizsa figure as a  
76 non-informative spatial ‘cue’ for a target that required a speeded choice reaction.  
77 Faster responses were obtained for a target presented inside, as compared to outside,  
78 the Kanizsa figure cue (Senkowski et al., 2005). Findings such as these suggest that a  
79 single integrated, illusory figure provides salient information, summoning an  
80 attentional orienting response to the region delineated by the grouped object (see also  
81 Marini & Marzi, 2016; Wiegand, Finke, Töllner, Starman, Müller, & Conci, 2015).

82 Whereas much of the previous work has elucidated how perceptual grouping  
83 modulates the allocation of selective attention across space, we know as yet little  
84 about how attentional selection is influenced by perceptual grouping over time.  
85 Temporal modulation of attention is frequently studied using the “attentional blink”  
86 (AB) paradigm, in which observers are asked to detect two targets presented  
87 successively within a rapid serial visual presentation (RSVP) stream of nontarget  
88 items (e.g., letters, words, or symbols) at a single location. While detection of the first  
89 target (T1) usually reveals a relatively high level of performance, detection of the  
90 second target (T2) is impaired if the temporal gap between the two targets is less than  
91 ~500 ms, while improving again at longer lags (Broadbent & Broadbent, 1987; Chun  
92 & Potter, 1995; Raymond, Shapiro, & Arnell, 1992). This transient drop in  
93 performance, which is referred to as the AB, has been assumed to reflect the temporal  
94 profile of attention.

95 The dual-target RSVP task can be thought of as a time-based analog of a  
96 visual search task (Vogel, Luck, & Shapiro, 1998). However, their underlying  
97 attentional mechanisms are not necessarily identical. Whereas processes of spatial  
98 attentional selection (e.g., in visual search) start to operate at an early, pre-attentive

99 stage of processing, before stimulus identification is complete (see Luck, 1998, for  
100 review), the AB potentially reflects a post-perceptual attentional mechanism that  
101 marks the transition between perceptual stimulus analysis and the subsequent storage  
102 of selected items in a capacity-limited working memory buffer (Vogel et al., 1998).  
103 For instance, a prominent two-stage model to account for the AB (Chun & Potter,  
104 1995) assumes that stage 1 involves perceptual coding of all stimuli in the RSVP  
105 stream; however, due to interference arising from the sequential mode of stimulus  
106 presentation, the encoded items decay rapidly over time, because each item is  
107 displaced by the one presented subsequently in the RSVP stream (see also Woodman  
108 & Luck, 2003; Moore & Lleras, 2005). To prevent or minimize interference,  
109 attentional resources are required to consolidate the “fragile” stimulus representations  
110 from stage 1 into a more stable and long-lasting format during stage-2 processing, that  
111 is, the consolidation of a selected number of items into working memory (see also  
112 Jolicœur & Dell’Acqua, 1998; Potter, Staub, & O’Connor, 2002; Shapiro, Raymond,  
113 & Arnell, 1997). Within this framework, an AB is thought to result from a failure of  
114 T2 to achieve stage-2 processing, because the capacity-limited consolidation  
115 mechanism is preoccupied with the processing of the preceding T1 stimulus (Vogel et  
116 al., 1998; Shapiro, Raymond, & Arnell, 1994).

117         Here, we investigated whether and how grouping structure in targets  
118 influences the profile of temporal attention. Although time-based selection operates  
119 only after initial visual processing, perceptual factors may nevertheless influence the  
120 AB (see e.g., Chen, Müller, & Conci, 2016, for effects of grouping on working  
121 memory). Previous studies, in fact, have shown that the AB is reduced when the  
122 perceptual salience of T2 is increased, for example, by increasing its featural and  
123 spatial dissimilarity to the distractors (Raymond, Shapiro, & Arnell, 1995) or by  
124 presenting highly arousing words (Anderson, 2005; Keil & Ihssen, 2004; Keil, Ihssen,  
125 & Heim, 2006) or familiar and emotional faces (Jackson & Raymond, 2006; Stein,  
126 Zwickel, Ritter, Kitzmantel, & Schneider, 2009) as T2s. To explain these findings, it  
127 has been suggested that salient stimuli are less susceptible to the AB because they  
128 generate a high level of (perceptual) activity that takes more time to decay, thus

129 bridging the temporal gap during which resources are unavailable for encoding items  
130 into working memory (Anderson, 2005). On this background, we hypothesized that  
131 grouping in Kanizsa figures would lead to the formation of a salient object (Davis &  
132 Driver, 1994; Senkowski, et al., 2005; Conci, et al., 2007a; Rauschenberger & Yantis,  
133 2001) that, in turn, would be relatively resistant against decay and more efficiently  
134 consolidated in spite of the limited capacity available, thus attenuating the AB.

135 To test this prediction, the present study investigated how perceptual grouping  
136 influences the AB using Kanizsa figures and comparable “ungrouped” control figures  
137 as targets. For instance, Experiment 1 implemented an RSVP stream of object  
138 configurations presenting circular placeholders in various colors. Observers were  
139 required to identify two uniquely colored (namely, red) target configurations. As  
140 illustrated in Figure 1A, the strength of grouping in the T2 configuration was  
141 gradually varied, ranging from a complete grouping (a Kanizsa star shape; Figure 1A  
142 left) through a partially grouped (three of six inducers form a Kanizsa triangle; Figure  
143 1A middle) to an “ungrouped” configuration (no closure, all inducers point outwards;  
144 Figure 1A right) – thus systematically varying closure in the Kanizsa-type  
145 configurations. Note that the various pacman configurations changed in terms of the  
146 strength of grouping they engendered, however without changing the low-level  
147 properties of the image. The crucial question concerned whether the accuracy of  
148 identifying the T2 target configuration would vary as a function of its grouping  
149 strength. That is, by systematically varying the T1–T2 lag, we examined whether the  
150 grouping structure of T2 would modulate the AB effect.

151

## 152 **Experiment 1**

153 Experiment 1 was performed to investigate how T2 grouping strength  
154 influences the AB. On a given trial, distractor arrangements of six colored disks (all  
155 disks of the same color, but not red) were presented in rapid succession. Within this  
156 stream, two arrangements were presented in red and these were defined as the target  
157 configurations. Targets were presented with small segments removed from each disk,

158 which, by appropriately rotating the cutout segments, would create the impression of a  
159 Kanizsa figure. T1 was always defined as a grouping (of cutout disks) that would not  
160 lead to the emergence of an illusory figure, and T2 was either a complete (Kanizsa  
161 star shape), or a partially grouped (Kanizsa triangle shape), or an ungrouped  
162 configuration (see Figure 1A). This manipulation permitted us to examine whether a  
163 systematic variation of the grouping strength in T2 would influence the AB. We  
164 predicted that the AB effect would be dependent on the grouping strength of the T2  
165 configuration, with a reduced AB for more strongly grouped T2 objects.

166

## 167 ***Method***

168 ***Participants.*** Fifteen right-handed volunteers (7 male; mean age:  $24.67 \pm$   
169 2.26 years) with normal or corrected-to-normal visual acuity and (self-reported)  
170 normal color vision participated in the experiment for payment of €8.00 per hour. The  
171 experimental procedure was approved by the ethics committee of the Department of  
172 Psychology, Ludwig-Maximilians-Universität München, and all participants provided  
173 written informed consent. Sample size was determined on the basis of previous,  
174 comparable studies (e.g., Stein et al., 2009), aiming for 85% power to detect a  
175 medium effect size (within-participants;  $f=0.25$ ; Cohen, 1988) given an alpha level  
176 of .05.

177 ***Apparatus.*** The experiment was conducted on a Windows computer using  
178 Matlab routines and Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).  
179 Stimuli were presented in different colors against a gray (RGB: 125, 125, 125; 51.7  
180  $\text{cd/m}^2$ ) background in the center of a 17-inch computer monitor (1024×768 pixel  
181 screen resolution, 85-Hz refresh rate). The experiment was conducted in a  
182 sound-attenuated room that was dimly lit with indirect incandescent lighting.

183 ***Stimuli.*** Each trial consisted of a series of configurations that were presented  
184 in different colors. Each configuration was composed of six colored disks (each  
185 subtending a viewing angle of  $3.3^\circ$ ) arranged around a circle (with a radius of  $5.2^\circ$ , at  
186 a viewing distance of 50 cm). Distractor configurations were composed of six



187 complete disks presented in four different colors – green (RGB: 75, 184, 72), purple  
188 (RGB: 137, 41, 143), yellow (RGB: 243, 236, 27), or blue (RGB: 22, 148, 210) –  
189 which were selected at random, with the only restriction that two consecutive  
190 configurations never shared the same color. Two target configurations composed of  
191 six pacmen inducers (i.e., disks with quarter segments removed) were presented in red  
192 color (RGB: 236, 30, 39). The first target (T1) was presented with all pacmen  
193 inducers oriented either up- or downwards (see Figure 1A). The second target (T2)  
194 either presented a complete Kanizsa figure (a star shape), a partially grouped Kanizsa  
195 triangle (with the triangle presented in up- or downward orientation), or an ungrouped  
196 object (with all pacmen inducers rotated outwards by 180°), thus gradually varying  
197 the grouping strength of T2 by means of a decrease in object closure (see Figure 1A).

198 ***Procedure and Design.*** As depicted in Figure 1B, each trial started with the  
199 presentation of a central fixation cross for 500 ms at the screen center, followed by the  
200 RSVP stream. Each configuration was presented for 100 ms, followed by a short  
201 blank interval of 20 ms, resulting in a stimulus onset asynchrony (SOA) of 120 ms.  
202 On a given trial, the first target (T1) was randomly allocated to one of three temporal  
203 serial positions, from 2 to 4, within the stream of 10 configurations. The second target  
204 (T2) was presented at one of four different temporal lags (120, 240, 360, or 600 ms,  
205 corresponding to serial lag positions 1, 2, 3, or 5) subsequent to T1. RSVP stream  
206 distractors continued to be presented during the lag and after T2. Following the  
207 presentation of the RSVP stream, a blank screen appeared until a response was issued.  
208 Participants were instructed to detect the two red targets. With regard to T1,  
209 participants were asked to identify the pointing direction of the T1 pacmen with a  
210 right (upward) or left (downward) mouse button press, using (the index or the middle  
211 finger of) the right hand. With regard to T2, the task was to report the number of  
212 triangles that were presented within a given target configuration, that is: “0” for the  
213 ungrouped object, “1” for the partially grouped object, and “2” for the complete  
214 object grouping. Participants responded with a left-hand button press via keyboard,  
215 pressing the left-, down-, or rightward arrow key for “0”, “1”, or “2” triangles,  
216 respectively. Feedback was provided at the end of each trial by displaying a white

217 and/or a red “—” sign for 500 ms on the screen if an error had occurred for the first  
 218 and/or the second target, respectively. Trials were separated from one another by an  
 219 interval of 1000 ms. Observers were instructed to respond as accurately as possible,  
 220 with particular emphasis on T1 accuracy in order to maximize the number of trials  
 221 available for the analysis of T2 accuracy. Every participant completed 20 blocks of 24  
 222 trials each, following one practice block of 24 trials (giving a total of 504 trials). After  
 223 each block, participants took a short break; they then proceeded to the next block by  
 224 pressing the ‘space’ bar following a message on the screen.

225 In summary, the experiment systematically varied two factors: T2-target type  
 226 (complete, partially grouped, and ungrouped object), and T1–T2 lag (Lag 1, 2, 3, or 5),  
 227 with all possible factorial combinations presented in random order.

228 *Figure 1 about here*

## 229 **Results**

230 **T2 accuracy.** Estimates of T2 accuracy were based solely on trials on which  
 231 T1 had been identified correctly (as it is hard to determine the effect on the processing  
 232 of T2 when the cause of the erroneous response to T1 is not known). Figure 2 presents  
 233 T2 accuracy as a function of lag, separately for the different target conditions. A  
 234 two-way repeated-measures analysis of variance (ANOVA) of correct T2 responses,  
 235 with the factors T2-target type (complete, partially grouped, ungrouped) and lag (1, 2,  
 236 3, 5), revealed both main effects to be significant: T2-target type,  $F(2, 28) = 6.67, p$   
 237  $= .004, \eta_p^2 = .32$ , 90% confidence interval, or CI [.07, .48]; lag,  $F(3, 42) = 24.12, p$   
 238  $< .0001, \eta_p^2 = .63$ , 90% CI [.45, .71]. For the post-hoc comparisons, given that such  
 239 repeated testing increases the chance of a significant effect, a Bonferroni correction  
 240 was applied (Neter & Wasserman, 1974). There was a graded effect of target type,  
 241 with the highest accuracy for complete configurations (86%), followed by partially  
 242 grouped (81%) and ungrouped (74%) configurations (complete vs. ungrouped:  $p$   
 243  $= .001$ ; partially grouped vs. ungrouped:  $p = .39$ ; partially grouped vs. complete:  $p$   
 244  $= .31$ ). In addition, there was a monotonic increase of performance from lag 1  
 245 onwards (76%, 77%, 83%, and 87% for lags 1, 2, 3, and 5, respectively;  $ps < .029$ ).

246 Furthermore, the T2-target type  $\times$  lag interaction was significant,  $F(6, 84) = 2.68, p$   
 247  $= .02, \eta_p^2 = .16, 90\% \text{ CI } [.01, .23]$ . To decompose this interaction, the AB amplitude  
 248 was computed (see also Anderson, 2005), which is defined as the maximum  
 249 difference in performance across lags, that is, contrasting the (early) lag(s) with the  
 250 lowest accuracy with (later) lag(s) that resulted in the highest level of accuracy (in  
 251 Experiment 1, the largest difference was revealed between lag 1 and lag 5).  
 252 Comparisons of the AB amplitude across target type conditions revealed the  
 253 difference in amplitude to be largest for ungrouped (15%), intermediate for partially  
 254 grouped (11%), and smallest for complete configurations (6%),  $F(2, 28) = 3.47, p$   
 255  $= .045, \eta_p^2 = .20, 90\% \text{ CI } [.00, .36]$ .

256 **T1 accuracy.** The mean percentage of correct responses for T1 was 90%. A  
 257 two-way repeated measures ANOVA with the factors T2-target type (complete,  
 258 partially grouped, ungrouped) and lag (1, 2, 3, 5) revealed only a lag effect:  $F(3, 42) =$   
 259  $35.49, p < .0001, \eta_p^2 = .72, 90\% \text{ CI } [.56, .78]$ . T1 performance exhibited a drop at lag  
 260 1: 80%, 92%, 93%, and 94% for lags 1, 2, 3 and 5, respectively ( $ps < .0001$ ); that is,  
 261 the short lag between T1 and T2 (also) impacted the accuracy of reporting T1.  
 262 Importantly, however, no (main or interaction) effect involving T2-target type was  
 263 revealed ( $F_s < 1.5, ps > .25$ ).

264 *Figure 2 about here*

## 265 **Discussion**

266 The pattern of results in Experiment 1 clearly demonstrates that T2-targets are  
 267 the less susceptible to the AB the higher their grouping strength: the AB amplitude  
 268 was smallest for the complete, intermediate for partially grouped, and largest for  
 269 ungrouped T2 configurations. In addition, the overall T2 accuracy also depended on  
 270 the grouping strength, with higher performance for the more strongly grouped objects.  
 271 Importantly, there was no influence of the T2 grouping type on T1, that is, the  
 272 enhanced accuracy for complete and partially grouped T2s cannot be explained in  
 273 terms of a trade-off between T2 and T1 accuracy. Our finding that grouping was  
 274 associated with a diminished AB suggests that attention was more effectively  
 275 allocated to grouped stimuli, in line with our initial prediction. This is consistent with

276 findings from previous studies on the spatial allocation of attention, which have been  
277 taken as evidence for the preattentive coding of Kanizsa figures (e.g., Davis & Driver,  
278 1994; Senkowski, et al., 2005; Conci, et al., 2007a; Rauschenberger & Yantis, 2001).  
279 This benefit of grouping manifested even though the complete and ungrouped objects  
280 consisted of identical physical stimulus components and were of equal object  
281 complexity (in terms of the descriptive criteria of Garner & Clement, 1963). As  
282 regards attentional guidance, the preattentive formation of a global object  
283 representation is beneficial even given minor variations in terms of the geometry and  
284 spacing of the local inducer elements that make up a given stimulus configuration  
285 (Chen, Glasauer, Müller, & Conci, 2018; Conci et al., 2007b).

286         However, there still remained a lag-dependent impairment for the grouped T2,  
287 which (although the decrement became smaller with increasing lag) would appear to  
288 be at variance with the view that the illusory shape is processed completely  
289 independently of attention (see also Joseph, Chun, & Nakayama, 1997). A potential  
290 explanation for selection of a grouped object being to some extent dependent on  
291 attention refers to the idea that featural and configural information are processed in  
292 somewhat different ‘channels’ (Awh et al., 2004) and that interference would arise to  
293 the degree to which T1 and T2 overlap in terms of the processing channels involved.  
294 In the present experiment, both T1 and T2 share information at the feature level (i.e.,  
295 they consist of the comparable inducer elements) – which would engender a degree of  
296 feature-based interference, resulting in an AB. However, the grouped T2 object would  
297 additionally be processed via the configural channel. This would reduce the total  
298 interference as grouping strength increases, especially when a global object emerges.

299         Note that Experiment 1 revealed monotonic increases in T2 identification with  
300 longer T1–T2 lags, while many previous studies have reported an effect of “lag-1  
301 sparing” in which performance is relatively unimpaired if T2 is presented directly  
302 after T1 (e.g., Chun & Potter, 1995; Raymond et al., 1992). A potential explanation  
303 for this sparing effect is that the visual system tends to process the two targets  
304 together (e.g., in a batch) as long as they appear in direct temporal succession (Chun  
305 & Potter, 1995). However, it has also been shown that lag-1 sparing occurs in

306 particular when no attentional switch (e.g., across locations, tasks, or categories) is  
307 required between targets (Kawahara, Zuvic, Enns, & Di Lollo, 2003; Di Lollo,  
308 Kawahara, Ghorashi, & Enns, 2005; Visser, Bischof, & Di Lollo, 1999). Lag-1  
309 sparing is in addition crucially dependent on the temporal separation between targets,  
310 with reliable sparing being evident predominantly with lags shorter than 100 ms  
311 (Olivers & Meeter, 2008; Potter, Staub, & O'Connor, 2002). The results from  
312 Experiment 1 failed to show spared lag-1 performance; rather, the AB was particularly  
313 pronounced at lag 1. This may have resulted from the task switch between two targets  
314 (from a local-object direction discrimination task to a global-shape “counting” task)  
315 and from the relatively long T1–T2 lag (120 ms; see also Conci & Müller, 2009).

316

## 317 **Experiment 2**

318 Experiment 1 showed that T2 grouping strength modulates the AB when T1 is  
319 an ungrouped configuration that requires the identification of the (individual)  
320 pacman’s pointing direction. In Experiment 2, we investigated whether grouping in  
321 T1 might also influence T2 processing. This was motivated by findings that the AB  
322 may actually be increased following a salient T1 (Martens & Wyble, 2010; i.e., the  
323 converse of the reduction of the AB by a salient T2). This has been attributed to the  
324 increased salience of T1 engendering a longer dwell of attention (on the T1) and thus  
325 reducing the capacity available for the processing of T2 (Stein et al., 2009; Huang,  
326 Baddeley, & Young, 2008). In Experiment 2, we therefore increased the strength of  
327 the T1 grouping by presenting a partially grouped Kanizsa triangle in order to  
328 examine whether the selection of a grouped T1 would impede the consolidation of  
329 complete, partially grouped, and ungrouped T2 configurations. Grouped Kanizsa  
330 figures have previously been shown to capture attention (see Introduction).  
331 Accordingly, we expected a salient T1 Kanizsa figure to lead to an overall increase of  
332 the AB. Moreover, when assuming that the (grouped) T1 stimulus is processed via  
333 separate, featural and configural “channels” (Awh et al., 2004), grouping in T2 should  
334 be associated with a reduced benefit when – that is, there should be a rather strong AB

335 for all types of stimulus. By contrast, a single processing “channel” account (as in  
336 Chun & Potter, 1995) would predict a strong effect of grouping in T2 (as in  
337 Experiment 1), because the grouped T2 would nevertheless be more likely to escape  
338 the AB than an ungrouped T2.

339 Recall that the AB modulation by means of the T2 grouping strength in  
340 Experiment 1 was maximal at early temporal lags, but a substantial difference  
341 between configuration types nevertheless remained until later lags. For instance, the  
342 complete T2-target gave rise to a significantly higher accuracy than the ungrouped T2  
343 across all lags (significant main effect of T2-target type), and this difference persisted  
344 even until lag 5, that is, 600 ms after the presentation of T1,  $t(14)=2.56$ ,  $p = .023$ ,  $d$   
345  $= .66$ , 95% CI [.09, 1.21]. A potential explanation for this sustained difference  
346 between T2 groupings might be that the temporal interval between T2 and T1 was  
347 simply not long enough, even at lag 5; that is, selection of T2 some 600 ms after T1  
348 might still be compromised due to the attentional demands of processing the  
349 preceding T1. However, an alternative explanation might be that the benefit of  
350 grouping at longer lags reflects an additional advantage that arises from post-selective  
351 processing (i.e., at stage 2). In this view, how efficiently a given target configuration  
352 is consolidated into short-term memory would vary for the various types of grouping.  
353 To address this issue, in Experiment 2, the temporal lags were extended (beyond lag 5)  
354 up to lags 6 and 7. More precisely, T2 was presented at one of four different temporal  
355 lags (120, 240, 720, or 840 ms, corresponding to serial lag positions 1, 2, 6, or 7), thus  
356 covering an extended time interval subsequent to T1.

357

### 358 ***Method***

359 Experiment 2 was methodologically identical to Experiment 1, except that the  
360 T1 configuration was always a partial grouping that induced a Kanizsa triangle which  
361 pointed either up- or downwards (see Figure 3). The T1 task was roughly comparable  
362 to Experiment 1: it required observers to identify the pointing direction of the  
363 triangular T1 grouping (up- vs. downwards). With respect to T2, observers had again

364 to determine the number of triangles (as in Experiment 1). In addition, compared to  
 365 Experiment 1, the T1–T2 lags were extended. On a given trial, T1 was randomly  
 366 allocated to one of three temporal serial positions, from 2 to 4, within a stream of now  
 367 12 configurations. T2 was then presented at one of four different temporal lags (120,  
 368 240, 720, or 840 ms, corresponding to serial lag positions 1, 2, 6, or 7) subsequent to  
 369 T1. As in Experiment 1, RSVP stream distractors continued to be presented during the  
 370 lag and after T2. A new group of fifteen right-handed volunteers (7 males; mean age:  
 371  $23.00 \pm 2.83$  years) with normal or corrected-to-normal visual acuity participated in  
 372 the experiment for payment of € 8.00 per hour. Each participant completed 24 practice  
 373 plus 480 experimental trials (divided into 20 blocks).

374 *Figure 3 about here*

### 375 **Results**

376 **T2 accuracy.** Figure 4 presents the T2 accuracy (given a correct T1 response)  
 377 as a function of lag, separately for the different target type conditions. A two-way  
 378 repeated-measures ANOVA of correct T2 responses with the factors T2-target type  
 379 (complete, partially grouped, ungrouped) and lag (1, 2, 6, 7) revealed both main  
 380 effects to be significant: target type,  $F(2, 28) = 14.12, p < .0001, \eta_p^2 = .50, 90\% \text{ CI}$   
 381  $[.24, .63]$  and lag,  $F(3, 42) = 28.80, p < .0001, \eta_p^2 = .67, 90\% \text{ CI} [.50, .74]$ . T2  
 382 accuracy was higher for complete (85%) than for partially grouped (73%;  $p = .004$ )  
 383 and ungrouped (71%;  $p < .0001$ ) configurations; there was no significant accuracy  
 384 difference between partially grouped and ungrouped configurations ( $p = 1$ ). Moreover,  
 385 T2 accuracy increased with T1–T2 lag (67%, 69%, 84%, and 86% for lag 1, 2, 6, and  
 386 7, respectively), revealing a significant increase from lag 2 onwards ( $ps < .001$ ), but no  
 387 significant difference for the lag-1 vs. lag-2 comparison ( $p = 1$ ). In addition, the T2  
 388 target type  $\times$  lag interaction was significant,  $F(6, 84) = 2.34, p = .039, \eta_p^2 = .14, 90\%$   
 389  $\text{ CI} [.00, .21]$ , mainly due to a performance difference between the complete and  
 390 ungrouped condition,  $F(3, 42) = 6.88, p = .001, \eta_p^2 = .33, 90\% \text{ CI} [.11, .45]$ : the AB  
 391 amplitude (lags 1/2 vs. 7) was larger for ungrouped (22%) compared to complete  
 392 configurations (13%),  $t(14) = 3.01, p = .009, d = .78, 95\% \text{ CI} [.19, 1.35]$ . The partially

393 grouped configuration exhibited an intermediate AB amplitude (20%), but this did not  
 394 differ from the ungrouped ( $p = .67$ ) or complete ( $p = .29$ ) configurations.

395 *Figure 4 about here*

396 **T1-T2 pointing direction.** In a subsequent analysis, we examined whether  
 397 the (up-/downward) pointing direction of the partially grouped triangle in T1  
 398 influenced the detection performance for the (up-/downward pointing) T2 in partially  
 399 grouped configurations. Figure 5B presents T2 accuracy as a function of lag,  
 400 separately for the same and different orientations of the Kanizsa triangles. A two-way  
 401 repeated-measures ANOVA of correct T2 responses with the factors T1–T2 direction  
 402 (same, different) and lag (1, 2, 6, 7) revealed all main effects to be significant: T1–T2  
 403 direction,  $F(1, 14) = 47.83, p < .0001, \eta_p^2 = .77, 90\% \text{ CI } [.52, .85]$  and lag,  $F(3, 42) =$   
 404  $14.05, p < .0001, \eta_p^2 = .50, 90\% \text{ CI } [.28, .60]$ . T2 accuracy was higher for matching  
 405 than for mismatching pointing directions (80% vs. 65%). T2 accuracy increased with  
 406 T1–T2 lag, as described above. The interaction was also significant,  $F(3, 42) = 3.08, p$   
 407  $= .038, \eta_p^2 = .18, 90\% \text{ CI } [.00, .30]$ : the accuracy difference between matching and  
 408 mismatching pointing directions was reliable for the first three lags ( $ps < .003$ ), but no  
 409 longer reliable (i.e., reduced) at lag 7 ( $p = .07$ ). Thus, in Experiment 2, the orientation  
 410 similarity of the (Kanizsa) triangles modulated performance.

411 An analogous analysis was also performed for Experiment 1 (Figure 5A),  
 412 comparing the same/different pointing direction of the T1 pacmen and the subsequent  
 413 T2 triangle configuration. This analysis revealed only a significant main effect of lag,  
 414  $F(3, 42) = 17.11, p < .0001, \eta_p^2 = .55, 90\% \text{ CI } [.34, .64]$ , illustrating the AB effect  
 415 pattern already described above (for Experiment 1). The fact that there was no effect  
 416 of the same/different pointing direction at any lag (all  $ts(14) < 1.35, ps > .20$ ; see  
 417 Figure 5A) means that, in contrast to Experiment 2, there was no influence of the  
 418 local pacman direction in T1 on the detection of T2 triangles in Experiment 1.

419 *Figure 5 about here*

420 **Cross-experiment comparison.** To examine whether the change of the T1  
 421 target across Experiments 1 and 2 affected the AB and processing of the  
 422 grouped/ungrouped T2 targets, we compared the AB amplitude between the two



423 experiments in a mixed-design ANOVA with the within-subject factor T2-target type  
 424 (complete, ungrouped) and the between-subject factor Experiment (1, 2). This  
 425 analysis revealed a significant main effect of T2-target type,  $F(1, 28) = 15.25, p$   
 426  $< .001, \eta_p^2 = .35, 90\% \text{ CI } [.12, .52]$ , with an overall larger AB amplitude for  
 427 ungrouped (19%) than for complete (10%) T2 configurations. There was also a  
 428 marginally significant main effect of Experiment,  $F(1, 28) = 3.12, p = .08, \eta_p^2 = .1,$   
 429  $90\% \text{ CI } [.00, .28]$ , reflecting a somewhat larger AB amplitude in Experiment 2 (18%)  
 430 than in Experiment 1(11%). The interaction was not significant ( $F < 1, p > .8$ ).

431 **T1 accuracy.** Accuracy of T1 identifications was again relatively high, with  
 432 an average of 90% correct responses, comparable to T1 performance in Experiment 1,  
 433  $t(28) = .33, p = .75, d = .12, 95\% \text{ CI } [-.60, .84]$ . A two-way repeated-measures  
 434 ANOVA with the factors T2-target type (complete, partially grouped, ungrouped) and  
 435 lag (1, 2, 6, 7) only revealed a significant main effect of lag,  $F(3, 42) = 13.60, p$   
 436  $< .0001, \eta_p^2 = .49, 90\% \text{ CI } [.27, .60]$ , with accuracy being reduced at lag 1 (86%,  
 437 90%, 93%, and 92% for lags 1, 2, 6 and 7;  $ps < .003$ ), comparable to the finding in  
 438 Experiment 1. There were no other significant effects ( $Fs < 1, ps > .35$ ).

439

#### 440 **Discussion**

441 The results of Experiment 2, in general, replicate those of Experiment 1, in  
 442 that performance was overall reduced and the AB amplitude was larger for ungrouped  
 443 relative to complete-object T2 configurations. Moreover, a comparison between  
 444 Experiments 1 and 2 showed that increasing the strength of the T1 grouping translated  
 445 into a somewhat increased AB overall. This pattern suggests that the effect of  
 446 grouping on T2 detection is largely independent of the perceptual structure of the T1  
 447 stimuli, even though increasing the salience of T1 (in the present experiment: from  
 448 “ungrouped” arrangements of pacmen to a coherent illusory triangle) leads to an  
 449 increased difficulty in the processing of T2, because of a prolonged dwell of attention  
 450 on T1. This outcome is hard to explain on the assumption of separate featural and  
 451 configural processing channels (Awh et al., 2014), because the grouped T1 would

452 have occupied both channels, thus reducing the impact of grouping in T2. Instead, the  
453 current results would appear to be more compatible with the assumption of a single  
454 channel (as, e.g., in Chun & Potter, 1995), according to which the salient T2 grouping  
455 would lead to a modulation of performance that is largely independent of the T1  
456 structure.

457         Despite the lag  $\times$  T2-target type interaction, there was still a significant  
458 difference between the completed and ungrouped T2 at both shorter lags ( $ps = .0001$ )  
459 and longer lags ( $ps < .001$ ), which mirrors the result pattern of Experiment 1. For  
460 instance, even with a T1–T2 separation of 840 ms (at lag 7), performance for the  
461 ungrouped T2 configuration was still reduced relative to performance for T1 (mean  
462 difference:  $-7.04$ ;  $p < .04$ ). By contrast, performance for the complete T2 was roughly  
463 comparable (if not, in fact, being somewhat higher compared) to performance for T1  
464 (mean difference:  $2.96$ ;  $p = .06$ ). This suggests that the reduced performance for the  
465 ungrouped T2 does not solely reflect the temporal dynamics of attentional selection,  
466 that is, a sustained difficulty in selecting T2 while being engaged with T1. Rather, this  
467 constant difference across groupings might point to a difference in the efficiency with  
468 which the ungrouped vs. the complete T2 is retained at a post-selective stage in  
469 short-term memory until the execution of the response.

470         A second influence of T1 processing on T2 performance was revealed by the  
471 analysis of the same/different triangle pointing directions across the T1 and T2  
472 (partially grouped) targets: accuracy was higher for T2 when the T2 triangle  
473 orientation matched that of T1, while accuracy was lower when they mismatched. No  
474 analogous effect was obtained in Experiment 1, in which the pacmen's local  
475 orientation and the global orientation of the triangle grouping could repeat across T1  
476 and T2.

477         One might argue that responding to T1 in Experiment 2 would not necessarily  
478 require the completion of an up- or downward-pointing triangle, but that instead the  
479 response might solely be based on the up-/downward-pointing indentation of a single  
480 pacmen inducer, for example, the upper pacman in the T1 configuration (comparable  
481 to the task in Experiment 1). However, this seems rather unlikely given the different

482 result patterns from the analysis of the (same vs. different) pointing directions across  
483 experiments. In Experiment 1, judging the orientation of ungrouped inducer elements  
484 (T1) did not influence the extraction of a grouped triangle (T2); in Experiment 2 by  
485 contrast, the extraction of a grouped T1 triangle substantially influenced the  
486 subsequent processing of the grouped T2 triangle. This indicates that performance  
487 was not simply modulated by some form of response priming between T1 and T2.  
488 Instead, observers did complete the presented shapes, and they did perform the task in  
489 line with the instructions provided.

490         The finding of a same-object benefit for identical T1 and T2 stimuli in  
491 Experiment 2 is also consistent with Raymond (2003; see also Conci & Müller, 2009).  
492 Our results mirror these previous findings and further show that repeated perceptual  
493 objects (Experiment 2), rather than repeated response-defining features (Experiment  
494 1), lead to a reduction of the AB. Note that repeating the perceptual objects from T1 to  
495 T2 led to an attenuation but not to complete abolishment of the AB. This “residual”  
496 AB might have resulted from the change in task demands from T1 to T2 (see Visser,  
497 Bischof, & Di Lollo, 1999).

498         Finally, it should be noted that performance for the “different” (up-/downward  
499 pointing direction) condition was relatively low (65%), which may, to some extent at  
500 least, be attributable to a variant of “accidental” binding (Karabay & Akyürek, 2017).  
501 On this account, the presentation of two triangles pointing in opposite directions  
502 might yield the erroneous percept of a single Kanizsa star, integrating the sequential  
503 triangles into a unitary configuration. Such erroneous bindings would be particularly  
504 prominent at short temporal lags. To examine for this, we computed the frequency of  
505 participants reporting an integrated percept (i.e., a Kanizsa star) for the partially  
506 grouped target, given different T1 and T2 orientations. Indeed, erroneous Kanizsa star  
507 reports were rather frequent at lag 1 (36%), and declined at longer lags (21%, 13%,  
508 and 11% for lags 2, 6, and 7, respectively), revealing a linear trend:  $F(1, 14) = 15.36$ ,  
509  $p = .002$ ,  $\eta_p^2 = .52$ , 90% CI [.17, .69]. This is consistent with observers tending to  
510 merge the two opposite triangles presented in succession into a single, coherent  
511 representation – consistent with the notion of “misbinding”. For the “same” condition,

512 by contrast, the erroneous star reports were significantly reduced (compared to the  
513 “different” condition),  $F(1, 14) = 23.50, p < .0001, \eta_p^2 = .63, 90\% \text{ CI } [.29, .75]$ ,  
514 revealing overall comparable rates of erroneous star reports across lags (12%, 11%,  
515 9%, and 8% for lags 1, 2, 6, and 7, respectively,  $ps > .28$ ).

516

### 517 **Experiment 3**

518 In the experiments presented thus far, participants were not just passively  
519 exposed to variants of Kanizsa figures (with varying grouping strength), but they were  
520 required to actively classify these configurations, that is, to report the number of  
521 triangles presented in T2. Both experiments demonstrated a comparable pattern of  
522 results, namely a diminished AB and enhanced performance across all lags when T2  
523 presented a complete (as opposed to an ungrouped) configuration. This pattern was  
524 obtained regardless of the type of object presented as T1, suggesting some  
525 automaticity in processing the grouped object. Experiment 3 was performed to further  
526 elucidate how the specific task to classify a given object configuration in T2  
527 determined the grouping effect. To investigate this issue, in Experiment 3, the T2 task  
528 was changed such that the requirements were unrelated to the object configuration  
529 presented. This was achieved by adding a small arrow (an oriented “>”-sign) to the  
530 (complete, partially grouped, or ungrouped) T2 configuration, and the T2 task was to  
531 report the orientation of the unrelated arrow while the grouping itself was essentially  
532 task-irrelevant (see Figure 6). It should be noted that the (red) color of the pacman  
533 inducers still acted as a target cue, intended to ensure that observers processed the  
534 stimulus, but the (color) cue was completely independent of the grouping structure  
535 displayed in T2. We expected that if grouping does require top-down attention, then  
536 the change of the task requirements (in Experiment 3) should eliminate the above AB  
537 modulation of grouping (as attention does no longer need to be paid to the grouping,  
538 but only to the task-relevant arrow). By contrast, if grouping engenders automatic,  
539 early perceptual processing, then one would expect that the T2 accuracy would still be  
540 modulated by the (in Experiment 3) entirely task-irrelevant groupings.

541

542 **Method**

543 Experiment 3 was similar to Experiment 1, except that the (complete, partially  
544 grouped, or ungrouped) T2 configuration was now presented for 70 ms, after which a  
545 small arrow ( $0.5^\circ \times 0.5^\circ$ ) was added to the RSVP stream for another 30 ms (see  
546 Figure 6). The presentation duration of the arrow (target) was determined based on  
547 pilot tests, which showed that a relatively short presentation time is necessary to  
548 guarantee a reasonable variability of performance (i.e., well below ceiling). As in  
549 Experiment 1, the presentation of the stimuli was followed by a 20-ms blank interval,  
550 yielding a 120-ms SOA as in Experiments 1 and 2. The T2 task was to report the  
551 up/down/left/right pointing direction of the arrow, which was randomly presented at  
552 three possible locations within a given configuration (i.e., at top-left, top-right, or  
553 bottom locations; see Figure 6). Participants responded with a left-hand button press  
554 via keyboard, pressing the corresponding up-, down-, left-, or rightward-pointing  
555 arrow key, respectively. On a given trial, T1 was randomly allocated to one of three  
556 temporal serial positions, from 2 to 4, within a stream of 12 configurations. T2 was  
557 then presented at one of four different temporal lags (120, 240, 720, or 840 ms,  
558 corresponding to serial lag positions 1, 2, 6, or 7) subsequent to T1 (i.e., the lags were  
559 the same as in Experiment 2). RSVP stream distractors continued to be presented  
560 during the lag and after T2. The T1 target and task and the distractors remained the  
561 same as in Experiment 1. Fifteen naive, right-handed volunteers (7 males; mean age:  
562  $23.67 \pm 2.66$  years) with normal or corrected-to-normal visual acuity participated in  
563 the experiment for payment of 8.00 Euro per hour. Each participant completed 24  
564 practice plus 480 experimental trials (divided into 20 blocks).

565 *Figure 6 about here*

566 **Results**

567 **T2 accuracy.** Figure 7 presents the T2 accuracy (given a correct T1 response)  
568 as a function of lag, separately for the different target type conditions. A two-way  
569 repeated-measures ANOVA of correct T2 responses, with the factors T2-target type  
570 (complete, partially grouped, ungrouped) and lag (1, 2, 6, 7), revealed both main

571 effects to be significant: T2-target type,  $F(2, 28) = 5.40, p = .01, \eta_p^2 = .28, 90\% \text{ CI}$   
 572  $[.04, .44]$ , and lag,  $F(3, 42) = 12.00, p < .0001, \eta_p^2 = .46, 90\% \text{ CI} [.24, .57]$ . There was  
 573 a graded effect of target type, with the highest accuracy for ungrouped configurations  
 574 (96%), followed by partially grouped (95%) and complete (94%) configurations  
 575 (complete vs. ungrouped:  $p = .02$ ; partially grouped vs. ungrouped:  $p = .40$ ; partially  
 576 grouped vs. complete:  $p = .29$ ). In addition, there was a monotonic increase in  
 577 performance from lag 1 onwards (92%, 94%, 97%, and 98% for lags 1, 2, 6, and 7,  
 578 respectively;  $ps < .017$ , except for comparable performance with lags 6 and 7,  $p = .56$ ).  
 579 The T2-target type  $\times$  lag interaction was also significant,  $F(6, 84) = 2.25, p = .046, \eta_p^2$   
 580  $= .14, 90\% \text{ CI} [.00, .20]$ : the AB amplitude (lag 1 vs. 6/7) was larger for complete (8%)  
 581 compared to ungrouped configurations (4%),  $t(14) = 4.20, p = .001, d = 1.09, 95\% \text{ CI}$   
 582  $[.43, 1.72]$ . Partially grouped configuration (5%) exhibited a marginal difference  
 583 relative to complete configurations ( $p = .067$ ), but did not differ from ungrouped  
 584 configurations ( $p = .61$ ). Thus, the AB was significantly modulated by grouping  
 585 strength. However, importantly, this grouping modulation occurred in the reverse  
 586 order compared to, for instance, Experiment 1, with the complete T2 configuration  
 587 now leading to the strongest (rather than the smallest) AB.

588 **T1 accuracy.** The mean percentage of correct responses for T1 was 97%. A  
 589 two-way repeated measures ANOVA with the factors T2-target type (complete,  
 590 partially grouped, ungrouped) and lag (1, 2, 6, 7) revealed only a lag effect,  $F(3, 42) =$   
 591  $15.71, p < .0001, \eta_p^2 = .53, 90\% \text{ CI} [.31, .63]$ : As in the previous experiments, T1  
 592 performance was somewhat reduced at lag 1 (95%;  $ps < .005$ ), while being  
 593 comparable for lags 2, 6, and 7 (98%, 98%, and 99%, respectively;  $ps > .83$ ). No main  
 594 or interaction effect involving T2-target type was revealed ( $Fs < 1.4, ps > .23$ ).

595 *Figure 7 about there*

## 596 **Discussion**

597 Experiment 3 showed overall a somewhat higher level of performance (possibly  
 598 due to the change of task), but nevertheless again demonstrated a graded effect of T2  
 599 grouping on the AB, indicating that, especially at short lags, discrimination of the

600 arrow target (orientation) was substantially influenced by the surrounding,  
601 task-irrelevant object configuration. Thus, grouping does modulate performance, in  
602 particular when resources are occupied by T1-related processing. It has been shown  
603 that a physically salient T1 stimulus engenders a reduction in performance at short  
604 lags even when there is no need to attend to T1 (Raymond et al., 1992). In the present  
605 study, we observed a modulation by the task-irrelevant grouping at short lags, which  
606 suggests the transient reduction in performance is not only owing to salient features  
607 (e.g. the red color) of the T1 object but also dependent on the irrelevant T2 grouping  
608 structure.

609         However, in contrast to Experiments 1 and 2, the effect of T2 configuration  
610 was *reversed*, with the smallest AB for ungrouped, an intermediate AB for partially  
611 grouped, and the largest AB for complete T2 configurations. This reversed AB pattern  
612 suggests that grouping, rather than being beneficial for the arrow discrimination task,  
613 did actually impair performance. An explanation for this pattern might be that  
614 attention was automatically captured by the task-irrelevant complete-object  
615 configuration, and as a result discrimination of the target orientation was hampered.  
616 Ungrouped T2 configurations, by contrast, attracted attention less and, consequently,  
617 more resources were available for the effective discrimination of the arrow target. In  
618 addition, unlike in the previous two experiments, T2 performance clearly reached the  
619 level of T1 accuracy at (or actually, well before) lag 7 (i.e., after 840 ms), for all types  
620 of configuration. This indicates that a task-irrelevant grouping may influence the  
621 efficiency of attentional target selection, thus modulating the AB primarily at short  
622 lags. However, the fact that this modulation was rather transient suggests that, in  
623 Experiment 3, grouping did not affect short-term memory consolidation (i.e.,  
624 post-selective, stage-2 processing) of the T2 target.

625         Of note, Experiment 3 did also not reveal evidence of lag-1 sparing. This  
626 might again be due to a rather long lag (i.e., > 100 ms, see Olivers & Meeter, 2008,  
627 and Potter et al., 2002) and because of category and location switches that occurred  
628 between the two targets presented, which have previously been shown to hamper T2  
629 processing (Kawahara et al., 2003; Di Lollo et al., 2005; Visser et al., 1999).

630

**631 General Discussion**

632           The AB phenomenon demonstrates that the human visual system is limited in  
633 its ability to extract durable mental representations from the rapidly changing,  
634 continuous flow of information across time. The present study investigated whether  
635 the AB effect is modulated by perceptual grouping in Kanizsa subjective figures,  
636 using a dual-target RSVP paradigm – the aim being to determine how attention is  
637 allocated to more or less structured visual information over time. Consistent with our  
638 predictions, the results showed that the AB effect is strongly modulated by T2  
639 grouping strength: In Experiment 1, complete T2 groupings resulted in a smaller AB  
640 and in an increased overall performance compared to ungrouped (control) stimuli that  
641 consisted of the same pacman inducers which did, however, not induce an integrated  
642 percept. Experiment 2 replicated this pattern of results and further showed that the  
643 benefit of grouping in T2 can arise irrespective of the perceptual structure in T1  
644 (Experiments 1 vs. 2). Finally, in Experiment 3, a modulation of grouping in T2 was  
645 obtained even though the task was entirely unrelated to the object configurations. In  
646 contrast to Experiment 1, performance in Experiment 3 revealed the largest AB when  
647 a T2 target was presented concurrently with a complete-object configuration. Together,  
648 this pattern of results suggests that identical inducer elements may differ in the extent  
649 to which an emergent global object is formed, which in turn affects the magnitude of  
650 the AB. Thus, grouping of separate parts into a coherent whole either attenuates or  
651 enhances the AB, depending on whether grouping is relevant or irrelevant to  
652 performing the task (Experiments 1 vs. 3). Overall, our results indicate that temporal  
653 attention is modulated by emergent objects.

654

**655 *Grouping modulates temporal object processing***

656           Why does grouping in T2 modulate the allocation of attention in time?  
657 According to the two-stage model (Chun & Potter, 1995), after initial perceptual  
658 processing of the incoming sensory information, the perceptual representation must be



659 encoded in a capacity-limited short-term memory system to ensure a stable and  
660 durable representation until a response can be issued. If this consolidation process is  
661 not accomplished, the perceptually processed item is ephemeral and rapidly  
662 overwritten by the items that appear subsequently in the RSVP stream. In this view,  
663 the AB reflects a post-perceptual, attentional mechanism of limited processing  
664 capacity, which subserves the consolidation of items into working memory (Chun &  
665 Potter, 1995; Jolicœur & Dell'Acqua, 1998; Vogel et al., 1998). With salient items –  
666 for instance, grouped objects such as Kanizsa figures (Rauschenberger & Yantis, 2001;  
667 Senkowski et al., 2005) – a processing advantage should arise relatively early, at the  
668 initial stage of perceptual coding, with the global structure of grouped objects  
669 allowing for more efficient detection compared to ungrouped configurations that lack  
670 a global representation (e.g., Conci et al., 2007a, 2009). That is, pre-attentive  
671 grouping would generate a salient structure that is more resistant to temporal decay at  
672 stage 1 – which would permit the global (structured) object to more efficiently  
673 consolidated at the subsequent, capacity-limited processing stage, effectively reducing  
674 the amount of interference in the AB. Thus, as a result of rather efficient and fast  
675 processing of a grouped T2, consolidation at stage 2 can commence earlier and  
676 proceed faster, as compared to a less structured T2, in turn facilitating the  
677 maintenance of the grouped object in working memory (see, e.g., Chen et al., 2016;  
678 Chen, Töllner, Müller, & Conci, 2018, for a related finding). In support of this view,  
679 Experiments 1 and 2 consistently showed overall superior performance for grouped  
680 than for ungrouped T2s, even at longer lags when T2 processing was no longer  
681 affected by T1 processing. This sustained difference indicates that retaining an item in  
682 memory is influenced by the object structure. Moreover, the performance difference  
683 for grouped (vs. ungrouped) T2s was largest at short intervals (in all experiments),  
684 where capacity-limited resources were most likely occupied by processes relating to  
685 T1. This further shows that, in addition, attentional limitations imposed by the AB can  
686 be overcome, to a significant extent, by grouping in the target, making processing  
687 more robust and more efficient in face of the lack of limited-capacity resources  
688 (Experiments 1 and 2).

689           However, it should be noted that – although grouping likely increased the  
690 coding efficiency of complete-object targets (i.e., it enabled consolidation to begin  
691 earlier and to require fewer attentional resources), which manifested in an attenuated  
692 AB (Experiments 1 and 2) – our results nevertheless revealed a clear AB for all  
693 grouping types. This might be taken to suggest that grouping of disparate items into a  
694 coherent whole nevertheless requires a certain amount of attentional resources in  
695 order to select and retain a relevant target item until the response is issued (Joseph et  
696 al., 1997; Braun, 1998; see also Gögler, Finke, Keller, Müller, & Conci, 2016; Conci,  
697 Groß, Keller, Müller, & Finke, 2018). However, increasing the efficiency with which  
698 the stimulus is encoded (e.g., by inducing grouping) in turn reduces the attentional  
699 load and, consequently, reduces the AB (see also Braun, 1998; Joseph, Chun, &  
700 Nakayama, 1998).

701           Additional support for an early-processing account of grouped objects derive  
702 from the results of Experiment 2, in which T1 presented a partially grouped (triangle)  
703 object that was more effective in binding attentional resources than the ungrouped T1  
704 in Experiment 1. While the global T1 triangle in Experiment 2 led – at least to some  
705 extent - to an overall increased AB effect (as compared to the local T1 configuration  
706 in Experiment 1), the modulation of grouping in T2 was unaffected by this change in  
707 T1. This further supports the view that the benefit of grouping occurs because salient  
708 perceptual structures by themselves allow for a more efficient encoding of the  
709 grouped configurations (rather than arising from some top-down mediated sharing of  
710 resources between T1 and T2). That is, grouping renders particularly stable perceptual  
711 representations that are resilient in the face of interfering stimulation when only  
712 limited resources are available.

713           Consistent with this view, in visual search tasks, Kanizsa figures can act as a  
714 (non-informative) spatial cue, or in terms of an attractor for spatial attention, that  
715 facilitates detection of a target appearing at the same, circumscribed location  
716 (Senkowski et al., 2005; Conci, Müller, & von Mühlénen, 2013). However, the results  
717 of the present Experiment 3 show that when a comparable setup is used in an AB  
718 paradigm, a cost associated with the grouped object is observed, rather than efficient

719 cueing of attention to the arrow target. This may come about as a result of the rapid  
720 succession of the stimuli in the RSVP stream. The Kanisza-type configuration may act  
721 as a salient distractor (i.e., it may capture attention), from which attention must be  
722 disengaged for the system to become able to discriminate the task-relevant arrow  
723 stimulus. However, by the time this is accomplished, the (briefly presented) target has  
724 already disappeared – resulting in a performance cost and in an increased AB. Of note,  
725 the task-irrelevant grouping modulated the detection of T2 primarily at short lags,  
726 whereas at longer lags T2 performance reached the same level as T1 performance, for  
727 all grouping types (complete, partially grouped, and ungrouped). This pattern  
728 contrasts with Experiments 1 and 2, in which (in these experiments) the task-relevant  
729 Kanisza grouping not only modulated the immediate allocation of attention, but also  
730 the subsequent short-term memory consolidation of T2 at longer lags. This illustrates  
731 that task-irrelevant groupings can generate transient costs, whereas task-relevant  
732 groupings can yield sustained benefits – where the latter effect is likely owing to the  
733 encoding-into-memory of the (more or less grouped) task-relevant items.

734

### 735 ***Representing higher-order object files***

736         When processing multiple objects in rapid succession, a key requirement of  
737 the visual system is its ability to select and consolidate potentially relevant  
738 information into an enduring representation, referred to as an “object file”  
739 (Kahnemann & Treisman, 1984). Raymond (2003) proposed that the creation of a new  
740 object file plays a key role in triggering the AB (see also Kellie & Shapiro, 2004;  
741 Conci & Müller, 2009). In line with such an object file account, we observed superior  
742 performance for T2 identification and an attenuated AB when T2 was identical in  
743 shape to T1 (see Experiment 2). Since an object file has already been set up upon the  
744 presentation of T1, with a same-object T2, the identical object file needs only to be  
745 updated – as a result of which the AB is reduced. In addition, integration might arise  
746 when two targets provide complementary shapes in close temporal proximity, as  
747 evidenced by a significant drop in performance across lags for partially grouped T2s

748 (i.e., when T1 and T2 present Kanizsa triangles of opposite orientations; see  
749 Experiment 2). In this case, a “star” representation was more likely reported for T2,  
750 indicative of some form of misbinding across T1 and T2. These findings support an  
751 integration account as proposed by Hommel and Akyürek (2005), which assumes that  
752 it is difficult to segregate a continuous, rapid stream of visual information into  
753 discrete events. In this view, the closer in time two pieces of information appear, the  
754 more likely they are integrated into the same episodic trace – a finding which has  
755 been demonstrated using various types of objects and groupings (Bowman & Wyble,  
756 2007; Karabay & Akyürek, 2017).

757

### 758 ***Conclusion***

759       Whereas perceptual grouping can modulate the allocation of selective  
760 attention across visual space, the present findings show that structures provided by  
761 grouping can also influence the processing of targets in time. For instance, grouped  
762 targets lead to overall enhanced performance and a reduced AB effect, where the  
763 benefits from grouping are sustained, suggesting that they arise at an early, perceptual  
764 locus prior to attentional selection, thus facilitating both the detection of integrated  
765 structures and their subsequent consolidation into an enduring object file in working  
766 memory. By contrast, grouping in task-irrelevant items can transiently impair  
767 concurrent target processing, where this cost (from complete-object distractors) may  
768 be attributed to attentional capture, hindering efficient selection of the target. Together,  
769 this set of findings shows that grouping can substantially modulate the processing of  
770 objects in time.

771

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776

777 **Open Practices**

778 All data have been made publicly available via the open science framework  
779 and can be accessed at <https://osf.io/we7aj/>.

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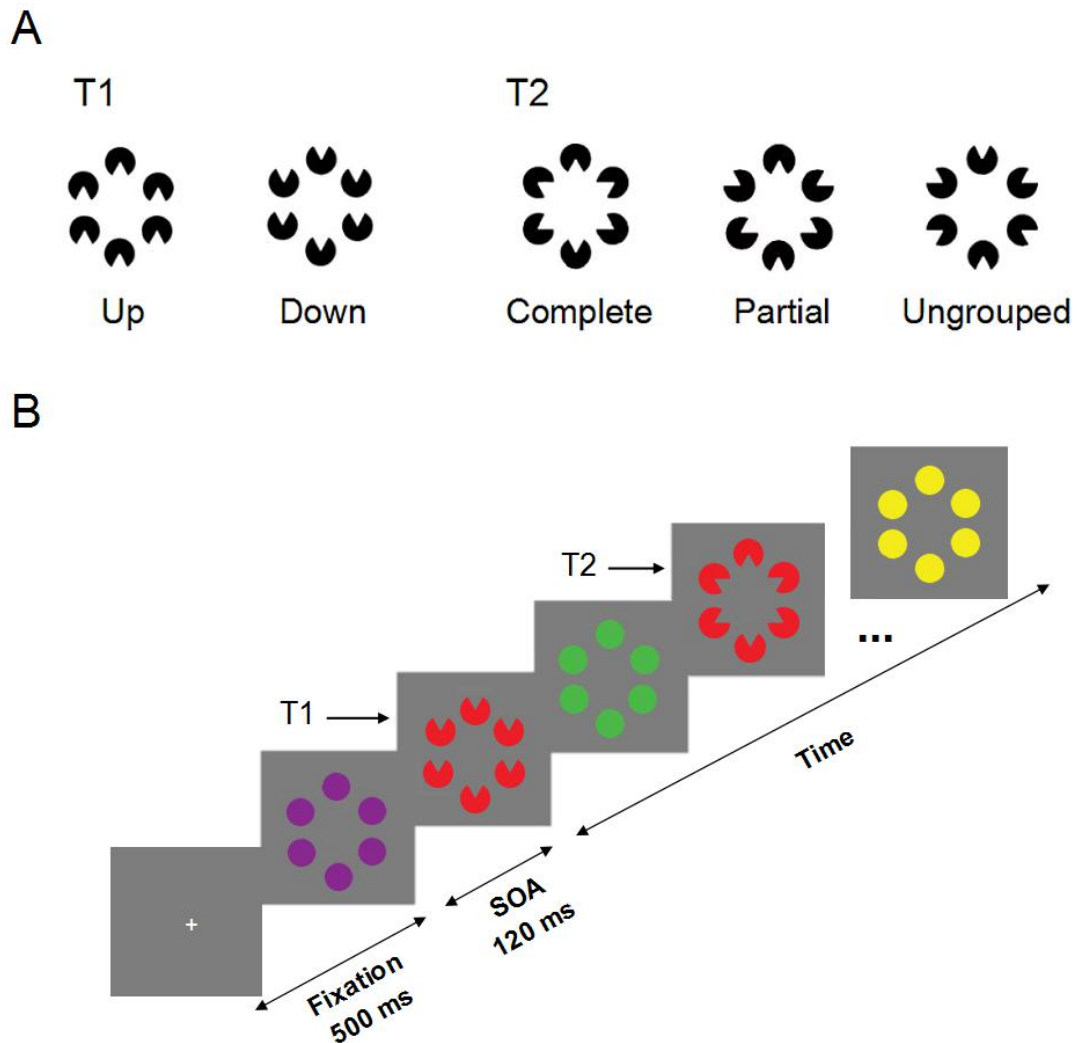
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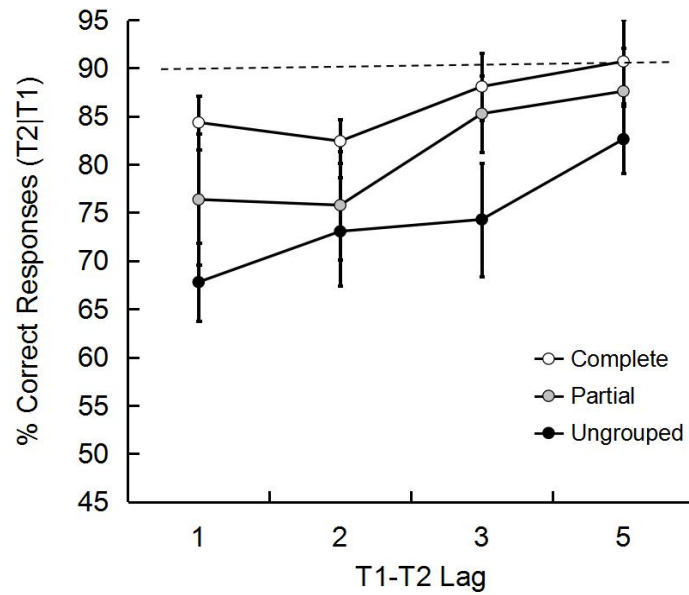
Figures



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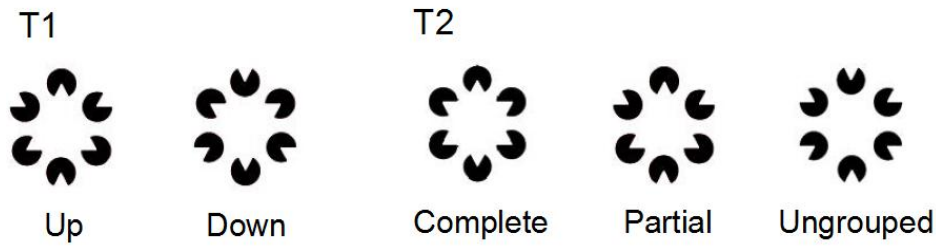
954 **Figure 1.** Stimuli and display sequence in Experiment 1. (A) Illustration of  
 955 experimental stimuli for T1 (all pacman inducers oriented either up- or downwards)  
 956 and T2 (left: complete; middle: partially grouped; right: ungrouped). (B) Schematic  
 957 example of the RSVP sequence. Each trial presented a sequence of 10 displays, which  
 958 consisted of either six complete distractor disks (non-red items) or the T1 and T2  
 959 target arrangements (red items).



960

961

962 **Figure 2.** Mean percentage of correct identifications of T2 (given a correct T1  
 963 response) in Experiment 1. Correct identifications are presented as a function of the  
 964 temporal lag from the onset of T1 to the onset of T2, separately for the different  
 965 T2-target types (complete, partially grouped, and ungrouped configurations). The  
 966 dashed horizontal line indicates the level of overall T1 accuracy. Error bars denote  
 967 95% within-subject confidence intervals.



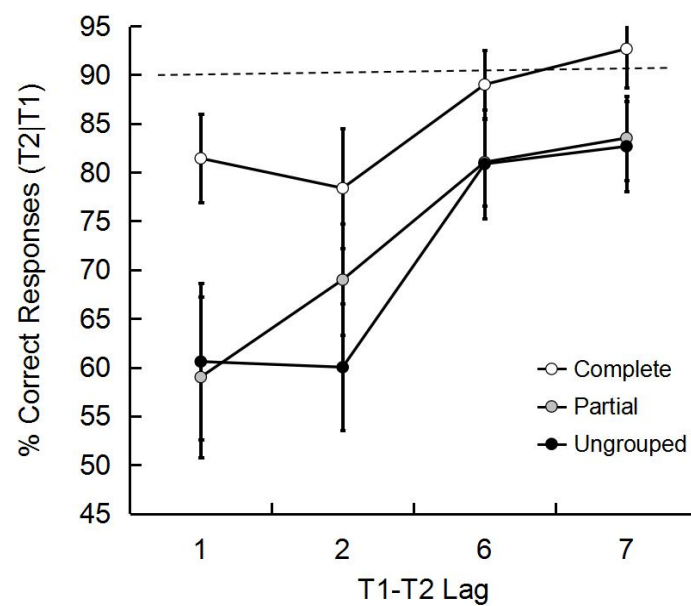
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969 **Figure 3.** Example target configurations for T1 (up vs. downward pointing triangles)

970 and T2 (complete, partially grouped, or ungrouped) in Experiment 2.

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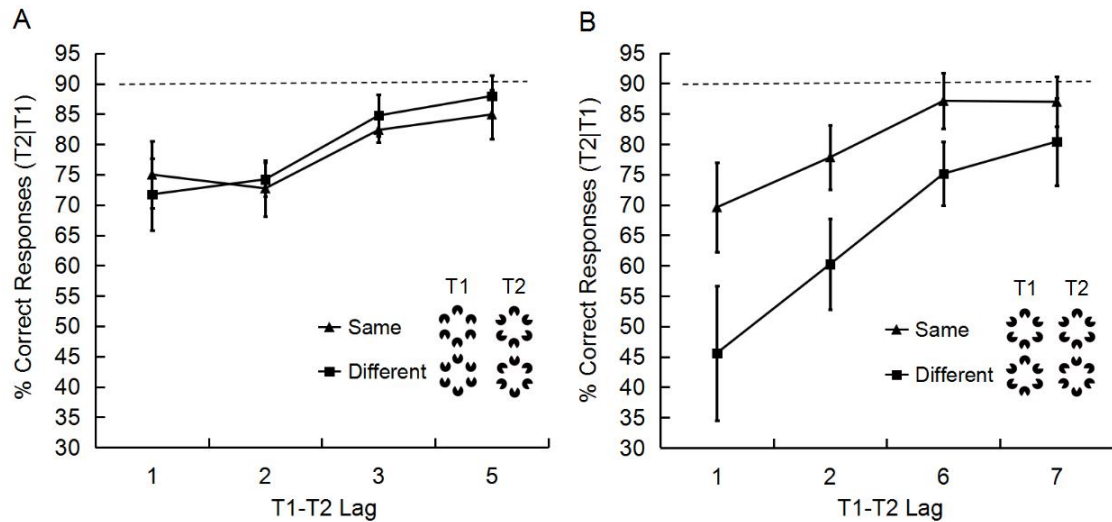
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975 **Figure 4.** Mean percentage of correct identifications of T2 (given a correct T1  
 976 response) in Experiment 2. Correct identifications are presented as a function of the  
 977 temporal lag from the onset of T1 to the onset of T2, separately for the different  
 978 conditions (complete, partially grouped, and ungrouped configurations). The dashed  
 979 horizontal line indicates the level of overall T1 accuracy. Error bars indicate 95%  
 980 within-subject confidence intervals.



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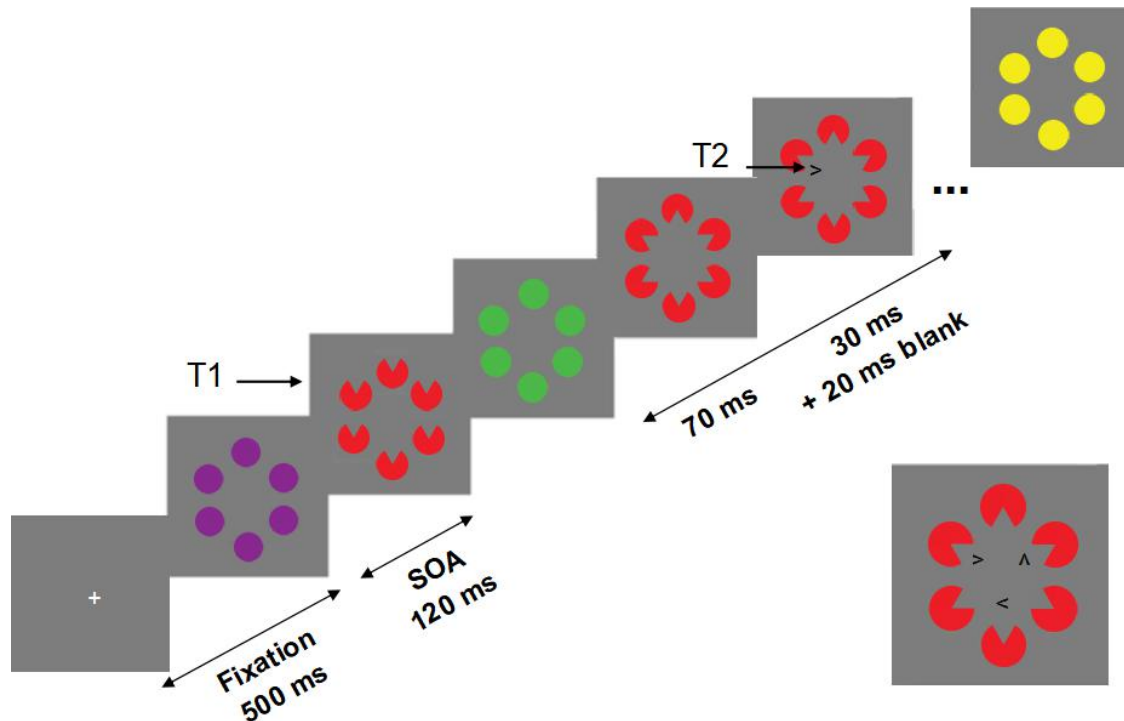
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983 **Figure 5.** Mean percentage of correct identifications of T2 (given a correct T1  
 984 response) in Experiment 1 (A) and in Experiment 2 (B). Correct identifications are  
 985 presented as a function of the temporal lag from the onset of T1 to the onset of T2,  
 986 separately for same (matching) and different (mismatching) T1–T2 pointing directions  
 987 (where T2 presented a Kanizsa triangle with up- or downward pointing direction). The  
 988 dashed horizontal line indicates the level of overall T1 accuracy. Error bars indicate  
 989 95% within-subject confidence intervals.

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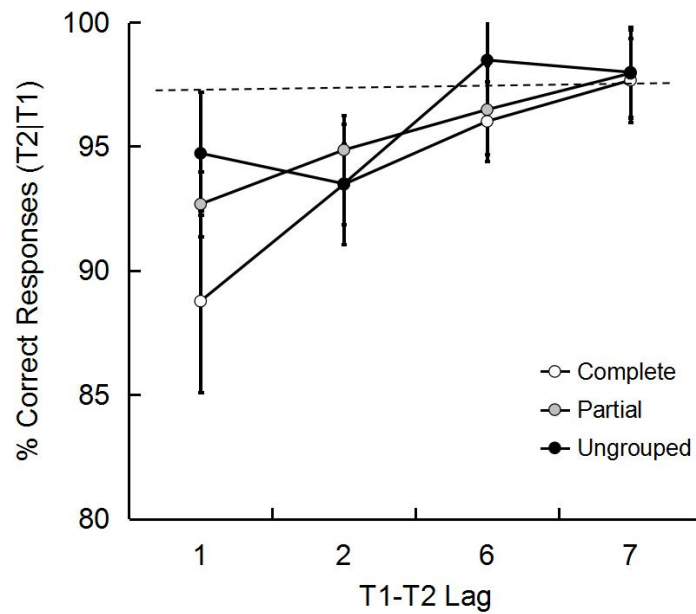
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994 **Figure 6.** Schematic example of the RSVP sequence in Experiment 3. Each trial  
 995 presented a sequence of 12 displays, which consisted of either six complete distractor  
 996 disks (non-red items) or the T1 and T2 target. For T2, a complete, partially grouped,  
 997 or an ungrouped configuration was presented (as in Experiment 1), but with an  
 998 additional target arrow (i.e., an oriented “>”-sign) added to the display. Note that the  
 999 T2 task was related only to the arrow (but not in any way to the grouping as presented  
 1000 in the Kanizsa-type configurations). The bottom right panel illustrates the three  
 1001 possible locations of the target arrow.



1002

1003

1004 **Figure 7.** Mean percentage of correct identifications of T2 (given a correct T1  
 1005 response) in Experiment 3. Correct identifications are presented as a function of the  
 1006 temporal lag from the onset of T1 to the onset of T2, separately for the different  
 1007 T2-target conditions (complete, partially grouped, and ungrouped configurations). The  
 1008 dashed horizontal line indicates the level of overall T1 accuracy. Error bars denote  
 1009 95% within-subject confidence intervals.