Dynamic Grouping Motion and Amodal Completion

by

Debarshi Datta

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Howard S. Hock, Department of Psychology, and has been approved by the members of his supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Master of Arts.

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In the end, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Abstract

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Objects in a scene are likely to occlude other objects partially and are itself likely to be partially occluded. A central question, therefore, is how the visual system resolves the resulting surface correspondence problem by successfully determining which surfaces belong to which objects. To this end, a recently developed *dynamic grouping* methodology has determined whether pairs of adjacent surfaces are grouped (Hock & Nichols, 2012). The grouping of adjacent surfaces, which depends on their affinity state, is indicated by the direction of perceived motion across one surface when its luminance is perturbed. In the current stimuli, which consists of a horizontal surface partially occluded by a vertical bar, *dynamic grouping* also can occur for nonadjacent surfaces, providing they are linked in two-dimensions by a connecting surface. Results indicate that the *dynamic grouping* motion is stronger for *amodal completion* entailing the perceptual grouping of nonadjacent surfaces behind an occluder.

Dedication

I dedicate my dissertation work to my kin. All inspirations came from my loving grandma Mrs. (Late) Sarbamangala Datta; she made me understand what the importance of becoming an educated individual is. A special feeling of gratitude to my loving parents, Mr. K. R. Datta, and Mrs. (Late) Bandana Datta whose words of encouragement and push for tenacity ringing in my ears. My dad Mr. K. R. Datta believed a long before then many others how is an important to have a public library which can help students and researchers to develop their critical thinking ability in various subjects. I appreciate his efforts and dedication what he put together throughout his life to build and preserve the function of a public library in my hometown, which is named as "Anandpur Public Library" up until today for rendering knowledge of local community people. My aunts Dr. Achala Datta-a pediatrician in Kolkata suburban areas, and Ms. Salila Datta, who is volunteering as a school teacher in a school, have never left my interest aside. I also dedicate this dissertation to my younger brother Rajarshi, and his wife Shraboni who have held me throughout the routine, and their sweetest daughter Rishika also continually inspired me to write my thesis.

Dynamic Grouping Motion and Amodal Completion

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Introduction

Most objects around us are partially occluded by other objects. For example, a chair can be perceived as a complete volumetric structure, even if it is partially hidden by a table. This is explained by amodal completion, defined as a phenomenon in which a partially occluded object is perceived as a continuous object arranged in depth (Calabi, 2013). In amodal completion, parts of objects are not present in the visual field stimulus, but we can register the perceptual appearance of complete objects (one behind another).

In the first part of the 20th century, Gestalt psychologists introduced a set of heuristics rules or laws of perceptual organization. The Gestalt laws, which form the foundation for object recognition, provide intrinsic properties for grouping of components of an object (Wertheimer, 1923/1938). These properties include proximity, the similarity of contour, the similarity of size, movement direction (common fate), and good continuation. In the current experiment, the stimuli are based on Gestalt principles whereby two surfaces are grouped by luminance similarity, good continuation, and proximity (Wertheimer, 1923/1938).

In an amodal completion, the perception of most things around us is partially occluded by other objects. The stimuli of the current study consisted of a horizontal surface occluded by a vertical bar. The effect of the occluder was to disconnect the continuation of a holistic object. Two black rectangular surfaces form one object, owing to Gestalt grouping conditions (connectivity, good continuation, and luminance similarity), contribute to the completion of contours that are not seen but appear to be hidden behind the front (vertical) surface.

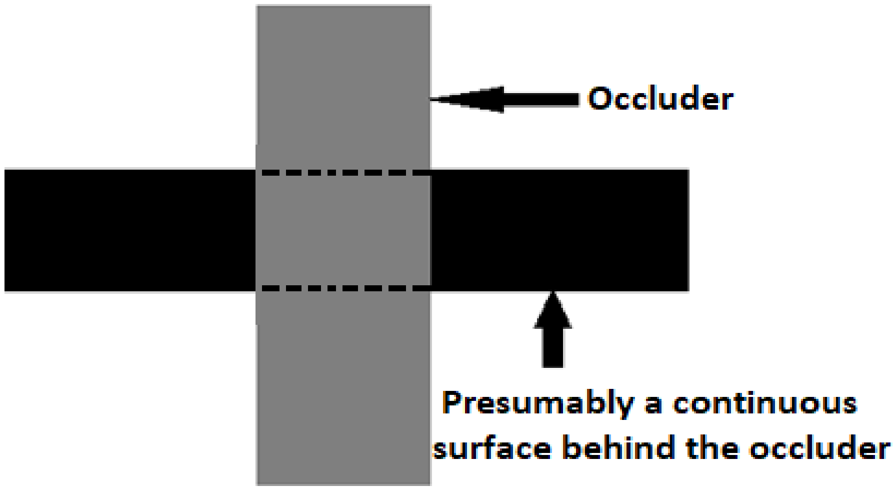


Figure 1: Amodal Completion. *Black surface completes amodally. The two black rectangular surfaces belong together because of good connectivity, continuation, and luminance similarity, completion of contours that are not seen seems to be hidden behind the front (vertical) surface.*

Since the 20th century, many scientists have tried to establish different theories of object recognition. One such theory, perceptual organization (Goldstein, 2012), describes the process by which the different components of an object are grouped (sometimes in an amodal completion) to make a holistic perception of an object. In this process, when a person view features information, he organizes a coherent unit, such as an object. According to this theory, there are two main aspects of the visual process necessary for a person to visually perceive an object appropriately: 1) figure-ground segregation and 2) grouping of elementary components within the figure. For example, each alphabetical letter is segmented from other nearby alphabetical letters (due to figure-ground segregation) and formed by line segments (known as grouping).

Dynamic Grouping (DG) motion is motion induced by changes in surface luminance Hock & Nichols (2012). The direction of the motion indicates how the surface is grouped with other surfaces, whether they are adjacent or non-adjacent. This novel paradigm of dynamic grouping, introduced by Hock & Nichols (2012), is relevant to the perception of objects composed of multiple connected surfaces. In their paradigm, the luminance of the target surface is always greater than the connecting surface (figure 2). Over the course of the trials in the experiment, the luminance of the target surface either increases or decreases, while the other grouping variables, such as connectivity and good continuation remain the same during the transition from the first trial frame in the second trial frame without qualitatively changing their perceptual organization. Changes in the affinity (grouping strength between the two surfaces) created by the dynamic grouping variables (here grouping variables are connectivity, good continuation, luminance similarity) when large enough, elicit the perception of motion across the changing surface (target; see Figure 2 for example). The direction of the DG motion is diagnostic for the affinity relationship between the two surfaces which was established in the first trial frame prior to change the luminance of the target surface (Hock, 2014).

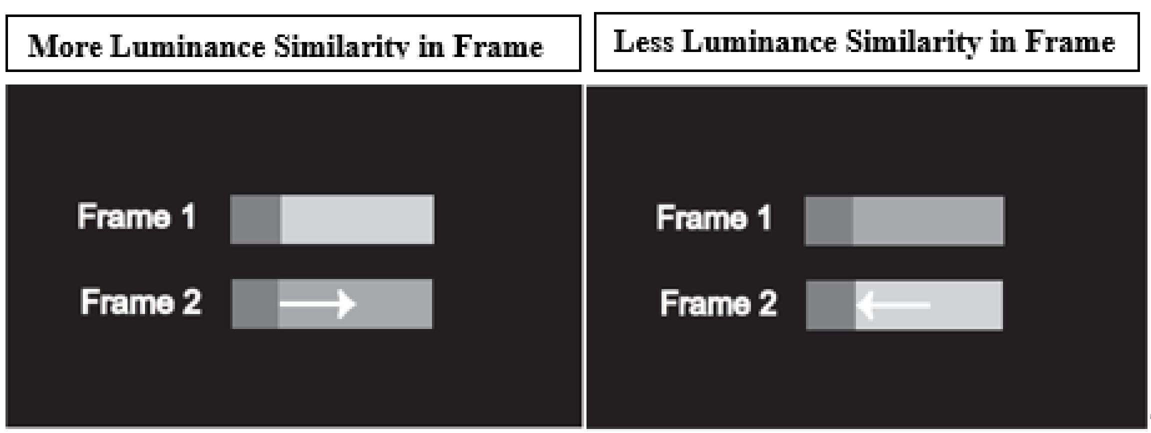


Figure 2: Dynamic Grouping Motion of Adjacent Surface. *More luminance similarity: The perception of motion is directed away from the boundary of the two adjacent surfaces when the affinity of two surfaces increases. Less luminance similarity: The perception of motion is directed toward the boundary of the two adjacent surfaces when the affinity of two surfaces decreases. The term 'affinity' entails the how a strong relationship between the two surfaces when they are grouped. (Hock & Nichols, 2012).*

Hock and Nichols (2012) assessed perceptual grouping of the adjacent surface of an object by determining to change the direction of DG motion for adjacent surfaces. Nevertheless, the current study investigated the property of DG motion for surfaces that were non-adjacent in the stimulus, but adjacent in representational space (as a result of amodal completion).

In the case of amodal completion, a change in luminance increases or decreases the affinity of one surface (target) with either the surface adjacent to it; vertical bar (occluder), or non-adjacent surface (other horizontal surface; see figure 3 for example). It has been shown that if changes (perturbations) in the surface created by a DG variable are large enough, a perception of motion across the changing target surface would be produced (Hock & Nichols 2012). Additionally, it has been shown that the direction of the DG motion depends on the affinity relationship among the stimuli's surfaces, which is established prior to changes in the target surface in the second frame (see details in the rational for DG motion section). In the current experiment, we consider only the surface changes that become darker in the second frame because that luminance decrease creates ore distinct DG motion than the luminance increases.

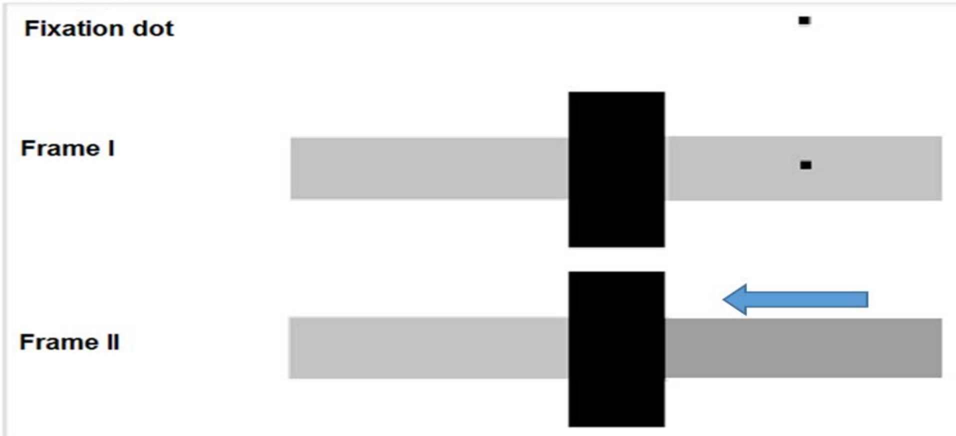


Figure 3: Dynamic Grouping Motion of Non-Adjacent Surface. *This is the stimulus used in the current experiment which is composed of 2-D objects composed of 3 adjacent surfaces. The stimulus is a horizontal surface occluded by a vertical bar. The effect of the occluder is to disconnect the continuation of a holistic object. In the experimental paradigm of the current research, the luminance value of the two other surfaces will be the same in the 1st trial frame. In the 2nd trial frame, the luminance value of one of the horizontal surfaces (target) containing fixation dot will be decreased. This fixation point will vary randomly from trial to trial. The luminance of the occluder is kept constant throughout.*

There are other experimental paradigms in which have demonstrated amodal completion include shape discrimination (Ringach & Shapley 1996), mental rotation (van Lier & Wagemans 1999; Koning & van Lier 2004), primed matching (Sekuler & Palmer 1992), and visual search (de Wit et al., 2005). Among them, the primed matching paradigm is one of the most studied techniques used in the different experimental designs of amodal completion. In these paradigms, observers are instructed to attend a specific part of a primed object for a short duration. Afterwards, observers are asked to judge test pairs as rapidly as possible, whether the two test figures are the same or they are different from one another. According to the rationale of the primed matching paradigm, participants respond more quickly to test pairs that were similar to the previously shown prime object compared to targets dissimilar to the prime object (Barlasov & Shaul, 2009; see figure 4 for example).

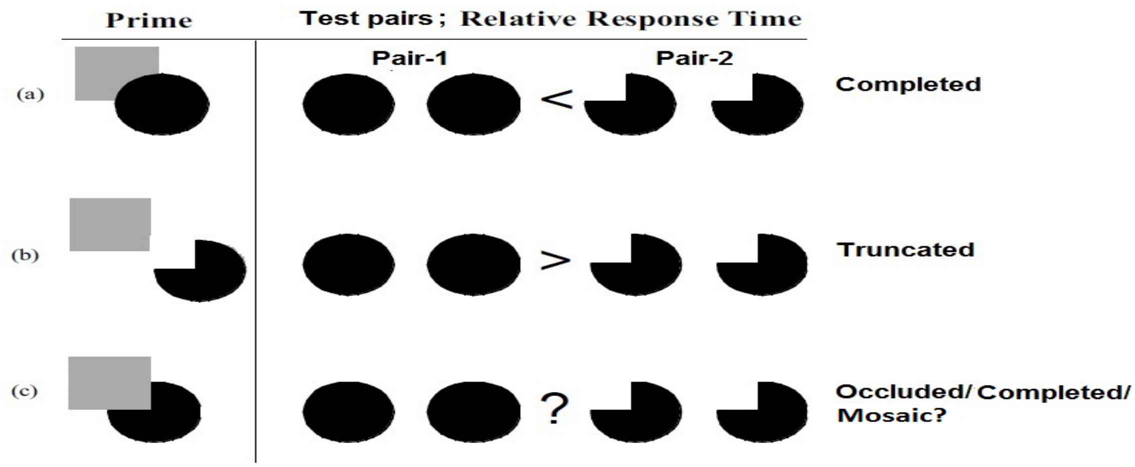
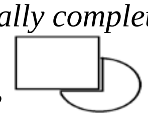


Figure 4: Stimuli for Priming. *A display comprising of a few stimuli combinations studied in the prime matching paradigm (Lier & Gerbino 2014). The priming stimulus is shown on the left and expected patterns of responses are shown on the right. In this example, observers are instructed to attend to the lower part of the two shapes in the priming stimulus. The relative response time is measured for different test stimuli to determine how similar the internal representations of priming and test stimuli are. (Figure 4a) After viewing complete circle prime for a certain period of time, observers are faster in responding Test Pair 1 (with the same shape as prime objects) than Test Pair 2 (with a different shape from the prime object). (Figure 4b) After viewing incomplete (a 3/4th- notched (paceman)) circle prime for a certain period of time, observers are faster in responding to Test Pair 2 (with a same shape as the primed object) than Test Pair 1 (with a different shape from the prime object). (Figure 4c) As described in the text below, the difference in matching time after viewing an occluded prime depends on the prime duration. After viewing incomplete (a 3/4th-notched(paceman)) circle prime for a short period of time, observers are faster in responding to Test Pair 2 (not 'amodally completed' objects where the square and paceman are attached like a 'mosaic'*  *) but, if prime duration is for a long period of time, observers' are faster in responding to Test Pair 1('amodally completed' where the circle is hidden by a square).*

It is also shown that when the prime duration is longer than 200 ms, the matching time of the test pair (Figure 4c) is quicker for the completed conditions (Test Pairs 1; Sekular and Palmer, 1992). However, for a short prime duration (50 ms), the observer's response to the partly occluded objects (a 3/4th- notched (paceman)) circle (Test pairs 2) is quicker than the complete circle (Test Pairs 1) (Sekuler & Murray, 2001). The prime duration is an important factor to determine whether objects are perceived when amodal completion occurs, or it is perceived as two distinct, separated objects.

An advantage of this paradigm is that it can be used to understand a different time sequence for visual completion. By presenting the prime stimulus in a varying amount of time while holding the inter-stimulus interval fixed, different durations of reaction time can be determined to match the test stimulus. However, the limitation of this paradigm is that it is not sensitive to a very rapid time course because the basic shape of priming can be difficult to detect when a stimulus is presented for a short duration (Sekuler & Murray, 2001).

In contrast to the prime matching paradigm, the DG method can provide evidence of spatial information for perceptual grouping when the segments of an object are invisible in amodal completion. This method enables us to measure the grouping strength, termed as the "affinity"—how strongly two surfaces are grouped of non-adjacent surfaces as if they were adjoined (Hock & Nichols, 2012).

Many previous studies suggested that the 'amodal presence' of an occluded surface can affect the perception of an apparent motion (Michotte 1954; Kanizsa 1979; Shimojo & Nakayama 1990, Ho-Kim 2012). Shimojo and Nakayama (1990) showed that the perceived depth of targets is determined by stereoscopic disparity (Shimojo & Nakayama 1990). To assess a role of occluded parts of the objects (under a condition of amodal completion) on an apparent motion correspondence, Shimojo & Nakayama (1990) presented a rectangular occluder in a crossed disparity, so that it would appear in front of the four flashing targets which are alternating between the position 1 and position 2 (Figure 5; right)).

The control condition when targets are without the occluder alternating between the position 1 and position 2 (Figure 5; left)).

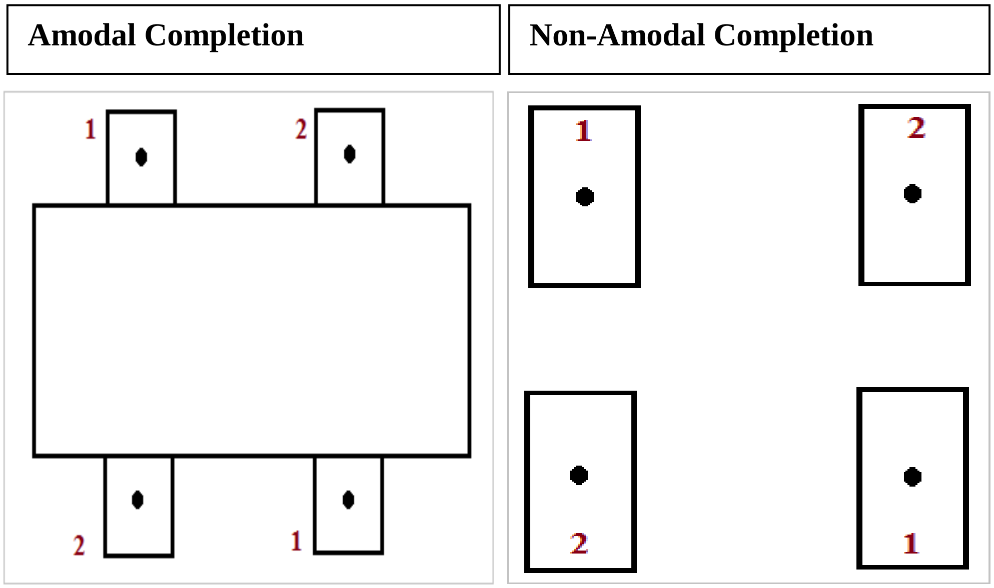


Figure 5: Amodal Presence of an Occluded Surface and Amodal Absence of Non-Occluded Surface. *Left side figure is showing the non-amodal completion when four targets when the occluder is absent. Right side figure shows that there is a rectangle shaped occluder in crossed disparity, so four targets are hidden by the occluder. In both conditions, targets alternate position 1 and position 2. Right side figure shows when targets alternate behind the occluder- this design provides an opportunity to perceive amodal completion* (Shimojo & Nakayama (1990).

The proportion of perceived motion was measured as a function of the horizontal/vertical (H/V) distance ratio of the flashing targets. The results showed that the motion was perceived horizontally more frequently when two flashing targets were closer horizontally than vertically. Similarly, a more vertical motion was perceived when two flashing targets were closer vertically than horizontally. So, larger H/V ratios, support a vertical motion, and smaller H/V ratios support a horizontal motion (Shimojo & Nakayama (1990).

However, the above results demonstrated that the psychometric function for the occluder condition was shifted more to the left than the no occluder condition, which meant the more vertical motion was perceived in occluder than the non-occluder condition.

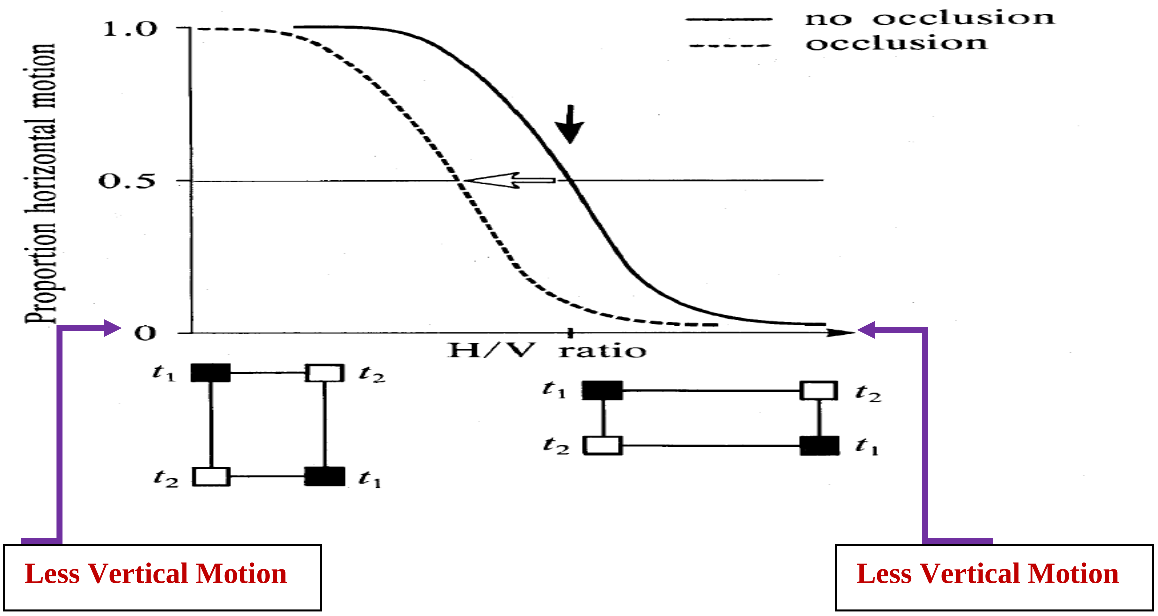


Figure 6: A Psychometric function for Amodal Completion and no occlusion. *Amodal completion is drawn with a dotted line. Motion is perceived horizontally or vertically that depends on the proximity between the two flashing targets. For example, the more vertical motion is perceived when the targets are less separated vertically than the horizontally. The psychometric curve for occluder condition is shifted left more the no occluder condition. T1 and T2 represent a time sequence when flashing targets are presented. (Shimojo and Nakayama 1990).*

The reason of perceiving more vertical motion in the occluder condition is perhaps a good continuation and connectivity of two vertically placed targets behind the occluder which would enhance amodal completion. It seems to be occluder reduces the perceived distance between the two vertically placed targets, and forms the two objects are perceived as a unified object.

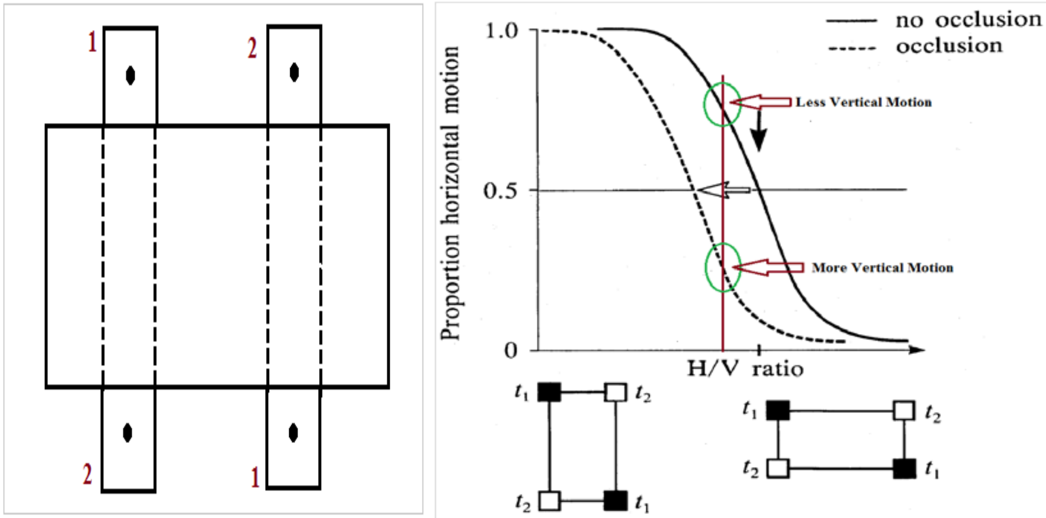


Figure 7: Good continuation and connectivity of two targets behind the occlude. *Figure (a) shows that the two vertically placed targets seem to be closer together than horizontally placed targets. Good continuation and connectivity of two targets behind the occluder made an effect of perceiving the distance between two vertically placed objects shorter when they are not. Dotted lines are the imaginary line which is joining the contours of the two vertically separated targets for figure 7 (a); it gives rise to the perception of an amodal completion behind the occluder. Figure 7 (b) shows that at the same H/V ratio (Red line) amodal completion (Occluder condition) perceives more vertical motion than the non-amodal completion (Non-occluder condition) (Shimojo and Nakayama 1990).*

Palmer and Rock (1994) first reported the principle of "uniform connectedness" (UC) when two regions are connected based on the uniform visual properties, such as luminance, color, texture, and motion which can combine the two regions of objects into a single perceptual organization. Figure 8 shows that how a horizontal line connects the two objects to unify into a single perceptual organization. The figure 8 (A) shows that a line connects pairs of equally spaced dots and make them into a strongly grouped unit. Figure 8 (B) to 8 (D**)** shows that how the powerful UC is in comparison to the classical grouping variables, such as proximity, size similarity or a combination of both variables.

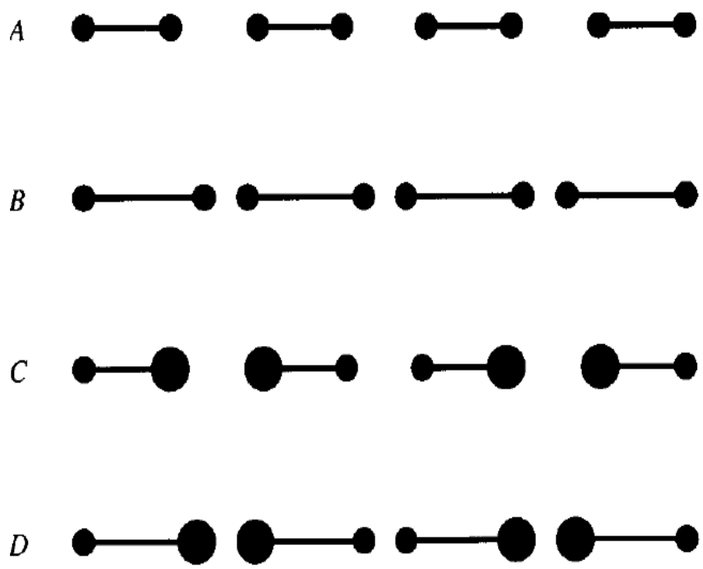


Figure 8: Demonstration of UC. *(A)The connected dots are grouped into pairs among the other equally spaced dots. UC is stronger than the classical grouping variable of perceptual organization described by Gestalt's psychologist, such as (B) proximity, (C) size similarity, (D) combination of the both (Palmer and Rock, 1994).*

UC takes precedence over "proximity," one the Gestalt's grouping variable of the perceptual organization while binding the two parts of an object into one.

Palmer and Rock (1994) argued that UC not form a classical grouping rather it accounted for an initial organization of the visual field into a primitive unit. To explain this, they described a 4-stage "part-whole" hierarchy, where the classical principle of grouping processes at the superordinate level after UC, which comprising of two or more basic level unit, processes at the entry level.

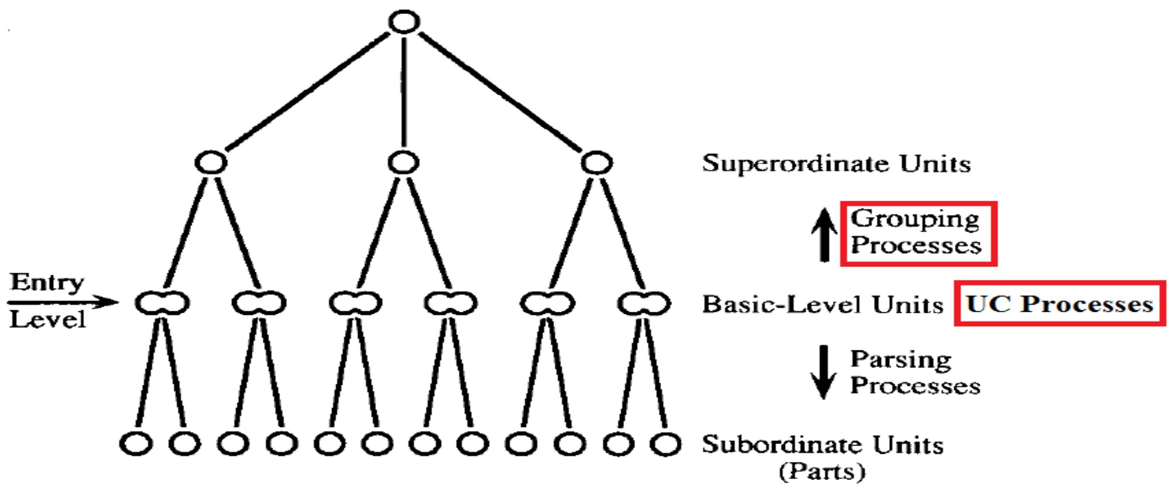


Figure 9: Demonstration of a 4-stage "part-whole" model. *UC processes at the entry level; these connected elements are imaged on the retina in the same depth planes, or else it fails to be perceived as units. After forming UC, either it reduces into superordinate units or parses into subordinate units (Palmer and Rock (1994).*

In summary of the previous research, a primed matching paradigm is sensitive to detect amodal completion when a stimulus is presented for longer time durations (200ms); however, a priming object can be difficult to detect whether it is amodally completed or not when a stimulus is presented for a relatively shorter time (50 ms) duration. This method only provides us temporal aspects of amodal completion (Sekuler & Murray, 2001). A smaller spatial separation between the two objects decreases the 'proximity,' and thus motion is perceived in that direction where surfaces are separated by a smaller spatial distance (thus two objects act as a group) (Shimojo and Nakayama 1990). Therefore, grouping is the function of amodal completion—thus the effects of the occluder make perceived distance shorter between the two targets behind the occluder. Uniform connectedness occurs when two regions of an object are connected with the homogeneous visual properties, such as luminance, color, texture, motion, and it occurs before the classical grouping happen, and UC unifies two objects stronger than the other Gestalt's grouping variables (Palmer and Rock, 1994).

Rationale of DG Motion

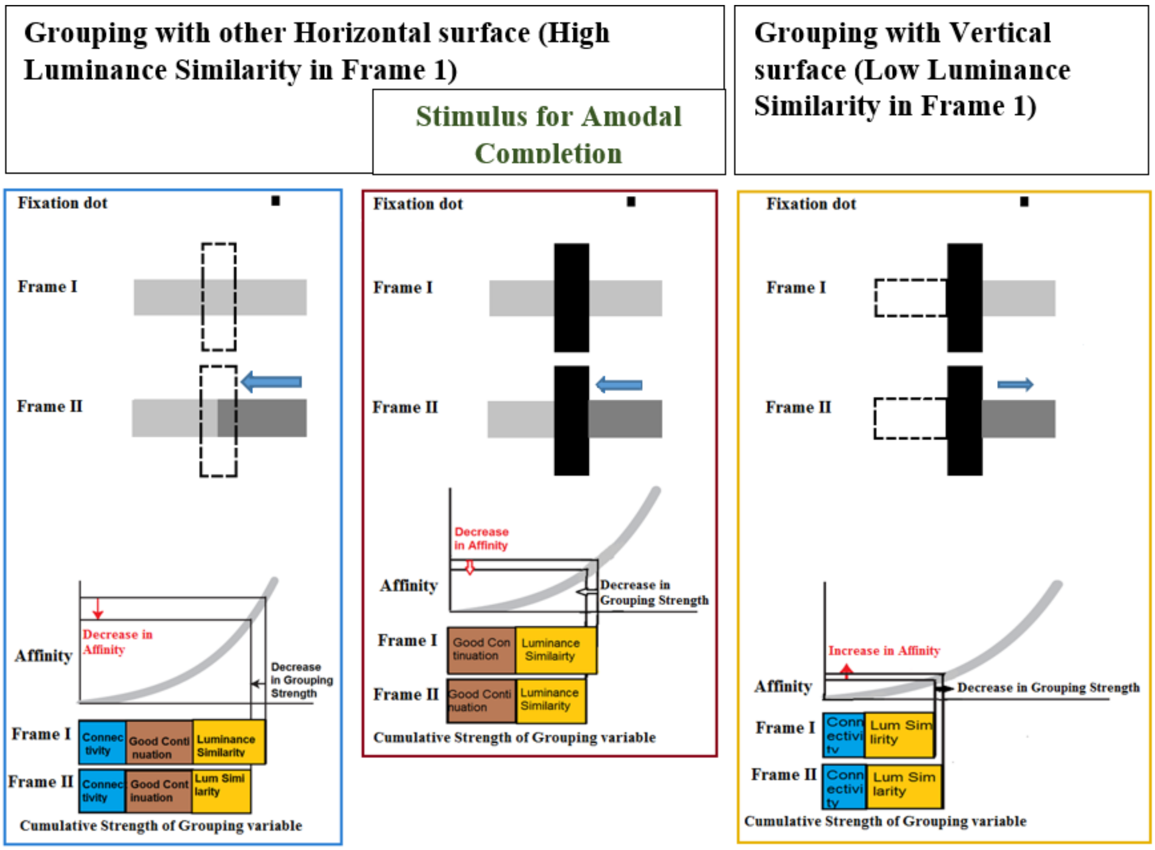


Figure 10: Rationale of DG Motion. *The gray curved bars in each graph represent the power functions of accelerating the non-linearity which is described as the accumulated effects of grouping variables (along with the x-axis of each graph) to the affinity of a pair of adjacent surfaces (along with the y-axis of each graph). The left figure showed that when two non-adjacent surfaces (two horizontal bars in the absence of the vertical bar) seems to be grouped. Right figures showed that when target horizontal surface grouped with adjacent vertical surface seems to be grouped.*

As illustrated in Figure 10, the affinity of the two adjacent surfaces depends on the nonlinear summation of the affinity values are ascribable to the individual grouping variables: connectivity, good continuation, and luminance similarity. In the current stimulus, connectivity and good continuation are kept unchanged in both frames. However, DG motion depended on the luminance similarity of two adjacent and non-adjacent surfaces in the first frame and decreased luminance similarity in the second trial frame of the stimulus presentation. Higher luminance similarity in the first frame and a larger decrease in luminance similarity in the second frame to produce a stronger DG motion. Grouping occurs when target horizontal surface either groups with the other horizontal surface or with the central connecting surface (occluder). When the grouping occurs between the target horizontal surface and the other horizontal surface, the initial luminance similarity is high, in this case (Figure 10 (a)), affinity state lies in the steeper portion of the gray curve. In the second trial frame (showing in Figure 10; left)), the luminance similarity decreases in the target surface, so there was a downward perturbation and thus, decreases the affinity between two horizontal surfaces. Here connectivity and good continuation remain the same in both frames. However, in Figure 10 (c) shows that when the grouping occurs between the horizontal target surface with the vertical bar, the initial luminance similarity is less, in this case, affinity state lies in the flatter portion of the curve. However, in the second frame the luminance similarity of target surface increases, so it increases the affinity between the target surfaces and central surface (occluder). Nonetheless, in this case, there is only dynamic grouping variable, that is "connectivity," remains the same in both frames, so the accumulated affinity state is less than the previous condition (Figure 10 (a)). In the middle diagram (Figure 10 (b) shows that when we consider grouping between the two horizontal surfaces, "good continuation" is the only grouping variable, in this case, remains the same in the two frames, but there is no connectivity between the two horizontal surfaces. Hence, the affinity state lies in the relatively on the middle portion of the curve. In the second frame, luminance similarity between the two horizontal surface decreases, and thus, decreases the "affinity" between the two surfaces. It is also noticeable in the figure that when affinity state lies on the steeper segment of the curve, the certain amount of grouping strength increases the proportionally more amount of affinity whereas when affinity state lies relatively on the flatter segment of the curve, the same amount of grouping strength increases the relatively smaller amount of affinity.

Research questions:

As explained earlier, the goal of the current study was to assess the perceptual grouping of adjacent surfaces to provide an evidence of dynamic grouping (DG) motion of non-adjacent surfaces under the condition of amodal completion.

Hock and Nichols (2012), described in their study that grouping phenomena of adjacent surfaces by motion perception via measurement of the grouping strength among those surfaces. This novel paradigm illustrated the technique to measure the affinity of two surfaces which helped us to measure the grouping strength of non-adjacent surfaces in our proposed study.

There were two research questions that were addressed in this study. The purpose of Experiment 1 was to determine whether the grouping effect was perceived if the amodal completion was eliminated, that was if the vertical length of the occluder was narrower than the target and other rectangular surfaces (Figure 10; condition I) or the connectivity alone would be sufficient to promote grouping (Figure 10; condition II and III). The first experiment was to determine whether the motion could be perceived toward the opposite horizontal surface in one condition (occluder condition, indicating grouping with the other horizontal surface), and away from the central surface or no motion in the other conditions (non-occluder condition, indicating grouping with the central surface).

Discontinuous central surfaces might promote the grouping between horizontal target surfaces and the central surface.

The pertinent research questions come after the first experiment whether a different-length of the width of a central surface (an occluder for the first part and a central surface of the remaining half the Experiment 2) affect grouping strength of two non-adjacent surfaces or not. There are two research questions examined in Experiment 2. First, does a gradual increasing width of an occluder affect grouping strength? The purpose of this experiment was to determine whether different-length of the width of the occluder might affect the grouping of the surfaces belonging to the same occluded surfaces (Figure 13).

Experiment 2 was also designed to test the differentiation between the 3-D connectivity (when the central surface is an occluder in Experiment 2(A)) from 2-D connectivity (when the central surface is a connecting surface in Experiment 2(B)). In the second part of the experiment, the lengths of the connecting surface between the target and the other horizontal surfaces are the same as the lengths of the widths of occluders in the first part of the experiment (Figure 14).

General Methods

Stimulus

The stimuli were presented on the darkened screen of a Mitsubishi Diamond Pro 930 ^{SB} monitor (luminance less than 0.01 cd/m^2). The viewing distance was 30cm maintained with a head restraint. Each trial composes of a 2000ms fixation dot presentation, a 500ms first frame presentation, and a 500ms second frame presentation.

Two-dimensional objects connecting three adjacent surfaces were presented in a randomized trial from the first frame to the second frame. The amodal completion stimulus was a horizontal surface that was partially occluded by the vertical bar as illustrated in Figure 11. The horizontal surface that was the target varied randomly from trial to trial while the luminance of the central surface and the non-target horizontal surface was kept constant throughout. The luminance value of the two other surfaces was the same in the first frame of a trial. However, in the second frame of a trial, the luminance value of one of the horizontal surfaces, the target for that trial, was decreased. The horizontal surface that was the target varied randomly from trial to trial while the luminance of the central surface and the non-target horizontal surface was kept constant throughout. A fixation dot appeared in the center of the target surface prior to the presentation of the first frame, and second frame trial when the luminance of the target surface was decreased.

The luminance values were measured by TEK Lumocolor illuminometer. The luminance values of the background, fixation dot, the central surface, and the other horizontal surface were less than 0.01cd/m^2, 90.1cd/m^2, 5.9cd/m^2, 56.5cd/m^2 respectively during frame 1.

The seven luminance values for the target surface in the second frame were less than 53.0cd/m^2, 51.9cd/m^2, 51.0cd/m^2, 50.0cd/m^2, 48.8cd/m^2, 47.8cd/m^2, and 45.5cd/m^2, resulting in decrements of luminance for the target surface in the second trial frame The smaller changes in luminance caused less perturbation, which reduced the likelihood that subjects would perceive motion. The changes in luminance were respectively from 3.5cd/m^2 to a maximum of 11cd/m^2 depending on the highest luminance changes (45.50cd/m^2) of the target bar.

The occluder had always been darker than the horizontal bars, so there was no edge/surface counter change. That is, changes in edge contrast at the occluder and the target surface boundary and changes in target surface to background contrast always had the same sign in the current experiment- it was always a negative sign. Each experiment varied with respect to the width or height of the central surface.

Procedure

After each trial, participants pressed a key on the computer keyboard to indicate whether they perceived motion or not. If they perceived motion, they indicated the direction of motion by pressing another key. There were three possible directional responses. Observers were required to indicate the direction of motion as rightwards, leftwards, or in both directions. Participants were tested over multiple sessions.

The first frame was presented for 500ms. This enabled the observers to concentrate and pay attention to the fixation dot, which was situated in the mid position of the target surface. DG motion might or might not be perceived across the changing target surface when the value of the luminance was changed during the second frame, which was presented for half of a second.

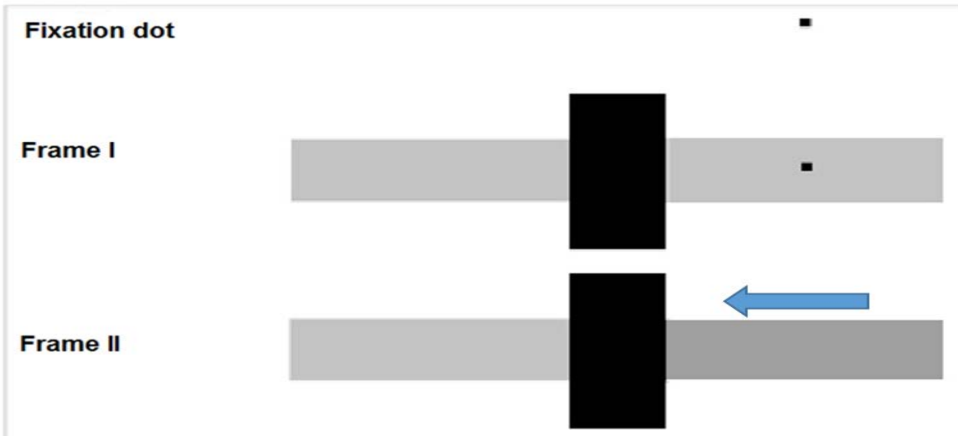


Figure 11: Stimulus of the Current Study. *The stimulus for DG motion: A vertical bar partially occludes the horizontal surface that is visible on both sides of the occluder. The luminance of the occluder and one horizontal other surface (it is shown on the left) remains the same in both frames, but the luminance of the horizontal other surface that is the target changes from the first frame to the second frame (the luminance of the surface on the right is decreased from the first frame to the second frame).*

Participants

We tested the same four students over the two experiments, undergraduates at the Florida Atlantic University, who registered for Directed Independent Study (DIS) credits. They are naïve to the purpose of the experiments. The protocol of the study was approved by FAU’s Institutional Review Board (IRB) (Protocol # H103-195).

Experiment-1

The purpose of experiment 1 was to determine whether there was a grouping effect between the two horizontal surfaces: a surface that was a target with the other horizontal surface when they were partially hidden by an occluder. The two conditions were tested in this experiment when two horizontal surfaces were amodally completed and when amodal completion was eliminated but maintained the connectivity of the surfaces. The stimulus was modified to eliminate the possibility of amodal completion. There were two possible outcomes that were anticipated for experiment 1 when the middle surface was no longer an occluder: the direction of the DG motion would be reversed because, in that case, the target surface would be grouped with the occluder or no motion would be perceived if the target surface stays an isolated as a single surface without grouping with the other horizontal or occluded surface. For testing non-amodal completion, two different heights of the stimulus were tested here to determine whether the perception of DG motion would depend on the length of the shared boundary separating the horizontal surface from the central surface.

Methods

Stimulus:

Experiment 1 was designed with the three different heights, and only one width (3.90° visual angle at 30 cm) of the central surface condition (Figure 12). There were three conditions. In the first condition, the central surface served as an occluder (8.30° visual angle at 30 cm) where the target and flanking horizontal surface were a continuous surface behind the occluder-this is an evidence of an amodal completion, or it served just a surface where the target and other surfaces were attached to the opposite side of the central surface. In the second condition, the height of the central surface (0.70° visual angle) was little shorter than the boundary of the two horizontal surfaces, and in the third condition, central surface (0.15° visual angle) was a thin connecting surface between the target and other horizontal surface. The width (horizontal dimension) of two horizontal bars-target and the others were the same (5.50° of visual angle at 30 cm.) for all three central surface conditions and two experiments.

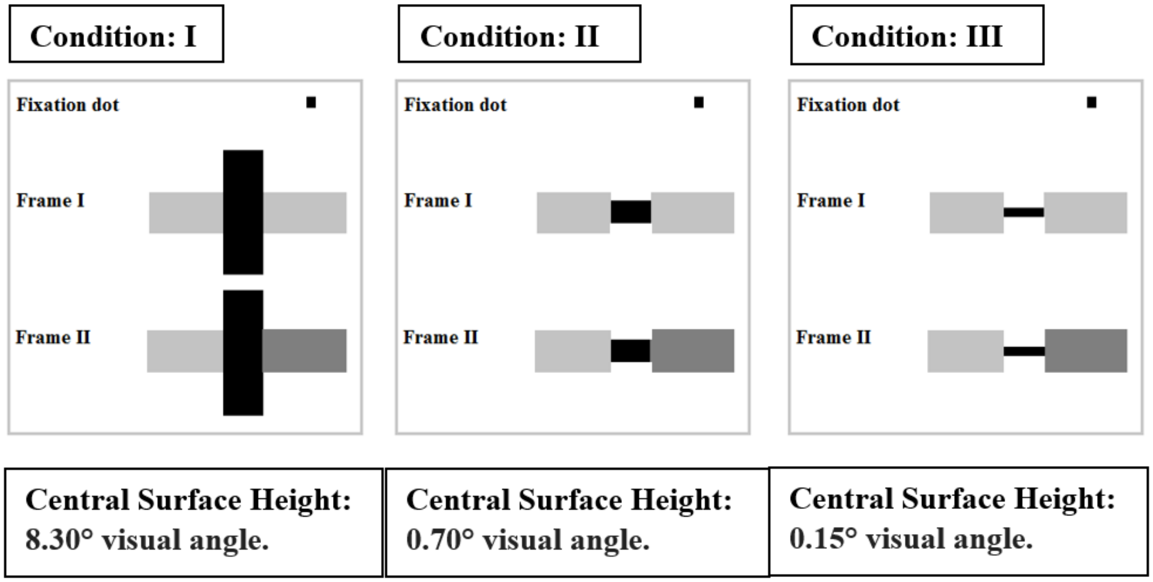


Figure 12: Stimuli of Experiment. *Three different heights of the central surface (8.30°, 0.70°, 0.15° visual angle). The two smaller heights (0.70°, 0.15° visual angle) eliminate the hypothesized amodal completion. We can see in the diagram that the two horizontal surfaces are no longer appear to be continuing behind the continues horizontal surface when the vertical height of the occluder was smaller than the height of the target and other horizontal surfaces.*

Design:

Each participant of the experiment was tested by three blocks of trials which were one for each of three heights of the central surface. Three blocks per session in a day in a counterbalanced order for the total six-day long experiment resulted in total 18 blocks of trials.

The orthogonal combination of seven different luminance decrements (3.5cd/m^2, 4.6cd/m^2, 5.5cd/m^2, 6.5cd/m^2, 7.7cd/m^2, 8.7cd/m^2, 11cd/m^2), two target locations (the right and left side of the central surface) and five repetitions comprised 70 trials presented randomly ordered in a single block of trials. In total, it took 7 to 8 minutes to complete a block of the trial. Luminance changes happened on the left side of the central surface for half of the trials and the right side of the central surface to the other half of the trials.

Experiment-2

Experiment 2 was premeditated based on the results of experiment 1 where we observed that there was a marginally significant difference of grouping effect between the target and the other horizontal surface when it was separated by an occluder (in the amodal completion) condition or a connecting surface (in the non-amodal completion) condition. In addition to replicating the results of experiment 1, the purpose of this experiment was to determine whether the width of the central surface could have an effect on the grouping of the surfaces when they were amodally grouped or when they are simply connected.

The experiment was divided into two parts, depending on the height of the central surface: Experiment 2 (A) when the central surface was an occluder (8.30^{o} visual angle height) and experiment 2 (B) when it was just a thin connecting surface (0.15^{o} visual angle height). In both parts of the experiment, the width of the central surface was 0.90^{o}, 3.90^{o}, and 6.90^{o}. If an effect of a central surface width were obtained in the non-occluder condition, it would be consistent with connectivity functioning as a grouping variable as reported by Palmer and Rock (1994).

Methods

Stimulus:

The stimulus in this Experiment 2 (A), a horizontal bar partially occluded by a vertical bar were simultaneously visible during both frames of each two-frame trial. The widths of the occluder were 0.90°, 3.90°, and 6.90° of visual angle (at 30 cm) during the three separate blocks of trials (figure 13). Visual angle of target and flanking horizontal surfaces are same throughout the experiments; as the width of the central surface increases, the width of the horizontal surface remains constant.

The stimuli in Experiment 2(B) were two separate horizontal bars, other and target, which were simultaneously visible during both frames of each two-frame trial. The width of the central connecting surfaces (0.90°, 3.90°, 6.90° visual angle at 30 cm., which were kept same as the central surface of the Experiment 2 (A)) varied in different blocks of the trials when height (0.15° visual angle) was kept constant (figure 14) throughout the experiment. The experimental procedure and the presentation time of both the stimuli were same as the Experiment 1.

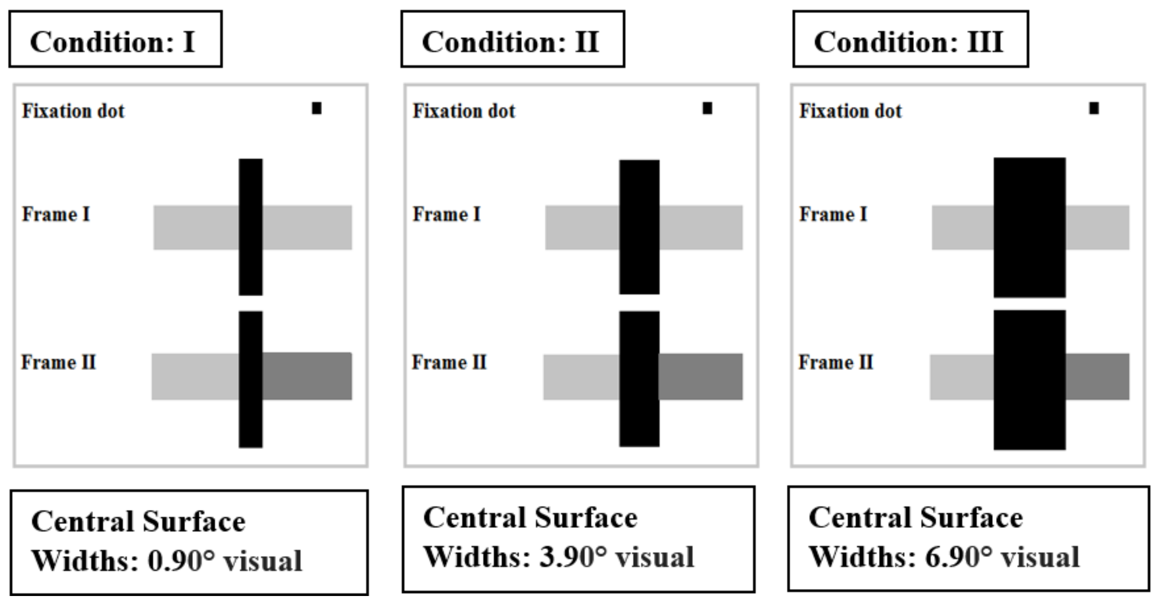


Figure 13: Stimuli of Experiment 2(A). *The widths of the occluder used in the current experiment subtended 0.90°, 3.90°, and 6.90° of visual angle in the retina at 30cm distance from the computer screen.*

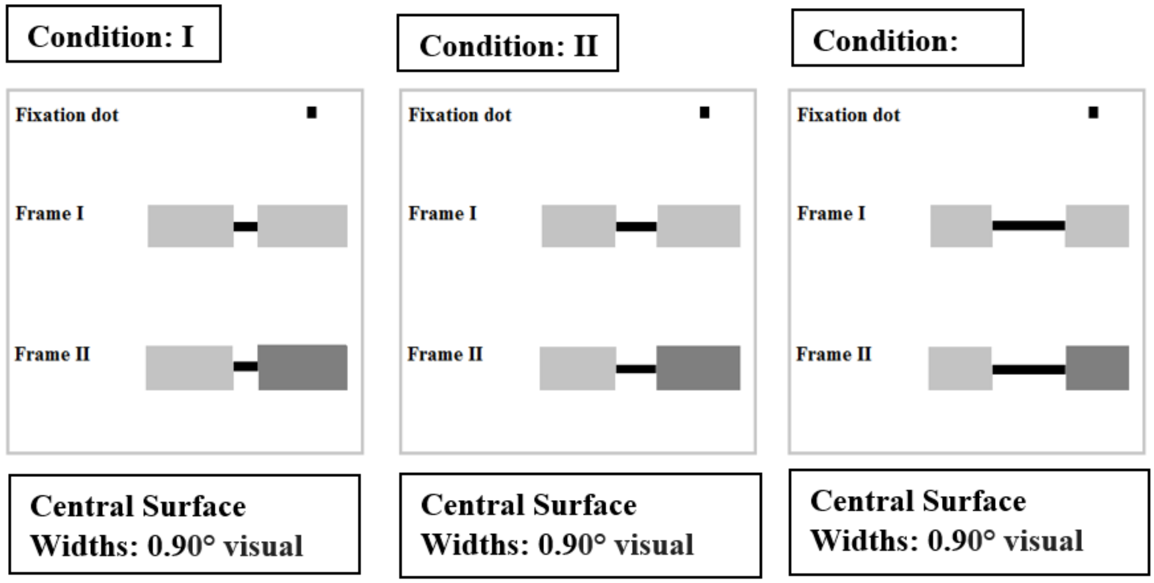


Figure 14: Stimuli of Experiment 2(B). *Lengths of the central surface varied from trial to trial when the height was kept constant at a 2° visual angle. If there were an effect of the width of the central rectangle, it would distinguish 2-D connectivity from 3-D connectivity behind an occluder. If there was any effect of the gradual increasing length of the central connecting surface, the response should be varied for the different length of the surface.*

Design:

Each participant of the experiment was tested by three blocks of trials which were one for each of three widths of the central surface. Three blocks per session in a day in a counterbalanced order for the total six-day long experiment resulted in total 18 blocks of trials. In the first part, the central surface is functioning as an occluder. In the second part, the central surface is functioned as a connecting surface.

The orthogonal combination of seven different luminance decrements (3.5cd/m^2, 4.6cd/m^2, 5.5cd/m^2, 6.5cd/m^2, 7.7cd/m^2, 8.7cd/m^2, 11cd/m^2), two target locations (the right and left side of the central surface) and five repetitions comprised 70 trials presented randomly ordered in a single block trial. In total, it took 7 to 8 minutes to complete a block of the trial. Luminance changes happened on the left side of the central surface for half of the trials and the right side of the central surface to the other half of the trials.

Results

Data analysis

Analyses of the results of Experiment 1 and 2 (A &B) were based on the proportion of the total number of trials during which unidirectional motion was perceived. If the motion were perceived in the simultaneous (Bidirectional), it would indicate that the surface grouping determined by the motion is bistable. In other words, bistable motion indicates the grouping of the target surface with the other two surfaces: central and other horizontal other surface at the same time. If the perceived motion were frequently in one direction, a single, monostable surface grouping would be indicated.

The motion was not always perceived, in these experiments, especially for the low luminance decrements conditions. Data analysis could have been based on the proportion of the motion-perceived trials in a particular direction amongst the total number of trials where motion was perceived. However, this would have resulted in an immense overestimation of a grouping of the target surface with one of other two surfaces. We could say that motion is grouping motion when it directs toward the other horizontal surface where the direction of motion indicates the grouping with a target and the other horizontal surface. For instance, if DG motion was perceived during only 15 out of the 70-total number of trials and 25 of total trials where motion was perceived. If the proportions of DG motions were based on the total numbers of trials where motion was perceived that would be incorrectly signifying a strong effect of grouping. For this reason, the proportions of DG motion were based on the total number of trials (21% in this example) instead of the number of motion-perceived trials (60 % in this example).

Experiment 1

The motion was perceived in similar fashion throughout the three-different central surface height conditions across the all seven-luminance values. The percentage of motions (both unidirectional and simultaneous (bidirectional)) were perceived in Experiment 1 were 31%, 35%, 35% of the central surface heights conditions respectively 8.30º, 0.70º, 0.25º.

For each subject, a motion was perceived toward the other horizontal surface more often than the other direction: away from the occluder or simultaneous (bidirectional). Observers barely perceived simultaneous (bidirectional) motion in all experimental conditions.

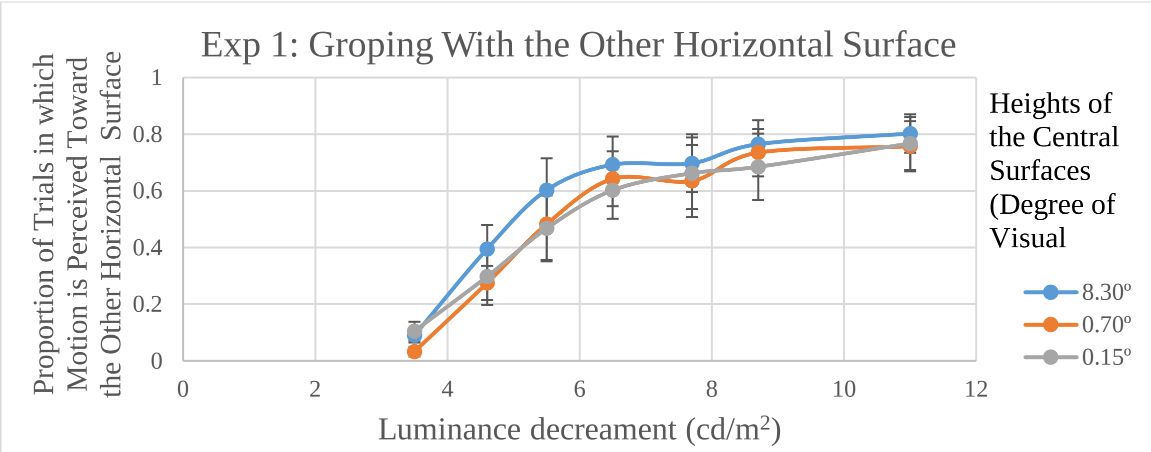


Figure 15: Exp 1: Groping With the Other Horizontal Surface. *The proportion of trials in which motion was perceived toward the other horizontal surface in a function of luminance decrement. There is no significant difference between the occluder condition and two non-occluder conditions.*

The effect of three different central surface height conditions for the grouping motion perception was marginally significant, F (2,6) =4.842, p=0.056. The effect of seven different luminance conditions on the motion perception was significant, $F (6,18) = 33.949$, $p \leq 0.05$. The motion was perceived across the target horizontal surface more often in higher than the low luminance decrements conditions through the three central surface heights and all subjects' conditions. Motion across the central surface determines the grouping between the target and other horizontal surfaces.

The results of Experiment 1 showed that the perception of motion toward the other horizontal surface which indicates the horizontal target surface was grouped with the nonadjacent, but connected horizontal surface.

Data was analyzed further based on the two conditions: when central surface partially occludes the continues horizontal surface and two non-occluder conditions when two horizontal surfaces are disjoined but attached to the adjacent surface of the central surface. The figure below shows that there is a marginal difference in motion perception between the occluder and non-occluder conditions. It is as expected, to perceive the more motion perception when the two surfaces are amodally completed.

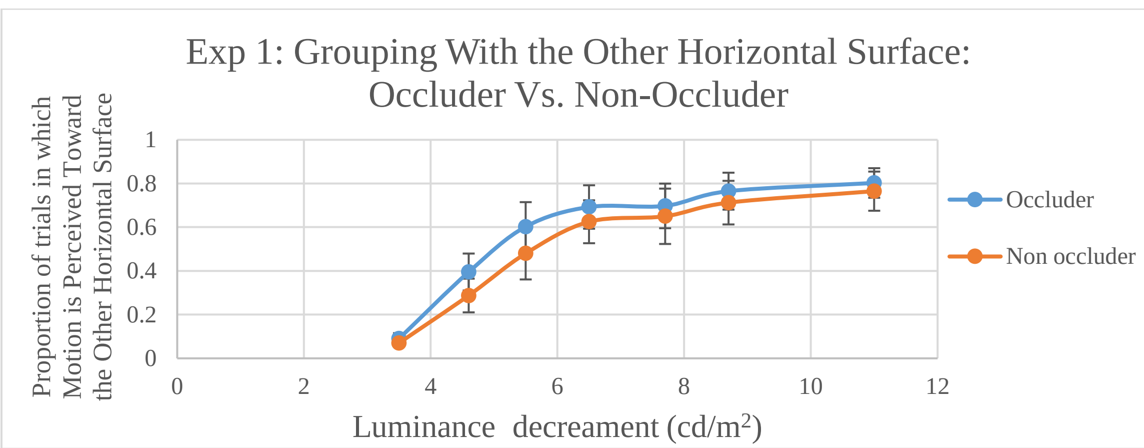


Figure 16: Exp 1: Grouping With the Other Horizontal Surface: Occluder Vs. Non-Occluder. *This figure shows that the proportion of trials in which motion was perceived toward the other horizontal surface for the two-different central surface height conditions-when it was an occluder or non-occluders. For the non-occluder condition, data were averaged to compare with the occluder condition.*

The effect of occluder conditions and non-occluder conditions for the grouping motion perception was marginally significant, F(1,3) =8.56, p=0.06.

Motion perception toward the other directions are less too; it does not have any indication in the grouping between the target horizontal surface with the central surface.

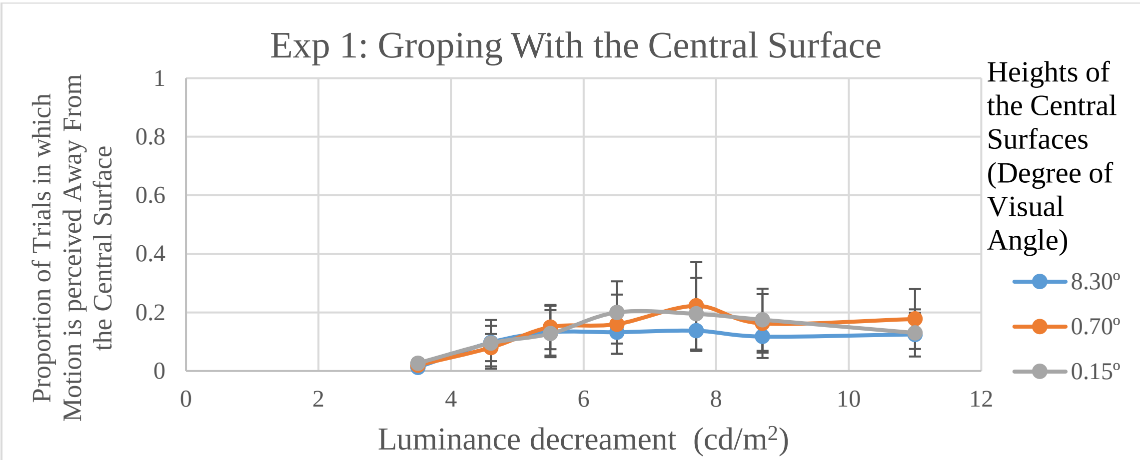


Figure 17: Exp 1: Groping With the Central Surface. *This figure shows that the proportion of the trials in which motion was perceived away from the central surface which indicates grouping between the target horizontal surface with the central surface.*

As expected that in the low luminance decrement conditions (low perturbation), the motion was not perceived in the most of the trials, however, motion perception gradually increases in the high luminance decrement (high perturbation) conditions in the subsequent trials.

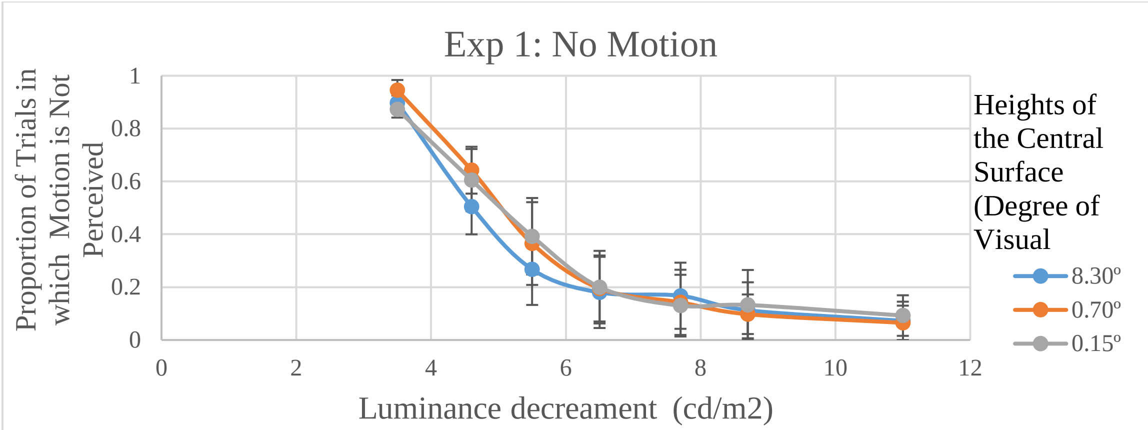


Figure 18: Exp 1: No Motion. *This figure shows that the proportion of the trials in which motion was not perceived. Motion perception is relatively high in the condition of amodal completion.*

Experiment 2

Experiment 2 (A)

The motion was perceived in similar fashion throughout the three-different central surface width conditions across the all seven-luminance values. The percentage of motions (both unidirectional and bidirectional) were perceived in experiment 2(A) was 36%, 35%, 36% of the central surface widths conditions respectively 0.90º, 3.90º, 6.90º.

For each subject, a motion was perceived toward the other horizontal surface more often than the other directions: away from the occluder or simultaneous (bidirectional). Observers barely perceived simultaneous (bidirectional) motion in all experimental conditions.

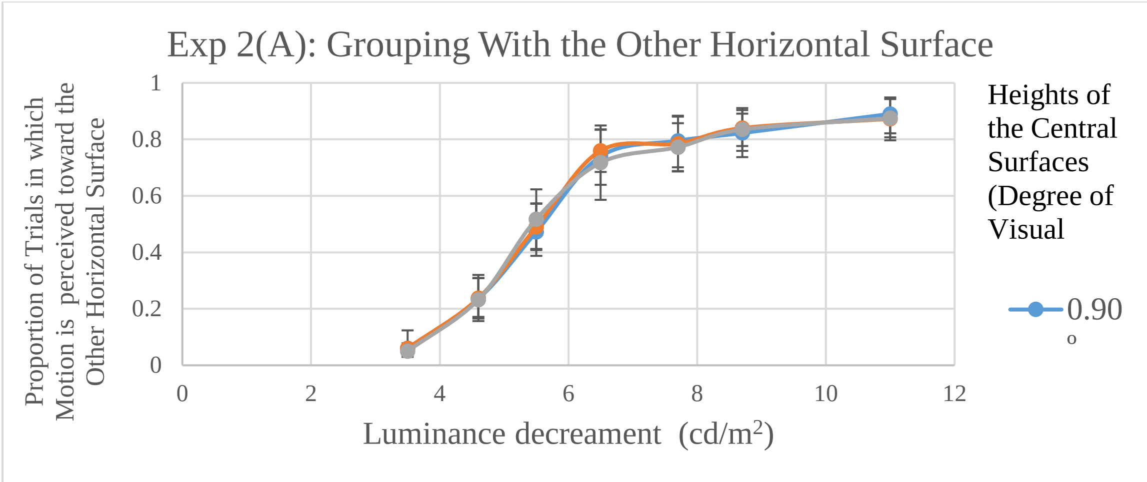


Figure 19: Exp 2(A): Grouping With the Other Horizontal Surface. *The proportion of the trials in which motion was perceived toward the-the other horizontal surface in a function of luminance decrement. There is no significant difference in motion perception between the three-different occluder width conditions.*

The effect of three different central surface width conditions for the grouping motion perception was not significant, F (2,6) =1.31, p=0.88. The effect of seven different luminance conditions on the motion perception was significant, F (6,18) =80.90, $p \leq 0.05$. The motion was perceived across the target horizontal bar more often in higher than the low luminance decrements conditions through all occluder and subjects' conditions. Motion to the other horizontal surface determines the grouping between the target and other the horizontal surface.

The results of Experiment 2(A) cannot nullify our research question that the gradual increase of occluder width does have an effect on the grouping of two surfaces when they are amodally completed. This non-significant effects of three different occluder widths on motion perception give us an intention to test further when the central surface was not an occluder but rather a connecting surface. This new experiment paradigm would help us to understand whether these results still replicate in the new paradigm.

Motion perception toward the other directions are too less; it does not have any indication in the grouping between the target horizontal surface with the central surface.

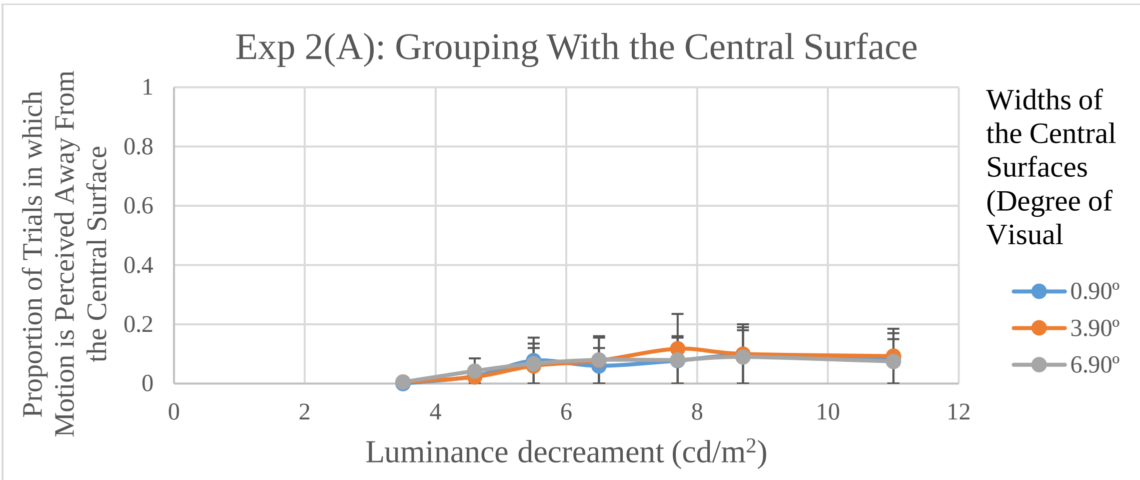


Figure 20: Exp 2(A): Grouping With the Central Surface. *This figure shows that the proportion of the trials in which motion was perceived away from the central surface which indicates grouping between the target horizontal surface with the central surface.*

As expected, in the low luminance decrement conditions (low perturbation), the motion was not perceived in the most of the trials. However, the motion perception gradually increased in the high luminance decrement (high perturbation) conditions in the subsequent trials.

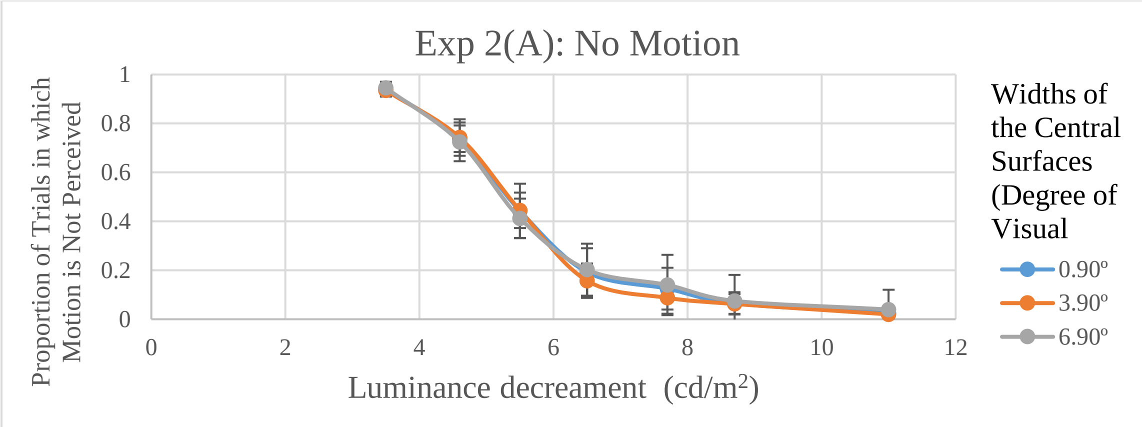


Figure 21: Exp 2(A): No Motion. *This figure shows that the proportion of the trials in which motion was not perceived.*

Experiment 2 (B)

The percentage of motions were (both unidirectional and bidirectional) perceived in experiment 2(B) was 37%, 39%, 38% of the central surface widths conditions respectively 0.90º, 3.90º, 6.90º.

For each subject, a motion was perceived across the central surface more often than the other motion directions: Away from the occluder or simultaneous (bidirectional). Simultaneous (bidirectional) motion perception was close to 0% in all experimental conditions.

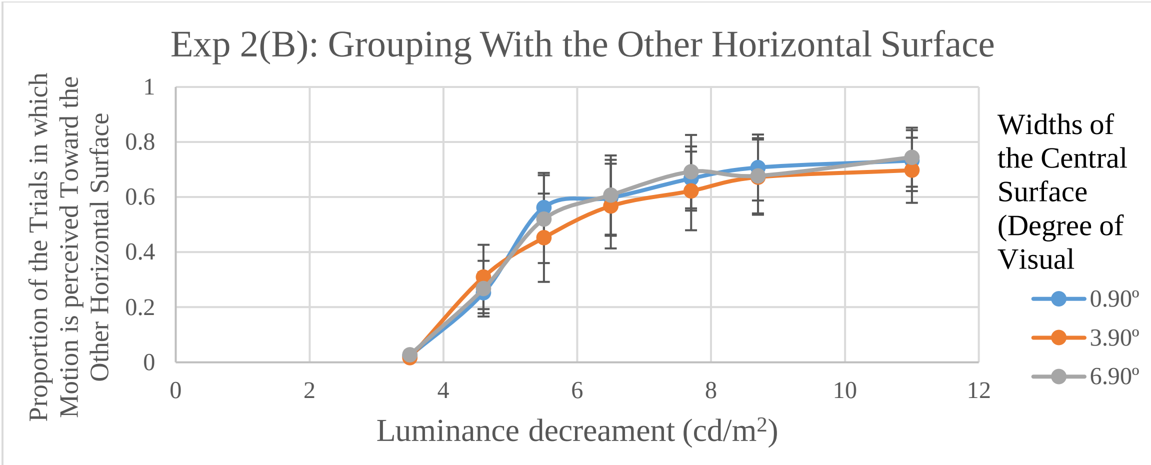


Figure 22: Exp 2(B): Grouping With the Other Horizontal Surface.*22.* *The proportion of trial in which motion was perceived as a function of luminance decrement. There is no significant difference between the three central surface conditions.*

The effect of three-different central surface width conditions for the grouping motion perception was not significant, $F(2,4) = 1.32$, $p = 0.37$. The effect of seven different luminance conditions on the motion perception was significant, $F(6,12) = 20.12$, $p \leq 0.05$. The motion was perceived toward the other horizontal surface more often in higher than the low luminance decrements conditions through all occluders and subjects' conditions. Motion toward the other horizontal surface determines the grouping between the target and the other horizontal surface. This was consistent with the connectivity functioning as a grouping variable, which was first reported by Palmer and Rock (1994).

Motion perception toward the other directions are too less; it does not have any indication in the grouping between the target horizontal surface with the central surface.

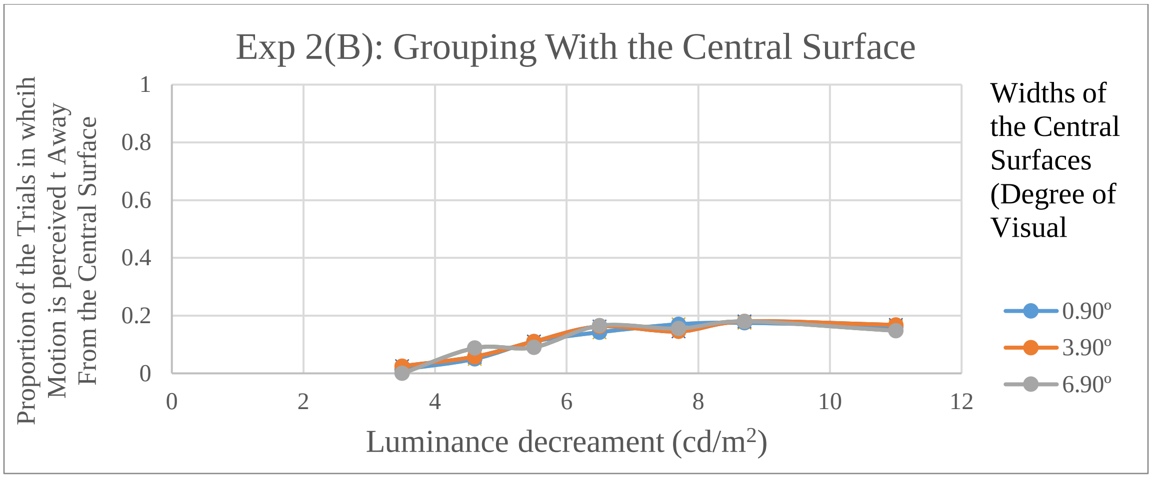


Figure 23: Exp 2(B): Grouping With the Central Surface. *This figure shows that the proportion of the trials in which motion was perceived away from the central surface which indicates grouping between the target horizontal surface with the central surface.*

As expected that in the low luminance decrement conditions (low perturbation), the motion was not perceived in the most of the trials, however, motion perception gradually increases in the high luminance decrement (high perturbation) conditions in the subsequent trials.

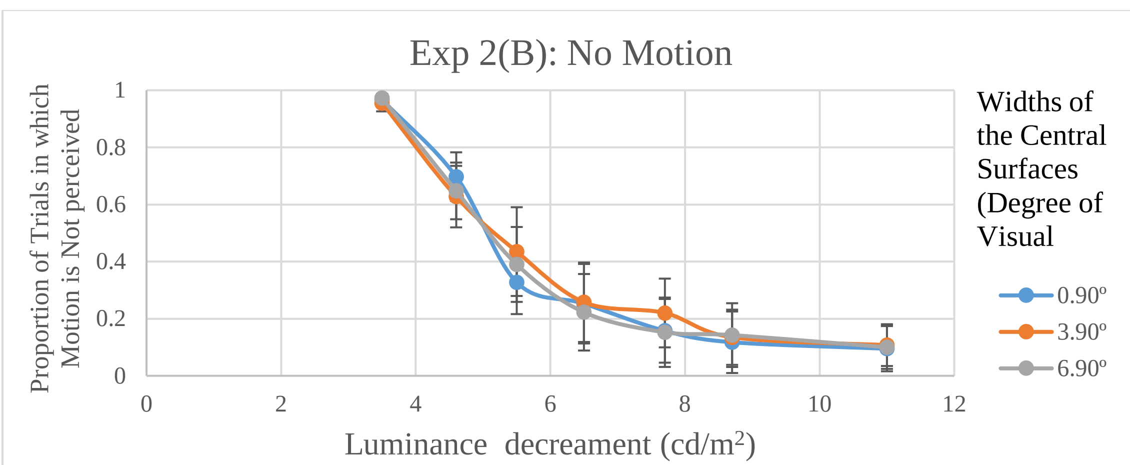


Figure 24: Exp 2(B): No Motion. *This figure shows that the proportion of the trials in which motion was not perceived. Motion perception is relatively high in the condition of amodal completion.*

Data was analyzed further based on the occluder conditions (Figure 24 (A)) and two non-occluder conditions (Figure 24 (B)). There is no difference between the results two experiments when the luminance decrement is less, but in higher luminance decrements conditions, there is a distinct separation between the two conditions: occluder condition (blue line; Figure 24 (A)) and non-occluder condition (red line; Figure 24 (B)). The proportion of motion in occluder condition is higher than the non-occluder condition in high luminance decrement conditions which indicates the more perturbation in the target horizontal surface during the amodal completion.

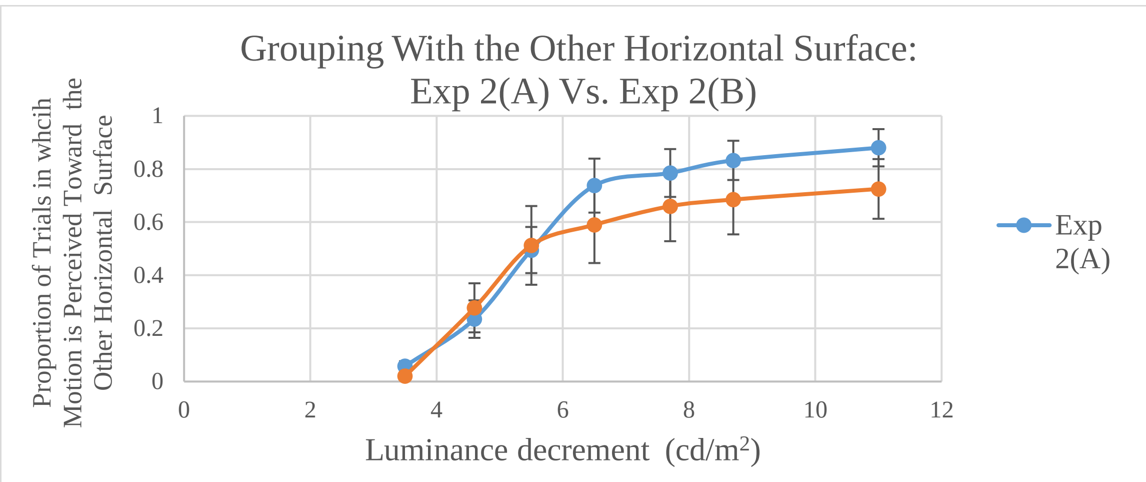


Figure 25: Grouping With the Other Horizontal Surface: Exp 2(A) Vs. Exp 2(B). *The proportion of the trial in which motion was perceived as a function of luminance decrement. It is shown in the figure that in higher luminance decrement conditions, there is a clear separation between the two conditions: occluder and non-occluder conditions.*

The effect of two experimental conditions for the grouping motion perception was not significant, $F(1, 3) = 0.429$, $p = 0.559$ The effect of seven different luminance conditions on the motion perception was significant, $F(6,18) = 58.530$, $p \leq 0.05$. The motion was perceived across the target horizontal bar more often in higher than the low luminance decrements conditions through all occluder and subjects' conditions. Motion to the other horizontal surface determines the grouping between the target and other the horizontal surface.

Summary and Discussion

In keeping with the previous accounts indicating that the directions of DG motion are a critical factor to determine whether the target surface is grouped with one or other adjacent surface (Hock and Nichols, 2012), the present results demonstrate the same concept when target surface is grouped with the non-adjacent, but connected other surface–particularly under the condition of amodal completion.

In the current study, the direction of motion toward the other horizontal surface indicates grouping between the target and the other horizontal surface which is on the opposite side of an intermediate connecting surface; the direction of motion away from the central surface indicates grouping with the central surface. In general, it was found that the motion was perceived in a similar fashion throughout the three-different central surface conditions across the seven-different luminance decrement values.

Interestingly, the observers still perceived motion toward the other horizontal surface, when central surface height (0.70°, 0.15° visual angle) for non-amodal (non-occluder) conditions are smaller than the central surface height (8.30° visual angle) for the amodal (occluder) condition. Non-occluder conditions eliminate the effects of amodal completion, although this finding indicates that target and other horizontal surfaces are still grouped when they are not amodally completed, which is consistent with the Palmer & Rock (1994) evidence for the connected surface for grouping (Figure 25). However, there

Is no difference in perceiving motion in different frequency toward the other horizontal surface (which indicates grouping between the two horizontal surfaces) in two-different non-amodal conditions (0.70°, 0.15° visual angle of the central surface). So, this result gives evidence that the strength of grouping between the two-horizontal surface is similar to both the non-amodal (non-occluder) conditions.

Also, there was a noteworthy aspect of results we found in experiment 1 that the motion is perceived more frequently toward the other horizontal surface in amodal completion than the non-amodal completion. Based on the results, there was a clear distinction between an amodal and non-amodal condition in perceiving motion toward the other horizontal surface, which indicates more stronger grouping effect between the target and other horizontal surface in occluder condition than the non-occluder conditions (Figure 25).

A possible explanation for the above results is that they are consistent with the connectivity functioning as a grouping variable, as reported by Palmer & Rock (1994) and might be an additional effect of reduced perceived distance between the two objects as described by Shimojo and Nakayama (1990).

Palmer & Rock (1994)

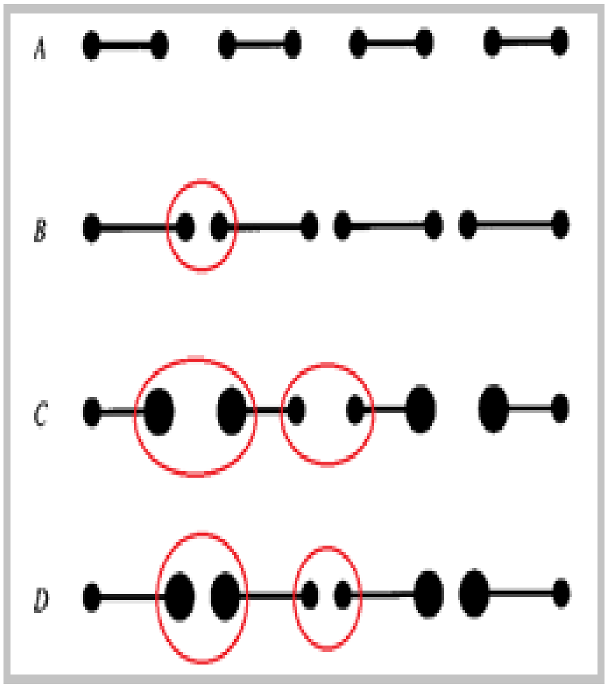


Figure 26: Uniform connectedness (UC). *UC was first reported by Palmer and Rock (1994). Red circles of both the diagrams which denoting the Gestalt's classical grouping variables such as proximity, size similarity, and combination of the both. "Uniform connectedness" (UC) takes a precedence over the Gestalt's classical grouping variables such as proximity, size similarity, and combination of the both.*

Palmer & Rock (1994) described "uniform connectedness" (UC) when two objects are adjoined by a surface to unify the two objects into a single perceptual organization. According to their theories, UC opposes the Gestalt's classical grouping variables such as proximity, size similarity, and the combination of the both over the precedence of UC.

Experiment 2 was designed based on the results of Experiment 1 where we obtained a marginally significant difference between the two conditions when the central surface was appeared to be an occluder (8.30° visual angle height), and when it was just an adjoining surface (0.15° visual angle heights) between the target and other horizontal surfaces. In experiment 2, we tested three-different widths of the central surface (0.90°, 3.90^{o}, and 6.90^{o}) in the two parts of the experiments: when it was a full occluder in experiment 2(A), and when it was just a thin connecting surface in experiment 2(B).

We did not find any significant difference between the three-different central surface width conditions when it was a full occluder (Experiment 2(A)), and it was just a thin connecting surface (Experiment 2(A)). According to the theory of UC, the distance between the two surfaces does not matter as long as they are adjoined by a connecting surface.

The above findings (Figure 25) showed that there is a stronger grouping effect on the amodal condition than in the non-amodal completion. Amodal condition enhances grouping effects more than the non-amodal completion because of the combination of effects of an occluder, which perhaps give us an appearance of the grouped surfaces form an object with a single surface behind the occluder, rather than 2 surfaces belonging to a 3-surface object, and an additional effect of a connecting surface when the occluder itself is working as a connecting surface (an effect of UC) between the two adjacent horizontal surfaces (Palmer & Rock, 1994).

To explain the stronger grouping effect in amodal completion than in the non-amodal completion in experiment 1, we thought that perceived distance between the two surfaces might be reduced because of the presence of the occluder and thus two surfaces are appeared to be grouped (Shimojo and Nakayama 1990), however this justification doesn’t help to explain the result in experiment 2 (A) where different-length of width of the occluders does not have effect on the strength of grouping. In the experiment, grouping effect is same for all three-different occluder width conditions.

Conclusions

The presence of a connecting surface promotes the grouping of non-adjacent surfaces, consistent with Palmer & Rock's (1994) evidence for the effects of connectivity on perceptual grouping.

Grouping of non-adjacent surfaces is stronger for amodal completion, perhaps because the grouped surfaces form an object with a single surface (behind the occluder), rather than two surfaces belonging to a 3-surface object.

The distance between grouped surfaces does not affect the strength of their grouping, providing they are joined by a connecting surface. This is consistent with evidence that connectedness trumps the effect of proximity on perceptual grouping.

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