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The Time Course of the Competition Between Grouping Organizations

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Previous research on the competition between grouping organizations focused mainly on their relative strength as measured by subjective reports of the final percept. Considerably less is known about the underlying representations of the competing organizations. We hypothesized that when more than 1 organization is possible, multiple representations are constructed for the alternative organizations. We tested this hypothesis using the primed-matching paradigm. Our primes depicted either a single grouping principle (grouping into columns or rows by brightness similarity, connectedness, or proximity) or 2 grouping principles (brightness similarity and connectedness, or brightness similarity and proximity) that led to competing organizations (e.g., grouping into columns by brightness similarity and into rows by connectedness, or vice versa). The time course of representation construction was examined by varying prime duration. Significant priming effects of similar magnitude were found for the individual grouping organizations. These effects were modified when 2 competing organizations were present in the prime, indicating that both organizations were represented and competed for dominancy.

Public Significance Statement

Most visual scenes are composed of pieces of visual information that need to be constructed into coherent images. In order to organize this visual clutter, our visual system utilizes grouping processes to determine which visual elements are "linked together" and are segregated from other elements. Previous research on the competition between grouping cues focused on the final percept as experienced by the observer. However, the current study examined whether a competition takes place between possible alternatives in the process of choosing the final percept. Our results suggest that when multiple visual percepts are possible according to different grouping cues in the scene, mental representations are constructed for the different alternatives. This result is counterintuitive when considering that our conscious experience usually contains only one of these alternatives.

Keywords: grouping, priming, time course, competition

The initial encoding of a visual input is composed of pieces of visual information that need to be constructed into coherent images. Grouping processes are utilized in order to organize this visual clutter by determining which visual elements are "linked together" and are segregated from other elements. Classic grouping principles, proposed in the early 20th century by the Gestalt psychologists, included proximity, similarity, closure, common fate, and good continuation (Wertheimer, 1923/1955). More recent studies added the principles of common region (Palmer, 1992) and element connectedness (Palmer & Rock, 1994; see Wagemans et al., 2012, and Peterson & Kimchi, 2013, for extensive reviews). Although many of the principles mentioned here can be present in the same visual scene, and may lead to several possible organizations, our conscious percept is usually of one stable organization at a time. This raises questions concerning what determines the final percept, and whether a competition takes place between possible alternatives. On the one hand, it is possible that when multiple grouping principles are present, only the stronger one is represented and ultimately reaches conscious perception. On the other hand, multiple organizations may be represented, constructed according to the conflicting grouping principles that are present in the scene. In this case, a competition would arise between alternative organizations, and our final percept contains the organization that won this competition.

Previous studies that focused on the competition between grouping principles examined the conditions that lead to dominancy of one organization over the other (e.g., Ben-Av & Sagi, 1995; Claessens & Wagemans, 2005; Han, 2004; Han, Song, Ding, Yund, & Woods, 2001; Hochberg & Hardy, 1960; Hochberg & Silverstein, 1956; Kubovy & van den Berg, 2008; Quinlan & Wilton, 1998). In many of these studies, the relative strength of the competing grouping organizations is measured through subjective judgments made by the observers (e.g., Claessens & Wagemans, 2005; Hochberg & Hardy, 1960; Hochberg & Silverstein, 1956; Kubovy & van den Berg, 2008; Quinlan & Wilton, 1998). For example, Hochberg and Silverstein (1956) used *split lattices* of proximity and luminance similarity (i.e., displays of elements grouped into columns by proximity and into rows by luminance

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similarity, or vice versa). When the display was first perceived as grouped by luminance similarity, they asked their observers to adjust the spacing between elements to the point at which the display organization was dominated by proximity. When the display was first perceived by proximity, the observers were asked to adjust the luminance differences of the elements to the point at which grouping by luminance similarity was the dominant organization. This kind of measure produces equilibrium (i.e., the point at which the two grouping principles are equal in strength). Importantly, Kubovy and van den Berg (2008) showed, in their analysis of Hochberg and Silverstein's (1956) data, that two different points of equilibrium are found, depending on which grouping principle was the first to dominate perception and which grouping factor had to be adjusted. This finding suggests that the competition between grouping organizations is determined through a dynamic process, instead of a rigid hierarchy implemented by an inherent dominancy of one grouping principle over the other. Still, because subjective reports were measured in that study, it is possible that the flexibility in point of equilibrium reflects dynamics of higher level operations and participants' strategy. Thus, the current study was designed to provide empirical evidence for a competition between representations of alternative grouping organizations, using an objective measure of priming instead of subjective reports.

Ben-Av and Sagi (1995) examined the time course of the competition between two grouping organizations (e.g., columns by proximity and rows by brightness or shape similarity) by manipulating the stimulus onset asynchrony (SOA) between the stimulus and mask displays. Their participants were instructed to report the orientation of the organization they perceived, allowing the authors to detect the point in time in which a switch in dominancy of the competing organizations occurred. Ben-Av and Sagi found that the organization by proximity was perceived at a short SOA of 60 ms, but grouping by brightness similarity or shape similarity emerged only with longer SOAs (160 ms). Thus, this study provided a time course for the competition between these grouping organizations. However, similar to the studies listed earlier its focus on subjective reports of the perceived organization provided a measure only for the end result, and not an insight into the processes underlying the progression of the proposed competition.

Razpurker-Apfeld and Kimchi (2007) examined the time course of different grouping organizations. To that end, they used the primed-matching paradigm (Beller, 1971) with varying prime exposure durations (e.g., Kimchi, 1998, 2000; Sekuler & Palmer, 1992). In the prime-matching paradigm, the observers are exposed briefly to a prime stimulus that is followed by a pair of test stimuli. The test pair can consist of identical or different stimuli, and the observer's task is to make a "same" or "different" judgment about that pair. The stimuli in the same-response test pair may or may not match the prime. When the stimuli in the test pair match (i.e., are similar to) the prime, correct "same" responses are faster than when the test stimuli do not match (i.e., are dissimilar to) the prime. That is, the priming effect measures the representational similarity between the prime and the test stimulus. Varying the duration of the prime makes it possible to reveal early and late representations of the priming stimulus. The primes employed by Razpurker-Apfeld and Kimchi (2007) included grouping elements into columns and rows or into a shape (e.g., square and cross) based on brightness similarity, and grouping a single homogenously colored group of elements into a shape (e.g., square and cross). They found that grouping occurred rapidly, as indicated by the emergence of priming effects under the shortest prime duration, when the prime grouped into columns or rows by brightness similarity or when homogenously colored elements formed a shape. However, grouping occurred later or more slowly when the grouping involved segregation of elements by brightness similarity, and required resolving figure–ground relations between segregated units. These results suggest that the time course of grouping varies as a function of the processes involved in it.

The goal of the current study was to examine the time course of the competition between grouping organizations. Because only one percept is available in our conscious experience at a time, it is possible that there is no competition between representations—only one organization is represented and, hence, ultimately reaches conscious perception. Alternatively, when more than one organization is possible in the visual scene, all of the possible organizations are represented (at least to a certain degree) and compete for dominancy in the final percept. In order to test these two alternative accounts, we used the primed-matching paradigm described earlier. In the current study, the organizations employed in the experiments were constructed by different individual grouping principles, or by two grouping principles leading to conflicting organizations. Thus, the time course of representation construction for an organization could be compared when it was the only possible organization in the prime and when there was also another possible organization in the prime, presumably resulting in a competition. Experiments 1 and 2 examined the time course of grouping based on brightness similarity and connectedness, respectively, and Experiment 3 examined the time course of the competition between these two principles. Experiment 4 examined the time course of grouping based on proximity, and Experiment 5 examined the time course of the competition between proximity and brightness similarity organizations.

If only one organization is represented, then the priming effects observed when the prime includes conflicting organizations should be similar to the priming effects that emerge when it includes only one, presumably the dominant organization. However, if both organizations are represented, then the pattern of priming effects when both organizations are present in the prime should be different from the pattern of priming effects that emerges when only one of them is present. Specifically, priming effects in the former are expected to decline relative to the latter, and may even be abolished altogether if there is a competition between the alternative organizations.

Experiments 1–3

Experiments 1, 2, and 3 examined the time course of representation construction for organizations formed by brightness similarity and connectedness. First, the time course of each grouping organization was examined individually in order to establish a baseline. To that end, in Experiments 1 and 2, participants were presented with prime displays depicting columns and rows organizations constructed by one grouping principle (brightness similarity, Experiment 1; connectedness, Experiment 2). Priming effects were expected to emerge at all prime durations in Experiment 1, replicating the results of Razpurker-Apfeld and Kimchi's (2007) of a similar condition. Priming effects were expected to emerge at all prime durations in Experiment 2 as well, because the organization did not require resolving figure–ground relations. The time course of the competition between these two organizations was examined in Experiment 3, in which the prime displays depicted the two grouping principles leading to opposite organizations: columns by connectedness and rows by brightness similarity, or vice versa. In this experiment, if only the dominant organization is represented in the competition, priming effects were expected to be found for the dominant organization, and these effects should be similar to the ones found for this organization when presented alone (e.g., if priming effects are found only for brightness similarity in Experiment 3, then the time course of these effects should be similar to those found in Experiment 1). However, if both organizations are represented in the competition, then priming effects in Experiment 3 would follow a different time course from those found in Experiments 1 and 2.

Method

Participants. Twenty-two students from the University of Haifa participated in Experiment 1, 18 participated in Experiment 2, and 23 participated in Experiment 3.[1] None of them participated in more than one of the experiments.[2] All had normal or corrected-to-normal vision, and all were naïve to the purpose of the study. The Human Ethics Committee of the University of Haifa approved this study, and all participants provided written informed consent in accordance with the Declaration of Helsinki.

Apparatus. The stimuli were presented using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) on a 17-in. CRT monitor of a Workstation HP Z200 computer. The experiment was conducted in a dimly lit room. The participants rested their heads on a chin rest at a viewing distance of 57 cm and watched the screen through a circular aperture of a matte black cardboard sheet.

Stimuli. Examples of the stimuli used in Experiments 1, 2, and 3 are depicted in Figure 1. Each priming stimulus included 36 solid dot elements, each 0.5° in diameter. The distance between vertically or horizontally adjacent elements was 0.5°. Prime stimuli subtended 5.5° × 5.5° each. In each experiment, there were three types of prime stimulus—columns, rows, and a neutral prime.

Experiment 1: Brightness similarity grouping. The elements in the primes were grouped into columns and rows by the grouping principle of brightness similarity; half of the elements were black and half were white, alternating either on the horizontal or vertical meridian (i.e., in columns, rows, respectively). In the neutral prime, the black and white elements were randomly scattered (Figure 1A).

Experiment 2: Connectedness grouping. The elements in the primes were grouped into columns and rows by the grouping principle of connectedness; every six vertically or horizontally neighboring elements were connected by a black straight line, 0.1° in width (i.e., columns or rows, respectively). The neutral prime depicted randomly scattered black elements (Figure 1B).

Experiment 3: Competition between brightness similarity and connectedness grouping. The elements in the primes were grouped by the two grouping principles into opposite orientations; when the brightness of the elements alternated on the horizontal meridian, producing columns by brightness similarity, they were

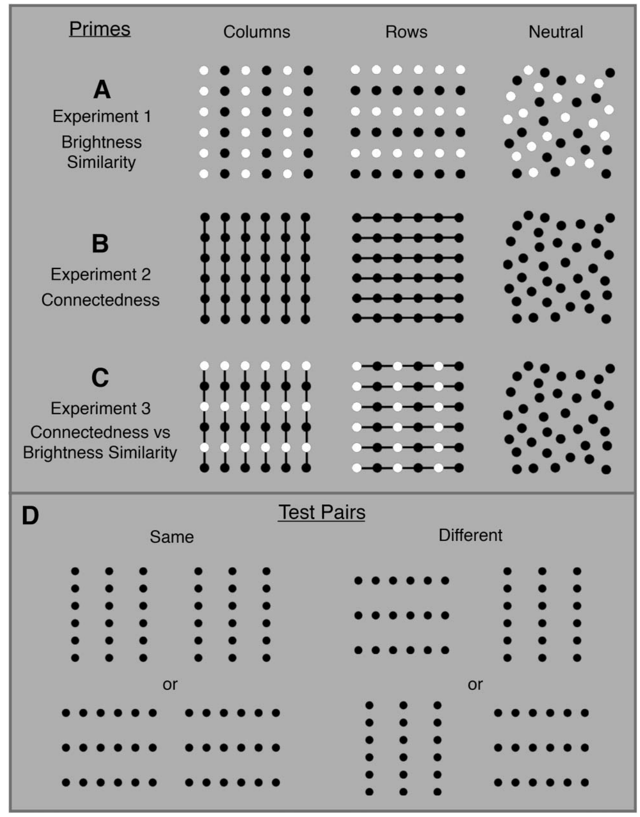

Figure 1. Examples of the stimuli employed in Experiments 1, 2, and 3. Prime stimuli included columns (left), rows (middle), or no grouping (right) in (A) Experiment 1 (brightness similarity grouping), (B) Experiment 2 (connectedness grouping), and (C) Experiment 3 (competition between brightness similarity and connectedness grouping). Note that in (C), the stimulus label indicates the organization formed by connectedness. (D) Test pairs: same-response test pairs (left) and different-response test pairs (right). The test pairs were identical for all of the experiments to allow direct comparison of priming effects for all grouping conditions.

also connected to their horizontally neighboring elements, creating rows by connectedness. In an equivalent prime, the elements were grouped into rows by brightness similarity and into columns by connectedness. The neutral prime depicted randomly scattered black elements (Figure 1C).

Test pairs. In all of the experiments, there were two types of test pairs: a same-response test pair and a different-response test pair (Figure 1D). The same-response test pairs included two 3-column stimuli (i.e., columns-columns test pair) or two 3-row stimuli (i.e., rows-rows test pair). Each column and row was made of six black circles. The size of the dots and the distance between adjacent dots within a column or within a row were the same as

[1] To reduce threats to internal validity, data collection in Experiments 2 and 3 overlapped, thus randomizing participants in the two conditions. The same was true for Experiments 4 and 5.

[2] The grouping factor was manipulated between subjects to avoid carryover effects, in which an organization in a prime not containing a competition will prime the same organization in the prime containing a competition, and thus strengthen that organization.

those in the priming stimulus. The distances between columns or rows in the test stimuli were 1.5°. Different-response test pairs included a columns stimulus and a rows stimulus (i.e., columns-rows/rows-columns test pairs), with their position within a pair (right or left) counterbalanced across trials. The nasal distance between the stimuli in each test pair was 5.8°.

Design and procedure. The design and procedure were similar in the three experiments. In each experiment, a 3 (priming stimulus: columns, rows, neutral[3]) × 5 (prime duration: 40, 90, 190, 390, 690 ms) × 4 (test pair: columns-columns [same-response], rows-rows [same-response], columns-rows [different-response], rows-columns [different-response]) within-subject design was used. The sequence of events in a trial is illustrated in Figure 2. Each trial started with a fixation cross that appeared for 500 ms in the center of the screen. Then one of the priming stimuli appeared in the center for 40, 90, 190, 390, or 690 ms. Immediately thereafter, a test pair was displayed until a response was made, or for a maximum of 3,000 ms. At this time, participants indicated whether the two stimuli of the test pair were the same as each other or different from one another. The participants were instructed to respond as rapidly and accurately as possible. Reaction time (RT) was measured from the onset of the test pair until a response key was pressed. Feedback about an incorrect response, or no response, was provided by an auditory tone as soon as the participant responded or when the time for response had passed. The intertrial interval (intertribal interval [ITI]) was 1,000 ms. All of the combinations of prime and test pair were randomized within blocks, as were the different presentation durations of the prime stimulus. There were 960 experimental trials administered in eight blocks, preceded by 20 practice trials.

Results and Discussion

RT summaries and analyses in all of the following experiments are based on participants' mean RTs for correct responses to "same" test pairs, because typically priming effects are not observed with "different" responses (e.g., Beller, 1971; Kimchi, 1998, 2000; Sekuler & Palmer, 1992). RTs less than 250 ms were discarded, as well as RTs ±3 standard deviations from condition mean for each observer. Data from one participant in Experiment 1 and one participant from Experiment 3 were excluded from further analyses because of extremely slow responses (mean RTs were 3 and 2.4 standard deviations above the group mean RT, respectively), and data from one participant in Experiment 2 were excluded because of extremely high error rate (ER; 20% errors). The mean percentage of discarded trials across remaining participants was less than 0.02% in each of the three experiments. The participants were highly accurate (mean ERs: 2.6% in Experiment 1, 1.7% in Experiment 2, and 2.5% in Experiment 3), and no indications of a speed–accuracy trade-off were found. Mean ERs and correct RTs are presented in Table 1 as a function of prime-test similarity and prime duration in Experiments 1, 2, and 3. Prime-test similarity refers to similarity between the organization depicted in the "same-response" test pair and the organization of the prime: A test pair is similar to the prime if the stimuli in the pair depict the same organization as the prime stimulus, and dissimilar if the test stimuli depict a different organization than the prime. In Experiment 3, each test pair is similar to one organization (e.g., the connectedness organization) and dissimilar to the other organization (e.g., brightness organization). Because there are no similarity relations between the test pair and the neutral prime, their combined condition serves as a control condition.

The main dependent variable was priming. The priming measure indicated how much the prime facilitated "same" responses to a test pair similar to the prime versus a test pair dissimilar to the prime. The amount of priming is defined by the RT or ER difference between "same" responses to dissimilar test pairs versus similar test pairs to a specific prime, minus the RT or ER difference for these test pairs in the neutral condition. For example, to calculate priming effects with RT for the columns prime, the RT to the similar *columns-columns* test pair is subtracted from the RT to the dissimilar *rows-rows* test pair when they followed the columns prime minus the difference between these two test pairs when they followed the neutral prime. Similarly, priming effects were calculated for the rows prime, and then priming was averaged across prime type (columns and rows). In Experiment 3, each test pair was similar either to the prime's organization according to connectedness (and dissimilar to the organization by brightness similarity) or to the prime's organization according brightness similarity (and dissimilar to the organization by connectedness). The amount of priming in this experiment was defined by the difference in same-response RT or ER to a test pair similar to the brightness similarity organization in comparison with a test pair similar to the connectedness organization after participants viewed the prime minus the response difference for these test pairs in the neutral condition. Priming of the connectedness organization should produce positive values, caused by an advantage in responding to the connectedness organization test pairs over the brightness similarity organization test pair in the prime condition relative to the neutral condition, whereas priming of the brightness

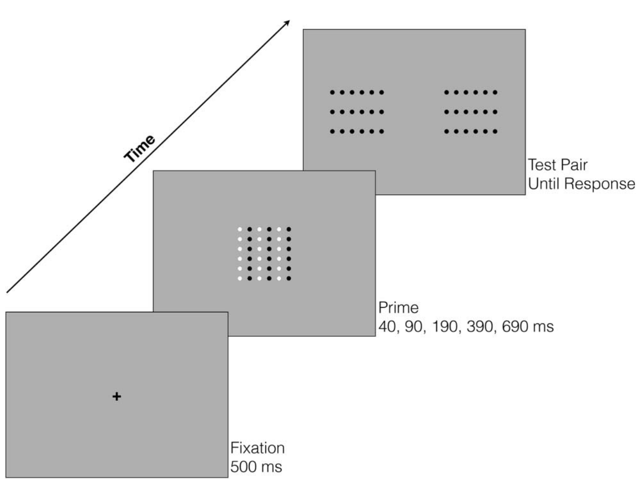

Figure 2. The sequence of events in a single trial. The illustration depicts a prime stimulus of columns by brightness similarity followed by a dissimilar same-response test pair (rows-rows). The test pair appeared on the screen until the participant responded, or until 3 s had passed.

[3] In Experiment 3, the values of the prime stimulus factor correspond to one of the grouping organizations depicted in the prime. That is, a "columns" prime depicts columns by connectedness and rows by brightness similarity, and a "rows" prime depicts rows by connectedness and columns by brightness similarity.

Table 1
Mean Correct RTs (Ms) and Error Rates (%, in Parentheses) as a Function of Prime-Test Similarity and Prime Duration (Ms) for the Different Grouping Organizations in Experiments 1, 2, and 3

	Type of organization								
	Brightness similarity (Experiment 1)			Connectedness (Experiment 2)			Connectedness vs. Brightness (Experiment 3)		
Prime duration	SIM	DIS	Control	SIM	DIS	Control	Connectedness SIM	Brightness SIM	Control
40	609 (2.2)	643 (3.7)	634 (2.2)	608 (1.3)	630 (2.9)	604 (1.5)	592 (2.1)	605 (3.4)	589 (2.6)
90	614 (1.3)	644 (4.0)	639 (2.8)	599 (1.8)	633 (2.9)	622 (.7)	587 (3.0)	597 (2.1)	579 (1.7)
190	601 (3.1)	634 (2.7)	626 (2.1)	576 (2.0)	594 (1.7)	600 (2.0)	569 (4.4)	570 (4.0)	572 (2.0)
390	596 (1.7)	613 (3.7)	615 (1.5)	573 (1.5)	593 (2.2)	584 (1.1)	563 (2.7)	562 (2.3)	554 (1.3)
690	589 (2.2)	623 (2.2)	606 (.6)	574 (1.1)	598 (2.2)	587 (.7)	549 (2.1)	564 (1.9)	550 (1.4)

Note. See text for details. SIM = similar; DIS = dissimilar.

similarity organization should produce negative values, caused by an advantage in responding to the brightness-similarity organization test pair over the connectedness organization test pair in the prime condition relative to the neutral condition. Note that because each test pair is similar to one organization in the prime and dissimilar to the other organization, the priming effect can result from facilitation, inhibition, or a combination of both. Therefore, the observed priming effects indicate relative dominance of either connectedness or brightness similarity.

Priming effects in the different experiments are presented in Figure 3 as a function of prime duration. The priming measures for ER and RT were subjected to a repeated measures one-way ANOVA (prime duration) for each of the individual experiments.

Experiment 1: Brightness similarity grouping. As can be seen in Figure 3A, strong priming effects were found at most prime durations. No effect of prime duration was found on the RT priming measure ($F < 1$), and it was marginally significant on ER, $F(4, 80) = 2.06$, $p = .09$, $\eta_p^2 = 0.09$. Planned t tests showed that priming effects were significantly greater than zero for all prime durations on RT (40 ms, $p < .02$; 90 ms, $p < .004$; 190 ms, $p < .02$; 390 ms, $p < .03$; 690 ms, $p < .002$). Priming effects on ER were significant for prime duration of 90 ms ($p < .003$) and 390 ms ($p < .03$). No other priming effects were found with ER (ps > 0.1). These results replicate those of Razpurker-Apfeld and Kimchi (2007), who showed significant priming effects for columns and rows organization by brightness similarity with the same range of prime durations.

Experiment 2: Connectedness grouping. Similar to the results of Experiment 1, strong priming effects were found for the various prime durations (Figure 3B). The effect of prime duration was not significant for either priming measure (Fs < 1). Planned t tests showed that priming effects on RT were significantly greater than zero for all prime durations (40 ms, $p < .02$; 90 ms, $p < .04$; 190 ms, $p < .002$; 390 ms, $p = .05$; 690 ms, $p < .002$). Priming effects were also found on ER for the shortest and longest prime duration (40 ms, 690 ms, $p < .02$). No other priming effects were found with ER (ps > 0.19).

Experiment 3: Competition between brightness similarity and connectedness grouping. Similar to the results of Experiments 1 and 2, the effect of prime duration was not significant with either priming measure (Fs < 1). However, as evident in Figure 3C, priming effects in the present experiment were different than those found in Experiments 1 and 2. Importantly, planned t tests showed that priming effects on RT were significantly greater than zero only for the shortest and longest prime duration (40 ms, $p < .03$; 690 ms, $p < .04$). No significant priming effect was observed for the 90-, 190-, and 390-ms prime duration (ps > 0.16). A marginally significant priming effect was with ER at prime duration of 40 ms ($p = .09$). No other priming effects were found with ER (ps > 0.61). These results suggest some advantage for the organization by connectedness over the organization by brightness similarity earlier and later in the course of grouping, but an overall disadvantage of both organizations when they are in competition.

The data from Experiments 1–3 was also subjected to a two-way mixed design ANOVA (with experiment as a between-subjects factor and prime duration as a within-subject factor). This analysis showed a significant effect of experiment with RT, $F(2, 57) = 5.67$, $p < .006$, $\eta_p^2 = 0.17$, which did not interact with exposure duration ($F < 1$). Bonferroni post hoc analysis showed no difference in priming between Experiments 1 and 2 ($p = .85$), a significant difference in priming between Experiment 1 and Experiment 3 ($p < .006$), and a marginally significant difference between Experiment 1 and Experiment 2 ($p < .07$), indicating that when presented alone, brightness similarity grouping and connectedness grouping produced similar amounts of priming, whereas when the two were in conflict, the overall amount of priming was smaller.

The results of these experiments clearly show different priming effects when grouping by connectedness and grouping by brightness similarity were in conflict compared with when each was present alone. Both organizations produced significant priming effects at all exposure durations when only one grouping organization was present in the prime (Experiments 1 and 2). However, a different pattern was observed when both grouping organizations were present and led to different organizations (Experiment 3). Priming effects of positive values (i.e., priming effect for the organization by connectedness) were found at the shortest and longest prime durations, and no priming effects were observed at the intermediate prime durations. A direct comparison between the priming effects of the three experiments showed that the overall amount of priming diminished when the two organizations were in competition compared with when each of them was individually presented in the prime. Taken together, these results suggest that when the two grouping organizations were in conflict, both were represented to a certain degree—not just the dominant one. Furthermore, a competition between the representations of these or-

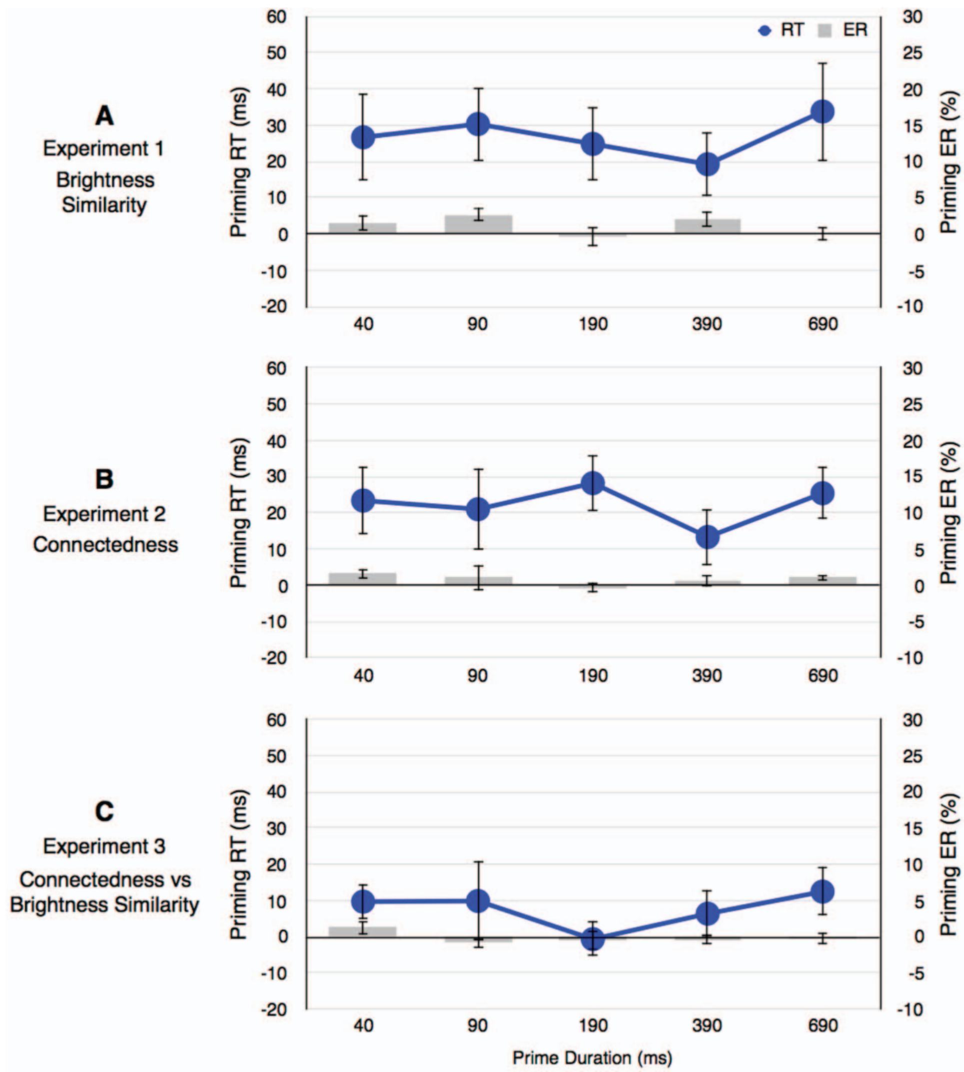

Figure 3. Priming effects as a function of prime duration for RT (blue circles) and ER (gray bars) in (A) Experiment 1 (brightness similarity grouping), (B) Experiment 2 (connectedness grouping), and (C) Experiment 3 (conflicting organizations by brightness similarity and connectedness). Note that in (C), positive values indicate priming for the organization by connectedness, and negative values indicate priming for the organization by brightness similarity (see text for details). Error bars indicate one standard error of the mean. RT = Reaction time; ER = Error rate. See the online article for the color version of this figure.

ganizations seems to have emerged with a relative dominance of the organization by connectedness early and late in the course of grouping, and no relative dominance of either organization in between. Interestingly, no relative dominance of the organization by brightness similarity was observed. Presumably, connectedness dominated brightness similarity at first, and then the competition between connectedness and brightness similarity increased to the point at which no organization had dominancy over the other, as indicated by the absence of priming effects for either grouping organization at the intermediate prime durations, and, finally, the organization by connectedness gained dominancy over brightness similarity again. This is consistent with previous demonstration of stronger grouping by connectedness than by similarity (e.g., Brooks, 2015; Palmer & Rock, 1994).

The following experiments examined whether a similar pattern of results, suggesting that conflicting grouping organizations are both represented to a degree, would emerge for a different combination of conflicting grouping principles.

Experiments 4 and 5

The next two experiments were designed to examine the time course of representation construction for organizations by proximity and brightness similarity. In Experiment 4, the time course of columns and rows organizations constructed by proximity alone was established. Then, in Experiment 5, proximity grouping was examined when it was presented in conflict with brightness similarity. That is, when proximity led to columns in the prime, brightness similarity led to rows, and vice versa. Proximity is considered a primary and dominant grouping principle that operates at very short durations (Ben-Av & Sagi, 1995; Ben-Av, Sagi, & Braun, 1992; Kurylo, 1997), and it relies on the relative distances of the local elements, which are available early in the course of visual processing (Han, 2004; Han et al., 2001). Thus, as in Experiments 1 and 2, strong priming effects were expected to emerge as early as the shortest prime duration when the organization by proximity was the only one present in the prime. The interesting question was whether a conflict between proximity and brightness similarity organizations will affect priming in a similar fashion as the conflict between connectedness and brightness similarity groupings (Experiment 3).

Method

Participants. Twenty-one students from the University of Haifa participated in Experiment 4, and 23 participated in Experiment 5. All had normal or corrected-to-normal vision, and all were naïve to the purpose of the study. None of them participated in the previous experiments. The Human Ethics Committee of the University of Haifa approved this study, and all of the participants provided written informed consent in accordance with the Declaration of Helsinki.

Stimuli, apparatus, design, and procedure. The stimuli, apparatus, design and procedure were identical to those of Experiments 1 to 3, except each prime stimulus included 24 solid dot elements, and the primes depicted either columns or rows organizations grouped by either proximity alone (Experiment 4) or by proximity and brightness similarity in competition (Experiment 5).

Experiment 4: Proximity grouping. Proximity grouping was achieved by manipulating the distance ratio between adjacent elements: In the columns prime, the vertical distance was 0.5° and the horizontal distance was 1.17°. In the rows prime, the distances were reversed. Proximity was tested alone in Experiment 4, and thus all of the elements were black (Figure 4A).

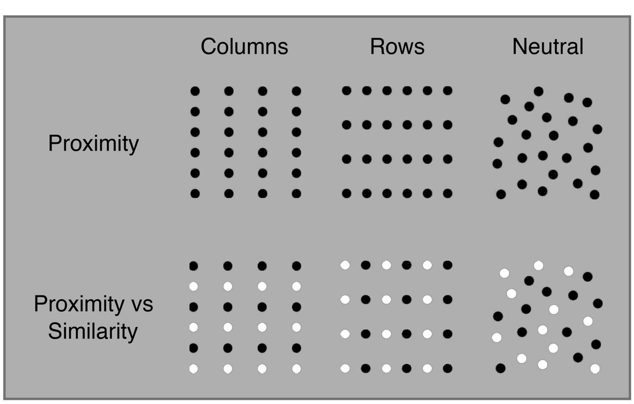

Figure 4. Examples of prime stimuli employed in Experiments 4 and 5. Prime stimuli included columns (left), rows (middle), or no grouping (right) in (A) Experiment 4 (proximity grouping), and (B) Experiment 5 (conflicting brightness similarity and proximity grouping). Note that in (B), the stimulus label indicates the organization by proximity. Test pairs were identical to those presented in Figure 1D.

Experiment 5: Competition between brightness similarity and proximity grouping. To generate a competition between brightness similarity and proximity grouping in the prime stimulus, half of the elements were black and half were white, alternating either on the horizontal or vertical meridian (i.e., columns or rows, respectively). Distance ratios of the elements in the primes were the same as those in Experiment 4. Critically, the organization formed by brightness similarity was always opposite the one formed by proximity (Figure 4B).

Results and Discussion

Data from one participant in each experiment were excluded from further analysis because of extremely slow responses (their mean RTs were 2.7 standard deviations above the group mean RT), and data from one participant in Experiment 5 were excluded because of extremely high ER (15% errors). Mean percentage of discarded trials across remaining participants was less than 0.02% in each experiment. The participants were highly accurate (mean ERs: 3.3% in Experiment 4, and 2.5% in Experiment 5), and no indications of a speed–accuracy trade-off were found. Mean ER and correct RT are presented in Table 2 as a function of prime-test similarity and prime duration in Experiments 4 and 5. Note that in Experiment 5, instead of similar and dissimilar conditions, the test pairs are either similar to the proximity organization or to the brightness similarity organization.

Priming effects in the different experiments are presented in Figure 5 as a function of prime duration. Note that in Experiment 5, the amount of priming was defined by the difference between same-response RT or ER to a test pair similar to the prime's brightness-similarity organization and a test pair similar to the prime's proximity organization minus the response difference for these test pairs in the neutral condition. Hence, priming of the proximity organization should produce positive values and priming of the brightness similarity organization should produce negative values. The priming measures for ER and RT were subjected to a repeated-measures one-way ANOVA (prime duration) for each experiment.

Experiment 4: Proximity grouping. As expected, similar to the results of Experiments 1 and 2, strong priming effects were found when the proximity organization was presented alone (Figure 5A). The effect of prime duration was not significant on either priming measure (RT, $F[4, 76] = 1.3$, $p = .28$, $\eta_p^2 = 0.06$; ER, $F[4, 76] = 1.2$, $p = .33$, $\eta_p^2 = 0.06$). Planned t tests showed priming effects on RT to be significantly greater than zero for all prime durations (40 ms, 90 ms, $p < .001$; 190 ms, $p < .03$; 390 ms, $p < .05$; 690 ms, $p < .02$). Significant priming effects were also found with ER at prime durations of 40 and 90 ms ($p < .05$). No other priming effects were observed on ER (ps > 0.33).

Experiment 5: Competition between brightness similarity and proximity grouping. As evident in Figure 5B, the pattern of priming when the proximity and brightness similarity organizations were in conflict was different from the pattern of priming observed when each grouping organization was present alone (Figure 5A and Figure 3A for proximity and brightness similarity organization, respectively). No significant effect of prime duration was found on either priming measure (RT, $F < 1$; ER, $F[4, 84] = 1.04$, $p = .39$, $\eta_p^2 = 0.05$). Planned t tests showed no priming effects on RT or ER at any prime duration (ps > 0.17).

Table 2
Mean Correct RTs (Ms) and Error Rates (%, in Parentheses) as a Function of Prime-Test Similarity and Prime Duration (Ms) in Experiments 4 and 5

	Type of organization					
	Proximity (Experiment 4)			Proximity vs. Brightness (Experiment 5)		
Prime duration	SIM	DIS	Control	Proximity SIM	Brightness SIM	Control
40	585 (1.9)	635 (3.6)	619 (2.0)	582 (1.6)	593 (1.9)	593 (1.3)
90	585 (2.7)	612 (4.6)	609 (2.7)	579 (2.6)	583 (2.8)	591 (2.4)
190	601 (5.2)	632 (5.0)	601 (3.0)	588 (4.7)	580 (3.7)	588 (2.3)
390	590 (2.8)	614 (3.3)	587 (2.7)	584 (2.3)	570 (1.9)	579 (2.1)
690	592 (2.8)	611 (2.5)	584 (3.5)	561 (2.1)	578 (3.1)	566 (2.6)

Note. See text for details. SIM = similar; DIS = dissimilar.

Thus, the results of Experiments 4 and 5 provide an additional indication for representation of multiple organizations and a competition between them when two conflicting grouping organizations are present. When the organization by proximity was presented alone (Experiment 4), strong priming effects emerged starting from the shortest prime duration, similar to the priming effects produced by brightness similarity. This finding is in accordance with previous studies showing rapid processing of proximity grouping (Han, 2004; Han et al., 2001; Kurylo, 1997). Critically, in Experiment 5, in which grouping organizations by proximity and by brightness similarity were in conflict, no priming effects were observed.

A two-way mixed design ANOVA (with experiment as a between-subjects factor and prime duration as a within-subject factor), including the data from Experiments 1, 4, and 5 provides additional support for these observations: A main effect of experiment was found with RT, $F(2, 60) = 10.99$, $p < .0001$, $\eta_p^2 = 0.27$, which did not vary with prime exposure duration, $F(8, 240) = 1.65$, $p = .37$, $\eta_p^2 = 0.02$. Bonferroni post hoc analysis showed no difference in priming between Experiments 1 and 4 ($p = .99$),

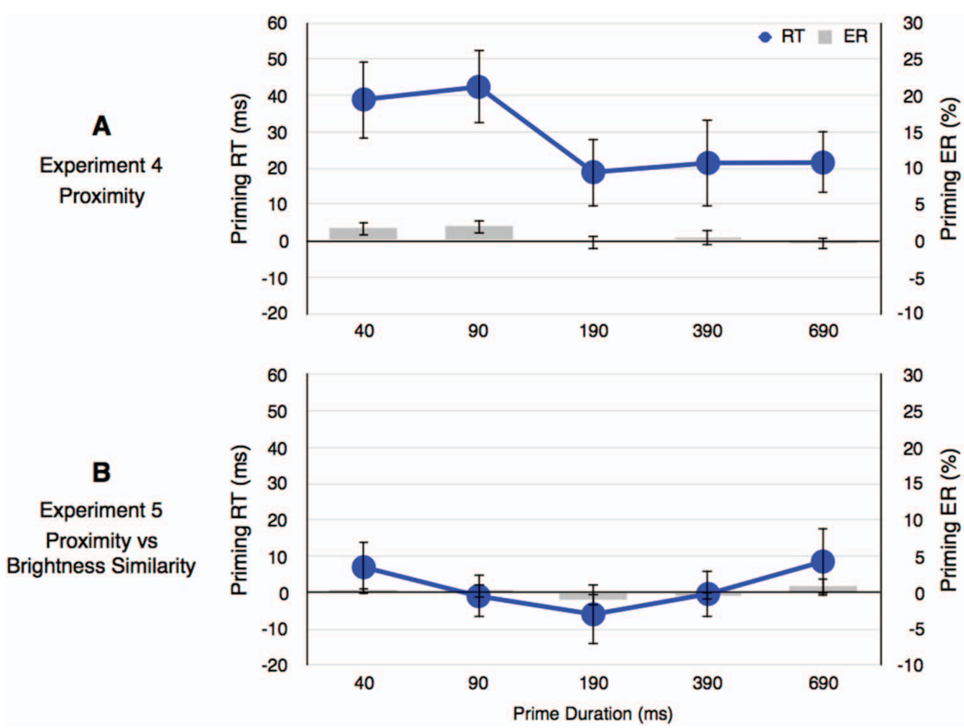

Figure 5. Priming effects as a function of prime duration for RT (blue circles) and ER (gray bars) for the different grouping organizations in Experiments 4 and 5: proximity (Experiment 4; top) and conflicting proximity and brightness similarity (Experiment 5; bottom). Note that in the latter, positive values indicate priming for the organization by proximity, and negative values indicate priming for the organization by brightness similarity (see text for details). Error bars indicate one standard error of the mean. RT = Reaction time; ER = Error rate. See the online article for the color version of this figure.

indicating that when present alone, brightness similarity organization and proximity organization produced similar amounts of priming, but significant differences in priming were found between Experiments 5 and Experiments 1 and 4 (ps < 0.001). Thus, these results also suggest representations for both organizations in the competition. Interestingly, as opposed to Experiment 3, no priming effects were observed for either the proximity or the brightness similarity organization. This suggests that the competition was not resolved within the time course tested here.

A direct comparison between the priming produced by brightness similarity (Experiment 1), connectedness (Experiment 2), and proximity (Experiment 4), when presented alone, revealed that the three grouping principles produced similar amounts of priming. A two-way mixed design ANOVA (with experiment as a between-subjects factor and prime duration as a within-subject factor) showed no main effect of experiment (Fs < 1 for RT and ER). Thus, although when present alone, the three grouping organizations produced similarly strong priming, the time course observed for the competition shown here is somewhat different from the one observed for the competition in Experiment 3, and this difference will be discussed in the General Discussion.

General Discussion

The goal of this study was to examine the time course of the competition between conflicting grouping organizations. To that end, we used priming as an implicit measure of representation construction for single or two conflicting grouping organizations. Prime exposure duration was manipulated in order to examine the time course of these representations. The results show equally strong and lingering priming effects when no conflict was present in the prime for organizations formed by brightness similarity (Experiment 1), connectedness (Experiment 2), and proximity (Experiment 4). However, these priming effects were modified when two organizations were in conflict; the amount of overall priming was reduced in Experiments 3 and 5. Specifically, when connectedness and brightness similarity competed, the results show priming only for connectedness at the shortest and longest prime durations, and no priming for either organization at the intermediate durations (Experiments 3). When proximity and brightness similarity competed, the results show no priming for either organization at any of the tested prime durations (Experiment 5). Taken together, these results suggest that when in conflict, both grouping organizations are represented, at least to a certain degree, and compete for dominancy. If no competition had emerged between the representations of the two conflicting organizations, priming effects in this condition would have resembled those observed for one of the individual organizations.

Note also that the two competitions yielded somewhat different time courses, showing priming effects for the connectedness organization in Experiment 3 at the shortest and longest prime durations (40 and 690 ms, respectively), but no priming at the intermediate durations. That is, the time course of the competition observed in this experiment suggests an early relative dominance of connectedness, then the brightness similarity organization gains some power, but then the connectedness organization regains dominancy. However, in Experiment 5, priming effects were absent at all prime durations. The time course observed in this experiment indicates that the dominant organization was not established early on, and presumably the competition requires more time in which both organizations are represented to a similar degree until one of them gains relative dominancy. These results may suggest that there is a hierarchy of grouping principles, such that connectedness is more dominant than proximity and brightness similarity, because the two organizations in the competition were essentially the same (depicting columns or rows). This is in accordance with previous demonstrations of connectedness grouping dominating proximity and similarity grouping (Brooks, 2015; Palmer & Rock, 1994), suggesting that connectedness is higher in the hierarchy than the other two principles. Presumably, this dominance hierarchy was not apparent when each grouping was present alone, but surfaced when there was a competition between grouping organizations. However, as previous findings suggest, proximity is achieved faster than similarity (Ben-Av & Sagi, 1995; Ben-Av et al., 1992; Han, 2004; Han et al., 2001; Kurylo, 1997). Thus, one would expect that proximity should show dominancy over similarity grouping in our study as well. However, it did not. Hence, we propose that the relative dominancy that we observe under competition is the result not only of a hierarchy of the grouping principles involved but also of the strength of the current instantiation of each principle. That is, the columns or rows organization produced by connectedness may have been stronger relative to the ones produced by brightness similarity and by proximity. Yet if, for instance, the distance ratio between the dots in the proximity organization in Experiment 5 was larger (i.e., less similar distances on the vertical and horizontal meridians), leading to a stronger proximity organization, then the interference from the brightness similarity organization in the competition might have been smaller, in which case priming effects for the proximity organization might have been observed at various prime durations and not only at the longest one. In contrast, if the distance ratio was smaller, leading to a weaker proximity organization, then brightness similarity might have been the dominant organization in the competition. Similarly, if the difference in element brightness was smaller (e.g., dark and light gray instead of black and white), then the interference from the brightness similarity organization in the two competition experiments might have decreased, resulting in priming effects for the connectedness and proximity organizations at other prime durations than the ones observed here.

The subject of relative strength of conflicting grouping organizations has been studied mainly with subjective reports of the final percept (e.g., Claessens & Wagemans, 2005; Hochberg & Hardy, 1960; Hochberg & Silverstein, 1956; Kubovy & van den Berg, 2008; Quinlan & Wilton, 1998). Moreover, Kubovy and van den Berg (2008) developed a probabilistic model in which the probability of an organization to be reported increased as the strength of the organization increased (i.e., increased distance ratio or luminance difference between elements). Their results also suggested that grouping principles of proximity and similarity work in an additive manner, mediated by different mechanisms. Evidence of additivity was also reported by Claessens and Wagemans (2005), who combined proximity and collinearity in Gabor lattices, in a procedure similar to the one used by Kubovy and van den Berg. An investigation of the role of these two factors, grouping principles and grouping strength, in the competition between organizations is currently underway.

The presumed multiple representations in the current study is compatible with the concept of additivity from different grouping mechanisms (Claessens & Wagemans, 2005; Kubovy & van den Berg, 2008). However, subjective reports only reflect the end result of the competition between grouping organizations and not its progression, and it is unclear how the variations we found in the representations over time correspond with the subjective experience of an organization. In studies in which the competition is examined with subjective measures, participants report the dominant organization they consciously perceive. In the current study, the presence of priming effects supposedly indicates relative dominancy for one organization over the other, implying that when no priming effects are found, there is also no dominant organization. If the time courses we found for the emergence of representations correlate with the participants' conscious experience, then the organization should be consciously perceived as ambiguous or switch between alternatives at the corresponding times (i.e., when no priming is evident).

Conversely, dissociation between subjective and objective measures of grouping strength may exist. Such dissociation was demonstrated in a study by Schmidt and Schmidt (2013), who examined the competition between grouping organizations in a response-priming task. Their participants first rated the strength of columns and rows organizations constructed by principles of brightness, size, or shape similarity. Then, these organizations were presented as primes and targets in a subsequent experiment. They found that prime stimuli that were rated as equally strong produced similar magnitudes of priming when they depicted organizations by brightness and size similarity. However, in order to obtain priming effects of similar magnitudes for organizations constructed by brightness and shape similarity, the organization by brightness similarity had to be subjectively perceived as much stronger than the shape similarity organization. Thus, the subjective scores of grouping strength did not correlate with the objective measure of response priming. Schmidt and Schmidt proposed that different representations are constructed for the physical parameters that determine grouping strength in two different systems: one that governs early visiomotor response, and a later one associated with subjective impressions. It is important to note, however, that in Schmidt and Schmidt's "primed-flanker" paradigm, the different grouping organizations were presented next to each other to create a competition between compatible and incompatible responses, and were not in conflict within the same stimulus as in the current study. Hence, the questions examined in the two studies might involve different mechanisms.

In sum, this study examined the time course of individual and conflicting grouping organizations, using priming as an objective measure for the emergence of representations for these organizations. We found significant priming effects when a single grouping organization was present in the prime at short, intermediate, and long prime durations. These priming effects were modified when the prime depicted two conflicting organizations. Furthermore, somewhat different time courses were observed for different competitions. These results indicate that when two grouping organizations are in conflict they are both represented and compete for dominancy.

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