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Top-down effects of higher-level object representations on perceptual grouping

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This study investigated whether higher-level object representations exert top-down effect in the grouping of visual elements. Stimuli with two uniformly connected regions were used. In one condition, they were meaningless while in another, they were meaningful Japanese kanji. In two experiments, participants judged whether two targets embedded within the stimulus figures were the same or different. The critical consideration, however, was whether the targets shared the same or different regions. Results revealed that when the two-region figure was meaningless, there was a significant advantage in responding to targets in the same region compared to those in different regions. However, when they were meaningful, this same region advantage vanished. These suggest that, in the meaningless figure, uniform connectedness influenced the parsing of the two-region figures into two distinct objects whereas, in the meaningful kanji, meaning representations influenced the grouping of the two-regions into a single object.

Key words: perceptual organization, grouping, parsing, uniform connectedness, meaning representation.

It has been widely believed that prior to object recognition, the visual system segregates pattern elements that constitute individual perceptual objects from those of other objects and the background, and groups them together for further processing (Wertheimer, 1958; Marr, 1982; Vecera & Farah, 1997). This perceptual organization of visual inputs into unit or collection of units makes people perceive an organized visual world consisting of discrete objects coherently arranged in space.

Perceptual grouping was traditionally said to rely on low-level bottom-up feature dimensions such as proximity, similarity, good continuation, symmetry, luminance, texture, orientation, and relative motion. These features are said to elicit bottom-up information processing in the sense that they are driven by the stimulus features and processed automatically, separately, and in parallel. The pattern elements get parsed/ segregated if they differ in one or more of these feature dimensions and tend to be grouped if they share similar features (Wertheimer, 1958; Baylis & Driver, 1992). Psychophysical data and theoretical analysis indicated also that perceptual grouping might occur in the early stages of visual processing (e.g., Nakayama & Shimojo, 1992; Grossberg, Mingolla, & Ross, 1997). Several findings from single unit recordings in monkey brain suggested that the primary visual cortex (areas V1 and V2) has responsive properties that can mediate the grouping of image fragments (e.g., Sugita, 1999; von der Heydt & Peterhans, 1989). In humans, functional magnetic resonance imaging (fMRI) studies also showed areas V1 and V5 as the prominent cortical regions responsible for the perceptual grouping operations involved in illusory contour perception (e.g., Seghier, Dojat, Delon-Martin, Rubin, Warnking, Segebarth, & Bullier, 2000). On these premises, several theories of perception assume that grouping and figure-ground segregation must occur at an early, preattentive stage of processing to come up with units to which attention is deployed for later processing, including object recognition and identification (Neisser, 1967; Pomerantz, 1981).

Against this backdrop of evidence showing that grouping happens in the early stage of vision and is

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influenced mainly by low-level representations, it is interesting and important to know whether higher-level meaning representations stored in memory can also influence perceptual grouping. This question is motivated by two precedent research trends: First, several studies have found that grouping does not only occur at the early stages of vision but also in a relatively late and post constancy representation of environmental surfaces. They have demonstrated that grouping works after depth information has been extracted (Rock & Brosgole, 1964), and lightness constancy (Rock, Nijhawan, Palmer, & Tudor, 1992) and perceptual completion (Palmer, Neff, & Beck, 1996) have been achieved. Palmer and Nelson (2000) showed that grouping could be influenced by the perception of illusory contours. They presented observers with rectangular arrays in which a central column of figures could group either with those on one side, on the basis of the perception of figures defined by illusory contours, or with those on the other side, on the basis of physically present inducing elements. Participants grouped according to the illusory figures more often than the physically present inducing elements with little or no illusory contours.

Second, increasing empirical evidence show that higher-level representations influence figure-ground segregation and image segmentation. In their series of studies, Peterson and colleagues (Peterson, Harvey, & Weidenbacher, 1991; Peterson & Gibson, 1993) showed that denotative regions (i.e., roughly meaningful) were more likely to be called figure compared to less denotative regions. They presented observers with visual stimuli composed of two regions separated by a contour and asked them to press a button corresponding to the side of the contour that appeared to be the figure as long as they could. The stimuli were figure-ground reversible because each region had equal bottom-up cues such as size, convexity or symmetry. However, one of the regions was highly denotative, while the other, not. Consistently, Peterson and colleagues found that highly denotative regions were reported as the figure longer compared to low denotative regions. Peterson and colleagues interpreted their findings as a top-down influence of denotativity in figure-ground assignment. In their parallel interactive model of figure ground organization (Peterson, de Gelder, Rapcsak, Gerhardstein, & Bachoud-Levi, 2000), they proposed that early object recognition processes proceed in parallel with processes assessing low-level configural cues and that the output of all these processes combine to determine figure-ground segregation. In the same vein, Vecera and Farah (1997) found that familiar figures (alphabets or alphabet-like) were segmented or parsed faster and more accurate than unfamiliar ones (rotated or distorted alphabets). Unlike the parallel interactive model, Vecera and O'Reilly's (1998) interactive model viewed these findings as evidence for the top-down interaction of higher-level representations with low-level bottom-up inputs that could bolster or alter the initially perceived figure.

A review of extant literature, however, revealed that to this date, no study has been conducted yet that directly investigated whether higher-level representations could exert top-down influence in perceptual grouping. Thus, this study was conducted. Its main purpose was to find out whether stored meaning representations could influence the grouping of uniformly connected (UC) regions into more meaningful collections. If so, then the previous findings that higher-level representations affected figure-ground segregation (Peterson et al., 1991, 1993) and image-segmentation (Vecera & Farah, 1997) will be extended into the domain of perceptual grouping. This study also aimed to clarify the levels of representations that are necessary in the grouping of visual regions. Finally, it hoped to enrich current understanding on perceptual organization processes by discussing the results in the light of perceptual organization theories and models.

In this study, two UC regions[1] were manipulated so that in one condition, they were totally meaningless while in another, they were meaningful when grouped together. In Experiment 1, two-region Japanese kanji characters were presented to kanji-literate Japanese and kanji-illiterate non-Japanese groups of observers. In Experiment 2, two-region meaningful Japanese kanji were pitted with two-region meaningless figures and were randomly presented to Japanese observers.

It was hypothesized that when the two-region figures are meaningless (meaningless condition), the UC character of the regions will influence their parsing into two distinct objects. On the other hand, when the two regions are meaningful kanji (meaningful condition), the

[1]Region/s refer to any figure or part that has a uniformly connected contour/lines such that when the contour/line is drawn, it ends where it starts.

stored meaning representation of the kanji would exert top-down influence that could override the UC qualities and metric distance of the regions and group them into a single object. Several studies have shown a strong tendency for UC regions of homogenous properties like texture, luminance, color, and motion, to be perceived initially as a single unit. For example, Ngohayon, Kawahara, and Toshima (1999) presented participants with two meaningless regions with uniformly connected contour and asked them to judge whether two targets embedded within the regions were the same or different. Results revealed that perceptual judgments were faster when the targets appeared in a single UC region than when they appeared in two different UC regions. The UC character of the regions overcame the similarity and proximity of the regions, conditions that could have biased their grouping into a single object[2]. Kramer and Watson (1996) also showed that perceptual judgments were faster when they involved two aspects of a single UC region than when they involved two different UC regions, suggesting that UC might define the units for selective attention.

The meaningful kanji stimuli used in this study differed greatly from the denotative figure stimuli of Peterson and colleagues. The kanji used in this study were real world meaningful stimuli regularly used by the Japanese in their everyday lives while those of Peterson and colleagues were constructed to denote certain objects solely for the purpose of their experiment. In addition, the kanji contains phonetic and semantic elements that even involve phonetic recoding at the working memory stage (Leong, 1986). Kanji developed from pictures used by the Chinese to represent objects and events in the world around them and because of that, some kanji have preserved their pictographic form and are still similar in appearance to the objects they represent (Tamaoka, Kirsner, Yanase, Miyaoka, & Kawakami, 2000). Thus, seeing a Japanese kanji is more than seeing a word in the English language because the reading of Japanese kanji was found to follow a graphic form-to-meaning process just as Chinese characters do (Perfetti, 1999). Peterson and colleagues' denotative or meaningful stimuli were ambiguous reversible figures with one side of the contour denoting a particular concept or meaning (e.g., a pineapple). It is therefore very clear that the present stimuli left behind these concept formulations or denotativities in favor of real world meaningful stimuli with concrete and clear stored representations.

[2]Object/s are image representations resulting from perceptual organization processes. An object can be an individual region or a group of regions.

Experiment 1

Experiment 1 first sought to replicate previous findings that UC regions tend to be parsed/ segmented as single objects. Then it tested whether stored meaning representations could exert top-down influence that will group two-UC regions into a single object. Japanese kanji stimuli were first presented to kanji-illiterate non-Japanese observers, and then to kanji-literate Japanese observers. It was ensured that the kanji stimuli are meaningless to non-Japanese while they are meaningful to Japanese observers. It was predicted that the non-Japanese observers will segment/parse the kanji stimuli into two distinct objects by virtue of the UC qualities of the regions while the Japanese observers will group them into a single object by virtue of their meaning. Responses of each group to targets in the same region were compared with those in different regions.

Method

Participants. Kanji-illiterate non-Japanese and Kanji-literate Japanese groups of observers participated in the experiment. The non-Japanese group was composed of 10 foreign students who have just arrived at Hiroshima University to pursue higher studies. The Japanese group was composed of thirty undergraduate native Japanese students of Hiroshima University. The non-Japanese group is said to be kanji-illiterate because they have just started studying the Japanese language but did not study nor were knowledgeable of any Japanese kanji yet. The Japanese group is said to be kanji-literate because the kanji stimuli were commonly used kanji that were mastered from grades 1-9. The participants confirmed these after the experiment when they were presented with the kanji stimuli used.

Stimuli. The stimuli consisted of 20 two-region Japanese kanji taken from the list of 1,945 commonly-used basic kanji, which the Ministry of Education, Science and Culture of Japan has prescribed as the standard for Kanji usage and are to be mastered from Grades 1-9 (Tamaoka et al., 2000). The kanji stimuli have two vertical regions, with each region meaningless when taken individually but meaningful when taken together. The stimuli had a mean size of 4.78Åãof visual angle presented 78 cm away from the observers' eyes. The stimuli appeared in line drawings on the screen with the target circles embedded within them as in Figure 1.

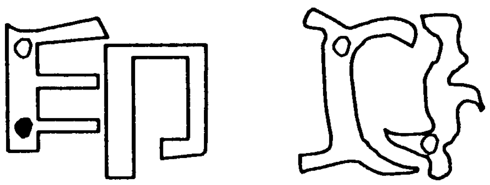

Figure 1. Example of stimuli used in Experiment 1 (left) and in Experiment 2 (both figures). Same region condition is in the left while, the different region condition is in the right.

Procedure. Every trial started with the presentation of a fixation display for 500 ms followed by the stimulus display presented for 182 ms and a blank display presented until a response was made. The next trial appeared 500 ms after the participants pressed a response key. The participants were instructed to fixate at the fixation mark ("+") and to indicate as fast and accurate as possible, whether the target circles were the same (both black or both white) or different (a black and a white circle). The critical consideration however, was whether the targets appeared in the same or different regions.

Practice trials were given prior to the actual experiment to familiarize the participants with the procedure. The experiment was carried out in two blocks with rest periods in between them. Thirty same-region and 30 different-region conditions were identified, randomly presented in the first block, and repeated in the second, for a total of 120 trials. Incorrect responses were automatically discarded and the incorrectly responded trial/s re-appeared until a correct response was given. The different conditions were counterbalanced across trials and groups.

Results and Discussion

In the Japanese group, only the data from 28 participants were analyzed because a participant was not able to finish the experiment due to poor visual acuity while another was excluded due to a very low percentage of accuracy (47%).

Mean reaction times were computed by averaging the median of each subject's data. Figure 2 shows the mean reaction times by the non-Japanese and Japanese groups. The data were subjected to a 2 x 2 mixed ANOVA with subject groups (Japanese & non-Japanese) as between-subject factor and target locations (same & different regions) as within-subject factor. There was a significant main effect of groups, $F(1,36) = 31.12$, $p<.0001$, no significant main effect of location, $F(1,36)=0.33$, and a significant interaction of groups and location factors, $F(1,36)=7.23$, $p<.02$. Further post-hoc analysis showed that in the non-Japanese group, reaction times for targets in the same region (634 ms) were significantly faster than those targets in different regions (648 ms), $F(1,36)=5.34$, $p<.03$, whereas, in the Japanese group of participants, there was no significant difference

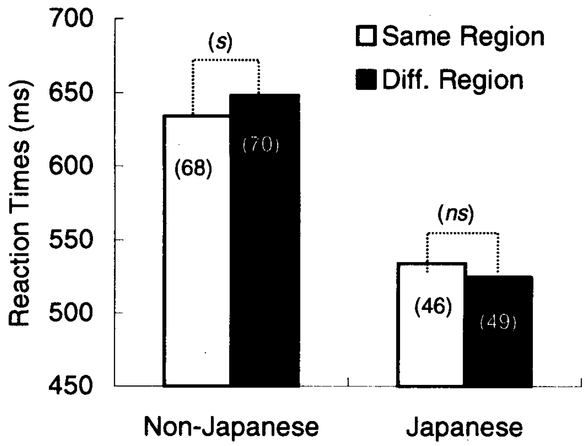

Figure 2. Mean reaction times and *SD* (in brackets) for targets in same and different regions by the non-Japanese and Japanese groups in Experiment 1. *s*=significant, *ns*=not significant.

(534 ms, 525 ms), $F(1,36)=2.23$. Error rate data showed similar pattern showing no speed-accuracy tradeoff.

Of great relevance to the present hypothesis and objective is the finding that in the non-Japanese group, reaction times for same region were significantly faster than those for different regions, while in the Japanese group, no significant difference was observed. These suggest that, among the non-Japanese participants, the two-region kanji were subsequently parsed or segmented into two distinct objects by virtue of their UC qualities. Hence, targets in same region were responded faster compared to those in different regions because in the former, target judgment was confined to a single object whereas in the later, it considered two objects causing a delay in response. On the other hand, for the Japanese participants, the two-region kanji were grouped into a single object by virtue of their stored meaning representations. Therefore, there was no difference in judging targets in the same region or in different regions because in both conditions, the two target circles were always in the same object. In other words, the different region condition did not exist anymore because the two UC regions separated by metric distance were grouped into a single object.

However, one might argue that the significant main effect of grouping shows a strong between-group variability, which in itself might account for the difference in the trends of reaction times. It must be noted that the participants were not carefully matched in number, age, IQ and other possible extraneous factors. To solve this problem, Experiment 2 was conducted.

Experiment 2

This experiment aimed to directly compare the reaction times for targets in the same region with those in different regions in two stimulus conditions using a single group of participants. In one condition, the two-region stimuli have no discernible meaning while in the other, they could be grouped into a meaningful kanji. Based on the previous result, it is hypothesized that reaction times for targets in the same region would be faster than those in different regions in the two-region meaningless figure condition whereas there would be no difference in the two-region meaningful kanji. This is based on the above argument that the UC qualities of the regions will guide the parsing or segmentation of the two-region meaningless figures into two distinct objects while stored meaning representations will override these UC qualities and influence the grouping of the two-region kanji into a single object.

This experiment had two major deviations from Experiment 1. The first was the random presentation of either the two-region meaningless figure or a two-region meaningful kanji (Figure 1) in the target display. The second was that, the fixation display also served as a cue that indicated whether the forthcoming stimulus was a meaningless figure or a meaningful kanji. This cueing method was done to highlight the differences between the stimuli used (one is meaningful, the other meaningless) and to ensure that they were processed to some degree before the response. The random presentation of the meaningless figures and meaningful kanji in short exposure duration might confuse the participants and force them to disregard the figures, in which the targets are embedded, and concentrate in judging whether the targets are the same or different. This will not only diminish the difference between the stimulus figures but also raise the specter of the figures not being processed at all. The cue was also used to counter any prior subjective predisposition, which the participants might have in relation to the stimuli that might confound the results. The familiarity and commonness of the kanji to the participants compared to the novelty of the meaningless two-region figures might predispose the participants to view the two-region figures as a meaningful kanji. Many studies have suggested that predisposition and other subjective factor affects visual processes. For example, Schafer and Murphy (1943) found that viewers were more likely to perceive as figure whichever region of an ambiguous figure-ground display was previously associated with a reward (see also Chen, 1998).

Method

Participants. Twenty-two native undergraduate Japanese students of Hiroshima University volunteered and participated for course credits.

Stimuli. Two groups of stimuli were used in this study, twenty (20) two-region meaningless figures and 20 two-region meaningful Japanese kanji (Figure 1). The overall make-up, appearance and size of the stimuli were the same as in Experiment 1.

Procedure. Aside from the major deviations previously mentioned, the overall procedure followed that of Experiment 1. In addition, participants were informed that the fixation mark, which was presented for 1500 ms, was programmed in such a way that a "+" fixation display was followed by a meaningful stimuli while a "-" fixation display was followed by a meaningless stimuli. There were 240 trials presented in two blocks. Each block was composed of 60 meaningless figure and 60 meaningful kanji condition with each condition having 30 same-region and 30 different-region trials. To avoid any response strategy that the participants might devise in relation to the cue, 7% of the total trial were invalidly cued and proportionately distributed across conditions.

Results and Discussion

Only the data from the valid trials were considered for further analysis because the very purpose of the cue was to highlight the difference between the two groups of stimuli, and this happened only in the validly cued trials. As in Experiment 1, the four stimulus conditions were collapsed into whether the targets appeared in the same or different regions, because there was no interaction between the response factors and the circle's locations. Thus, the critical conditions were whether the stimuli where the targets were embedded were meaningless or meaningful (meaningfulness factor) and whether the target circles appeared in the same or different regions (location).

Figure 3 shows the mean reaction times for the meaningless figures and meaningful kanji condition, computed by averaging the median of each subject's data. A 2 x 2 analysis of variance with meaningfulness (meaningless or meaningful) and target location (same region or different regions) as within-subject factors revealed a significant interaction between meaningfulness and target location, $F(1,21) = 5.51$, $p < .03$, although there were no significant main effects of meaningfulness, $F(1,21) = 0.46$, and target location, $F(1,21) = 0.53$. Further post hoc analysis showed that in the meaningless figure condition, reaction times for targets in same region (553 ms) was significantly faster compared to those in different regions (562 ms), $F(1,42) = 5.01$, $p < .04$, manifesting *a same-region-advantage*. However, in the meaningful kanji condition, there was no significant difference between the reaction times for targets in the same region (562 ms) compared to those in the different regions (557 ms), $F(1,42) = 1.20$. Again, the error rate data revealed similar trend of results, discounting any speed-accuracy tradeoff.

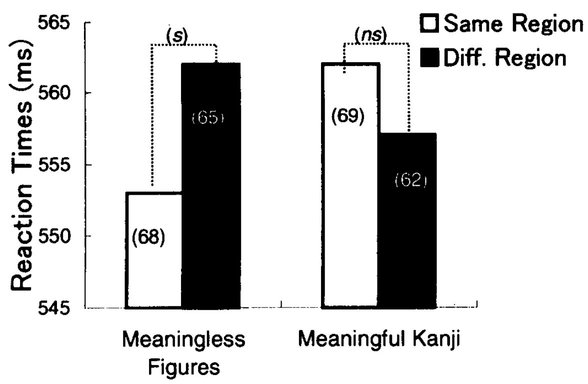

Figure 3. Mean reaction times and *SD* (in brackets) for meaningless figures and meaningful kanji in Experiment 2. s=significant, *ns*=not significant.

The *same-region-advantage* found in the meaningless figure condition confirmed and clearly replicated the data from the non-Japanese participants in Experiment 1 above and that of Ngohayon et al.'s (1999) Experiment 1 where they used the same meaningless figure stimuli to Japanese participants. These results suggest that the UC qualities of the regions of the meaningless figures influenced their parsing or segmentation into two distinct objects. On the other hand, the absence of any regional advantage in target judgments in the meaningful kanji condition despite having two metrically distant UC regions suggests that the meaning representation of the kanji influenced the grouping of the two UC regions into a single object. Such grouping eliminated the regional boundaries, in essence forming a single object composed of grouped regions, hence there was no significant difference in the latency of judging targets found in the same region compared with those in different regions. These results lend credence to the result of Experiment 1 above, overcoming alternative explanations and confounding factors.

General Discussion

This study examined two critical conditions: one in which two paired but metrically distant UC regions could be seen as two distinct objects, and another in which they could be grouped together and seen as parts of a single object (kanji). In Experiment 1, two-region Japanese kanji stimuli were presented to a group of kanji illiterate non-Japanese and a group of kanji literate Japanese observers. In Experiment 2, two-region meaningful Japanese kanji and two-region meaningless figures were randomly presented to a single group of Japanese observers. Experiment 1 showed a significant advantage in responding to targets found in the same region compared to those in different regions by the non-Japanese group of observers, while there was no significant difference in the Japanese group of participants. Experiment 2 confirmed and replicated these results by showing that responses of Japanese observers to targets in the same region were significantly faster compared to those in different regions only in the two-region meaningless figures but not in the two-region meaningful kanji condition.

These results suggest that higher-level meaning representations influence perceptual grouping. This top-down influence can even override the UC properties of stimuli. It adds to the growing number of empirical studies showing that stored representations affect perceptual organization. The present results have important implications to previous research findings on perceptual organization. First, it extends the findings of Peterson and colleagues on the effect of denotativity/ meaningfulness in figure-ground segregation to the domain of perceptual grouping. As was mentioned previously, Peterson and colleagues showed that denotativity influenced figural judgments in figure-ground reversible stimuli. The present results showed that meaning influenced the grouping of two-region stimuli into a single object. Therefore, it is suggested that the parallel interactive model of Peterson and colleagues (Peterson et al., 2000) be broadened to cover not only figure-ground segregation but also grouping process. Meaning representation belongs to the separate pathway for object representations that directly exerts top-down inputs to the grouping process. It operates in parallel with various other pathways that exert bottom-up inputs to the grouping process (e.g., monocular cues, binocular cues, & configural cues).

Second, this study also broadens the findings of Vecera and Farah (1997) in that, while they showed that similarity exerts top-down influence in the segmentation of letter stimuli, it showed that meaning exerts top-down influence in the grouping of kanji stimuli. For this reason, it is proposed that the interactive model of Vecera and O'Reilly (1998) be extended to include meaning as a higher-level representation that interacts with bottom-up inputs in the grouping of visual stimuli. The model argued that partial result from figure-ground processing is sent to subsequent object representations. The object representations, in turn, send activation back to the figure-ground units, providing top-down inputs before a stable figure-ground percept has been established. However, the third level of processing exclusively mentioned object representations that coded for "familiar shapes" only. This was because, only familiarity was then sufficiently found to exert top-down influence on segmentation (Vecera & Farah, 1997; Vecera & O'Reilly, 1998).

Third, the results indicate that grouping process extends to the extraction of meaning representation and that these influence the outcome of grouping. This supports Rock, Palmer and colleagues' assertion that grouping works after the extraction of depth information and illusory figures (Rock & Brosgole, 1964; Palmer & Nelson, 2000) and the achievement of lightness constancy and perceptual completion (Rock et al., 1992; Palmer et al., 1996).

Finally, the present findings elaborate further the flowchart of perceptual organization processes of Palmer and Rock (1994). Specifically, the results confirmed that UC regions have the strong tendency to be parsed or segmented as subordinate units, while higher-level meaning representations can group these UC regions into a single object. In relation to Palmer and Rock's (1994) flowchart of processes in perceptual organization, the two-region meaningless figures and meaningful kanji stimuli yielded two UC regions as initial units. Different processes followed thereafter with the two-region meaningless figures parsed or segmented on the basis of UC that yielded two subordinate units while the two-region meaningful kanji were grouped on the basis of their meaning yielding a single superordinate unit.

In summary, perceptual grouping might be thought of as a continuum of processes that starts in the early stages of vision and extends to later stages of processing. Bottom-up feature dimensions such as edges, contours, proximity, similarity (in size, color, motion), good continuation and UC among others might activate grouping process in the early stage of vision. The processing in this stage might be localized in areas V1 and V2 of the cortex. These processes may yield initial percept or outcomes such as those of Marr's (1982) primal sketches. Processing continues when newly derived intrinsic properties (Barrow & Tennenbaum, 1978) or higher-level representations exert top-down inputs that dictate alternative groupings or further reorganizations. These activated higher-level representations such as familiarity, meaning, perceived 3-D space, lightness constancy, completed shape and illusory contours may directly (Peterson et al., 2000), or in collaboration with the low-level representations, influence the grouping process. However, this does not warrant any stronger inference that grouping occurs only after these surface-based representations have been constructed.

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