THE INFLUENCE OF GESTALT GROUPING PRINCIPLES ON ACTIVE VISUAL REPRESENTATIONS: NEUROPHYSIOLOGICAL EVIDENCE

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The cognitive ability to group information into chunks is a well known phenomenon, however, the effects of chunking on visual representations is not well understood. Here we investigate the effects of visual chunking using Gestalt grouping principles in two tasks: visual working memory change detection and multiple object tracking. Though both these tasks have been used to study cognitive functions in the past, including object-based attention, attentional control and working memory capacity, the effect of grouping on mental representations in these tasks has not been well characterized. That is, while researches have measured effects of grouping on behavioral output in similar tasks, there are few studies of the effects of grouping on neurophysiological indices of object representations. Indeed, these current studies are the first to use event-related potentials (ERPs) to elucidate the effect of grouping on active mental representations of visual stimuli. In the visual working memory task, observers remembered either the color or orientation of pacman stimuli across a delay. We manipulated the collinearity of these objects, whether or not they formed a Kanizsa triangle figure, and measured the behavioral and electrophysiological effects.

In the multiple object tracking task, a subset of identical stimuli were briefly cued as targets and then their motion was tracked by participants. We manipulated whether and which Gestalt heuristics were used to bind targets together during their motion and measured the effects on behavior and electrophysiology. In both tasks we compared the grouped to ungrouped conditions. We found that across experiments and tasks behavioral performance was enhanced in grouping conditions compared to ungrouped conditions. Furthermore, the waveforms evoked by grouped stimuli were reduced compared to waveforms produced in response to locally identical but ungrouped stimuli. These data suggest that the mental representation of visual objects may be reshaped moment-by-moment by grouping cues or task demand, giving rise to a flexible, active and dynamic yet parsimonious representation of the visual world.

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I dedicate this dissertation to Stephanie.

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CHAPTER I

GENERAL INTRODUCTION

Max Wertheimer noted in his 1920 monograph, "I stand at the window and see a house, trees, sky," meaning by this that the phenomenal visual world consists of the unified perception of objects placed in space and time. Despite the knowledge that the actual image projected onto the retina by the optic lens is a patchwork of colors, except under the extraordinary conditions of disease, neurological tissue damage, pharmaceuticals, or similar perception-altering influence, the mental representations of apprehended objects appear as unified, whole object in the world. It is important to note that contours or color swatches which, in the completed percept seem united on a continuous surface or bounded by a closed contour, in the initial retinal patchwork may be widely separated in retinotopic space or divided by disparate colors or edges. Thus, the question of how an initially disorganized and inchoate visual riot of color may be sewn together in the mind's eye to create the phenomenological world has intrigued psychological researchers from William James and Max Wertheimer to the present day. Through processes not yet fully understood, individual swatches in the visual field are patched together, edges are discovered and contours are formed, followed, and completed. The figure is separated from the background, and an object is presented to awareness to be remembered, manipulated, or stored. Some of these processes have been described at various levels of analysis: modal completion of camouflaged items, or amodal completion of occluded figures, Gestalt grouping principles linking elements together to form composite objects and the maintenance of those objects in visual memory within static or dynamic tasks. This dissertation will consider the behavioral and electrophysiological correlates of visual awareness in both static and dynamic tasks, and investigate the influence of contour completion phenomena and select Gestalt grouping principles on behavioral and electrophysiological indices of active visual representation.

As noted by Wertheimer, grouping allows an individual to organize large amounts of information into smaller chunks which may then be more easily managed in memory. The subject visual world does not consist of hundreds of color patches, but unified percepts. These percepts persist in visual memory as active visual representations, and it is not yet fully understood how these bottom-up or top-down grouping processes affect visual representations. The next sections will selectively review visual working memory, gestalt perception, and multiple object tracking literature in order to provide a background against which the studies in this dissertation will be presented.

1.1. Visual Working Memory

Visual working memory (VWM) is a cognitive system that enables us to maintain information about objects in the immediate visual environment in order that those objects may be manipulated, evaluated, or acted upon. This memory subsystem is comprised of several processes which sustain the operations of VWM. These include the encoding or consolidation, of incoming visual information (W. Phillips, 1974; W. Phillips & Christie, 1977), maintenance or storage (Luck & Vogel, 1997) of information in memory and comparison processes whereby the information maintained in memory is matched against other external or internal information (Hyun, Woodman, Vogel, Hollingworth, & Luck, 2009).

Research has demonstrated that this visual working memory system is severely constrained and able to hold only a few objects at a time (Sperling, 1960; Pashler, 1988; Luck & Vogel, 1997). The degree of resolution, defined as the amount of detail maintained about the object, is also limited in visual working memory (Wilken & Ma, 2004; Alvarez & Cavanagh, 2004; Awh, Barton, & Vogel, 2007; Scolari, Vogel, & Awh, 2008; Zhang & Luck, 2008).These properties of visual working memory are distinct and uncorrelated, and this distinction between visual working memory capacity and resolution is supported by both empirical data as well as computational models(Wolters & Raffone, 2008). However, investigation of which characteristics of memory are altered with expertise has been sparse in the visual memory literature, though there are recent exceptions (Curby & Gauthier, 2007; Scolari et al., 2008; Curby, Glazek, & Gauthier, 2009; C. D. Moore, Cohen, & Ranganath, 2006).

1.1.1. Limited Capacity

Questions central to the understanding of visual working memory are what are the significant constraints on working memory (capacity limits, resolutions limits) and what is the nature of the representations maintained? Since Sperlings partial report Sperling (1960) task short-term memory researches have been interested in these questions (W. Phillips & Christie, 1977). Luck and Vogel 1997 examined both questions as using a change detection task. In this task, frequently used to study working memory of all types, the items to be remembered are briefly presented, followed by a retention interval, followed by a probe testing the items that were to be remembered. In Luck & Vogel 1997, the memory arrays consisted of colored squares in several set sizes (1–12 items in the memory array). At the test array, subjects were asked to respond whether the test array was the same as or different to the initial memory array. Under these conditions, subjects generally displayed a memory capacity of 3–4 items, averaged across several set sizes. Through this experiment and experiments of a similar nature (Luck & Vogel, 1997), mnemonic capacity in VSWM is generally thought to be no greater than 3–4 items at any one time (Cowan, 2001).

1.1.2. Object Maintenance

In this experiment, however the subjects were required to remember only a single feature per object. Thus, item capacity and feature capacity in that experiment were confounded. In order to better delimit the nature of the VWM representations, Luck & Vogel also examined conjunctions of features within a single item. That is, they examined whether increasing the number of feature dimensions memorized would change mnemonic capacity. This experiment alone, however, does not address the nature of mnemonic representations, that is, whether they exist as integrated objects or collections of features, and whether or not there is a cost to remembering greater numbers of feature dimensions per object. They therefore presented subjects with colored lines and asked the subjects to to remember either orientation (orientation condition) their color (color condition) or the conjunction of color and orientation. In this experiment they found that orientation was remembered slightly better than color, but the conjunction of both was remembered just as well as color. That is, there was no cost to remembering twice as many features, so long as the features were within a single object (Luck & Vogel, 1997). But, see (Xu, 2002, 2006; Delvenne & Bruyer, 2006).

1.1.3. Information Load

More recently, the hypothesis that feature dimensions of mnemonic items could be represented for free has come under fire. Alvarez and Cavanagh investigated memory for simple and complex objects, from simple colored squares to two dimensional projections of cubes and Chinese ideographs. A strong object-based representation scheme, assuming that feature dimensions are bound at no cost in an integrated object, should predict that accuracy would be the same across all object types. However, using a change detection paradigm similar to that of Luck & Vogel, they found that change detection accuracy dropped according to the complexity of the type of item to be remembered, that is, even holding the number of items the same, as the total information in the array increased, accuracy dropped. They then proposed that VWM is not constrained by the number of items to be remembered, but rather by the total amount of information being maintained. Thus, in contrast to a slot or object model of memory, they propose a pool of resources model of memory. In this model, a given representation is allocated an amount of general mnemonic resources, which could, in principle, be subdivided ad libitum. Thus, according to these results there is no a priori limit to the number of items represented, it is simply that as more items are represented each item gets fewer resources and thus becomes less and less likely to be recalled correctly at test (Alvarez & Cavanagh, 2004).

This contrary hypothesis ignited a debate in the literature. On the one hand is the strong hypothesis that items in memory are represented in an all-or-none fashion, or slot-like more recent investigations using identical stimuli have proposed an alternative interpretation of the results. Awh et al. (2007) using the same stimuli, examined whether the Alverez and Cavanagh data are best explained by a pool of resources model or some other way. They presented subjects with various set sizes of items in a similar change detection paradigm as Alvarez and Cavanagh, using simple and complex stimuli, but probed subjects on their ability to report a change either between categories (color to cube, for example) or within category (cube to cube). Their results demonstrated that large changes across categories were as easily detected as color to color changes, whereas changes within a category, such as cube to cube or ideograph to ideograph, were more difficult to remember. Awh et al. argue that for subjects to perform well at this task they would need to be able to have a representation of all the items in the memory array, since they were able to perform normally on large change trials, but that there is a resolution limit for each of the items which decreases the subjects accuracy when comparing the mnemonic items with the probe array. Furthermore, they found no correlation in the subjects capacity limit for large-change trials and small-change trials, further arguing for separable processes or mechanisms in detecting large (number limited) and small (resolution limited) changes. Thus, according to these data, both the number of objects as well as the resolution with which those objects are held affect the ability of the subject to detect a change. In this view, greater complexity increases the number of errors but those errors are caused by a failure during the comparison of the test array with mnemonic objects rather than the number of items held in memory. That is, the items, though represented, are not represented with sufficient precision to enable accurate change detection. Therefore, memory capacity (during maintenance) is limited by the number of objects, but that the comparison process is limited by the precision or resolution with which those items are represented.

1.1.4. Capacity and Resolution

Xu and Chun (2005) have begun to explore possible neural substrates for these separable limits for VWM in fMRI change detection experiments which used stimuli having the same number of features spread over fewer or more items. In these experiment, one or more shapes could posses one or more features in a change detection task performed in an event-related fMRI experiment. During this task activation in the IPS was observed. This activation in inferior IPS increased according to the number of mnemonic objects, however, activation in superior IPS increased according to the number of features to be remembered. Thus for simple objects the limit was about 4 or 5 in both areas, and remained so for inferior IPS. However, as complexity per object increased, the number of features represented in superior IPS decreased so that fewer complex objects were represented during the memory retention interval. Xu & Chun propose a model of visual working memory which assumes separate limitations for the number of objects remember, individuation of objects, and a second, resolution-limited constraint for the identification of items. In their model, early individuation is accomplished, perhaps pre-attentively, using coarse information, whereas later identification requires more features to be maintained in memory and thus the total number of features the objects posses also limit mnemonic capacity. Olson & Jiang examined the affect of configuration on mnemonic representations during a color change detection task. They varied the amount of configural information which was preserved from the memory array to the test array, either by varying the number of items which reappeared in the test array (spatial configuration) or by varying the colors which reappeared in the test array (color configuration) and found that disruption of spatial configuration significantly lowered change detection accuracy more so than the disruption of color configuration information. These and other results imply a hierarchy within VWM such that spatial location is identified first followed by other featural information (Jiang, Olson, & Chun, 2000). These results also provide further behavioral evidence for the Xu & Chun model. The Xu & Chun data do not, however, entirely resolve capacity limitation debates in VWM. The Alvarez and Cavanaugh model allow for some core features to be stored without cost as part of an object, and number + resolution models does not address what resolution consists of, how it may be allocated across items, and whether some items may be flexibly allocated more resolution than others. Some questions which arise while considering this hypothesis are: what are candidate core features? Can resolution be flexible allocated? Can resolution for an object be enhanced or trained such that objects of expertise are remembered with greater fidelity? Vogel, Woodman, and Luck (2006) demonstrated that features of an object may be flexibly maintained or selected according to task demands. They measured consolidation times of colored, oriented bars by using a mask presented and various intervals subsequent memory array presentation in order to disrupt VWM encoding. They then measured working memory capacity for colors, orientations, or the conjunction of the two. Vogel et al. found that while capacity was nearly equivalent for colors, conjunctions, and orientations, if the mask was presented during encoding capacity was decreased more for the conjunction condition than for the other conditions. These data were interpreted to mean that, even though both color and orientation may be stored with no additional cost in terms of capacity, there is a tradeoff in terms of consolidation time. Thus, multiple features require longer to store in memory than single features.

1.1.5. Complexity

Faces are complex, highly salient objects in the visual environment and it is has been previously demonstrated that faces are percieved in a holistic manner Inverted faces, however, though equally complex are not perceived in holistically (Yin, 1969; R. Phillips & Rawles, 1979; Eimer, 2000). If the number of faces that can be remembered is greater for upright faces than inverted faces, or other complex objects which are not expertise objects, than it may be the case that the capacity these objects (number) has been enhanced by expertise. Curby and Gauthier used a change detection task to estimate capacity for faces, comparing memory for upright faces to inverted faces and other complex, familiar objects which were not objects of expertise, watches and cars Curby and Gauthier (2007). They found that memory for upright faces was greater as measured by K (Pashler, 1988; Cowan, 2001) for the upright faces than for inverted faces or other objects. Furthermore, this effect interacted with exposure duration, such that longer memory array durations, 500,1500 2500 ms monotonically increased the number of faces remembered, up to an average of about 2.5, what is typically seen for VWM capacity (Cowan, 2001). Curby and Gauthier interpreted this data is a perceptual expertise effect enhancing the number of items which can be remembered in the domain of expertise. However, the two-factor model of VWM also allows another possibility. Both number of items and complexity/visual information are factors, so it may be that Curby and Gauthier, instead of demonstrating a greater memory for faces (in terms of number of items) per se, demonstrated enhanced resolution for faces. Scolari et al. (2008) tested this hypothesis in a change detection task comparing cross-category changes (face/inverted face or face/cubes etc.) with within-category changes (face to face or cube to cube). If expertise increases the number of items in memory then the advantage for upright over inverted faces should be maintained under these conditions. On the other hand, if expertise simply enhances the resolution, or allows more information to be stored for a given item, then they should only find and advantage for upright faces in the within-category condition. That is exactly what Scolari and Awh found; an expertise advantage for upright faces but only in the within-category (small change) condition. They interpret this data as providing evidence that expertise, rather than increasing the number of items which can be remembered, may only increase the amount of information maintained per item. This conclusion fits well with the expertise literature showing an increase per chunk information storage but equivalent chunks for both experts and novices (Gobet & Simon, 1996b; Saariluoma & Laine, 2001; Gobet & Clarkson, 2004). This is in contrast to the Zhang and Luck model which posits a fixed number of slots for item, each item having a fixed resolution, or amount of information that it can store (Zhang & Luck, 2008; Hyun et al., 2009). In this model, if more resolution is required to remember an object with high fidelity, then several of these slots may be averaged together. The recent Scolari and Awh data show that resolution may not be a fixed value at all, at least not for objects of expertise. These results are not necessarily contradictory; for items which are not within the experts domain the resolution available for several slots may be pooled and a single, high-fidelity item may be remembered. For objects in the domain of expertise, if items in working memory are the activated portion of LTM (Cowan, 1999, 2001), then items within domain expertise may simply have more associated information which then fit within the basic capacity limits.

1.1.6. Computational Models

Rafone et al. have proposed a computational model using biological constraints which provide a plausible analytical explanation for a four item limit in working memory. They model a system of dynamically interacting neurons and found that integrated item representations could be represented in a network of reverberating, synfiring nodes. The total number of neurons firing together (perhaps representing the amount of information) was not a constraining factor in this model, but rather the number of synchronously firing neuron groups. That is, using biologically plausible parameters for neuronal firing rates, no more than four synchronous patterns could be represented in the network simultaneously. Attempting to insert another pattern caused catastrophic interference, entirely degrading both or multiple signals. Thus, they found that items were encoded in an all or none fashion within what they refer to as a chunking field, a system of neurons firing coherently in a reverberating manner (Raffone & Wolters, 2001; Wolters & Raffone, 2008). The evidence is growing, then, that visual working memory is limited in both the number of items that may be represented as well as the total number of features or visual information that may be stored concurrently.If that is the case, then expertise may enhance memory by either increasing the number of items (increasing capacity) or by increasing the visual information/resolution of a fixed number of items (increasing resolution) or both. Not considered here is the further possibility that expertise may enhance the selection of items to be remembered (Woodman, Vecera, & Luck, 2003; Fukuda & Vogel, 2009).

1.1.7. Expert Memory and Visual Working Memory

Working memory in general, and visual working memory in particular, is theoretically constructed as a system that enables the online and offline maintenance and manipulation of information so that it may be acted upon. Elite performance, or expertise, often places extraordinarily high demands upon memory systems and working memory in particular. In those domains which involve extensive manipulation of visual information, such as chess, Othello, music, scrabble and other domains which nonetheless require support from visual working memory such as poker, bridge etc. (Charness, 1979; Wolff, Mitchell, & Frey, 1984; K. Ericsson & Lehmann, 1996; Kalakoski, 2007; Halpern & Wai, 2007). It follows, therefore, that if visual working memory is to some degree trainable then extended, intensive, deliberate practice required for expertise (A. Ericsson, Nandagopal, & Roring, 2007) may be able to modify some aspects of working memory to better adapt to the domain requirements. This section will examine how the theoretical construct of VWM may interact with the phenomenon of expert memory.

Visual memory studies require care to prevent grouping and enable accurate estimates of capacity, as noted by Cowan (2001). More ecologically, studies of chess board recall, have demonstrated precisely this effect in experts, showing that extensive practice in the domain enables greater recall of chess positions (Gobet & Simon, 1996a), with higher accuracy, and that such recall is modulated by the constraints of the game, that is, legal board positions are better remembered than illegal board positions, (Chase & Simon, 1973). Even the in-game strategic positions of the pieces can influence memory performance (McGregor & Howes, 2002)

VWM supports problem solving, mental manipulation and search in chess (Gobet, 1997; Schultetus & Charness, 2000). Experiments using either a interpolated visual working memory secondary task or a verbal task during a chess task a found that the verbal load had no affect on expert memory, but performing a secondary visual task interfered with the the chess task (Saariluoma, 1992). However, not only does VWM support expert memory performance directly, they also appear to share neural structures. That is, brain regions correlated with VWM tasks have been shown to be modulated by the degree of expertise of the subject (C. D. Moore et al., 2006). Furthermore, working memory regions have also been demonstrated to be involved in the strategic recoding of information, chunking, a critical theoretical aspect of expert memory (Bor & Owen, 2007; Bor, Cumming, Scott, & Owen, 2004; Bor, Duncan, Wiseman, & Owen, 2003). The two-factor model of visual working memory, consisting of a capacity and resolution limited store, provides a plausible pathway by which intensive practice may be able to affect the nature, number, or contents of mnemonic representations. While great deal of the available evidence indicates that the number of items may be fixed, e.g. Luck and Vogel (1997), the amount of detail within each item, as well as what may be considered an item or object, is probably plastic and can be altered by experience (Zimmer, 2008; Scolari et al., 2008). Therefore, even if the absolute number of items maintained in working memory is fixed, there exists a plausible cognitive mechanism and putative neural substrates, whereby items could be recoded into more information-dense representations. The computational modeling of visual working memory of Raffone and Wolters (2001) also provides support for the hypothesis that, though the number of representations in memory may be fixed, increasing the amount of information contained in each item may be malleable. Rafone et al. modeled reciprocally firing neurons connected in reverberating circuits. They found, using biologically plausible parameters for each neuron, that information could be stored in synchronously spiking neurons. Each of these chunking fields could store an arbitrary number of features as neurons were added, however, in their model a maximum of four distinct ensembles could oscillate without degrading. Expert memory is also characterized by the selectivity of the information chosen to be remembered (Ericcson, Chase, & Faloon, 1980; Saariluoma & Kalakoski, 1997). This point of intersection between visual working memory and expert memory is the filtering process which constrains the information that is allowed into working memory (Saariluoma & Kalakoski, 1997; Vogel, McCollough, & Machizawa, 2005). Recent work (Vogel et al., 2005; Woodman & Vogel, 2008; McNab & Klingberg, 2008; Fukuda & Vogel, 2009) have demonstrated that visual working memory is highly dependent on selection mechanisms to modulate the information stored in memory, and that differences in these mechanisms are correlated with differences in capacity as well as intelligence. Inefficiency in these filtering mechanisms have also been correlated with unnecessary storage of task-irrelevant information (McNab & Klingberg, 2008; Fukuda & Vogel, 2009). The Constraint Attunement model of Vicente and Wang (1998) may fit this concept the best, however, as early as de Groot it was recognized the experts perceive a scene differently than novices, extracting the relevant information at a glance (Groot, 1965). While some video game studies suggest that attentional filtering may be modified in this way (Day, Arthur, & Gettman, 2001; Green & Bavelier, 2003), more research needs to be done to clarify the role of selective attention in expert memory.

Recent data suggests that the effective operation of visual working memory requires the existence of distinct categories (Olsson & Poom, 2005; Zimmer, 2008). For example, Zimmer et al. presented subjects in a change detection task with Chinese ideograms to remember, as well as a change detection task with psuedorandom, or a false-font chinese character. The subjects where either Germans with little or no exposure to Chinese characters, or educated native Chinese speakers and readers with extensive training in reading these characters. Though performance on the false-font characters where equivalent between Chinese and German native speakers, Chinese speakers where able to remember more of the actual ideograms. Similar results have obtained in the visual working memory domain as well, Olsson and Poom (2005) used unfamiliar and difficult to classify objects in a change detection task. They found that subjects were able to remember objects which fit discrete categories at normal rates, but objects which varied along a continuous shape or color space were poorly remembered, reducing memory capacity to only one item. One aspect of the resolution of items in memory, then, may simply be whether there is a sufficiently robust representation of the category in long term memory. Gordan Logan has proposed an Instance Theory of Attention and Memory, which suggests that object recognition and working memory are equivalent. The process of recognizing and object and the process of encoding the object are, in this theory, equivalent processes (Logan, 2002). In this model then, the recognition of an object would necessarily entail the immediate access to all the information available for that object, yet not necessarily require any more slots in memory. Further, an object which had no corresponding representation in LTM, an entirely novel object, would be correspondingly difficult to remember.

1.1.8. Neural Measures of Visual Working Memory

Neural data is important in order to further constrain theoretical models of working memory. Functional Magnetic Resonance imaging, an indirect measure of metabolic activity in the brain, and Event Related Potentials, which are electrophysiological measures of neural activity, have in recent decades been able to use their highly spatially or temporally resolved imaging data to constrain cognitive theories. On the one hand, fMRI provides highly spatially resolved images of neural activity with low temporal resolution, while on the other, ERPs display highly temporally resolved images of electrical activity within the brain, at a low spatial resolution. Both techniques have contributed substantially to the development of working memory theory.

The high spatial resolution of fMRI, event-related potentials (ERPs) provide an online measure of cognitive processing with excellent temporal resolution (Picton, Hillyard, Krausz, & Galambos, 1974; Hillyard & Picton, 1978). Several ERP studies have observed a large, broadly distributed negative slow wave during the retention interval of WM tasks (D. Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992; D. Ruchkin, Johnson, Canoune, & Ritter, 1990). This component has been shown to be sensitive to task difficulty (D. S. Ruchkin, Grafman, Cameron, & Berndt, 2003), and appears to have a somewhat different scalp distribution for spatial and object WM tasks (D. Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1997). However, the degree to which this activity is specifically related to WM per se has not yet been definitively demonstrated. That is, there are several potential non-mnemonic processes that may occur during the retention period that could contribute to this activity. For example, during the retention period, in addition to maintaining the memory items the subject also anticipates the onset of the test display and e. Consequently, it is plausible that this negative slow wave may not only reflect the maintenance of information in WM, but is also partially due to this anticipation process. Indeed, the contingent negative variation (CNV) is a well studied ERP component that has similar characteristics to this negative slow wave (e.g., polarity, scalp distribution, timing) (Tecce, 1972). It has been shown to precede the onset of a task relevant stimulus and is thought to reflect, in part, the anticipation of making a behavioral response. While it is possible that this negative slow wave does reflect a memory process, the general problem with using this activity as a neural correlate of WM is that it is non-specific with regard to the items that are being held in WM. Consequently, it is difficult to disentangle the memory processes from other task- general processes such as arousal, attention, or simply the anticipation of making a response. More recently, Klaver, Talsma, Wijers, Heinze, and Mulder (1999) have reported a similar ERP component that appears to provide a more specific measure of maintaining information in visual WM. In this study, subjects were presented a display containing two abstract shapes (one in each hemifield) and were cued to remember the item on either the left or right side of the display over a 1500 msec blank interval. Shortly following the onset of the memory array, a negative wave was observed at posterior electrode sites that were contralateral to the position of the memory item which persisted throughout the retention period.

This sustained contralateral activity is potentially a good candidate for a neural correlate of visual WM because it provides more specific information with regard to the position of the remembered item, which makes it less likely to be due to more task-general processes.

The CDA (Contralateral Delay Activity) is a lateralized ERP component that reflects the encoding and maintenance of object representations in VWM (McCollough, Machizawa, & Vogel, 2007; Vogel & Machizawa, 2004), and is sensitive to the individuals ability to exclude irrelevant items present in the memory display (Vogel et al., 2005). The CDA is maintained during the delay period of lateralized visual working memory tasks such as change detection. CDA amplitude increases as a function of the number of items that the subject is currently holding in visual WM and reaches an asymptotic limit for array sizes of 3–4 items. That is, the CDA reaches asymptote at the same set size as behavioral measures of memory capacity and is different for each subject depending on individual memory capacity. Therefore, the CDA provides a measure of the number of items currently in memory and is also sensitive to individual differences in distractor exclusion and item maintenance.

1.2. Gestalt Grouping and Figure Completion

Max Wertheimer described figural Gestalt Grouping principles in his classic 1932 monograph, “The Laws of Organization in Perceptual Forms”. He described basic rules by which the visual world is organized into forms or objects that are perceived:,figure/ground articulation, proximity, similarity, common fate, continuation, good gestalt, past experience, closure etc.(Wertheimer, 1938; Westheimer, 1999). More recently, perception researches have proposed principles of common region, (S. E. Palmer, 1992) convexity (Liu, Jacobs, & Basri, 1999) and element connectedness (Han, Humphreys, & Chen, 1999). It is important to note that this taxonomy is concerned with what is subjectively perceived, and that each principle holds, ceteris paribus, the other grouping principles. A detailed hierarchy describing which Gestalt principle dominates over others has not yet been determined, however, generally when Gestalt principles cohere, they increase the perceived grouping strength of the figure, while in cases of competition the overall perceptual organization of the figure is degraded or the figure becomes perceptually ambiguous. The canonical gestalt grouping principles are as follows: similarity, continuation, closure, proximity, figure/ground, common fate, good gestalt, past experience. Similarity is the principle by which items are grouped together which share some common feature such as shape, color, orientation etc. Good continuation is describes that items will be grouped together if they perpetuate or continue some global aspect of the figure. Closure describes the situation where elements or lines complete a figure by forming a closed boundary. Common fate describes the grouping together of elements which share movement, that is move in the same way. Good gestalt refers to the grouping of elements which provide the simplest grouping out of many possibilities. Past experience describes how some elements of a figure may be grouped together because in the past they have always been grouped together, not from any particular perceptual grouping properties (Wertheimer, 1938).

Modal and amodal completion are also common perceptual phenomena which aid in parsing the visual world. These terms refer to the process by which elements in a display are unified by the perception of a single whole in one of two modes, modal or amodal. Modal completion refers to such perception when the completed parts are out of sight and based on the visible elements, the completed percept possess actual visual properties: color, contour etc. Amodal completion refers to the perceptual completion of a figure behind an occluding form, in this mode there is no visual percepts associated with the amodally completed object. As in interesting aside, these processes appear to be evolutionarily conserved, evidence for the perception of illusory figures has been observed in monkeys, cats, fish and even insects (Grosof, Shapley, & Hawken, 1993; Chen, Zhang, & Srinivasan, 27; Sovrano & Bisazza, 2009). This highlights the critical nature of these mechanisms for visual processing across species.

1.2.1. Completion

Completion processes aid in separating figure from ground. Objects in front of the background. Modal completion completes objects in the foreground, amodal completion completes objects that are in the background and occluded by foreground objects. That is, foreground objects which are camouflaged and background items which are partially obscured. Earlier studies of the time course of perceptual completion showed that modal completion occurs within 100 - 200 ms, and shorter presentations leave the fragmented figures uncompleted (Ringach & Shapley, 1996) There are two kinds of completion processes, modal and amodal. Completion of camouflaged objects, that is objects in the foreground, Figure 1.1. on page 21 , is called modal completion, since these type of figures are completed "in the visual mode" such that actual percept of contours, contrast, color etc. is perceived. This is in contrast to objects which are partial occluded by foreground objects and are amodally completed (Kanizsa, 1985; S. Palmer, Neff, & Beck, 1997). These since the objects are completed behind the occluder without any perceptual component, as in the outline of the triangle in Figure 1.1., for example.

There is debate over weather illusory figures are generated in a bottom-up manner utilizing neural paths laid down early in development, or generated in a top-down process that utilizes later cognition. These figures are supported by illusory contours constructed by the visual system based on perceptual input but without an actual visual contour being present. Such subjective contours, as simply created by Kanizsa figures, are constructed by arranging elements, or inducers, that produce the illusory contour (Singh, Hoffman, & Albert, 1999). They have been shown to be created by re-entrant feedback between V2 and higher areas and low-level processing in V1 (Lee & Nguyen, 2001; Mendola, Dale, Fischl, Liu, & Tootell, 1999; Murray, Schrater, & Kersten, 2004) The amodal completion occurs at early stages of the visual system: amodal completion of contours in macaques and humans has been observed in V1 (Sasaki, 2007). However, there is considerable debate as to whether modal and amodal completion reflect the output of a single processes or multiple processes.

The segregation of background and foreground, established by depth information, may be the mechanism which drives boundary ownership, which in turn drives modal/amodal completion mechanisms(B. L. Anderson, Singh, & Fleming, 2002; B. Anderson, 2007). A controversy exist as to whether identical underlying processes drive the formation of Amodal and modal contours, however, and while a consensus has not yet been reached, there are several distinctions which can be made. Using stereoscopic displays, and thus identical information, binocular disparity can be used to force the percept of either modally completed figures or amodally completed figures using visually identical stimuli and only switching which eye sees which stimulus, e.g. this Figure 1.3. on page 24 from B. L. Anderson et al. (2002). In contrast to predictions of the strong "identity hypothesis" these figures produce markedly different percepts, such as in the serrated edge illusion (B. L. Anderson et al., 2002;

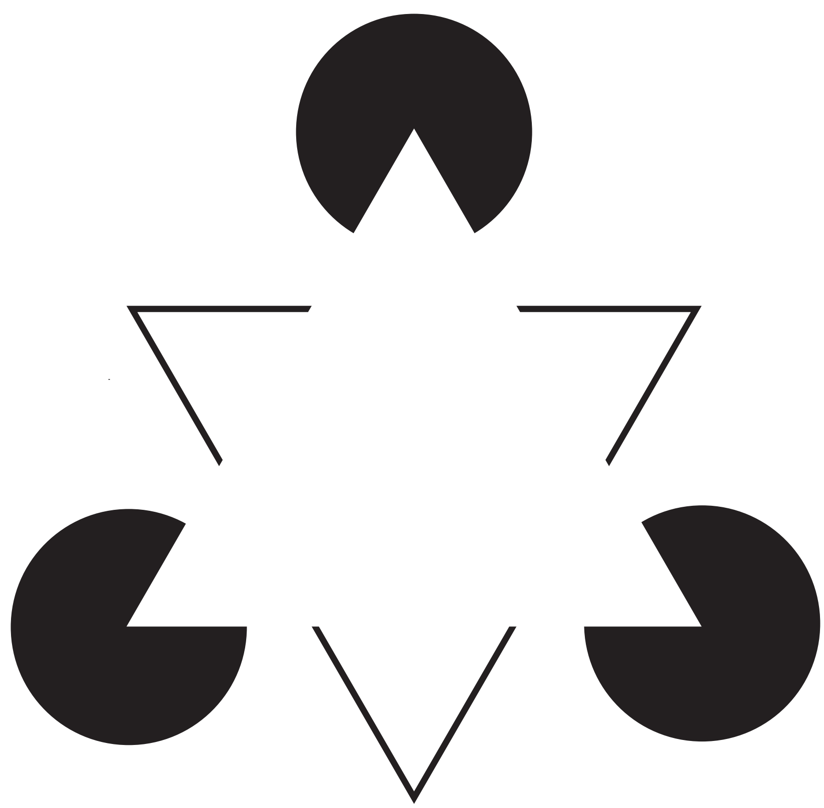

FIGURE 1.1. Kanizsa Figure

B. L. Anderson, 2007). See Figure 1.2. on page 23 for examples. This demonstration makes it difficult to suppose that a single completion process can produce different structures and contours.

Neural evidence also supports the dissociation of modal and amodal processes. A amodal completion occurs earlier in the visual stream, as early as V1 and in the initial feedforward processing of visual information, under some accounts. However, V1 activity for illusory, modal contours has also been observed, but later and subsequent to illusory-contour activity in V2 and LOC (Lee & Nguyen, 2001). Further, modal completion is differentially affected by disease conditions such as simultanagnosia.(Milner, Perrett, Johnston, & Benson, 1991; Huberle, Rupek, Lappe, & Karnath, 2009), as well as having a different time-course of development, with modal completion developing earlier in normal neonates (Otsuka, Kanazawa, & Yamaguchi, 2006).

Theoretical approaches to Gestalt grouping have been from either a bottom-up, stimulus driven manner, or from a top-down, higher cognition manner. The gestaltists tend to favor a bottom-up approach, while others have attempted to explain the origin of Gestalt principles as visual heuristics which are derived from the natural image properties of the visual environment. At some level, these two approaches do not differ, fundamental properties of the perceptual system have become fundamental because they are selected for in this environment. What is more to the point is to what degree these perceptual rules are obligatory, if they are learned or not, and to what extent visual experience can engender or modify gestalt principles. The work of Pawan Sinha, for example tends to favor the learned approach; cataract surgery on congenitally blind children have demonstrated an initial inability to perceptually group in an appropriate way, but after just a few weeks, perceptual grouping occurred

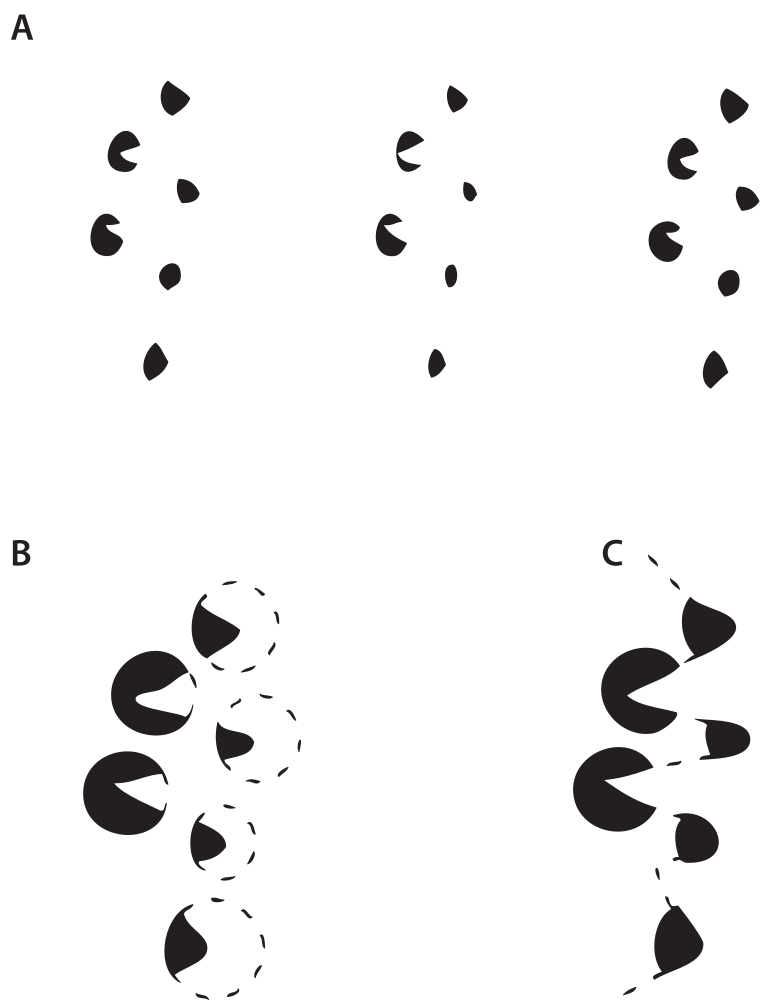

FIGURE 1.2. Serrated Edge Illusion

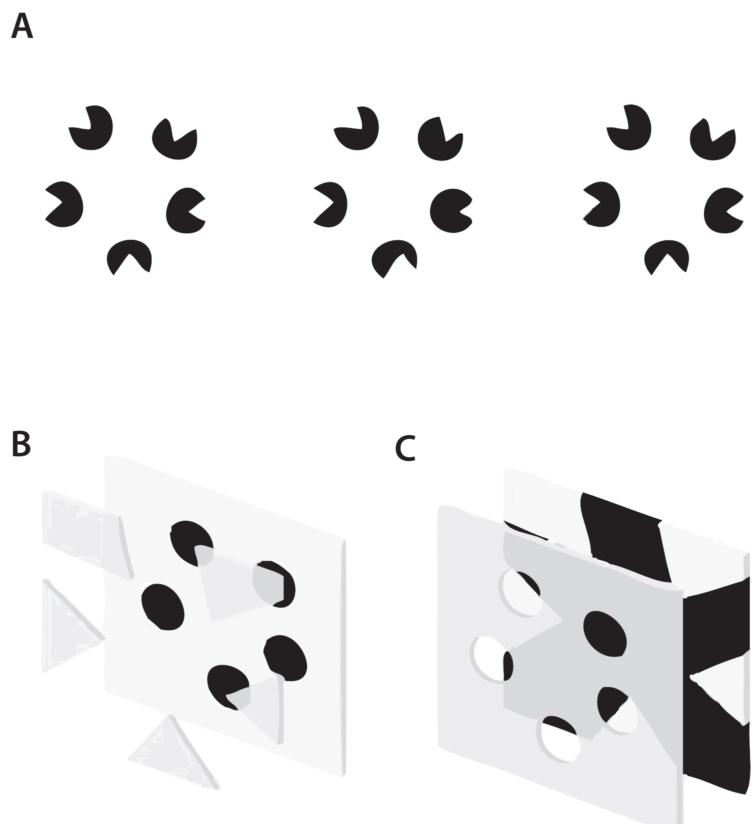

FIGURE 1.3. Star Edge Illusion

(Ostrovsky, Andalman, & Sinha, 2006; Ostrovsky, Meyers, Ganesh, Mathur, & Sinha, 2009; Kimchi & Hadad, 2002).

1.2.2. Development and Disorders

Importantly, Gestalt grouping is not only a matter of perception or the ability of individual to make sense of the visual world. Or rather, since perceptual grouping is a core cognitive ability which develops over the lifespan, and central to the visual systems ability to decode the world, is necessarily of importance. Perceptual grouping can be perturbed by visual disorders, and thus neuropsychological studies can use failures of perceptual grouping to better understand the system as a whole. Attentional deficits are reduced when gestalt grouping cues are used across the midline (Brooks, Wong, & Robertson, 2005)and extinction in Balint's syndrome can also be eliminated using gestalt grouping (Riddoch, Rappaport, & Humphreys, 2009) cues. There is impaired global processing in autism(Scherf, Luna, Kimchi, Minshew, & Behrmann, 2008), indexable using grouping cues, and visuospatial organization is disrupted in patients with schizophrenia (Anne, Assche Mitsouko, Caroline, & David, 2010). Organic damage can also impair gestalt grouping, as in a clinical case study of a woman with visual form agnosia, who, despite normal visual acuity and intelligence showed an inability to use Gestalt cues of proximity, continuity, or symmetry.(Milner et al., 1991). Nonetheless, patient D.F. was able to read words, and discriminate orientations, hence failure to process whole figures was not caused by a deficit in low-level edge or orientation detectors per se, but rather a deficit in the perception of higher-level figures. Her lesion was located in lateral occipital cortex. EEG studies of gestalt perception in schizophrenia have also demonstrated poorer recognition of gestalt stimuli (contour grouping in a texture field) than controls, (Vianin et al., 2002). Modulation of the P300, which is commonly taken to indicate updating of visual working memory, and modulate in categorization tasks, was also reduced in schizophrenic individuals compared to controls (Vianin et al., 2002), providing evidence for a deficit in the integration or mis-integration of information this condition. Studies of patients with hemispatial neglect have shown that perceptual grouping may occur independently of attentional allocation.(Shomstein, Kimchi, Hammer, & Behrmann, 2010) Patients were asked to perform a fine same/different judgement of checkerboard patterns, while in the neglected hemifield a corresponding grid of dots grouped by color into either horizontal or vertical stripes was presented. The grouping array was then either changed or not. Behavioral data indicated that there was a congruency effect caused by the perceptually grouped array, despite being consciously unavailable to the subjects. Notably, this effect was greater for neglected distractors than unattended distractors (when the irrelevant grouped items were presented in the same hemifield), providing further evidence for the dual role of attention in both enhancing target processing as well as suppressing irrelevant distractors. In the same-hemifield (ipsilesional) condition, for both patients and controls, attention could operate normally, however, when the distractors were in the contralesional hemifield, normal attentional suppression did not occur. However, simultaneous changes on left and right hemifields were detectable by an extinction patient when those changes produced an illusory object, but not otherwise.(Mattingley, Davis, & Driver, 1997) Huberle et al. investigated whether temporal as well as spatial integration mechanisms are disrupted in simultanagnosia, they presented patients and controls with shape-from-motion and biological-motion point-light displays which require integration of local cues over time in order to perceive the figure. They found preservation of the identification of biological motion displays, but not for object recognition in shape-from-motion displays. Thus arguing both for dissociable processes for general object and specific biological motion detection, as well as an arguing against working memory per se as being the cause of impaired global shape perception (Huberle et al., 2009). Further evidence of the utility of gestalt cues at understanding the underlying cognitive disfunction comes from dynamic and static visual memory paradigms. In the ball flight task, an object moves across a screen and then after a delay a static ball "trajectory" is displayed. Schizophrenic patients demonstrated a selective recency strategy, memorizing the last 3 or 4 end segments, compared to controls who showed no bias. In a static version of the task, essentially a working memory change detection task with a single, complex line, schizophrenics again demonstrated a deficiency in the integration of the separate line segments into a unified whole (Cocchi et al., 2007).

1.2.3. Attention and Gestalt Processing

In what way is perceptual grouping influenced by attention? ERP studies of early visual components have demonstrated attentional spreading across visual objects, as indexed by enhanced performance on detection tasks (Duncan, 1984; Egly, Driver, & Rafal, 1994) or increased increased amplitude for the P1 or N1 to probes on objects or at equidistant locations.(Luck, Heinze, Mangun, & Hillyard, 1990; Mangun & Hillyard, 1991; Heinze et al., 1994; Mangun, Buonocore, Girelli, & Jha, 1998; Hillyard, Vogel, & Luck, 1998; Hopfinger, Buonocore, & Mangun, 2000; Hopf, Vogel, Woodman, Heinze, & Luck, 2002; Martínez et al., 2006).
Similar behavioral effects have been found for subjective figures, (Dodd & Pratt, 2005), slowed reaction time for subjective figures in attentive processing (Pritchard & Warm, 1983) ERP components & attention Several components of the visual

evoked ERP have been shown to be sensitive to modulations of attention, particularly early components of the visual evoked potential, the N1 and the P1. These early components have been shown to be enhanced at at locations or objects which are attended, compared to items or locations which are unattended (Mangun et al., 1998). This enhanced component amplitude has also been shown to spread through an object, such that locations within an object also show increased response to probes, compared to equidistant locations in an unattended location or on an unattended object (Martínez et al., 2006). Similar attentional effects, both behavioral and electrophysiologically, have been found in subjective objects, such as Kanizsa triangles or amodal rectangles. For example, attention has been shown to confer similar advantages in search task using real, illusory, and occluded objects. When attention was directed at a part of an object, whether the object is defined by contours, illusory contours, or is partially occluded, other parts of the object show advantages.(C. Moore, Yantis, & Vaughan, 1998) Similarly, Davis and Driver (1994) showed that in search for illusory objects may occur in parallel in a pop-out task, but search was impaired for targets which appeared behind illusory objects. Specifically, search for a notched circle among whole circles and Kanizsa illusory objects was serial when the notch of the circle was located same position as a Kanizsa inducer, so that the circled appeared to amodally complete behind the illusory figure (Davis & Driver, 1994, 1998).

Using Kanizsa inducers arranged in a square Korshunova showed that the N100 response greater from the figure when the the inducers were arranged to form an illusory square compared to when the inducers where orientated to prevent illusory contour formation (Korshunova, 1999). In another experiment, analogous to the Egly and Driver study discussed above, Han et al. cued ends of subjective rectangles and showed that the contralateral N1 was enhanced for both modally and amodally completed rectangles. (Han, 2004) These results were replicated by Proverbio et al. in a subjective square detection task using modally completed figures, again Kanizsa stimuli. In this task, foveally presented Kanizsa inducers were oriented to either produce a subject illusion or not; both symmetric and asymmetric inducers were used and they topographically mapped the ERP responses. They found greater N1 response in trials in which the inducers formed illusory squares than when the inducers did not form a subjective square (Proverbio & Zani, 2002) Extending these findings, van der Helden replicated the Egly & Driver cued object advantage data with modally and amodally completed figures. RTs were faster and early ERP components (the N1) were greater for both modally and amodally completed objects (Helden, 2010). This is particularly interesting in that this provides evidence against purely low-level accounts of object formation, such as texture or continuous contours as entry-level representations (S. E. Palmer, 1992). However, larger N1s have been found for modally completed compared to amodally completed or randomly oriented Kanizsa inducers (Brodeur, Lepore, & Debruille, 2006). The Davis and Driver results have been further supported by evidence that illusory figures influence attention comes from a visual search and cueing experiment. In the first experiment Kanizsa triangles lead to rapid, pop-out in a complex search, in the second experiment the Kanizsa figures were used to as non-informative cues in a choice-RT task. The contralateral N1 to the target was greater when the Kanizsa triangle was a valid cue compared to invalid or no-target trials (Senkowski, Röttger, Grimm, Foxe, & Herrmann, 2005). Taken together, these studies support the hypothesis that the objects of attention are objects and that these objects are direct the distribution of attention at an early stage. If so that is the case, what might be the underlying neural substrates of perceptual grouping? Initial demonstrations of the locus of the neural correlates of perceptual grouping early in the visual stream comes from single-unit recording studies of the macaque visual cortex. Illusory figures (both Kanizsa triangles and "wrench head" inducers) elicited single-unit responses in area 18 (V2), though not in area 17 (V1). These responses were sensitive to manipulations of the illusory contours which strengthen or weaken subjective illusions in humans (non-linearity, distance, contrast) even if the inducers themselves were not in the receptive field of the recorded neurons (Heydt, Peterhans, & Baumgartner, 1984). But see Grosof et al. (1993) for evidence of illusory contour response in V1. These data are in accord with a model of perceptual completion proposed by Grossberg. In this model, contour completion is accomplished through feed-forward and feedback loops in V1 and V2, with longer-range connections being supported by V2 activity and feedback through the LGN (Grossberg, Mingolla, & Ross, 1997). Dynamics of subjective contour formation in the early visual cortex(Lee & Nguyen, 2001)

fMRI studies have also found evidence in humans that perceptual grouping early in visual stream. Murray et al. demonstrated that line segments organized in to 2D or 3D shapes increased activity in LOC while simultaneously decreasing activity in V1, compared to the same line segments when randomly displayed. Structure from motion displays are stimulus displays in which individual elements are perceptually joined together by their common movement, a form of Gestalt common fate grouping. In a subsequent experiment Murray et al. used exactly such SFM displays in contrast to velocity-scrambled displays to replicate their results (Murray et al., 2004; Murray, Kersten, Olshausen, Schrater, & Woods, 2002). Similar results have been reported by others. Intriguingly, there is evidence from fMRI that the formation of a perceptual group may reduce activity in visual cortex. Object parts which were arranged to suggest objects reduced activity in primary visual cortex, compared to when the same parts were distributed randomly. This decrease in V1 activity was associated with increased LOC activity, providing further evidence for feedback models of perceptual organization (Fang, Kersten, & Murray, 2008). See also (Stanley & Rubin, 2003; Han, Song, Ding, Yund, & Woods, 2001; Mendola et al., 1999; Seghier & Vuilleumier, 2006) for similar results. This may be taken as evidence that the perception of visual objects requires interaction between areas of the visual cortex, and early activity in V1 is not simply a reflection of the incoming visual stream, but instead shows that even the earliest cortical processing stages reflect re-entrant processing that must be understood in terms of non-linear feedback cycles. However, see Ffytche and Zeki (Ffytche & Zeki, 1996) for evidence suggesting that V2 is capable of processing illusory contours in isolation.

As the majority of tasks reviewed presented the stimuli foveally, or directed attention to the stimuli, another question which arises is whether or not perceptual grouping, requires attention to operate, or does it act "pre-attentively." Feedback models do not necessarily address this question. There have been several attempts to answer this question (Driver, etc) through both behavioral tasks as well as using ERP components to index the rapid allocation of attention within and between objects. With some authors contending that attention is necessary to form subjective figures (Rock, Linnett, Grant, & Mack, 1992; Mack, Tang, Tuma, Kahn, & Rock, 1992; Pritchard & Warm, 1983) and others arguing that attention is not necessary (C. Moore et al., 1998; C. M. Moore & Egeth, 1997; C. M. Moore, Hein, Grosjean, & Rinkenauer, 2009; Lamy, Segal, & Ruderman, 2006; Kahneman & Henik, 1981). The Mack et al. results have been explained by the fact that, rather than subjects reporting whether there was grouping or not, subjects reported their memory of whether there was grouping, in this inattention task. Unfortunately, a results from the inattentional blindness literature has demonstrated that items which are unattended are typically not reportable and thus these negative results may be interpreted as the subjects' failing to remember the items, not necessarily failing to perceive them.

To summarize, the literature is divided on the degree to which attention is required for perceptual grouping or completion, whereas other questions of timing and which neural areas are involved have achieved much more of a consensus. Though see ((S. Palmer, 2002)) However, of more interest here is the effects of perceptual organization principles on active visual representations. It is apparent from the above review that perceptual grouping occurs early in the visual stream, it is able to influence the distribution of attention, and that subjectively completed objects are similar to other types of objects and direct attention in a similar manner. Evidence from visual search shows parallel, rapid detection of illusory figures, and that illusory figures are able to hide the presence of targets. Completion, whether modal or amodal appears to occur in V1 and V2, with interaction and feedback from higher cortical areas such as LOC, and that organized percepts reduce BOLD activity in striate cortex. However, it is still an open question as to whether the reduction in early cortical activity corresponds in some manner to a reduction the resources required to maintain the active visual representation.

1.2.4. Discussion

As can be seen from the above review, Gestalt grouping and completion phenomena are fundamental to the way in which the visual system across species creates the subjective visual percept. These mechanisms are dysfunctional in disease, develop over time, depend on visual experiences to develop, and underlie the visual experience. These phenomena are cornerstone to the way in which the visual world is organized, perceived and represented in memory, and therefore it is important to further develop our understanding of visual memory. In the next section studies which have examined the interaction between visual memory and gestalt principles will be reviewed.

1.3. Objects, Grouping and Multiple Object Tracking

Chunks are commonly defined as, "A collection of elements having strong associations with one another, but weak associations with elements within other chunks." (Gobet et al., 2001). The extensive literature on expertise and memory contrasts with the relatively few studies which have examined expertise effects on visual working memory, or the effects of perceptual grouping phenomena in particular on the storage and maintenance of items if memory. This is especially surprising considering the well-known confound of chunking in attempts to establish baseline figures of merit for visual working memory, such as encoding speed, maintenance capacity, retrieval precision etc. See Cowan (2001) for a review of paradigms designed to reduce the contributions of long term memory and chunking. In some theoretical views the elimination of long-term contributions is not even possible (Cowan, 2008), since the representation itself is by definition reactivated long-term memory representations. In any case, the quantification of the grouping effects is a desirable goal. Specifically, understanding how does perceptual grouping affect items in memory in terms of the quantity, organization, or type of the visual representation? Several early attempts to quantify the nature of visual chunking mechanisms in working memory used dot stimuli. Wilton and File (1975) used memorized random patterns and asked subjects to report the relationships between selected dots.

Quadrants were drawn on each dot and subjects responded with the quadrant through which a line would pass from the center of X to Y. Some of the possible relationships were eliminated by blacking out certain quadrants so that the number of dots and the number of spatial relationships could be varied independently. Subjects' responses depended on the number of dots they were required to memorize, but not on the number of relationships between. Thus, it appears that knowledge of spatial relationships in this experiment was computed as necessary rather than drawing on a store of memorized relationships. In a subsequent experiment they demonstrated that subjects' accuracy on a old/new task using memorized patterns was greater on trials that used dots from a memorized pattern that were located near to each other in the pattern than on trials in which the probe dots were selected at random from the memorized pattern. This was used as evidence to suggest that subjects group the memorized dots into higher order patterns which are subsequently more easily recalled. By analogy, imagine a picture of a president in which only a few points are sampled at random: the image would be difficult or impossible to identify. On the other hand, if the same number of points were clustered together some feature may be revealed in sufficient detail to enable the recall of the entire face (Wilton & File, 1975). A more pertinent attempt to the study of visual working memory was Bartram 1978 who examined, as it was termed, "post-iconic visual storage" using a tachistoscopic reconstruction, or recall paradigm with random dot figures. Subjects were presented with patterns of dots in a four by five array and then recreated the pattern on demand. The first experiment showed that subjects tended to recall the dot patterns in spatial clusters, or chunks, consisting of three or four spatially adjacent discs when the order or of recall was unconstrained. When the order of recall was constrained, e.g. top-down or bottom-up, subjects attempted to create these chunks in accordance with the recall constraint. Bartram suggested that items are encoded according to the distribution of attention across the visual field, and this distribution influenced by both visual information (the a priori distribution of dots in the unconstrained condition) as well as being flexible enough to organize chunks to best satisfy task demands, as when the order of recall was constrained. (Bartram, 1978) Similarly, Woodman et al. asked subjects to detect color changes in squares arranged according gestalt principle of proximity. In a change detection task, a single item in the memory array was pre-cued, directing attention to a specific quadrant of the display. The items in the memory array were arranged according to gestalt principles of proximity (Experiment 1) or connectedness (Experiment 2). After a brief retention interval, subjects responded as to whether a single cued item in the whole-probe test array had changed color or not. Change detection accuracy was greater for items at the cued location than other locations, and greater in the larger set size for items in the cued perceptual group. Similar results were found for connectedness cues as well, indicating that perceptual grouping can influence which items are selected for representation in memory (Woodman et al., 2003).

1.3.1. Benefit of Objecthood

Correspondingly, evidence has accumulated that supports an object benefit in visual working memory. Across several paradigms and methodologies converging evidence suggests that the information represented in visual memory is encapsulated to form a unitary construct. The exact form of that representation is not yet known, however, the representation (Xu, 2002) appears to be flexible, depends to some degree on prior experience, is influenced by gestalt cues etc. Amodal completion has been used to study object affects on visual working memory capacity. When eight colored line segments were presented such that a gap divided collinear segments, individual's working memory capacity was less than when when a task-irrelevant occluder filled the gap and allowed modal completion to connect the line segments. (Walker & Davies, 2003). These data suggest, along with Luck and Vogel (1997), that the basic units of visual working memory are objects, not unbound features, and that multiple feature values are better stored within an object then segregated among several objects. In a series of experiments using conjunctions of features, Luck & Vogel showed that change detection accuracy for multiple features within objects incurred no cost, compared to when subjects were required to detect changes in single features. Similarly, in a fMRI experiment, simple objects grouped by placing them within an enclosure were better recalled. In addition, fMRI BOLD activation in the inferior intra-parietal sulcus tracked the number of composite (grouped) objects rather than the number of simple elements (Xu & Chun, 2007). In a series of change detection studies with objects composed of parts, subjects detected changes better when the features can from the same part of an conjoint object rather than different parts or from disjunct parts (Xu, 2002). These results were replicated when subjects remembered multiple features, colors and orientations, of objects consisting of a body and tail. Again, co-localized features were remembered better than when features were distributed over separated parts, or when an occluder obscured the junction between the parts. This is in contrast to Walker and Davies (2003), however, in this case the occluded parts differed across feature dimensions as well as proximity or connectedness. Further experiments contrasting proximity and connectedness demonstrated that element connectedness conferred greater "object hood" and a greater accuracy benefit than proximity alone (Xu, 2006). But see a contrasting viewpoint suggesting that the benefits observed may be due to global configurations (Delvenne & Bruyer, 2006). The issue of a configuration effect on working memory was also taken addressed by Jiang et al. using multiple types of conjunction stimuli. As noted above, the relationship of parts and wholes, as shown above, is important for the creation of subjective objects. However, the interrelationship between elements or objects in the scene may also be important for memory storage. Jiang et al. demonstrated an asymmetric effect of global item configuration on color change detection accuracy such that changes in global configuration reduced performance, even if the item to be probed was cued in advance of the test and showed an effect of type of test (single or whole probe) on change detection, interpreting these results as providing evidence that some color information may be stored relationally. However, these experiments also allowed multiple repetitions of colors and this may have encouraged other forms of grouping. It is well known that such chunked information is better recalled when recall is prompted within rather than across chunk boundaries. Breaking such configurations may be one mechanism by which accuracy was reduced in the single probe condition. Subsequent experiments replicate similar studies by Walton and file, showing that visual memory for spatial locations is utilizes ad hoc configurations to enhance performance and test arrays which break these configurations reduce performance (Jiang, Chun, & Olson, 2004; Jiang et al., 2000). Concluding that grouping affects representation even when the grouping is irrelevant. As will be seen, this is not the case for some kinds of stimuli.

1.3.2. Multiple Object Tracking

Even a simple activity such as watching birds in flight requires the ability to attend multiple moving objects in the visual world. This ability is known to be highly limited, such that on average only about four items may be followed at any one time

(Z. W. Pylyshyn & Storm, 1988; Scholl, Pylyshyn, & Feldman, 2001; Cavanagh & Alvarez, 2005). However, how these items are selected and tracked through their movements, and the characteristics of their representations during tracking are not well understood.

In the basic multiple object tracking (MOT) paradigm, a number of items are presented on the screen and a subset of those items are designated as targets during a cue phase. Subsequent to the cueing phase, all the items become identical and begin to move around the field of view, this is termed the tracking phase. finally, all the items stop moving and a single item is selected to be probed. Participants then indicate whether the probed item was or was not a member of the original set of target items (Z. W. Pylyshyn & Storm, 1988).

This task can be conceptually divided into several cognitive phases: first, targets must be located among distractors, then those target items must be maintained as target items, and finally the probed item must be assigned to either the target set or distractor set during probe phase. The underlying cognitive and neural processes supporting these divisions are not fully understood, and there are several competing models and debates over specific aspects of those models within the literature (Z. W. Pylyshyn & Storm, 1988; Scholl et al., 2001). The are several controversies which have arisen concerning the nature of multiple object tracking. Those controversies fall into three main groups: debates of the nature of the items to be tracked, the "what is tracked" question. Arguments over how these items, however defined, are tracked, and finally, what are the nature of the limits (capacity, identity etc) of multiple object tracking. I will only specifically address the debate of what the nature of active representations may be in MOT, and how tracking them maybe accomplished.

Some questions arise in multiple object tracking. first, what exactly is tracked? Objects, features, locations etc. Secondly, how is that tracking accomplished? Finally, what kinds of limitations constrain performance in MOT? Evidence from Scholl et al suggest that what is tracked is an object. In their experiments, subjects tracked four targets among four distractors. In the critical condition, targets were joined to distractors by lines so that target-distractor pairs formed extended objects, or barbells. Though subjects could track four targets independently when there were eight total objects in view, when their where only four objects, yet joined as target-distractor pairs, subjects could not track the targets at all (Scholl et al., 2001). Further evidence from VanMarle and Scholl (2003) demonstrated that objects where easier to track than equivalent displays in which the subjects were required to track substances instead. Finally, recent neural data from Drew and Vogel (2008) have also demonstrated ERP component which closely indexes the number of items accurately tracked regardless difficulty manipulations, spacing etc. There are several models which have attempted to address the question of how the tracking of objects is accomplished. These models, broadly defined, consist of models of pre-attentive indexes, single focus attentional switching, grouping items within a single focus or multifocal attention (Cavanagh & Alvarez, 2005; Howe, Cohen, Pinto, & Horowitz, 2010; Z. W. Pylyshyn & Storm, 1988; Yantis, 1992). Furthermore, whatever model is chosen it must attempt to answer first, how items that are to be tracked are selected, and secondly, the and updating process which maintains tracking of those items during the tracking period (Alvarez & Scholl, 2005; Z. Pylyshyn, 2006).

The MOT task was initially developed to test ideas concerning the visual indexing of objects in the visual world in order to attempt to ground cognitive concepts with preconceptual objects. That is, it is logically necessary in order for concepts to exist that pre-concepts must also exist. Therefore, for those concepts to be attached to items in the real world, there must be some mechanism which itself does not depend on pre-existing concepts in order to bridge the gap between concept and object. Hence the idea of FINST, or fingers of INSTantiation. In the same way that a child which does not posses the word for "moon" can nonetheless point to the object in the world, Pylyshyns "FINST"s can index (literally, point) to objects in the world without recourse to existing concepts in the mind; thus providing a demonstrative mechanism for situating visual cognition within the world. A further, crucial aspect of FINSTs is that provided an extended means of indexing the individual item across time without respect to specific features or locations that that item may have (Z. W. Pylyshyn & Storm, 1988). As applied to MOT, FINST pre-attentively indexes some number visual objects which attentional functions of feature binding or recognition may or may not then operate over. In the original conception, these indexes are "sticky" and automatically track the targets. Many researchers have pointed out that this is contrary to the subjective difficulty of this task, and the necessity of continuous attention to the targets in order to prevent the targets from being lost during the tracking phase. However, the alternative of rapidly switching singular focus of attention was shown to be a poor explanation for the tracking data, and other researchers have shown switching times to exceed fastest estimates of the reallocation of spatial attention (Yantis, 1992; Cavanagh & Alvarez, 2005).

Experiments from visual search have demonstrated that while pre-attentive objects exist, they exist as unbound (un-categorized or within-object perceptually organized feature-bundles) (Wolfe & Bennett, 1997). Thus, in MOT, the property of an object on the screen, and one that is blinking, requires the active binding of attention. Hence the limited number. However, all items on the screen are indexed. That is, some information about all the items on the screen is known pre-attentively. However, if attention slips, then the binding of the target concept to a particular instance of a moving item on the screen is lost. Pylyshyn is correct in that ontologically demonstratives are required, however, he goes to far in proposing that these pre-attentive processes are further able to maintain information about the items they are tracking. Rather, these are pointers, demonstratives, which in fact do not contain or retain information about the items on the screen per se. As described by Z. W. Pylyshyn and Storm (1988):

> (1) Early visual processes segment the visual field into feature-clusters which tend to be reliable proximal counterparts of distinct individual objects in a distal scene; (2) Recently activated clusters compete for a pool of four to five visual indexes or FINSTs; (3) Index assignment is primarily stimulus-driven, although some restricted cognitively mediated processes, such as scanning focal attention until an object is encountered that elicits an index, may also result in the assignment of an index; (4) Indexes keep being bound to the same individual visual objects as the latter change their properties and locations, within certain as-yet-unknown constraints (which is what makes them perceptually the same objects); and (5) Only indexed objects can enter into subsequent cognitive processes, such as recognizing their individual or relational properties, or moving focal attention or gaze or making other motor gestures to them.

This may be explained by asserting that the indexing process is automatic and operates continuously and promiscuously: attention is needed to prevent distractors from becoming indexed. Indeed, even after attention is applied to an item, Wolfe et al. have demonstrated that post-attentively no perceptual information is maintained about that item in visual search tasks, with obvious application to MOT (Wolfe & Bennett, 1997). If MOT is considered as a series of instantaneous search tasks. When considered in this light, the FINST theory is less a model of how MOT is performed and more a model of how items in the world are connected to their object files. Thus, while FINST fails as a model of MOT, it may succeed as a bridge from pre-conceptual things in the environment (FINGS) to recognized objects. In this view, all (or some large subset) of items are indexed as existing by FINST, but attention is required to maintain specific identity of distractors and targets. In a related paper, Wolfe, Klempen, and Dahlen (2000) further showed that while conceptual knowledge of a scene may build up over repeated scans, the perceptual qualities of items in a scene, particularly the binding of multiple features into coherent objects, are not maintained after attention has shifted to a new item or location.

Leaving FINST aside, there are two other general categories of MOT models: singular attentional spotlight (usually considered to be a rapid serial deployment of attention model or grouping) and multifocal attention. Singular attentional spotlight admits of only a single focus of attention that is either rapidly shifted from tracked object to tracked object, or in the case of Yantis' grouping models, tracks a single multi-vertexed polygon. The multifocal model of attention allows attention to be split over multiple locations, simultaneously following individual tracked items. As mentioned above, the serial, rapidly shifting models of singular attention are effectively defunct, since data from several experiments have demonstrated that attention in such a model would be required to shift from object to object at speeds far exceeding the most optimistic estimates of attentional shifts.(Yantis, 1992; Cavanagh & Alvarez, 2005; Z. W. Pylyshyn & Storm, 1988). However, it is known that attention can spread within an object, and that perceptually grouped items as well. Thus, if it is possible to group multiple items into a single, composite unit (imagine tracked items as the vertices of a polygon), then it should be possible to track that unit as a whole with a single focus of attention on a gestalt object. Steven Yantis performed several experiments to determine whether or not MOT may be explained as a singular spotlight tracking just such a composite object. In a series of seven experiments he showed that tracking performance may be improved by presenting the items to be tracked in arrays which support perceptual grouping processes, or by suggesting a grouping strategy to participants. Further experiments demonstrated that subjects were better able to track items when those items shared a common fate, and failed at tracking when targets and distractors were similarly bound together by common motion. This evidence was taken to support a model in which subjects effortfully track a single, composite object constructed by pre-attentively grouped elements using a singular focus of attention (Yantis, 1992). According to this model of MOT, the constitution of an object depends on the perceptual grouping processes in play and these grouping processes may be modulated by task, attention, or other top-down influence independently of the effects of stimulus-driven processing. This is in contrast to the FINST model, in which the computationally intensive tracking task is performed automatically by early, cognitively impenetrable processes, and in accord with object-file concepts of Kahneman and Treisman, at least so long as the object files can be composed of at least spatially and potentially featurally disparate items (Dam & Hommel, 2010; Scholl et al., 2001; Yantis, 1992). Finally, the model of multifocal attention has received much support, and in fact may be the best model to date. In this model, attention is simply split among each of the target items, up to some limit. There is considerable converging evidence that, contrary to the prior, widespread belief that attention is limited to a single location or object, in fact attention may be split between two or more locations, limited to as many as four(Awh & Pashler, 2000), and this limit converges with estimates of memory capacity. If this is the case, as it seems to be in MOT as well, then items may be tracked by continuously monitoring the disparate items in parallel, updating spatial references as necessary. This concept is supported by behavioral as well as recent neural tracking data (Drew & Vogel, 2008) , as well as evidence from measuring the enhancement of early ERPs on tracked targets during MOT (Drew, McCollough, Horowitz, & Vogel, 2009). This model has the advantage of being conceptually intuitive as well as corresponding to the introspection of the task.

Multiple Object Tracking and Perceptual Grouping As the research review has suggested, multifocal attention combined with some sort of grouping strategy may support the tracking of multiple objects. That is, observers may track multiple items by spontaneously grouping disparate items into a single “virtual object”. This object however, in order to respond to changing demands in the real world, may need to be flexible, such that the active representation at any moment may reflect competing perceptual cues or top-down attentional requirements. A strict reading of FINST does not allow for such flexibility; tracking is automatic and insensitive to direct manipulation by higher cognition. The multifocal model does not allow for the possibility of grouping effects underlying tracking, and the Yantis model of grouping does not accommodate multiple attentional foci. A synthesis approach may be fruitful in this case.

Considerable evidence from the perceptual literature supports an early segregation of the visual world into perceptual units,(Ehrenstein & Gillam, 1998; Marr, 1976; Sayim, Westheimer, & Herzog, 2010; Herrmann & Bosch, 2001; Westheimer, 1999; Kovács, 1996; Sugita, 1999; Kovács, 2000; Wertheimer, 1938;

S. Palmer & Rock, 1994; Merikle, 1980; Attneave, 1968; Han et al., 1999; Pomerantz, 2003), and evidence from visual search supports the hypothesis that these units are bundles of features (Wolfe & Bennett, 1997) that are temporarily bound into discriminable objects when "moused over" with attention. These early features can guide attention to these locations,(Wolfe & Horowitz, 2004) as information is fed back into processing in a recurrent, or reentrant manner. Applied to the MOT task, targets are quickly selected from distractors in a pop-out manner, guided by a simple feature search. However, during the tracking phase all features are identical, only the history of the item as remembered segregates target from distractor, in the typical MOT task. It is here that FINST fails completely, since fundamental to the hypothesis is the proposition that FINSTs maintain the history of the item despite changes in local features or location. This proposition is unsupported by any data. Some questions remain, however. For example, to what extent are are grouping processes used in MOT and are the effortful grouping strategies demonstrated by Yantis (1992) equivalent to bottom-up perceptual gestalt processes? If they are not equivalent, would further perceptual support provide evidence for rapid and automatic tracking mechanisms vis a vis FINST? Do the active representations reflect the number of physical items in view, or the subjective percept? Furthermore, the difference between subjects to whom strategic grouping was suggested and those who did not receive that instruction only existed during the first several blocks, indicating that subjects rapidly learned some strategy, either a "polygon" strategy or some other with similar effect. Nonetheless, subjects were able to track multiple targets in early blocks with lower accuracy. Thus the assertion that MOT is accomplished by linking items to an internal polygon representation which is constantly updated to match the environment is not the only interpretation of the data.

Recently, Drew, Horowitz, Wolfe, and Vogel (2011) reported an electrophysiological measure of tracking multiple objects, describing an ERP index of the number of items being tracked at any one time. This component is a tracking homolog to the working memory index, the CDA. The tracking component was shown to be modulated only by the number of items tracked rather than the number of distractors, speed or difficulty, or tracking area. This chapter and the following chapters will use this component to more precisely investigate the nature of the active visual representation during tracking. Though Yantis (1992) showed a behavioral benefit of perceptually supported tracking it is unknown whether or not bottom-up perceptual grouping mechanisms may influence the representation of items during tracking. Given the putative connection between visual working memory and tracking as demonstrated by Oksama and Hyona (2004) and Drew and Vogel (2008), as well as the above-discussed MOT perceptual grouping experiments of Yantis, it is not too speculative to suggest that the manipulation of grouping cues during an MOT task may also manipulate the tracking load and thus the indexed ERP activity, providing a window into the moment-by-moment representation of atomic or composite objects in MOT. If so, this tool may enable parsing the tracking mechanism among automatic processes, gestalt perception, and strategic, effortful control. Here, we investigate whether supplying the participant with low level cues such as connecting lines, common motion, or proximity could improve tracking performance, and whether these manipulations also affect the neural representations as indexed by the online tracking activity.

1.3.3. Discussion

Altogether, converging evidence indicate that the unit of visual memory is the object, however undefined and flexible that term may be. Object benefits in visual memory has been found for single and multiple feature detection and conjunctions of features. There is some evidence that directed attention may serve as the active means by which items are segregated or joined into composite objects; certainly configural and grouping cues as well as task constraints guide which items may be stored int memory. FMRI data, in addition, demonstrate that the grouping cues or complexity may affect the atomic or composite nature of the active visual representation. Further evidence is needed to understand under what conditions disparate items may be composed or disjoined, and some of these questions may be better answered via electrophysiological measures of perceptual grouping of active visual representations. Additionally, of particular interest is the temporally extended nature of objects in the world, as distinct from the typical brief presentation of information (Sperling 1972) in visual memory paradigms. In the following section a relatively recent experimental paradigm is reviewed which may be better able to address the temporally extended nature of object formation or transformation, the multiple object tracking paradigm.

1.4. Conclusions and Overview of Present Studies

1.4.1. Dissertation Outline

> The gist of the matter is this: Every impression that comes in from without, be it a sentence which we hear, an object of vision, or an effluvium which assails our nose, no sooner enters our consciousness than it is drafted off in some determinate direction or other, making connection with the other materials already there, and finally producing what we call our reaction. The particular connections it strikes into are determined by our past experiences and the 'associations' of the present sort of impression with them. -William James

The empirical chapters of this dissertation that follow this introduction are focused on the behavioral and electrophysiological indices of actively represented visual object representations. Chapter Two describes the results of a behavioral and electrophysiological study on the effects of modal completion, using Kanizsa objects, on visual working memory representations. The experiment shows that perceptual grouping effectively reduces working memory load in an orientation memory task, as demonstrated by increased accuracy in the task and reduced contralateral delay activity and investigates whether or not these effects seen are obligate or voluntary, that is, whether top-down attentional control is able to selectively alter the effect of perceptual grouping on visual working memory representations. Using Kanzisa stimuli, in both an orientation and a color change detection paradigm this chapter demonstrates that attention can successfully alter the visual representation depending on the relevance of the grouping cues to the task. Individual differences in grouping ability are also correlated with the electrophysiological measures of working memory load. Chapter Three extends these results to another gestalt grouping cue, element connectedness, and determines that the presence of a task-irrelevant connecting lines between independently moving tracked objects in a dynamic visual task is sufficient to alter tracking load and enhance performance. Chapter Four investigates the gestalt grouping cue of common fate to investigate the effects of grouping on visual object representations during a multiple object tracking task, finding a benefit for some kinds of common motion and not others in reducing tracking load as measured by contralateral delay activity and the N2pc.

Chapter Five extends these MOT results further and further investigates the relationship between proximity cues and motion grouping cues in representing visual items in active representation. In Chapter Six the preceding empirical studies are summarized and general conclusions are drawn.

1.4.2. Thesis Statement

Taken together, these studies address the question of the influence of Gestalt grouping principles and illusory completion processes on object representations in both static and dynamic tasks involving the maintenance of visual information in an immediately accessible state, the active visual representation, and examine the degree to which individual differences may affect the active maintenance of unified object representations.

CHAPTER II

MODAL COMPLETION AND VISUAL WORKING MEMORY: BOTTOM-UP AND TOP-DOWN INFLUENCES

2.1. Introduction

In order to make sense of the visual world scene components must be organized in some fashion. Gestalt theorists have provided a general framework by which we can understand this visual organization; however, how, when, and where perceptual grouping is performed in the brain is currently controversial and incompletely understood. In addition to classical gestalt grouping cues, a basic operation of the visual system is figure completion. That is, an object in the visual world that is partially occluded by foreground objects, or partially camouflaged against a matching background, are not perceived as a fragmented collection of objects but rather a unified whole behind the occluders, e.g. a cat moving behind a picket fence, or the sudden perception of a tiger.

There are two general completion phenomena: modal and amodal. Amodal completion is so termed because the subjective percept is created outside the visual mode, that is, there are no specific sensory components of texture, color etc. of the occluded parts of the cat behind the fence. Conversely, one can imagine tiger camouflaged against a background of tall grass. In this case the foreground object, the tiger, is hidden unless cues such as common motion, contour completion, or other pattern recognition processes allows the segregation of the patchwork tiger from the background. Specifically, the phenomenon of modal completion occurs when inducing elements (such as tiger stripes or Kanizsa pac-men) induce a subjective percept of an object, even though there exists no objective contour, texture, or color. See Figure 1.1. on page 21.

Many questions are being debated in the literature concerning the process of figure completion: is this a singular process, or are there multiple processes of completion? When does figure completion occur? What downstream effects does this processes have on further encoding? While the process of amodal completion is interesting in its own right it will not be considered further here. Instead, this chapter describes the use of modal completion phenomena to investigate the nature of working memory representations. These experiments use the behavioral and electrophysiological measurements of active visual representations in order to attempt to answer some of these questions.

Specifically, the nature and number of active contents of visual working memory may be assessed in several ways, however, a common means by which to do so is the change detection task. In this task, a number of items are displayed and the subject is asked to remember as many of the items as possible. Typical change detection tasks probe the subjects' ability to detect changes in simple geometric stimuli with few feature dimensions, such as item orientation, color, shape, or conjunctions of multiple features. Care must be taken in any task attempting to probe memory and which assess the capacity of memory, to obtain a pure estimate of visual memory capacity without intermodal contamination, such as re-encoding of visual stimulus as verbal information (See Cowan (2001) for an exhaustive discussion), as well as possible long-term memory, or chunking contributions. That is, chunking as described in the verbal literature is a means by which information may be more rapidly organized and remembered with higher accuracy. While chunking and LTM have been studied intensively for decades in the verbal realm, as discussed earlier, and chunking via long-term memory organization, e.g. chess grandmasters, has been described as well, relatively few researchers have examined the process of chunking within visual memory. Particularly, how might chunking via perceptual grouping principles or top-down attention affect the nature of active memory representations?

Previous studies of working memory have typically confounded objects, features of objects, and subjective percepts of objects. It is clear, for example that several randomly arranged and differently colored items are subjectively perceived as separate objects, and that the capacity to remember such items is severely limited. However, it is not known whether perceptual grouping may reduce the active memory load or merely enhance subsequent recall. The strong subjective percept produced by Kanizsa triangles is an ideal tool with which to investigate this question. Three coherently organized Pac-men inducers form a percept of a singular triangle, allowing for the separable dimensions of element or inducer number and perceptual object. Thus, orientation change detection may be used to asses the behavioral enhancement provided by perceptual grouping, if any. Additionally, the ongoing load in visual working memory may also be indexed using neural data via the contralateral delay activity. Thus, the affects of perceptual grouping on active representations may be assessed. Furthermore, it may be that any effect of perceptual grouping on memory load is automatic and occurs irrespective of task demands. On the other hand, it may be that subjects strategically allocate memory resources in such a way as to represent the information in memory in as compact a form as possible. In this experiment I investigate the effects of perceptual grouping on active visual memory representations, and ask whether these effects are obligate or to some extent voluntary. Specifically, are perceptual elements themselves maintained in visual memory, or only a subjective percept? Is modal completion an efficient process to reduce working memory load?

Are perceptual grouping effects driven by bottom-up or top-down processes or both? What individual differences, if any, exist in this interaction? In this experiment I used pac-men inducers colored from a set of highly discriminable colors in a change detection task with either one, three, or three grouped inducers in two blocks of trials. In the first block subjects were asked to remember the the orientation of the inducers irrespective of color and in the second block the were asked to remember the color irrespective of the orientation of the inducer. If features are obligatorily encoded in working memory, than behavior and ERP for three element and grouped displays should be equivalent between blocks. On the other hand, if top-down attention is able to selectively encode task-relevant features in order to reduce memory load, then trials in which the task relevant feature can be grouped should show a behavioral advantage as well as a reduction in online memory load as indexed by the CDA. One alternative hypothesis might be that, rather than any reduction in working memory load being the product of a reduction in the number of objects, perhaps it could be a result of an increase in the efficiency of processing provided by the perceptual grouping cues. If this is the case, then we should expect that grouping cues should facilitate the processing of Kanizsa figures either when the color or the orientation of the items are relevant. On the other hand, selective reduction of CDA amplitude in groupable vs non-groupable conditions would support an information chunking account rather than a processing efficiency account.

2.2. Experiment Description

In this experiment we intended to test the question of how strong visual grouping cues and task demand jointly influence the active representations in visual working memory. In order examine the effect of grouping cues we utilized the classic Kanizsa figure, as well as one isolated pacman figure or three pacman figures randomly oriented. To test the effect of task demand, the identical stimuli were presented in first an Orientation block, where only the orientation but not the color of the probe pacman item was changed, followed by a Color block in which only the color but not the orientation of the probe item was changed. See Figure 2.1. for details.

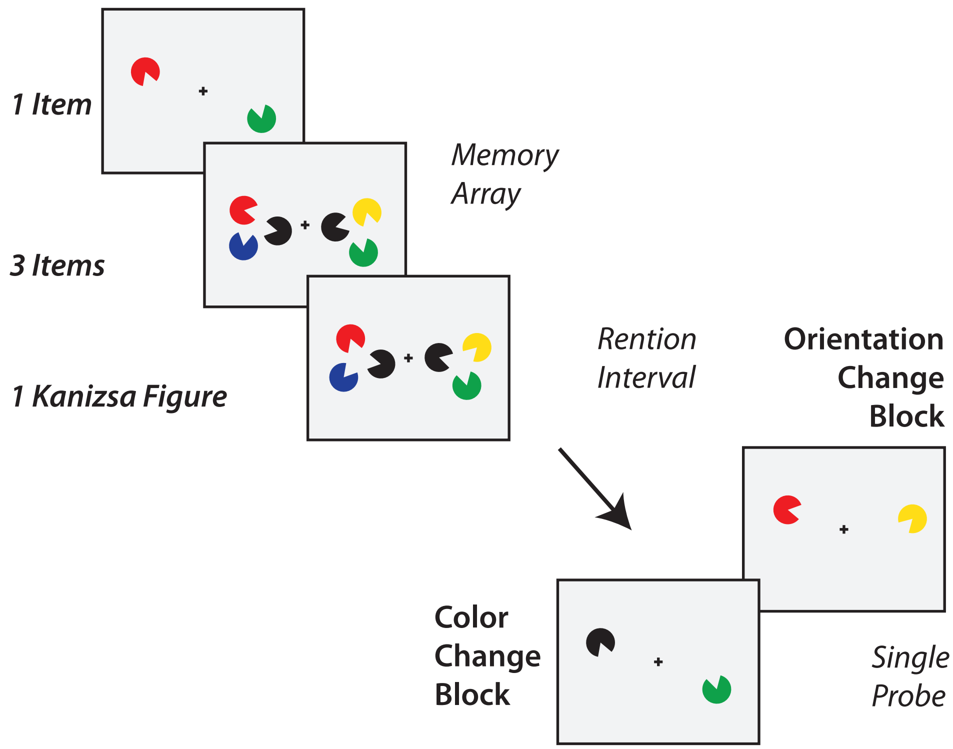

FIGURE 2.1. Experiment 1 Paradigm

2.3. Method

2.3.1. Participants

Sixteen college undergraduates, ages ranging from 18–30, were paid to participate in this experiment. These participants reported no history of neurological problems, reported having normal color vision and normal or corrected-to-normal visual acuity and gave informed consent according to procedures approved by the University of Oregon

2.3.2. Stimuli and Procedure

Stimulus arrays were presented within 4°x 7.3° rectangular regions that were centered 3° to the left and right of a central fixation cross on a gray background (8.2 cd m^2) viewed at a distance of 70cm. The memory array consisted of 3 colored inducers in each hemifield. The color of each inducers was selected at random from a set of highly discriminable colors (red, blue, violet, green, yellow, black and white) and a given color could appear only once in an array. Stimulus orientations were randomized on each trial in the one element, three element condition. Inducers the grouped condition were arranged to form a Kanizsa triangle. Each inducers subtended 0.65° x 0.65° of visual angle. Each trial began with a 200 ms arrow cue presented over a fixation point, followed by a 500 ms memory array, a 900 ms blank period and finally, a 2,000 ms test array. Stimulus Onset Asynchrony (SOA) was 300–400 ms. Subjects were instructed to keep their eyes fixated while remembering the inducers in the hemifield indicated by the arrow cue. Subjects held these items in memory over a blank interval, after which a test array was presented bilaterally. The test array consisted of a single item, and one feature of the item in the test array in the memorized hemifield was different from the memory array in 50% of the trials. Subjects responded by pressing one of two buttons on each trial to indicate whether the memory and test arrays were the same or different. When a feature changed between sample and test array the new value was selected at random from all of the other feature values. The responses were unspeeded, with the accuracy rather than the speed of the response stressed during instruction. Each of the participants were tested in a single session of 90 minutes, with each trial block lasting ∼6 minutes with two short breaks of 20s spaced evenly throughout each block. Each subject performed at least 240 trials per condition in each experiment.

2.3.3. Electrophysiological Recording and Analysis

Electroencephalographic (EEG) activity was recorded from 20 tin electrodes mounted in an elastic cap (Electrocap International), using the International 10/20 System, along with several costume locations. In addition to the standard sites, four additional sites were used: OL and OR, positioned midway between O1 and T5 on the left hemisphere and O2 and T6 on the right; Poz, located on the midline between Pz and O1-O2, and PO3 and PO4, located halfway between POz and T5 on the left and POz and T6 on the right. See Figure 2.2. on page 57 for the electrode montage. All sites were recorded with a left-mastoid reference, and the data were re-referenced offline to the algebraic average of the left and right mastoids. The horizontal electrooculogram (EOG) was recorded from electrodes placed approximately 1cm to the left and right of the external canthus of each eye to measure horizontal eye movements. In order to detect blinks and vertical eye movements the vertical EOG was recorded from an electrode mounted beneath the left eye and referenced to the right mastoid. Trials containing artifacts: ocular, movement, or amplifier saturation (blocking) were excluded from further analysis, which accounted for the exclusion of an average of 29% of trials. Three subjects with trial rejection rates in excess of 35% were excluded from the sample. The EEG and the EOG were amplified with a SA Instrumentation amplifier with a bandpass of 0.01–80 Hz and were digitized at 250 Hz in LabView 6.1 running on a Macintosh.

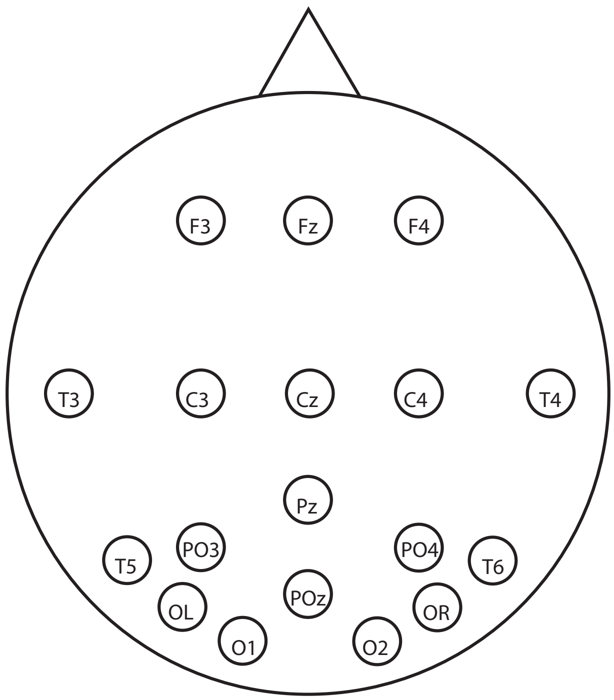

FIGURE 2.2. Electrode Montage

2.4. Results

2.4.1. Behavior

Performance on the task overall was good and within the range usually seen for change detections tasks. In the Orientation block, overall mean performance was (M = .88, SE=.017), while in the Color block mean performance was also high, M = .93, SE = .01. Differences existed between the conditions, such that the performance best on 1 item, worst on 3 items, and between 1 and 3 items for the Kanizsa condition, (Kanizsa: M = .89, SE=.02), (Three Items: M = .78, SE=.02), (One Item: M = .98, SE=.01) in the Orientation block, while in the Color block performance was also greatest for one item, but worse for three and kanizsa, (Kanizsa: M = .92, SE=.01), (Three Items: M = .88, SE=.01), (One Item: M = .98, SE=.01). See Figure 2.3. on page 59. A two-way analysis of variance (Block x Set Size) yielded a main effect for the Block, $F(1, 14) = 15.00$, $p < .01$, such that the average accuracy was significantly higher on the Color block (M =.92% , SD = 0.03) than on the Orientation block (M = 0.88%, SD = 0.05). The effect of Set Size, $F(2,28) = 78.83$, $p<0.001$ was also significant. In addition, the interaction effect was significant, $F(2,28) = 9.93$, $p < .001$, indicating that the Set Size effect was greater in the Orientation condition than in the Color condition. Planned comparisons indicated that the Kanizsa group (M = 91.5 %, SD = .04) in the Color block was significantly greater from three elements ungrouped (M = 88.6%, SD = 0.09) at $t = 2.13$, $df = 26$, $p=0.04$) from three elements ungrouped.

Behavioral performance on the memory task varied as a function of the number of groups and elements in the display with the highest accuracy for one element (95%), the lowest accuracy for three elements (70%). There was an effect of grouping such

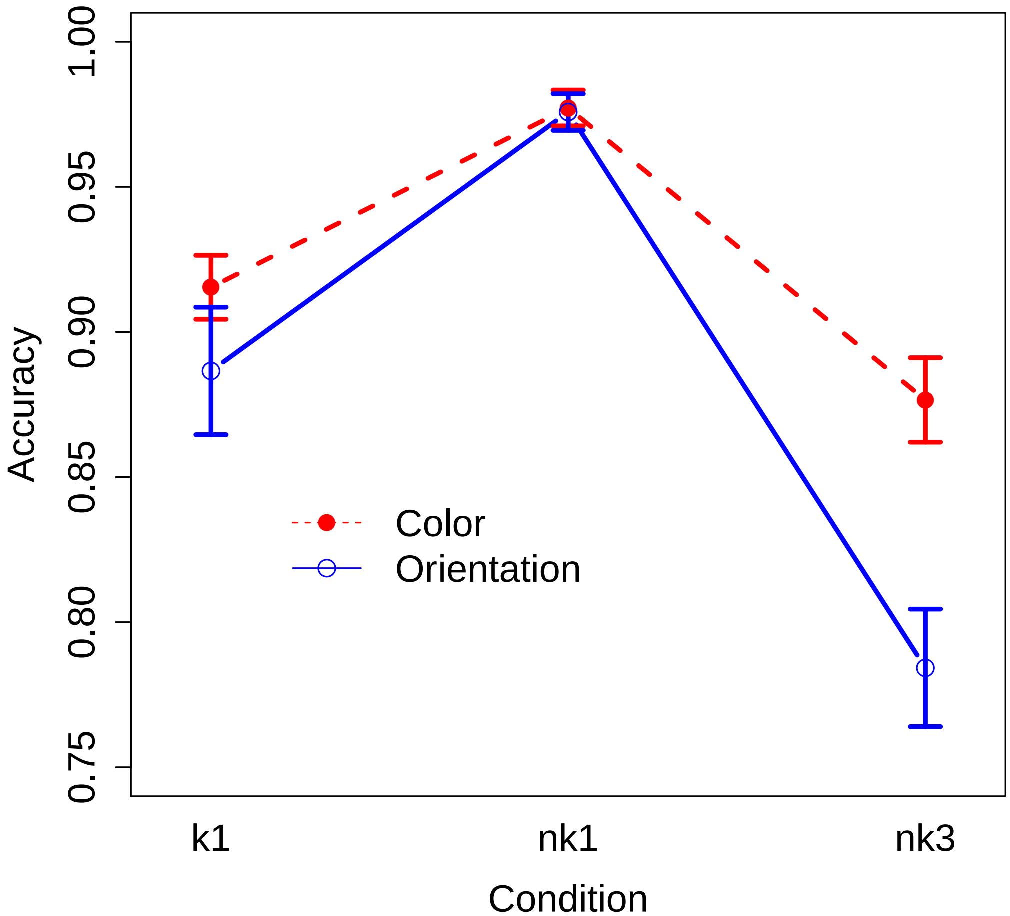

FIGURE 2.3. Experiment 1 Behavioral Performance

that accuracy for three elements grouped together into a single perceived object was 88%, in between one element alone or three elements ungrouped. These differences were found to be highly reliable in a 1-way ANOVA [$F(2,15) = 20.00$. Of particular interest is whether there is a benefit for the groupable dimension when that dimension is being tested, e.g. whether there is a benefit of the Kanizsa configuration in the Orientation block. A paired t-test revealed significant difference between 3 elements grouped and three elements ungrouped ($t(14) = 8.17$, $p < .001$) for the Orientation block, and the Color block ($t(14) = 3.52$, $p<0.001$), with Color memory in the grouped condition approximately .2 objects greater and approximately .8 objects greater in the Orientation block. Furthermore, there was a reliable difference between the performance benefit between Color and Orientation blocks, ($t(14) = 5.26$, $p<.001$). In order to determine the relationship between behavioral conditions, a correlation matrix was calculated for working memory capacity in each condition. Performance between three items grouped and ungrouped were highly correlated for Color ($r = .77$, $p<.01$) and Orientation ($r=.77$, $p<.05$), but not between Color and Orientation. However, the there was no significant correlation between performance on three ungrouped items between the Color and Orientation blocks. A multiple regression analysis was performed to determine which variables were predictive of the grouping performance in each block. The results of the regression indicated that orientation K and color grouping performance predicted orientation grouping performance, explaining 57% of the variance ($r^2 = .47$, $F(2,12) = 8.03$, $p < .01$). Orientation K significantly predicted grouping performance (= .08, $p<.05$) as did Color grouping performance (= .89 $p<.05$), with performance on the grouping task contributing more. Performance on the ungrouped items in each corresponding block did not increase the model fit. However, how did individual differences in working memory capacity relate to the degree of grouping benefit? To answer this question, a grouping benefit score was calculated by subtracting the performance on three ungrouped items from the performance on three grouped items for Color and Orientation separately, using Cowan's formula. There was a reliable relationship between Color K and performance in the Color Kanizsa condition, ($r = .77$, $p < .01$). A similar relationship existed between Orientation K and performance on the Orientation Kanizsa condition ($r = .77$, $p < .01$). A grouping efficiency score was calculated by dividing the difference between the grouped and ungrouped conditions by the difference between the 1 element and ungrouped condition.

2.4.2. Electrophysiology

Two hundred milliseconds after the onset of the cue array we observed a transient negative going waveform over the hemisphere that was contralateral to the attended hemifield. This activity was followed by a larger and sustained activity which lasted the duration of the trial. See 2.4. on page 64 for difference waves. Analysis were performed over a 400 ms time window within each trial. ERP data were averaged into Color and Orientation blocks on three factors of Set Size (Kanizsa, non-Kanizsa, 1 element). Mean amplitudes for each condition in both blocks were calculated from the grand average of the difference waves for each condition at electrode sites P3/P4;OL/OR; T5/T6;PO3/PO4, see 2.5. on page 65. A two-way ANOVA yielded a main effect of Block ($F(1, 14) = 15.00$, $p < .001$) and Set Size ($F(2,28) = 78.83$, $p < .001$) and a significant set size by block interaction ($F(2,24) = 3.05$, $p < .02$). Further planned analysis reveal that the amplitude of the CDA in the Color condition depended on set size and was greater for 3 elements than 1 element ($t(14) = 5.09$, $p < .001$), but that there was no difference between amplitude for 3 elements and Kanizsa set size overall in the Color condition ($p>.3$). However, in the Orientation block the amplitude for 3 elements was reliably greater than for 1 element ($t(14)=5.18$, $p<.001$ or a Kanizsa group ($t(14)=2.33$, $p<.05$). In addition to the mean differences between conditions, of interest is the individual response to the grouping cues. Accordingly, a difference score was calculated by taking the difference between 1 and three elements ungrouped and 1 Kanizsa and 3 elements to create an electrophysiological measurement of maintenance in memory of grouped and ungrouped elements. This grouping measurement was then correlated with behavioral performance. As seen in other experiments, working memory capacity correlated with the difference between 1 and 3 elements ($r=.6$, $p<.05$). In addition, the difference measuring of grouping correlated with the amplitude difference between grouped and ungrouped items in the Orientation block, but not the Color block.

The data were further analyzed by examining the ipsi-contra waveforms. It may be the case that the reduction in amplitude in the CDA is due to a ipsilateral effect (not associated with objects in memory) in contrast to a contralateral effect. If this is the case, then the ipsilateral waveforms should differ from each other, and the contralateral waveforms should be equivalent. To test this hypothesis, mean amplitudes were compared for each of the color and orientation blocks between the kanizsa condition and the ungrouped condition. There was no effect of grouping on the ipsi waveforms for the Color block ($p>.5$) or the Orientation block ($p>.7$). As noted above, there was no reliable correlation between Color K and Orientation K. However, what about the relationship between working memory capacity for color or orientation and the CDA amplitude? Capacity scores for each condition were correlated with the amplitude difference between 1 element and 3 elements in Color and Orientation blocks, as well as the amplitude difference between 3 elements and 1 group in both

Color and Orientation blocks. Replicating previous research (REF), a correlation was seen between working memory capacity and the amplitude difference between 1 and 3 elements in the Color block, however these effects were marginal r = .41, (t(13) = 1.64, p =.06). No correlation was observed between Orientation capacity and CDA amplitude difference between 1–3. However, of particular interest is the putative grouping effect, that is, what is the correlation of the CDA grouping effect (difference between grouped and non-grouped elements) and working memory capacity. There was a correlation between grouping efficiency and the grouped-ungrouped amplitude in the orientation block (r = .41, p = .11).

2.5. Discussion

Despite the fact that visual working memory is capacity limited and the visual world contains many items, we are nonetheless able to glean a large amount of information from the world. One possible mechanism which may explain this discrepancy between the myriad objects available in the world and the constrained space in mind is the is the ability of the visual system to group or chunk incoming stimuli into a form which best reduces online storage requirements. Accordingly, in this experiment we asked three main questions about perceptual grouping interactions with working memory: 1) Is modal completion an efficient process to reduce working memory load?; 2) are items which can be perceptually grouped together actively represented as fewer items in working memory than those items which cannot be so grouped; 3) Are perceptual grouping effects driven by bottom-up or top-down processes or both? 4) Are there individual differences in these grouping processes? In order to answer these questions we presented subjects with pac-man shaped objects either singly, in a group of three elements randomly oriented, or in a group of

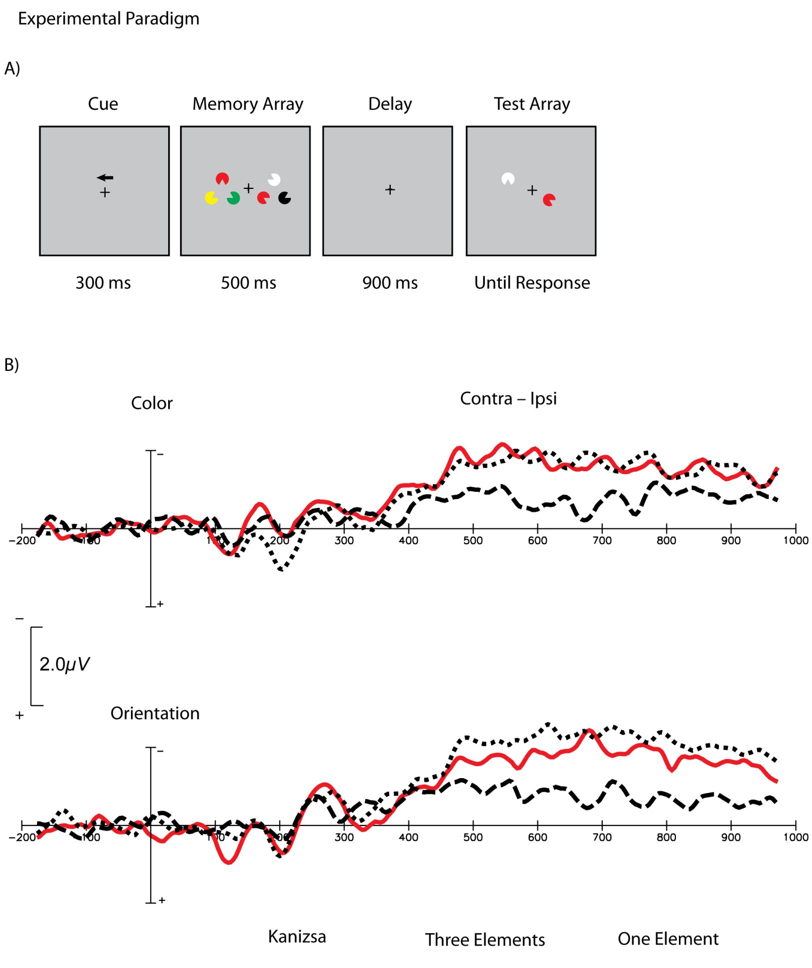

FIGURE 2.4. Experiment 1 Grand Average Difference Waves

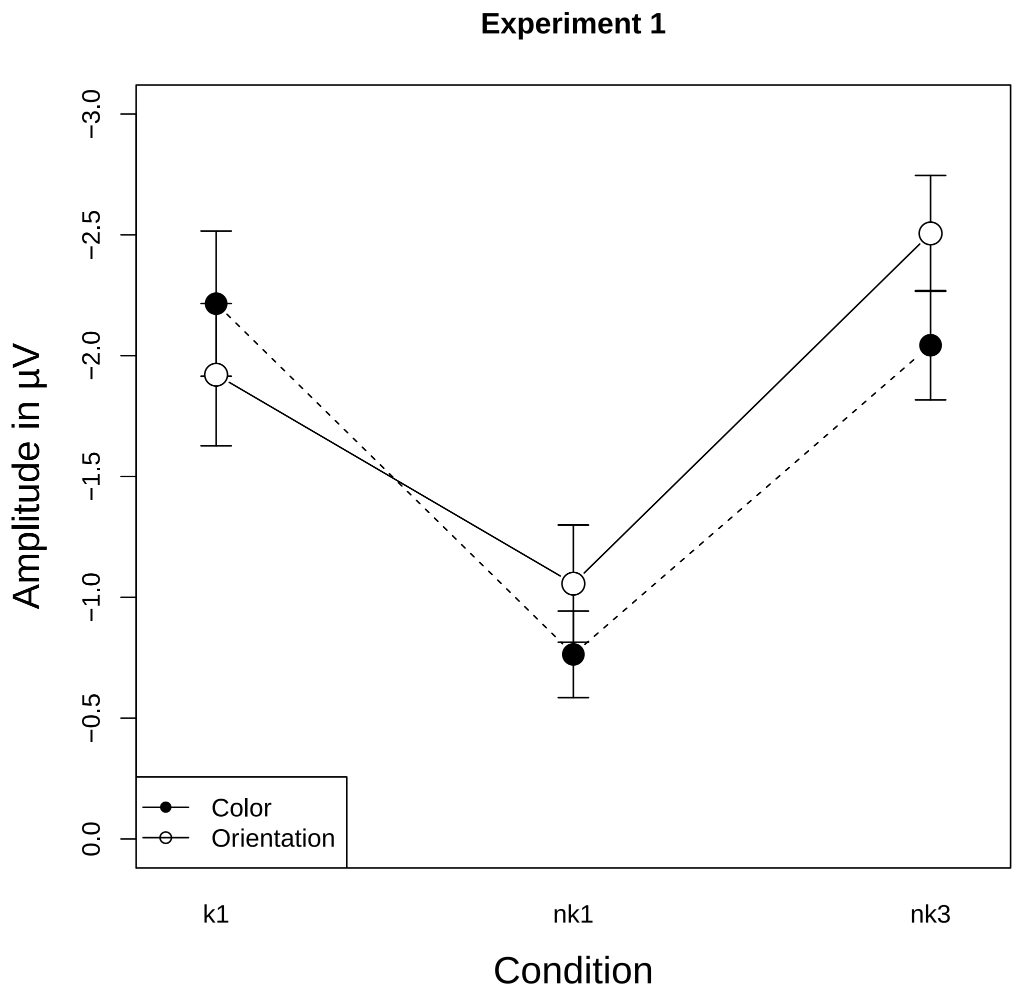

FIGURE 2.5. Experiment 1 Mean Amplitudes

three elements arranged to amodally complete a triangle in both remember-color and remember-orientation blocks. We asked subjects to report the correct feature of the mouth of a single pac-man element selected at random. Groupable (orientation) features in these displays improved behavioral performance in the Kanizsa triangle trials, while ungroupable (color) features, despite being presented in the same groupable configuration, did not show a behavioral benefit. Working memory capacity for orientation and color was calculated from the scores on three ungrouped items in the color block and the orientation block, using the Cowan's formula for k-estimate for single probe displays. An index of active online representations was obtained using the CDA. We found a reduction in amplitude for this component for Kanizsa displays in the orientation condition, but no effect of the Kanizsa display in the color condition. Working memory capacity was correlated with overall performance, but the increase in performance benefit due to grouping present in the Orientation block was inversely correlated with capacity, with lower capacity individuals gaining more from grouping than higher capacity individuals. Moreover, the the degree of reduction in the CDA amplitude was correlated with the behavioral benefit derived from the Kanizsa display. If subjects obligatorily maintain separate elements from a brief display then behavior and the online memory load for the three-element amodal completion condition should be equivalent to that from the three elements oriented randomly. On the other hand, if the elements in the amodal completion display are grouped together into a single representation, or virtual object, in working memory, then the amplitude of the delay activity should be reduced and the accuracy increased, which is precisely what was found. The evidence further suggests that when grouping is possible, it is the lower capacity individuals who are more likely to group, at least in this display. Indeed, a higher degree of accuracy should certainly be obtained by maintaining distinct representations of each item, rather than pooling those representations together. However, it is better to pool representations, or apprehend the gestalt and thereby lose detail or specificity for individual items, if overall accuracy may be improved. This is apparently the result here. Indeed, there was reduction in load for both the color and orientation conditions, however the reduction was much greater for orientation than color. Suggesting that even if there is a perceptual processing efficiency for Kanizsa figures, there is a greater benefit for groupable and task relevant features. It is important to note that an alternative explanation to the above hypothesis is that on some orientation Kanizsa trials subjects simply remembered one or two of the inducers and then “reconstructed” the triangle at test. This is implausible for the following reason. Other research (Halgren, Mendola, Chong, & Dale, 2003; Lee & Nguyen, 2001; Herrmann & Bosch, 2001; Senkowski et al., 2005; Davis & Driver, 1994) has shown that modal completion operates early in the visual stream and thus this hypothesis would suggest that subjects first perceive a completed figure and then forget the completed figure in order to remember only one or two inducers. This seems un-parsimonious. Admittedly, however, this experiment alone cannot entirely rule out this hypothesis. Thus, in the next experiment we will investigate this question using a experimental paradigm that requires continuous monitoring of the items individually in order to perform the task. Under these circumstances, only tracking a single item among distractors will result in complete loss of the other items. In addition, further experiments are required to anatomize the interaction of attentional control mechanisms, grouping, and storage capacity in working memory.

In previous research we have shown that behavioral measures of memory capacity strongly predict ERP measurements of online load. However, in these experiments, behavioral estimates of working memory capacity did not reliable predict the CDA in every condition. One explanation for this might be that this decoupling between working memory and performance is chunking, or pooling, individual representations to form single, larger, object but one which by definition is less distinct. The degree to which the CDA might be reduced could depend on how well the objects were chunked as well as an individuals WM capacity, task demand (e.g. whether fine or gross change detection is required to perform the task). Modal completion, then, may be one mechanism by which the overwhelming amount of visual information is reduced to a manageable degree by online processes. This hypothesis is supported by the negative correlation between memory capacity and grouping efficiency, and the trend toward a greater boost in memory performance for lower capacity individuals. However, grouping is not a perfectly obligatory processes, as the identical stimuli in the Color block produced a much reduced benefit for Kanizsa displays than the Orientation block. Further, the electrophysiological evidence supports the proposition that these grouped representations require less storage space, as indicated by the reduced CDA amplitude in the Kanizsa condition. Here we presented empirical evidence in support of this hypothesis and demonstrated top-down control of the grouping process in a gestalt task. We recorded electrophysiological data which suggest that online memory load is reduced, where possible, chunking or grouping the items at encoding. We further demonstrated that though perceptual grouping processes can alter the number of items perceived in working memory, it is not obligatory. In sum, we demonstrated that perceptual grouping processes can influence the representation of items in memory by directly reducing the perceived number of items to be retained and that these processes are not obligatory but modulated by attentional demands.

CHAPTER III

MULTIPLE OBJECT TRACKING AND CONNECTEDNESS

3.1. Introduction

In the previous chapter perceptual grouping in static displays using modally completed Kanizsa triangles demonstrated a reduction in working memory load for items which could be grouped together compared to items which could not, and that this reduction in load was feature specific, such that attended items whose features were groupable (colors) did not show either a behavioral benefit or reduced CDA amplitude. However, it is possible that rather than maintaining a single, grouped percept in memory the subjects merely selected a subset of the cued items to remember in the Kanizsa condition and reconstructed the necessary angle of the probed inducer if that inducer was not in the memorized subset. While that seems unlikely, given the reasons stated previously, the previous static display could not rule out that possibility. Therefore, in this experiment we used a multiple object tracking paradigm. See Figure 3.1. on page 72 for an explanation of the task. The nature of the task requires that the subject maintain attention on individual items because a lapse of attention results in irretrievably losing the identity of the target items. Therefore, if grouping benefits are found then a simple reconstruction hypothesis would be falsified. The combination of perceptual grouping and multiple object tracking while recording online neural activity may also allow us to disentangle the question of whether multifocal attention or a single attentional focus on a polygon is the mechanism underlying the ability to track multiple items simultaneously. Current outstanding debates in MOT concern whether objects are tracked in unison via a grouping mechanism, or in parallel, with all the objects are tracked simultaneously through the splitting of attention to each target separately. Previous behavioral investigations of this question have been unable to resolve this debate unambiguously. However, perceptual grouping requires, by definition, the agglomeration of disparate elements into a single unit. Therefore, if a multiple-focus/item account is correct, we should expect the neural signature of tracking to be reduced when perceptual conditions favor grouping and enlarged when items are no longer perceptually grouped. On the other hand, a single-focus account would predict no difference between the multiple items or multiple items grouped together, since the same mechanism should be active in both cases. Note that simply manipulating set size alone cannot disambiguate this question, even if set-size effects on amplitude are observed, since it may be that the overall size of the focus of attention may be sufficient to alter the amplitude of the component. However, by specifically manipulating grouping, and thereby what counts as an object, we can specifically dissect the nature of the active item representation, whether it is singular, composite, or multi-element. A strong grouping cue is that of element connectedness, the extent to which regions of a visual display share connected, continuous color, texture, contours etc. Evidence from the clinical literature demonstrates that even a simple connecting line between two items, turning two dots into a single barbell, is sufficient to rescue Balint's syndrome and generate the precept of a single item. Attention has been shown to spread along such connecting lines between otherwise independent items (Mattingley et al., 1997). Previous research has suggested that perceptual grouping may significantly aid performance in Multiple Object Tracking (MOT) tasks. That is, observers may track multiple items by spontaneously grouping disparate items into a single "virtual object". According to this hypothesis a virtual polygon is initially created and then updated during tracking, with the vertices of the polygon consisting of the tracked elements (Yantis, 1992). Recent research has shown that targets linked to distractors are in fact more difficult to track, perhaps because attentional spreading confounds linked targets and distractors into a single, erroneously merged percept (Scholl et al., 2001).

Recently our lab has demonstrated an ERP component, the CDA, sensitive to the number of successfully tracked items in a MOT task such that the amplitude of the component increases with increasing set size up to the individual subjects tracking capacity (Drew & Vogel 2008 J. Neuroscience). Here, we investigated whether a real or virtual polygon between targets in a tracking task would enhance behavioral performance and reduce tracking load (as indexed by a reduction in amplitude of the CDA). We attempted to answer several questions, specifically: 1) Do grouping cues alter how items are represented during tracking? 2) If so, in what way and what kinds of cues are the most effective? 3) Do perceptual grouping cues affect tracking performance? 4) What are the neural measures of individual differences in perceptual grouping during multiple object tracking?

In this study MOT performance was measured by asking subjects to track 1, 3, or grouped objects among 10 total objects in a single visual hemifield. The effect of the perceptual grouping cue, in this case, common fate, on behavioral performance as well as electrophysiological measure of online tracking activity were measured. If the strong perceptual grouping hypothesis for MOT is correct, that is, if the tracking of multiple objects is facilitated by the combination of several objects into a single percept, then this effect should be stronger in the explicitly grouped condition than in the standard task. Furthermore, the online measure of activity should enable the degree to which disparate items are grouped into a single unit for the purpose of tracking. If the presence of actual grouping lines connecting the three targets in a

MOT task reduces tracking load when the lines were present as compared to when they were absent, as indexed by the tracking activity, then the strong claim that tracking is always performed by utilizing a grouping strategy may not be correct. That is, there should be no difference in internal representation. However, if instead the there is a benefit for grouping when the items are connected, and there is also a decrease in active visual representation, then the claim that perceptual grouping per se mediates multi-element tracking is weakened.

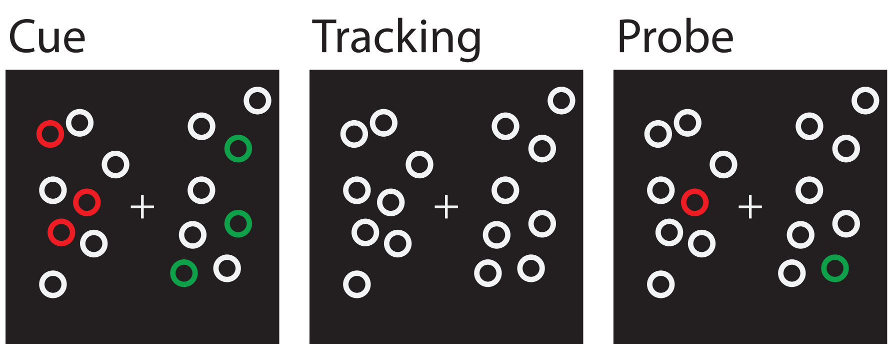

FIGURE 3.1. Multiple Object Tracking: Basic Design

3.2. Experiment Description

On each trial subjects were presented bilaterally with eight items randomly placed in each hemifield, with either 1 or 3 targets and the remainder distractors, on a black background. See 3.2. on page 75. On one third of the trials there was one target, one third of trials were 3 targets, and one third of trials there were 3 targets connected together with joining lines of the same color forming an irregular triangle. Each trial consisted of an initial cue phase lasting 500ms and a longer tracking phase lasting 3000 ms. For the first 500 ms of each trial, the cue period, all the items were stationary with a subset of the items, the targets, drawn in red (in the attended hemifield) while the remaining items in that hemifield, the distractors, were drawn in blue. In the unattended hemifield a number of items equal to the number of red targets were drawn in green with the remainder of items rendered in blue. Following the cue period, all the items turned to white (including joining lines) and began moving within their respective hemifield for 5 seconds, the tracking period. In all conditions the items moved randomly; the lines joining targets did not constrain the movement of the joined items. The tracking period was divided into a short 500 ms period, during which the joining lines on both sides faded completely away, and the remainder of the tracking period during which the items continued to move randomly. At the end of the tracking period all motion ceased and a single item on the attended side turned red. Subjects were asked to track the targets and report via button press whether the final red item was one of the tracked items or not. In experiment 1 we asked subjects to track one, three, or three joined targets in each trial to so that we could determine whether tracking load, as measured by the ERP index of tracked items, was modulated by the bottom-up perceptual grouping cues provided by the bottom-up perceptual support of the joining lines. We time locked to the onset of the cue array and recorded throughout the duration of the trial until the test array so that we could observe transient selection of targets, memorial representation of items, tracking during perceptual support, and tracking after perceptual support. If tracking load were reduced with perceptual support then we should expect a concurrent reduction in the amplitude of the tracking CDA and a subsequent enhancement of behavioral performance, both behavior and ERP should look more like the one item condition. On the other hand, if the tracking load remained constant and was not reduced by perceptual support during tracking we should expect that the amplitude of the ERP measure and the behavioral performance in the grouped condition to be similar to the baseline three target condition.

3.3. Method

3.3.1. Participants.

Neurologically normal participants (26 subjects) from the Eugene, OR community gave informed consent according to procedures approved by the University of Oregon institutional review board.

3.3.2. Stimulus displays and procedure.

All the multiple object tracking experiments used the same general procedure, which is described below.

3.3.3. Experiment Procedure

In all of the following multiple object tracking experiments the following general protocols were observed. The stimuli were presented with Presentation software (Neurobehavioral Systems) on a CRT screen in a semi-dark room. Subjects sat approximately 1 meter from the CRT screen while items were presented within 4°x 7.3° rectangular regions bilaterally, centered 3°to the left and right of the middle of the screen. A white fixation cross was presented in the center of the screen, against a black

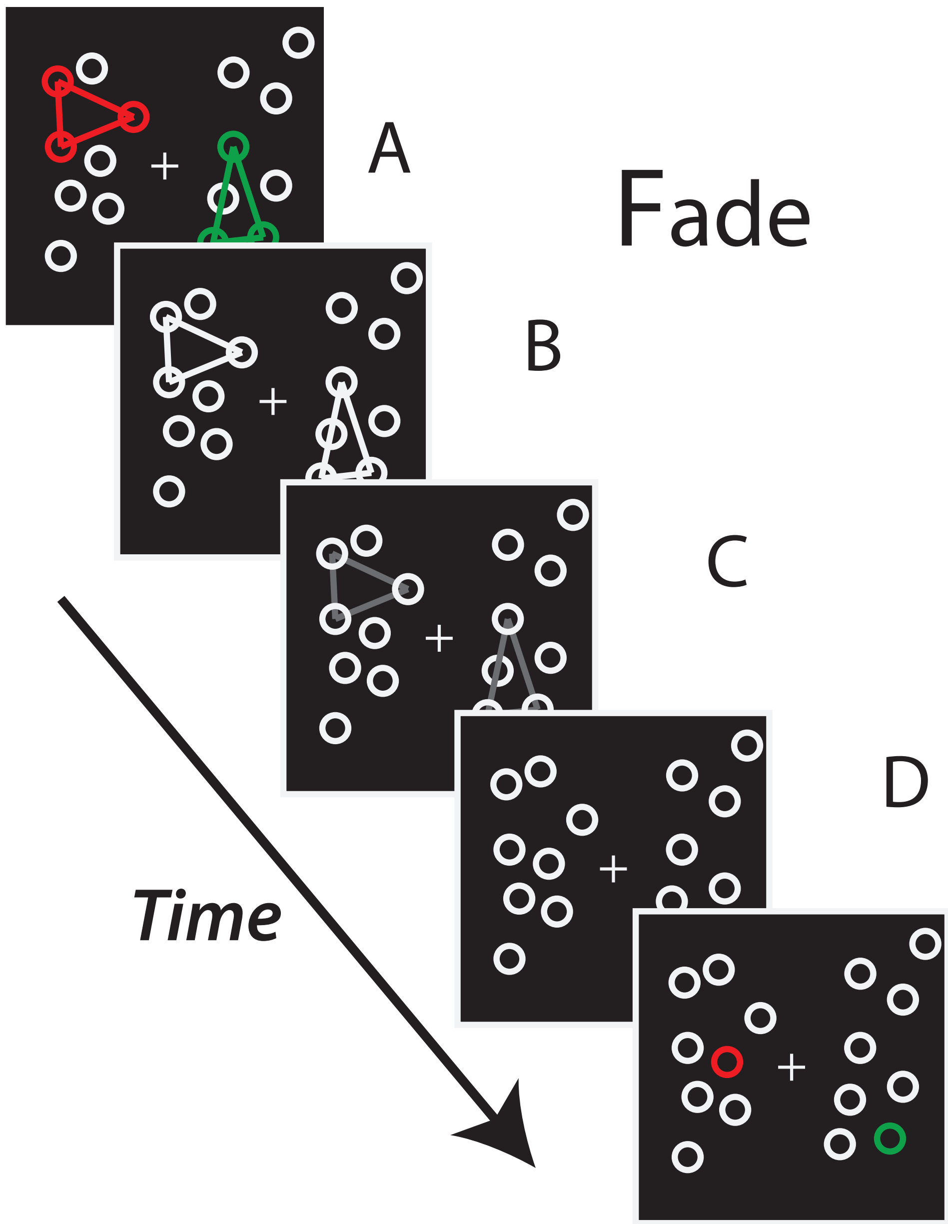

FIGURE 3.2. Experiment 2 Paradigm

background, throughout the trial. Items were presented bilaterally with the items to be tracked cued in red and distractor items in white. Contralateral to the cued side an equal number of items were presented in green and white. After a brief cueing period all items turned white and began to move randomly on their respective hemifield. After the tracking interval was complete, the display ceased moving, a single item was cued by turning red, and the subjects responded with a button press indicating whether or not the cued test item was one of the original cued targets. The probed square was one of the original targets on 50% of trials and was a randomly selected distractor within the hemifield on the remaining trials. Each participant completed 240 trials per condition in the first experiment, 200 in the second experiment, 160 in the third experiment, and 224 in the final two experiments.

The schematic of a trial is illustrated in Figure 3.1. on page 72. Subjects were instructed to fixate the white cross. Each trial consisted of an arrow cue (200 ms), cue array (100–500 ms depending on experiment), tracking period (6000 ms), a test array (until response), and the inter-trial interval (ITI: 500 ms).

Subjects attended to the cued visual field and remembered the identity of the cued target items. At the onset of the test phase one item was cued by turning red. Subjects responded whether the cued test item was one of the original target items or not by a button press (same vs. different). Subjects were instructed to make a button press as accurately as possible. Item movements were randomized between the trials and occlusion was possible. Subjects tracked under 3 conditions (2 targets, 3 targets, 4 targets), and all conditions were intermixed within blocks. All subjects completed a total of eight blocks of 100 trials each, resulting in 200 trials per condition.

3.3.4. Motion Parameters

The direction of motion varied randomly, and the annuli bounced off the border of the viewing area, but not off of each other (brief occlusion possible). The speed of motion varied from 0.25 to 1.86 of visual angle per second with an average of $1°/s$. Motion trajectory was linear and changed at random intervals or when the object made contact with the (invisible) outer barrier of the viewing area. Several of these parameters were modified slightly in the subsequent experiments in chapters 4 and 5. In particular, the circles bounced off (no occlusion) of each other when they made contact, vibrated in place, moved together, or other modulation of movement parameters which will be explicated further in the relevant chapter. These changes made no observable difference in the ERP data or behavioral performance between experiments for baseline conditions.

3.3.5. Measuring Tracking Capacity

The formula of Scholl et al. (2001) was used to derive the effective number of objects tracked: $M = n(2P)$, where M is the effective number of objects tracked, n is the number of targets, and P is the empirically observed proportion of correct answers.

3.3.6. Electrophysiological Recording and Analysis

ERPs were recorded in each experiment using our standard recording and analysis procedures, including rejection of trials contaminated by blocking, blinks, or large ($> 1°$) eye movements (Vogel et al.,1998; McCollough et al., 2007). EEG was recorded from 22 tin electrodes mounted in an elastic cap (Electrocap International, Eaton, OH) using the International 10/20 System.10/20 sites F3, FZ, F4, T3, C3, CZ, C4, T4, P3, PZ, P4, T5, T6, O1, and O2 were used along with five nonstandard sites: OL midway between T5 and O1; OR midway betweenT6 and O2; PO3 midway between P3 and OL; PO4 midway between P4 and OR; andPOz midway between PO3 and PO4. All sites were recoded with a left-mastoid reference, and the data were re-referenced off-line to the algebraic average of the left and right mastoids. Horizontal electrooculogram (EOG) was recorded from electrodes placed ∼1 cm to the left and right of the external canthi of each eye to measure horizontal eye movements. To detect blinks, vertical EOG was recorded from an electrode mounted beneath the left eye and referenced to the left mastoid. Subjects with trial rejection rates 30% were excluded from the sample. Contralateral waveforms were computed by averaging the activity re- corded over the right hemisphere when subjects tracked items in the array at the left side of screen. Contralateral tracking activity was measured at posterior parietal, lateral occipital, posterior temporal,parietal, and occipital electrode sites as the difference in mean amplitude between the ipsilateral and contralateral waveforms. Five temporal measurement windows were used for analysis of ERP components, specifically the N2pc, CDA, and tracking activity. These temporal windows were 150 –200 ms, 300–600ms and 800–1000ms post-stimulus onset.

3.4. Results

3.4.1. Behavior

Behavioral performance within multiple object tracking was measured with accuracy at each set size. The data displayed in 3.3. on page 79 show the results for 24 subjects for each set size, 1, 3, and 3 grouped targets (SS1 M = 0.79, SE = 0.02, SS3 M = 0.63, SE =.02, SSG M =0.68, SE =.02). As can be seen in 3.3. on page 79 performance was best for tracking a single item, worst for 3 items, and in between for 3 items grouped, demonstrating an apparent performance enhancement when tracked items had at one point in their trajectory been grouped with each other. These results were confirmed with a repeated measures ANOVA which demonstrated a main effect of set size ($F(2,46) = 78.558$, $p < .05$). Planned comparison revealed a large and reliable difference between set size one and three ($t(23)=10.54$, $p < 0.001$) and between three targets and three grouped ($t(23)=4.64$, $p < 0.001$).

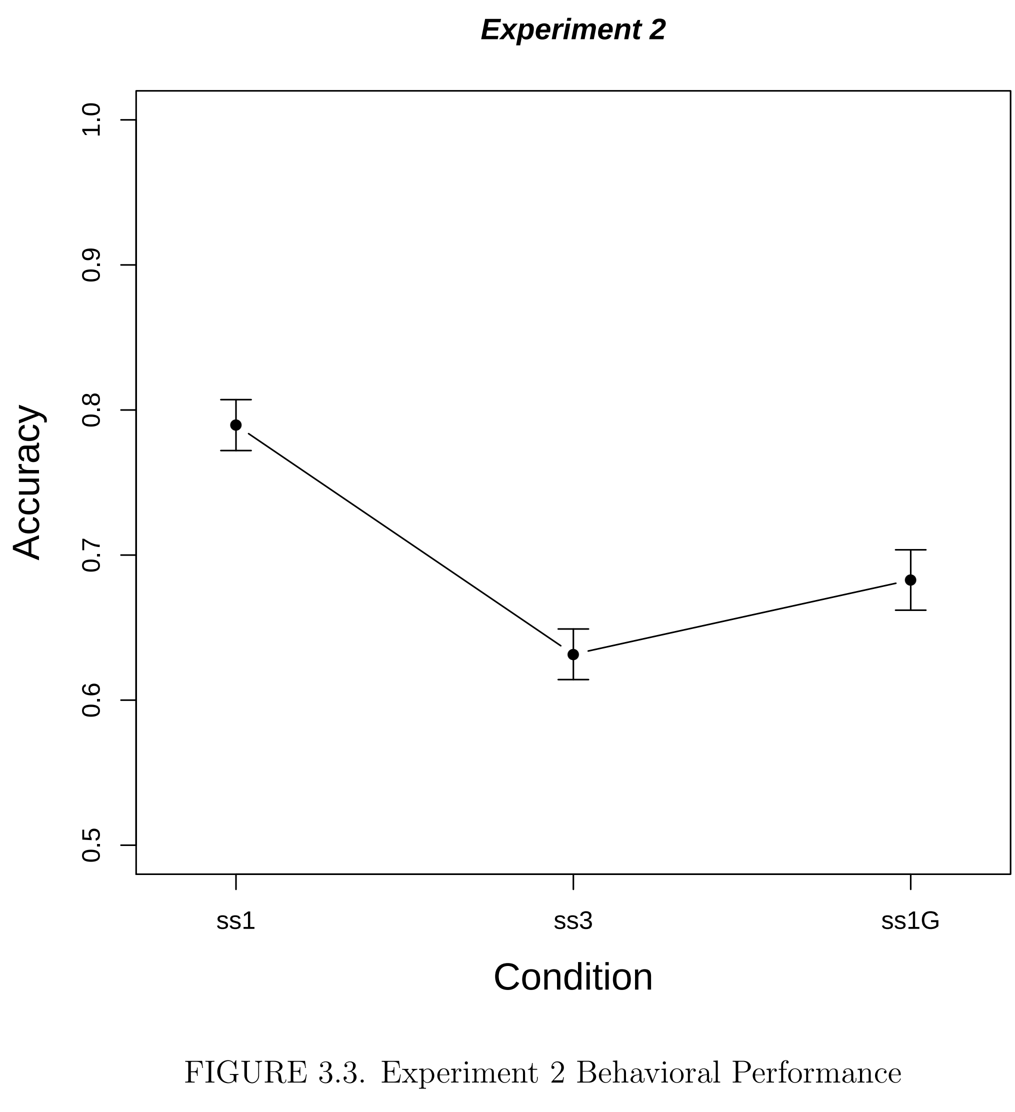

FIGURE 3.3. Experiment 2 Behavioral Performance

3.4.2. Electrophysiology

Two hundred milliseconds after the onset of the cue array we observed a transient negative going waveform over the hemisphere that was contralateral to the attended hemifield. This activity was followed by a larger and sustained activity which lasted the duration of the stationary cue phase. Following motion onset this contralateral sustained activity further increased in amplitude and maintained throughout the duration of the trial until the test was presented. This pattern of activity corresponded closely to ERP waveforms previously reported (Drew & Vogel, 2008).

Analysis were performed over five time windows within each trial: an early cue phase, late cue phase, early tracking phase, late tracking phase. These time windows are termed N2pc, Early CDA, Late CDA, Fade, and MOT, corresponding to 150–200 ms, 200–300 ms, 300–700ms, 700–1200 ms, and 1200–2200 ms post-stimulus onset. Amplitude of the negative-going amplitudes are shown in 3.4. on page 82. The transient activity during the cue phase was primarily located over posterior electrodes, and maximally over lateral occipital electrodes (OL/OR). The sustained activity during the cue phase was broadly distributed over the posterior electrode sites with a maximum over posterior parietal electrodes (P03/P04). The sustained activity during the early tracking phase was significantly modulated by set size as well as by presence of grouping lines, such that the amplitude of waveform when there were three joined targets being tracked was less than that of three targets not so joined, yet greater than one item tracked alone. In order to better view this differences, difference waves were constructed by subtracting the ipsiliateral waveforms from the contralateral waveforms for electrodes F3/F4;C3/C4;P3/P4;O1/O2; OL/OR; T5/T6;PO3/PO4. See 3.5. on page 83.

Furthermore, the activity in the late tracking phase was also modulated by set size and grouping condition, such that the ERP amplitude for three items that had been previously joined with lines was greater than three items and one item ($p < .05$) The time window by condition interaction was also significant ($p < .05$) indicating that the removal of the grouping lines was associated with a significant increase in amplitude.

Within each analysis window grand average difference waveform amplitudes were constructed for each condition, see 3.7. on page 86 and the mean amplitude for each window time-locked to the beginning of the epoch was calculated. Amplitude differed as a function of analysis window, as well as by condition within each window, see 3.6. on page 84. Mean amplitude for each time window were; N2pc (SS1, M = –0.34, SE = 0.12; SS3, M =–1.0412500, SE =0.1217659 ; 1Group, M= –0.7775000, SE = 0.1375184), Early CDA (SS1, M =–0.3287500, SE = 0.1142593 ; SS3, M =–1.0050000, SE = 0.1952071 ; 1Group = –0.8712500, SE = 0.1267562), Late CDA (SS1, M = –0.2966667, SE = 0.1222949 ; SS3, M = –1.0841667, SE = 0.1785671 ; 1Group M =–1.0554167, SE = 0.1169788), Fade (SS1, M = –1.0554167, SE = 0.1169788 ; SS3, M = –1.1375000, SE = 0.1635379 ; 1Group M = –2.2691667, SE = 0.2903240), MOT (SS1, M = –1.8708333, SE = 0.1991612 ; SS3, M =–1.6375000, SE = 0.2134849 ; 1Group = –2.1137500, SE = 0.3158499).

These differences were confirmed with repeated measures ANOVA for each time window, N2pc ($F(2,46)=10.3$, $p < .001$), Early CDA ($F(2,46)=10.69$, $p < .001$), Late CDA ($F(2,46)=20.19$, $p < .0001$), Fade ($F(2,46)=14.44$, $p < .0001$), MOT ($F(2,46)=14.59$, $p < .0001$). Planned contrasts confirmed reliable differences in the ERP amplitude between the 1 and 3 target conditions in all analysis windows; N2pc ($t(23) = 4.67$, $p < .001$), Early CDA ($t(23) = 4.35$, $p < .001$), Late CDA ($t(23) = 5.14$, $p < .001$), Fade ($t(23) = 4.92$, $p < .001$), MOT ($t(23) = 2.27$, $p < .01$). However,

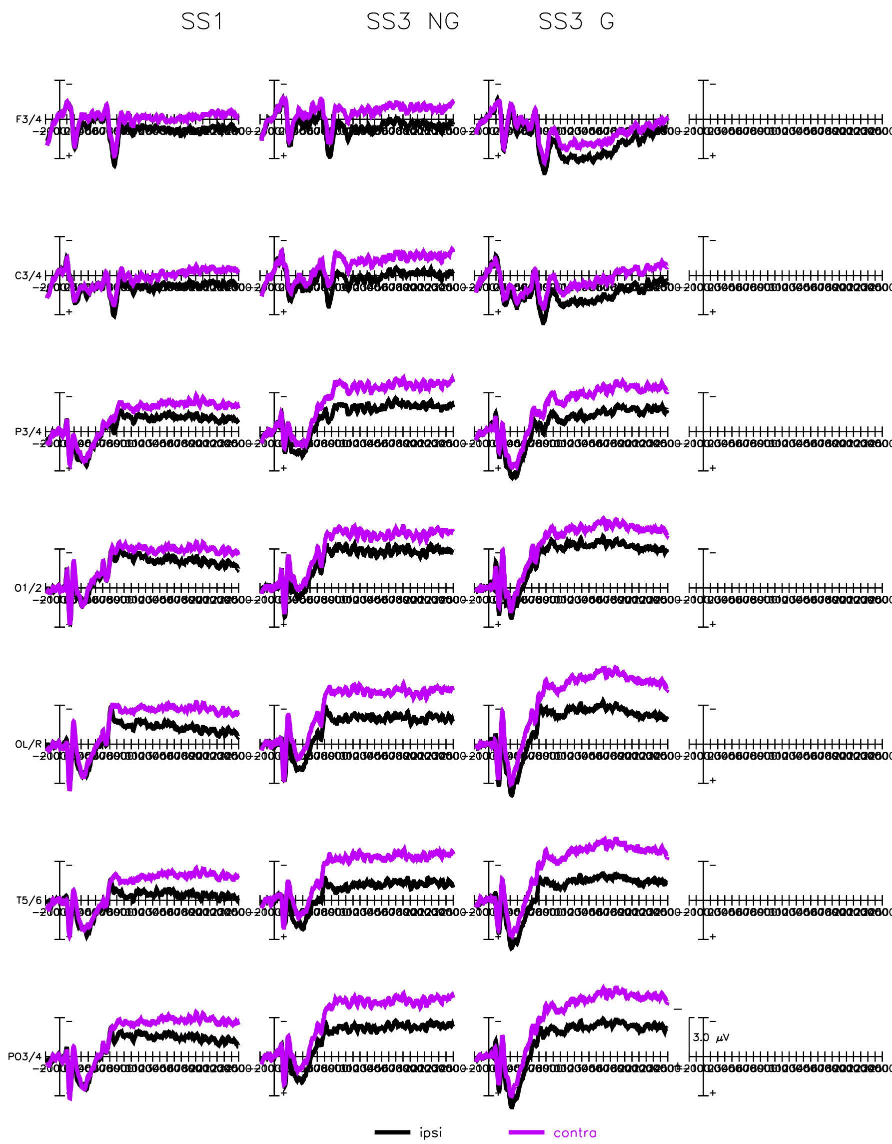

FIGURE 3.4. Experiment 2 Ipsi-Contra Waves

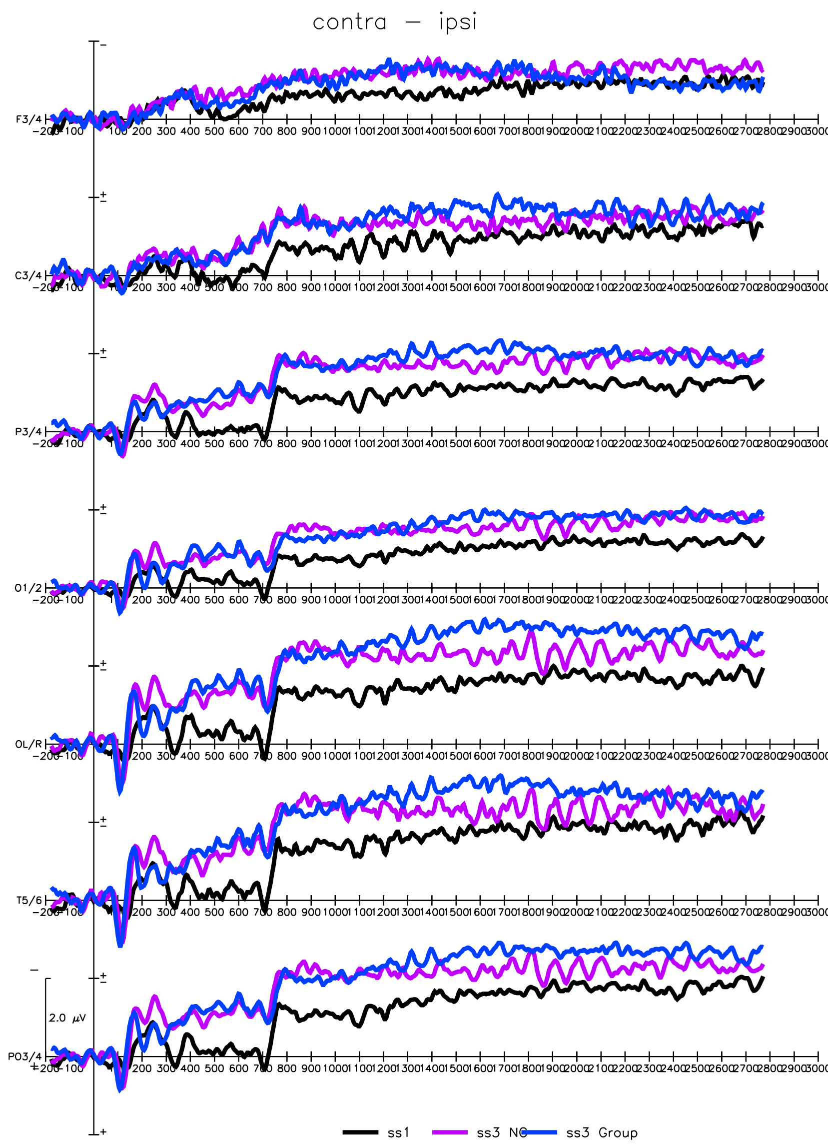

FIGURE 3.5. Experiment 2 Difference Waves

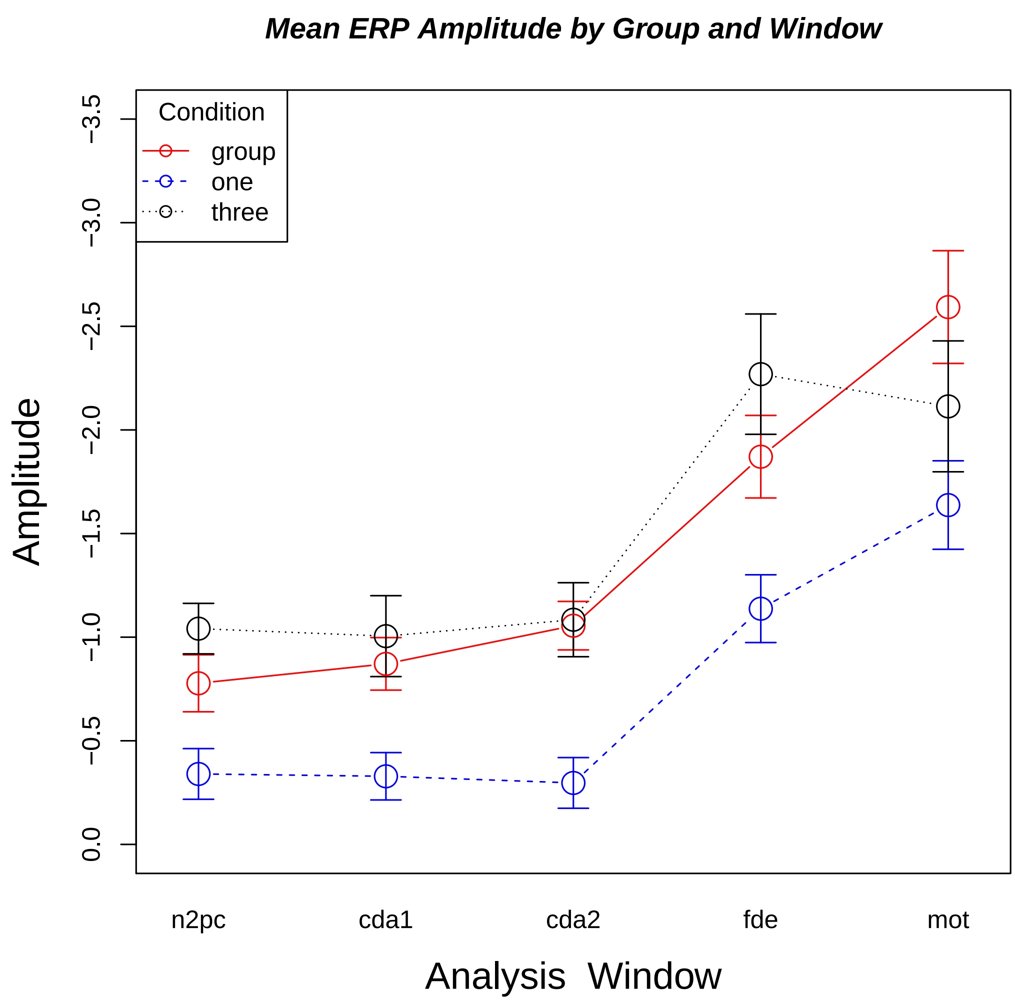

FIGURE 3.6. Experiment 2 Mean Amplitudes

differences between 3 targets or 3 targets grouped together depended on the time window of analysis, and hence the ERP component of interest. Reliable differences where found between the mean amplitudes between 3 targets and Grouped targets at the MOT ($t(23) = 2.77$, $p < .02$), and a trend toward significance in the Fade condition ($t(23) = 1.7$, $p < .1$).

The transient wave during the early cue period matches the latency of the N2pc wave which has previously been shown to reflect the selection of targets among distractors in visual search tasks (Woodman & Luck, 2003) as well as multiple object tracking tasks (Drew & Vogel, 2008). The later sustained wave during the cue period matches the CDA, a waveform that we and others have shown to reflect the number of active item representations in visual short term memory. The sustained activity during the tracking phases also appears related to the CDA, which we have previously shown to reflect the number of items being tracked in MOT. Both the N2pc and later the CDA (in both cue and tracking phases) was modulated by the number of items in the display(Drew & Vogel, 2008).

The presence of grouping lines did not modulate the N2pc, CDA during the cue phase, indicating that the items were both selected and represented in memory in similar manner whether there were three items plus joining lines or three items alone. However, during the early tracking phase, when configural or joining information might be expected to convey a benefit in tracking, the presence of joining lines did in fact reduce the online tracking load as indexed by the tracking activity. In order to measure this effect of grouping lines on tracking activity the Fade and MOT ERP amplitudes where compared directly. See 3.8. on page 87. A two-way repeated-measures ANOVA of Window x Condition (Grouped and Ungrouped) confirmed a significant main effect of time window ($F(1,23= 4.55$, $p<.05)$ and a significant

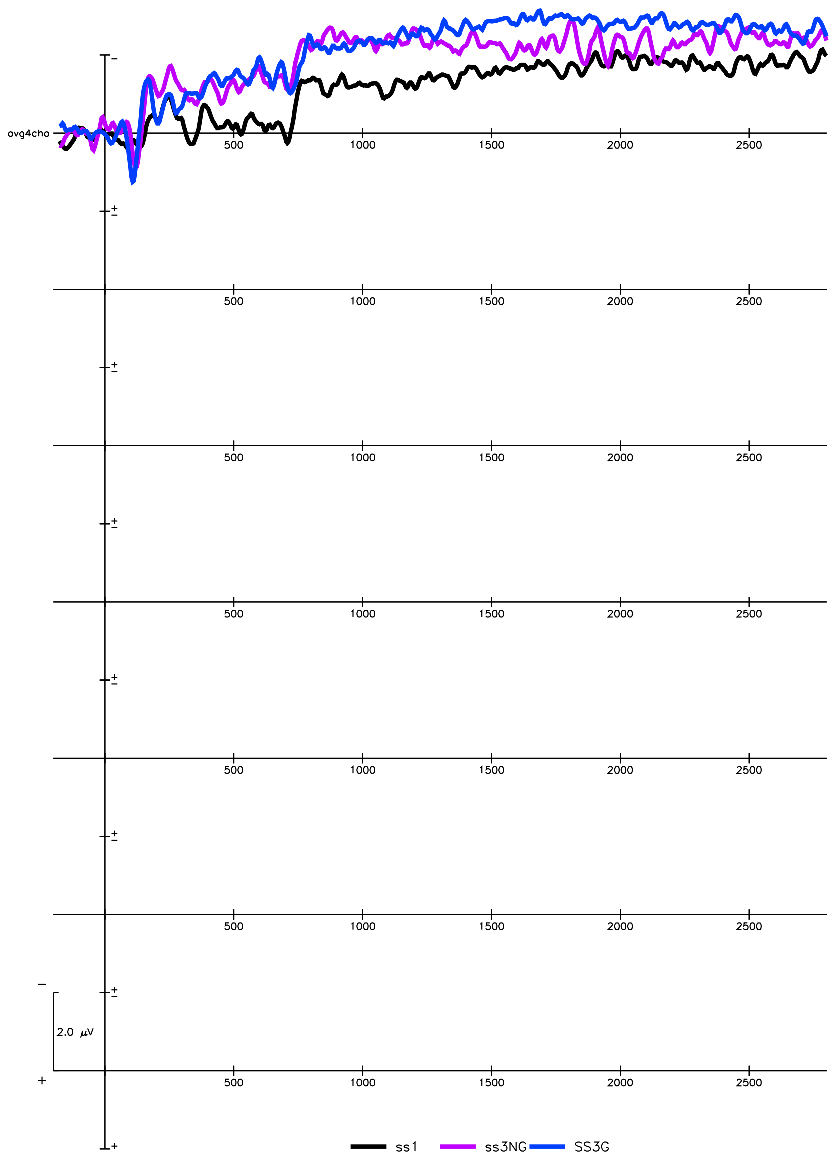

FIGURE 3.7. Experiment 2 Grand Average Difference Waves

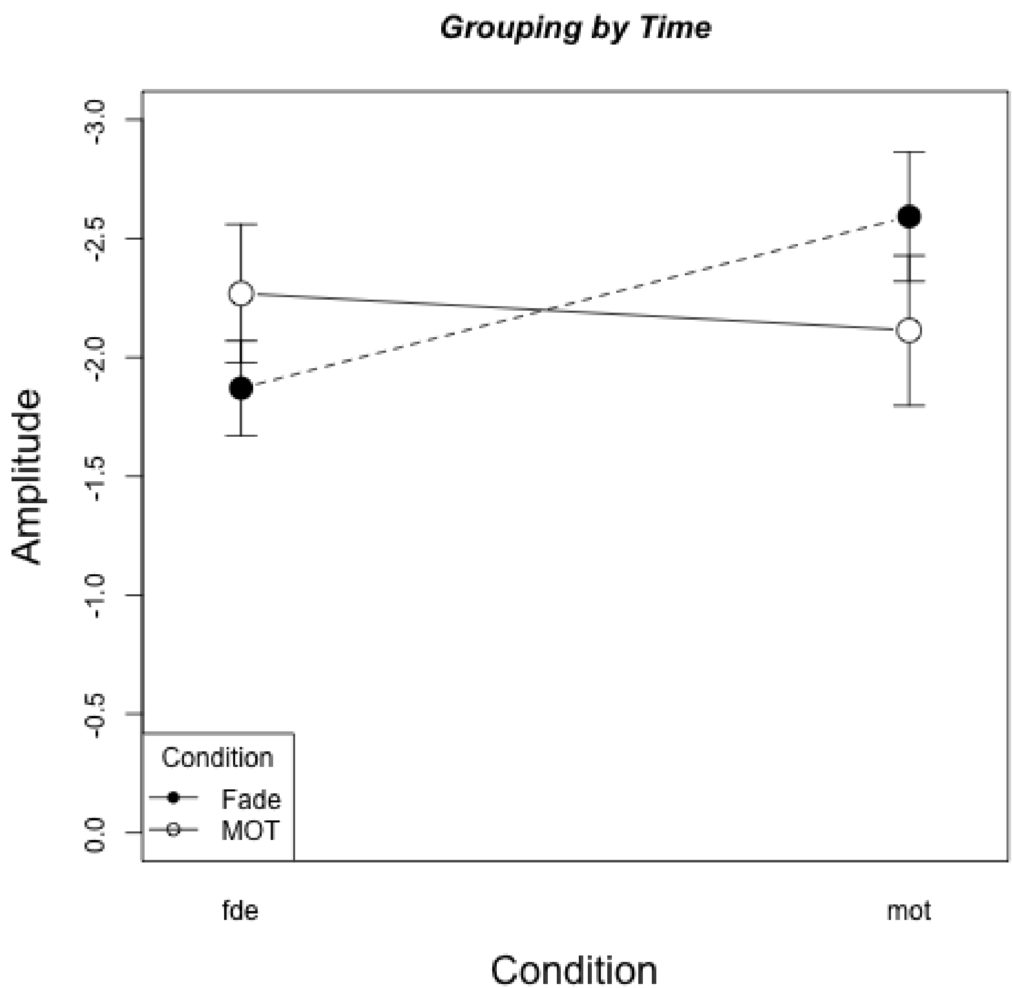

FIGURE 3.8. Experiment 2 Amplitude Differences

interaction of condition and window ($F(1,23)=19.95$, $p<.001$). This reduction in amplitude is unlikely to have been caused by simply tracking one item alone, since the grouping lines faded quickly are were gone after 500ms and therefore tracking only one item initially would have resulted in a later poor behavioral performance as well as a immediate reduction in tracking load. In fact, the opposite was the case with a significant condition by time interaction after the lines faded, showing a negative going increase in tracking amplitude during late tracking phase, as well as a later behavioral benefit, indicating that in the critical grouping condition the presence of bottom-up perceptual support decreased tracking load as indicated by both the reduced tracking activity and increased later behavioral performance. Interestingly, unlike previous experiments, the correlation between tracking capacity and tracking activity was only marginally significant ($t(22) = -1.43$, $p=.08$). The correlation between capacity in the grouped condition and tracking activity was also marginally significant, ($t(22)=-1.56$, $p = .067$).

3.5. Discussion

In this study MOT performance was measured by asking subjects to track 1, 3, or grouped objects among 10 total objects in a single visual hemifield. The effect of the perceptual grouping cue, in this case, common fate, on behavioral performance as well as electrophysiological measure of online tracking activity were measured. The study was motivated by four main questions; 1) Do the results from the previous Kanizsa study replicate in a new paradigm? 2) Is there support for the “reconstruction” hypothesis? 3) If so, does perceptual grouping mediate multi-element tracking? 4) Does neural tracking activity reflect the moment-by-moment visual representation? We found that, indeed, bottom-up perceptual grouping cues modulate online neural activity both during cue phase and later tracking, and that there is no evidence for a reconstruction hypothesis. That is, if subjects had merely been tracking a single target (one element of the figure), then when the connecting line faded away there would have been no way to recover the other targets. However, there was still a reduction in tracking amplitude (as well as the early CDA) and subsequent benefit in performance. Given this additional evidence, it seems that the reconstruction hypothesis is unsupported, at least in every case. Interestingly, however, even though the perceptual grouping lines had faded shortly into the tracking phase, there was nonetheless a benefit for grouping. Why might this be? Yantis found that subjects who were presented with targets in a canonical polygon, or were instructed in the strategy of mentally constructing a polygon to connect all the targets together, performed better then in other trials or if they had not been so instructed. Therefore, it seems that the initial connecting lines, even though they did not constrain the movement of the items whatsoever, nonetheless enabled the subjects to bind the items together, perhaps using internal model suggested by Yantis. Even if this the case, however, the difference in the ERP tracking activity indicate that this top-down strategy, if employed, is distinctly different from the bottom-up perceptual grouping effects we have seen. The observation that there is a clear disjunction between online representation of items which are grouped together compared to when they are no longer linked together indicates that these processes, at least at the level of active visual representations, are dissociated. The internal model hypothesis then, or strategic grouping, if it is correct, must occur at a later processing stage. In subsequent experiments we will attempt to test these ideas further and attempt to establish whether, even in the absence of a reduction in ERP activity a benefit of ongoing perceptual support, as distinct from perceptual grouping, is supported. An alternative explanation is that, perhaps it was not the establishment of an internal representation of a polygon which mediated the enhanced behavior, but rather that the bottom-up grouping cues tagged the targets during the early phase of tracking, essentially prolonging the selection or cue phase and providing an attentional buffer against distractors during early tracking. This hypothesis substitutes top-down modeling of the stimuli for bottom-up, stimulus driven processes. If this is the case, then manipulation of the grouping cues may allow us to further dissect this process. For example, through manipulation of perceptual grouping cues such as common fate or proximity. As an interesting aside, even though there were more visual elements on the screen in the grouped condition, online activity was actually less then when the subjects were tracking ungrouped targets. This indicates that it is not the number or amount of visual elements per se that drive the component and by implication, the active visual representation, but the subjective percept. Here, we investigated whether a real or virtual polygons between targets in a tracking task would enhance behavioral performance and reduce tracking load (as indexed by a reduction in amplitude of the CDA). We found that the the presence of actual grouping lines connecting the three targets in a MOT task reduced tracking load when the lines were present as compared to when they were absent, as indexed by the tracking activity and behavioral performance. These results suggest that perceptual grouping does indeed play a role in tracking, but this role may be primarily restricted to situations when there are strong bottom-up cues for grouping the objects together, rather than as the default mode of tracking.

CHAPTER IV

MULTIPLE OBJECT TRACKING AND COMMON FATE

4.1. Introduction

The previous chapter provided evidence that real or virtual polygons between targets in a tracking task enhances behavioral performance and reduce tracking load, suggesting that, in agreement with Yantis (1992), perceptual grouping does indeed play a role in tracking. However, we also found a difference in the ERP index of the active visual representation for trials in which an actual but not a strategic polygon was present. This could be taken as evidence that a strategic contribution of an internal model does not alter the perceptual qualities of the target ensemble. In contrast to the grouping hypothesis of MOT however, those data do not support a singular focus of attention, since tracking activity for explicitly grouped items was reduced compared to ungrouped items, indicating a greater tracking load for ungrouped items. A single-focus model would be hard pressed to explain this result. However, it may be that grouping separate target items with visible lines drives low level visual processes to create an explicit single object representation. That is, there may be a qualitative difference among grouping cue types, such that items connected by a single contour are processed differently to items which, though groupable via other cues such as proximity etc., are not so connected. There is some evidence to suggest that this is, in fact, the case (S. Palmer & Rock, 1994). Therefore, in order to further understand the role of grouping in MOT and in order to disambiguate the contributions of top-down strategy, ongoing perceptual support, and differences among explicit grouping cues, this chapter will examine the contributions of two such cues: common fate and proximity. Specifically, this chapter addresses the questions: 1) Do the results from the element connectedness experiment extend to other principles? 2) are there differences in the behavioral and ERP effects? 3) What are the effects on the active visual representation? 4) How does strategic grouping differ from perceptual support or grouping? This chapter will present evidence to disambiguate the contributions of top-down strategy, ongoing perceptual support, and explicit grouping cues in a MOT task. In order to do this, subjects were asked to track three items that were either grouped or independently moving so that the observed tracking load, as measured by behavior and online electrophysiological activity, could be modulated by perceptual grouping cue of common motion or proximity. Grouping was accomplished either through common fate or proximity. The common fate, or common motion, cue was further divided into either common local motion (jiggling in place) or global motion (items moving together across the viewed hemifield). Furthermore, at the midpoint of the tracking phase all grouping cues were removed and the targets allowed to move without constraint. Thus, this paradigm allows the contrast between continual perceptual support via two types of common movement, explicit perceptual grouping via proximity, and strategic grouping of randomly moving targets. If tracking load is reduced with perceptual grouping support then we should expect a concurrent reduction in the amplitude of the sustained tracking activity and enhanced performance in the behavioral task. On the other hand, if perceptual grouping cues do not affect tracking, such that perceptually grouped items are tracked identically to items which are not so grouped, online tracking activity and behavior should be equivalent in each condition. Moreover, by comparing grouping by common fate with proximity or random motion, the contribution of ongoing perceptual support distinct from obvious grouping cues may be obtained.

4.2. Experiment Description

In order to do this we made a modification of the previous experimental procedure. Here, on each trial subjects were presented bilaterally with eight items randomly placed in each hemifield on one fourth of trials there were three randomly placed targets which moved independently during the tracking phase, on one fourth of trials there were three targets were clustered together such that the targets were touching to form a line, one one fourth of trials the targets were randomly placed but moved together during the entire tracking phase, and one fourth of trials the randomly placed targets jiggled together in place during the tracking phase. See 4.1. on page 94. Each trial consisted of an initial cue phase lasting 500ms and longer tracking phase lasting 3000 ms, followed by a final test phase continuing until subject response. For the first 500 ms of each trial all the items were stationary with the targets drawn in red in the attended hemifield, and the remaining distractor items drawn in blue. Three random items in the unattended hemifield were drawn in green, with the remaining distractors drawn in blue. Movement of all items in the displays were random, constrained by the movement parameters of each condition, such that in group movement (Jiggle, Group Move, Cluster) conditions the items moved together until the Break phase and then were allowed to move independently, except for the Group Move condition for which the targets continued to move together until the test phase. Items moved at a constant velocity without occlusion. The Break occurred 1500 ms after the start of motion. During the test phase all motion ceased and a single item was indicated by turning red. Subjects then indicated whether that item was a target or distractor.

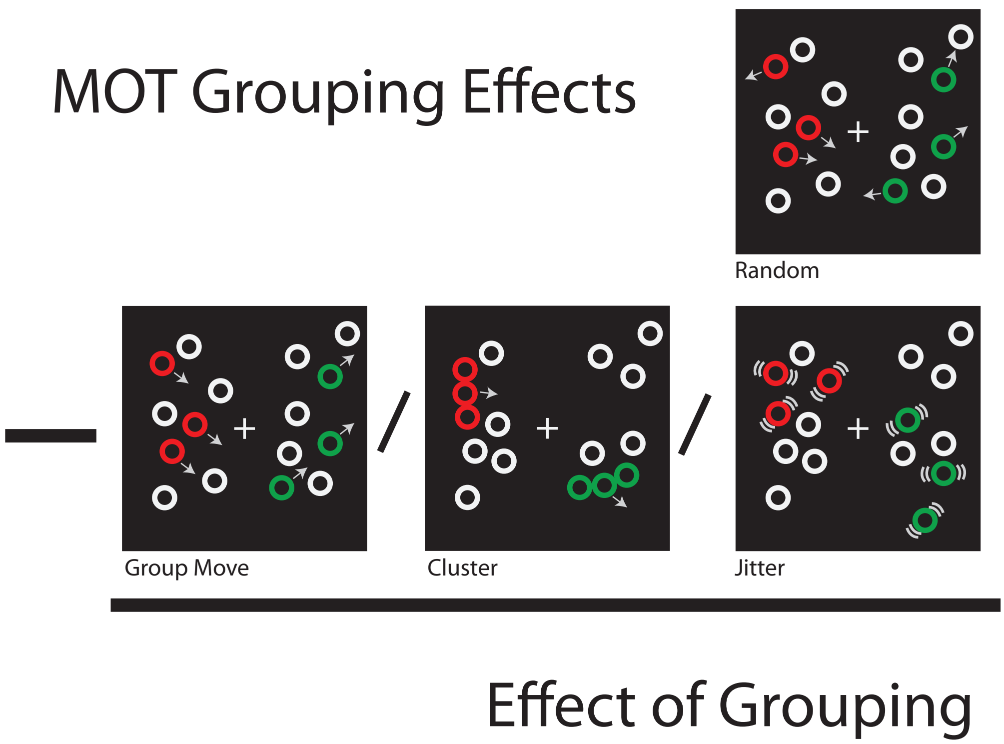

FIGURE 4.1. Experiment 3 Paradigm

4.3. Methods

4.3.1. Paricipants

Neurologically normal participants (17 subjects) from the Eugene, OR community gave informed consent according to procedures approved by the University of Oregon institutional review board. Three subjects were rejected from analysis utilizing the criterion previously stated in Experiment 2.

4.3.2. Stimulus and procedure

The general procedure for stimulus presentation and parameters as well as EEG recording, measurement and analysis for this experiment was identical to Experiment 2. See Figure 4.1. on page 94 for experiment and condition diagram. This experiment consisted of four conditions: Random, Cluster, Jiggle, Group. The Random condition served as a baseline MOT condition in which participants tracked three items among five distractors. In the Cluster condition three items were placed adjacent to each other so as to form and apparent dotted line or beads on a string percept. The third condition consisted of three targets, randomly placed but whose motion was bound such that they moved in formation, sharing a common group trajectory as if fixed on the vertices of a randomly generated triangle. The fourth condition, Jiggle, was similar to the Group condition, except that the bound targets "jiggled" back and forth in place in a vibratory motion at approximately 20 Hz with a displacement no greater than 1/2 object diameter. In all conditions the distractors moved randomly. In all conditions, in the non-tracked hemifield, the differently (green) distractors moved among blue distractors. Motion for grouped target items the "Jiggle" and "Cluster" conditions decohered at the midpoint (3000ms), the "break" , in the tracking period.

Motion for the other two conditions remained unchanged. Each trial lasted for 3600 ms; for analysis purposes, the EEG data was analyzed for five time windows: 150–250ms, 250–700ms, 800–1200ms, 2700–3100 ms, and 3400–3600 ms. These correspond to the N2pc, CDA, and three tracking period time windows: early tracking, late tracking (after the break), and trailing (the last few ms of the tracking period).

4.4. Results

In the previous experiment we found that the presence of strong bottom-up perceptual grouping reduced tracking load and increased behavioral performance. In this experiment we investigate whether other forms of perceptual grouping, here common motion and proximity, might also reduce tracking load and increase performance. On each trial subjects were presented bilaterally with eight items randomly placed in each hemifield, with three targets and the remainder distractors, on a black background, in one of three conditions. In one third of trials were three targets which moved randomly after motion onset, on one third of trials there were three targets placed in a line with edges touching which moved as one item, and in one third of trial there were three randomly placed items which moved as one item. Each trial consisted of an initial cue phase lasting 500ms and a longer tracking phase lasting 3000 ms. For the first 500 ms of each trial, the cue period, all the items were stationary with a subset of the items, the targets, drawn in red (in the attended hemifield) while the remaining items in that hemifield, the distractors, were drawn in blue. In the unattended hemifield a number of items equal to the number of red targets were drawn in green with the remainder of items rendered in blue. Following the cue period, all the items turned to white and began moving within their respective hemifield for 5 seconds, the tracking period. In the random condition all the items moved randomly throughout the entire tracking period. In the cluster condition, items moved together for 1500ms after which the clustered items broke apart and began moving separately, thus dividing the tracking period into an early 1500 ms period and a later 1500 ms tracking period. In the group motion condition all the items continued to move together until the end of the tracking period. In all conditions the items were tracked for the same duration. At the end of the tracking period all motion ceased and a single item on the attended side turned red. Subjects were asked to track the targets and report via button press whether the final red item was one of the tracked items or not. We asked subjects to track the three targets in each trial to so that we could determine whether tracking load, as measured by the ERP index of tracked items, was modulated by the bottom-up perceptual grouping cues provided by the bottom-up perceptual support either close proximity or group motion. We time locked to the onset of the cue array and recorded throughout the duration of the trial until the test array so that we could observe transient selection of targets, memorial representation of items, tracking during perceptual support, and tracking after perceptual support.

4.4.1. Behavior

Performance was measured by button press, and as can be seen from Figure 4.2. on page 98), performance was generally high, the average across conditions was .89, SE = .016, and there were small, if any differences in performance across the conditions as can be seen from the behavioral performance in Figure 4.2.. This was confirmed with a one-way repeated measures ANOVA, ($F(3,39) = 0.77$, $p = .52$). Collapsing across conditions by averaging values for Break and Non-break conditions revealed only a marginal effect of grouping ($t(13)=1.43$, $p=.088$).

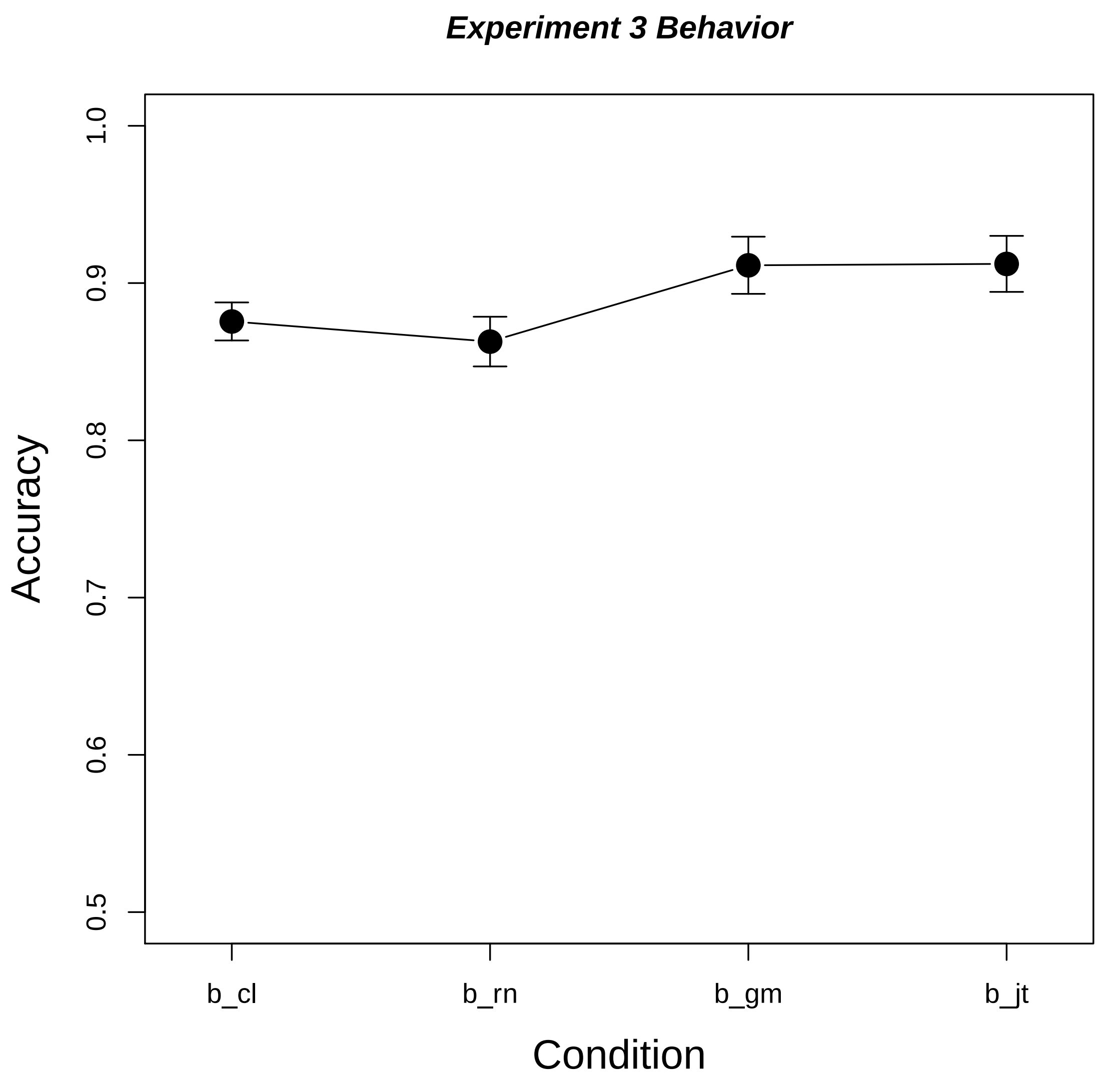

FIGURE 4.2. Experiment 3 Behavioral Performance

4.4.2. Electrophysiology

Two hundred milliseconds after the onset of the tracking array we observed a transient negative going waveform over the hemisphere contralateral to the attended side. Subsequent to this waveform, sustained activity which lasted duration of the cue period was observed. Following motion onset during the tracking phase, this contralateral activity increased in amplitude and was maintained throughout the duration of the tracking period. Figure 4.3. on page 100 shows ipsi-contra difference waves for electrodes F3/F4;C3/C4;P3/P4;O1/O2; OL/OR; T5/T6;PO3/PO4.

Analysis were done over the five time windows within each trial: early cue phase, late cue phase, early tracking phase, break, and late tracking phase. Grand average difference wavefoms for P3/P4;OL/OR; T5/T6;PO3/PO4 are shown in Figure 4.4. on page 101 , and as can be seen by visual inspection, the waveforms were differentially modulated by perceptual grouping cues at each phase.

Data were averaged for each time window, in Figure 4.5. on page 103 the mean amplitude for each time window and condition is displayed. Mean amplitudes for each condition and time window were submitted to a repeated measures anova. Confirming visual inspection of the mean amplitude data, reliable differences were found in each time window between conditions. Repeated measures anovas confirmed this intuition in each time window: N2pc, ($F(3,39) = 9.76$, $p < .001$), CDA ($F(3,39) = 16.2$, $p < 0.001$), Grp ($F(3,39) = 18.3$, $p < .001$), Break, ($F(3,39) = 9.94$, $p < .001$), Late Tracking, ($F(3, 39) = 3.67$, $p < .02$), all p-values corrected for sphericity using the Greenhouse-Geisser correction. Planned comparisons between the conditions revealed further differences between the conditions. The critical grouping conditions in this experiment were the Cluster condition and the Jitter condition. Mean amplitudes for each of these conditions in each time window were compared to the baseline

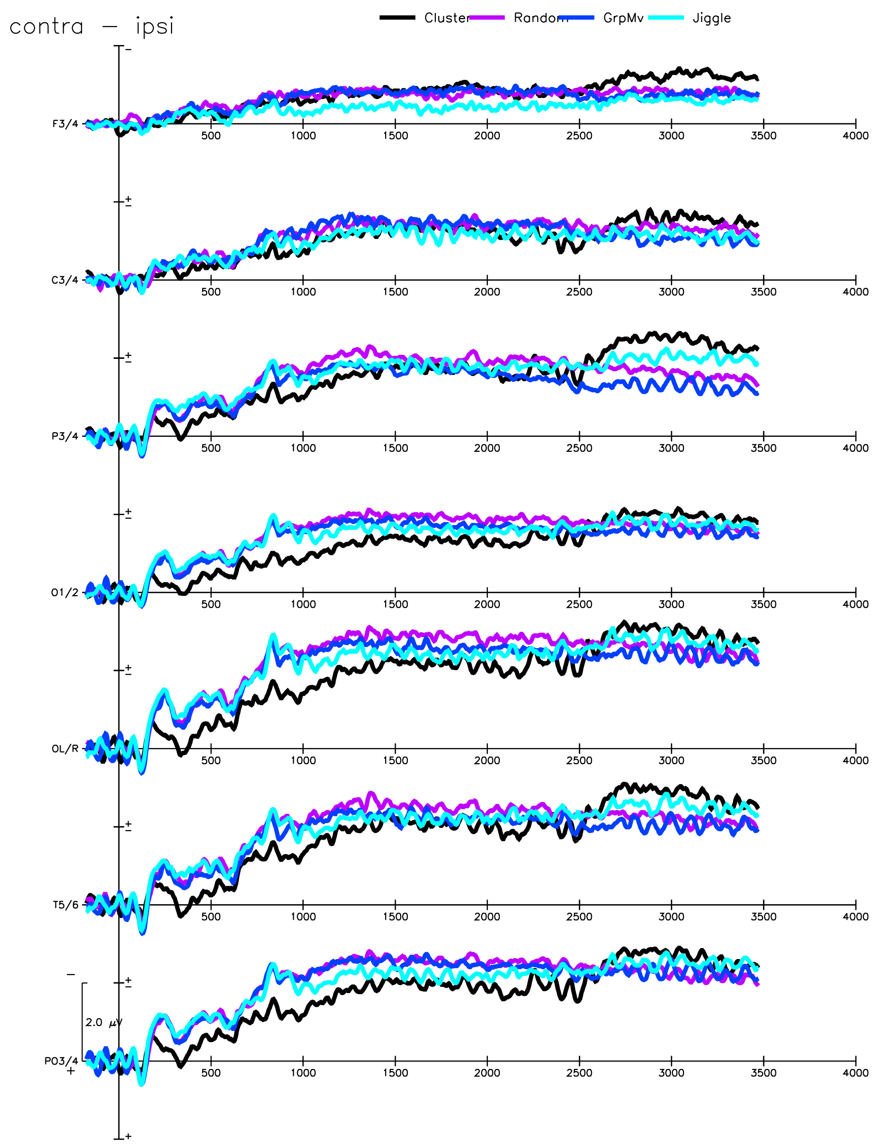

FIGURE 4.3. Experiment 3 Difference Waves

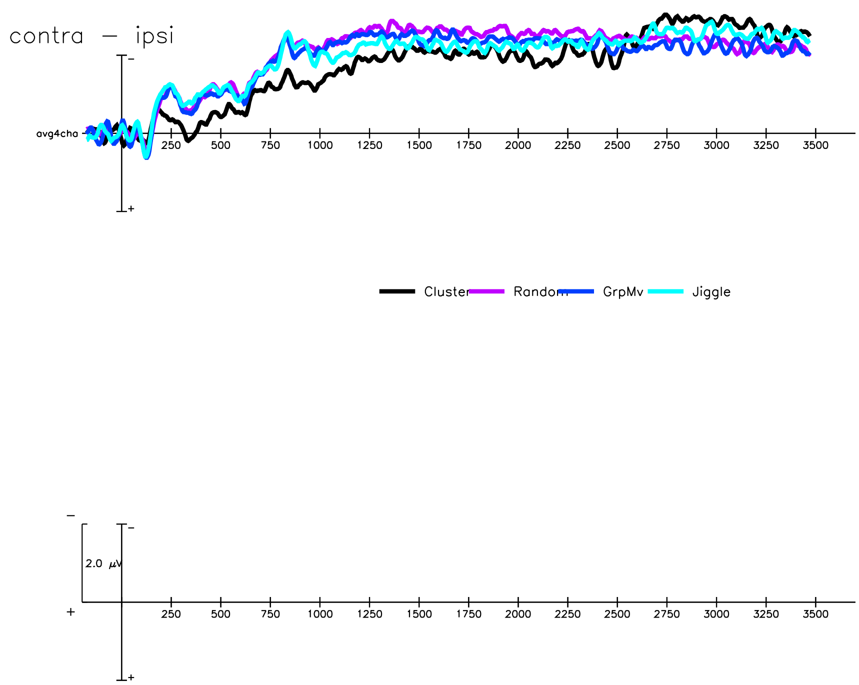

FIGURE 4.4. Experiment 3 Grand Average Difference Waves

Random condition. Reliable differences were found between the Cluster condition and the Random condition in each time window; N2pc, ($t(13)=3.52$, $p < .05$), CDA, ($t(13)=6.11$, $p < .0001$), Grp, ($t(13)=5,55$, $p < .0001$), Break, ($t(13)=5.15$, $p < .001$), and Late Tracking phase as well, ($t(13)=2.24$, $p < .03$). The ERP amplitudes in the Jitter condition were also compared to the amplitudes in the Random condition for each time window, however only marginally significant differences were found between these two conditions in the Break analysis window, ($t(13)=2.08$, $p < .06$). However, reliable differences were found in the Late Tracking window, ($t(13)=2.31$, $p < .05$). In order to better illustrate the differences between baseline and grouping conditions, difference scores were calculated by subtracting the ERP mean amplitudes in each grouping condition (Cluster, Jitter, Group Move) from the baseline Random condition in Figure 4.6. on page 105.

The change in amplitude in the grouping conditions from “grouped” to “ungrouped” at the Break point was also of interest. In order to examine this amplitude change, a two-way repeated measures ANOVA with factors of Condition and Analysis Window (GRP, BRK) was conducted. This analysis revealed a significant effect of analysis window ($F(1, 3) = 59.9$, $p < .0001$), and a significant interaction between Condition and Window ($F(3,39) = 49.47$, $p < .0001$).

Previous MOT studies with ERPs have demonstrated a correlation between the difference in ERP amplitudes between low and high set size conditions and tracking performance in these conditions. In addition, enhanced N2pc amplitude as also been correlated with an increase in tracking performance. Importantly, simple amplitude of the ERP does not so correlate, rather, it is the difference in amplitude between set sizes that correlates with performance. Analogous results have also been demonstrated using the CDA. In this experiment, however, only set sizes of

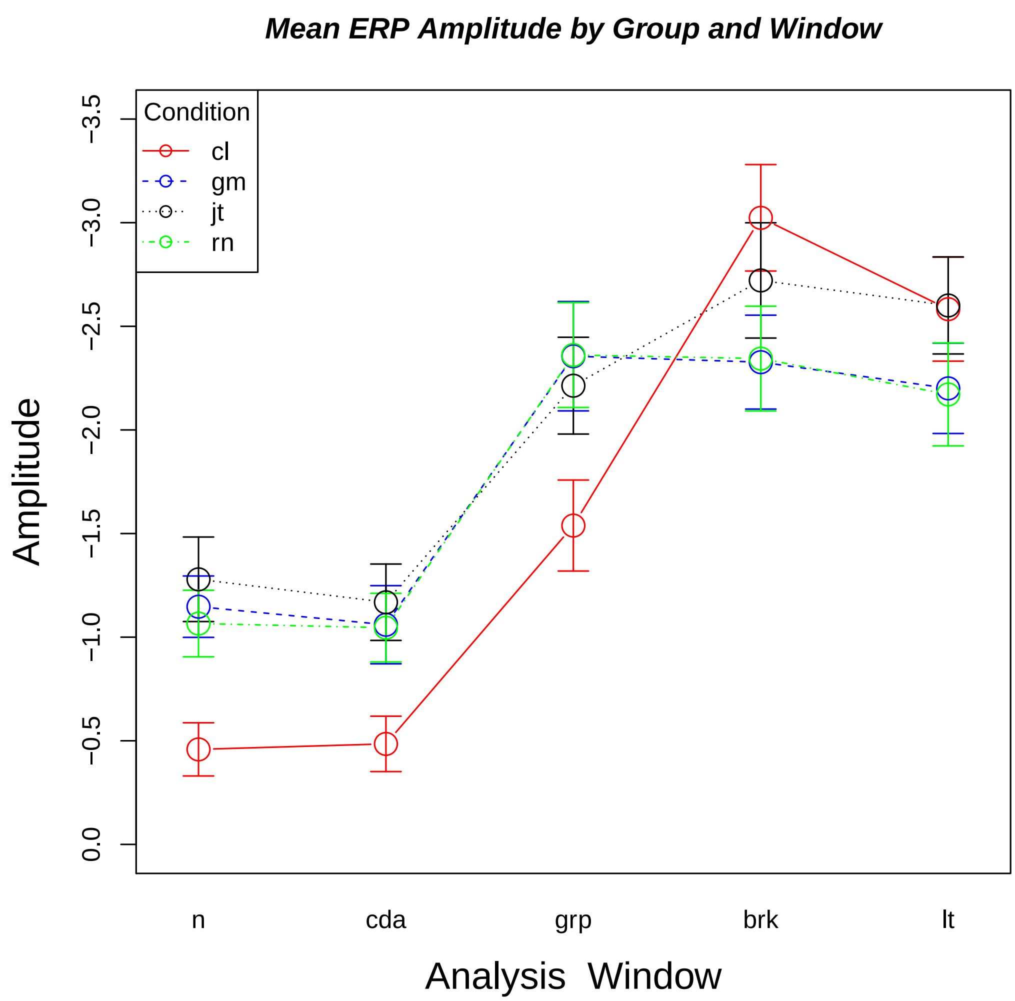

FIGURE 4.5. Experiment 3 Mean Amplitudes

three items were tracked. Accordingly, the differences were calculated by taking the difference between the baseline Random condition and each of the grouped conditions by analysis window. These difference scores were then correlated with behavioral performance in each condition. Differences in ERP amplitude between grouping in the group move and jitter conditions and baseline condition correlated significantly with behavior at all time windows. See Appendix A for all correlations. However, the amplitude difference between Cluster and Random did not correlate significantly at any analysis window. However, the difference within the Cluster condition between the Grouping window and the Break window (the increase in amplitude from grouped to ungrouped) was positively correlated with behavior in the Cluster condition, ($t(12)=2.36$, $p < .05$) though not with any other condition. Differences between Group and Break time windows for all other conditions (Random, Group Move, Jitter) did not significantly correlate with performance.

4.5. Discussion

In the previous MOT experiment we observed that the presence of explicit grouping cues, the connecting lines between target elements, was sufficient to enhance tracking performance and reduce online tracking load as measured by the ERP tracking activity. However, from that experiment it is not clear whether the grouping effect was due to a simple bottom-up stimulus driven binding of objects together (by literally connecting the dots), or rather due to the subjects actively binding disparate objects together. Element connectedness is extremely strong grouping cue, as elements are directly tied together (Han et al., 1999). In this experiment we sought to discover whether other, less bottom-up cues may also induce the binding of the distinct elements together, vis a vis Gestalt heuristics, reduce electrophysiological

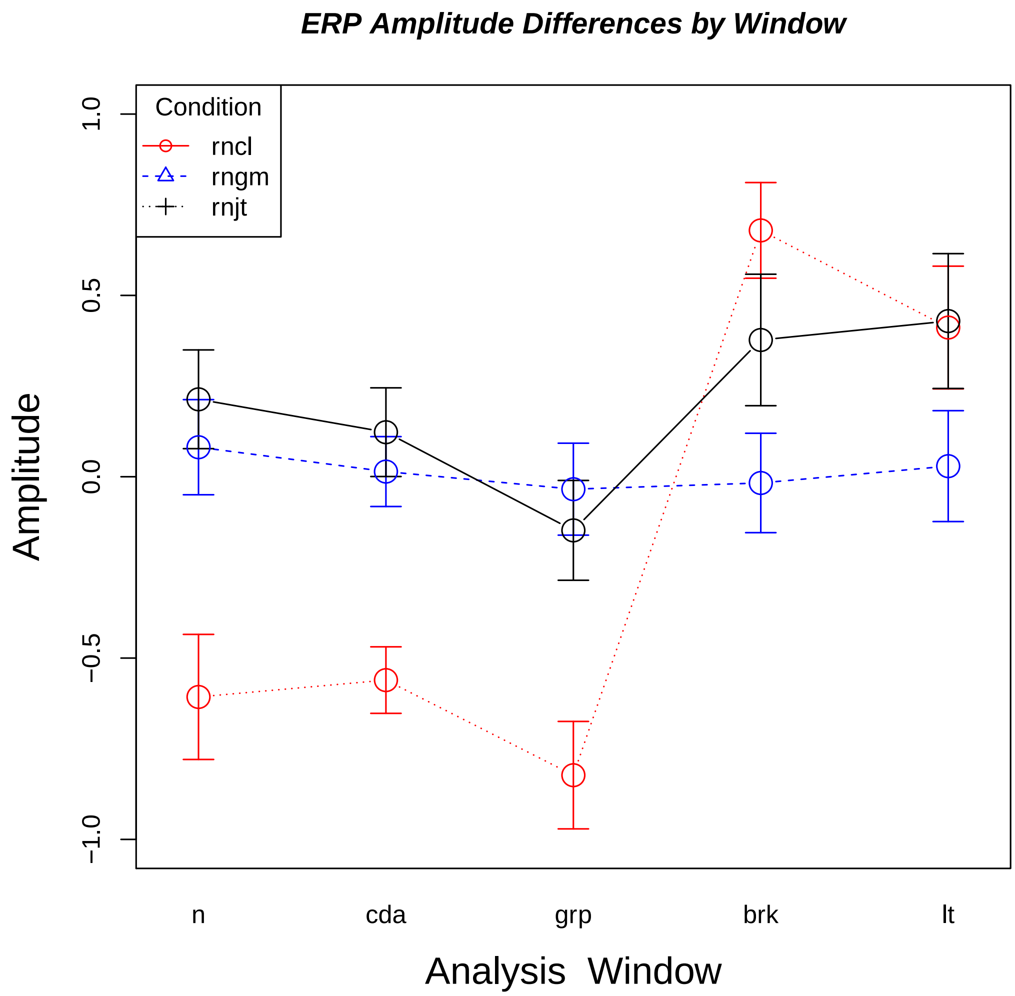

FIGURE 4.6. Experiment 3 Difference Amplitudes

tracking activity or enhance tracking performance. In particular, it should be the case that if tracking load is reduced by perceptual grouping then we should expect a concurrent reduction in the amplitude of the sustained tracking activity and enhanced performance in the behavioral task. On the other hand, if perceptual grouping cues other than element connectedness do not affect tracking, then online tracking activity and behavior would be the same in all conditions, since all conditions contained equivalent numbers of elements. Furthermore, the Group Move condition allowed us to ask whether, even in the absence of a clear reduction in tracking activity, performance could be enhanced. First, we found that that strategic grouping, the Cluster condition, in which the elements moved together in close proximity, was sufficient to reduce the online electrophysiological activity during cue and tracking phase, as compared to the Random condition. Though that reduction per se did not correlate with behavioral differences, and in fact there were no overall behavioral differences between the conditions, there was a significant correlation between behavioral performance and degree to which the elements were initially bound and then unbound. This unbinding effect, in which the amplitude of the tracking activity increased when motion coherence decreased, was also seen in the Jitter condition. In this experiment there was no reliable difference in tracking activity for elements that moved together and for random elements. It may be the case that the grouping cue was not strong enough to induce this reduction. This chapter presented evidence to disambiguate the contributions of top-down strategy, ongoing perceptual support, and explicit grouping cues in a MOT task. Subjects were asked to track items that were grouped with differing Gestalt cues, or none. Grouping was accomplished either through common fate or proximity. We found that separate items which were grouped by proximity demonstrated a marked reduction in online tracking load as indexed by the ERP. Not only that, but when the items were separated, the amplitude of the tracking waveform increased to that of items that were individually selected and tracked. The data here support the hypothesis that there are differences in strategic grouping, such as when a subject deliberately imagines connecting polygons, compared to bottom-up perceptual grouping in which Gestalt cues drive subjective perception of an composed object. That evidence is from two sources: the behavioral benefit in tracking accuracy in the Cluster condition compared to ungrouped conditions, and the ERP component amplitude in those same conditions. Specifically, the correlation between electrophysiology and behavior in the proximity grouping condition, closely spaced yet distinct target items was enhanced compared to the separate target condition. However, no such differences existed between the global common motion condition and the ungrouped condition in terms of tracking activity, suggesting that there were no differences in those conditions in the active visual representation. Perceptual grouping cues can reduce online tracking activity and enhance performance, but there are important differences among types of cues. Explicit spatial cues can quickly segregate targets and cohere initially separate items into a unified percept. On the other hand, extended temporal or motion cues may not result in such immediate segregation and grouping, depending on the cue. Overall, the grouping results from the previous experiments were replicated and extending with other gestalt cues. Furthermore, the novel “break” time point demonstrated that perceptual grouping is updateable from moment to moment. Finally, strategic grouping differs from ongoing perceptual support in that perceptual support did not result in a decrease in ERP tracking component; the amplitude did not decline over time, suggesting that targets, if lost, were rapidly regained, and that percepts of the disparate objects remained separable.

CHAPTER V

MULTIPLE OBJECT TRACKING AND PROXIMITY

5.1. Introduction

In the preceding chapters we have demonstrated that the perceptual cues of completion, common fate, line groups etc. can influence the representation of items in active representation, whether in memory or actively tracked. Furthermore, we have demonstrated that the sustained activity is updated in a dynamic fashion, that is, what constitutes an "item" in memory, as indexed by sustained neural activity, is not only not the raw sensory data, rather perceptual groups, but that these perceptual groups are flexible: they are actively updated and modified over time as needed to perform the task. Furthermore, we offered some evidence that perceptual support can increase behavioral performance and enhance the representations of items even if they are not explicitly joined together into a single representation. That is, tracking may be improved in at least three ways: by enhancing the selection of the targets to be tracked, by supporting the more effective tracking of targets or by enabling the more efficient suppression of distractors.

The N2pc is a early ERP component that is thought to index the selection of targets. Previous research, Drew et al. (2011) has shown that the amplitude of the N2pc is correlated with behavioral performance in a MOT task. Facilitating target selection by providing a strong grouping cue such as common location, proximity, or systematic regularity in item presentation, should improve the selection of targets and therefore enhance the active representations of the items and provide a strong correlation with behavior. This experiment seeks to confirm and extend the results of the previous chapters and address the following questions: 1) Are early components, such as the N2pc sensitive to the number of items that are proximate to each other, or only sensitive to the number of items and can an "individuation" hypothesis be explored with this data? 2) How sensitive is the proximity cue in perceptual grouping? 3) Can early perceptual grouping distinguished from later tracking? 4) What is the speed of perceptual grouping/segregation? 5) Does the early benefit provided by perceptual grouping occur even if grouping cues are removed immediately? 6) How crucial is ongoing perceptual support, as compared to perceptual grouping, for modulation of the tracking ERP component? It this modulated by increasing the effectiveness of target selection or enhancing distractor suppression?

The CDA, as demonstrated previously, indexes the perceived number of objects. During the cue phase of the MOT task we are able to observe the number of items the subject perceives. If object individuation in working memory is critical during this phase, then the correlation with behavioral performance should reflect this.

In this experiment, we attempt to further test these hypothesis by manipulating the strength of the proximity and motion grouping cues in a MOT experiment. That is, is it the case that merely grouping items together at some stage of the task provides tracking enhancement, or does the timing and duration of the grouping cues play a critical role? Here, three types of target grouping were contrasted with each other and with ungrouped targets. Subjects were asked to track targets that were either grouped proximal to each other for the duration of the cue phase and tracking phase, or were initially grouped and then ungrouped during the entire tracking phase. Additionally, subjects tracked randomly spaced targets which moved independently, or targets that were randomly spaced but moved in a linked fashion.

5.2. Experiment Description

Identical stimulus and recording parameters were used in this experiment as in the previous MOT experiments. Four stimulus conditions, similar to the previous experiments, were used each consisting of three targets and five distractor elements. The conditions can be divided into three grouping conditions and one baseline condition. The grouping conditions were Cluster, Cluster Break, and Group Move. In contrast to the previous experiments, all elements here were presented in a circle. In the Cluster condition, items appeared on the circle next to (though not touching) each other, and moved with each other. At the midpoint of the tracking phase the Cluster elements began moving independantly. The Cluster Break condition was identical to the Cluster condition for the first 500 ms, but at the end of the cue period the Cluster Break targets began moving randomly. The Group Move elements were presented on the circle during the cue phase with at least one distractor interpolated between each target. Elements in the Group Move condition moved together throughout the duration of the trial. Finally, elements in the Random condition were presented randomly in the circle and moved randomly during the tracking phase. See Figure 5.1. on page 111 for a graphical depicition of the conditions.

5.3. Methods

On each trial subjects were presented bilaterally with eight items placed in each hemifield, three targets and the remainder distractors, on a black background, in four conditions. In one half of trials were 3 targets placed sequential around an invisible circle (the cluster and break conditions), in one fourth of trials there were 3 targets placed randomly around the circle (random), and in one fourth of trials target items were placed with at least one distractor between (group motion). Each trial consisted

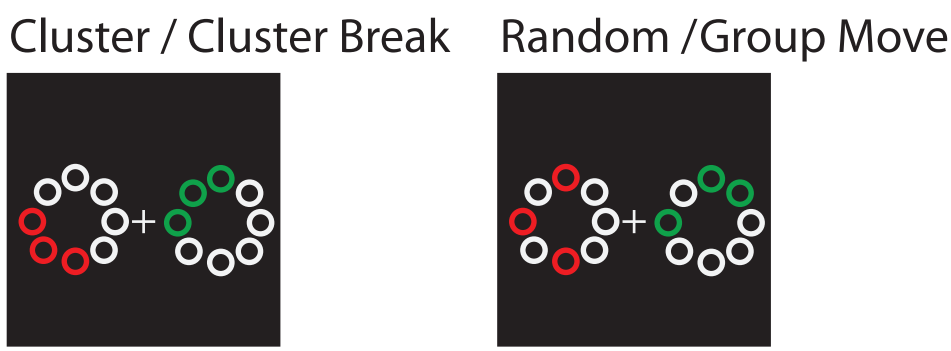

FIGURE 5.1. Experiment 4 Paradigm

of an initial cue phase lasting 500ms and a longer tracking phase lasting 3000 ms. For the first 500 ms of each trial, the cue period, all the items were stationary with a subset of the items, the targets, drawn in red (in the attended hemifield) while the remaining items in that hemifield, the distractors, were drawn in blue. In the unattended hemifield a number of items equal to the number of red targets were drawn in green with the remainder of items rendered in blue. Following the cue period, all the items turned to white and began moving within their respective hemifield for 5 seconds. The movement was random unless constrained by the condition (cluster items and group motion items moved together). The tracking period was divided into an early tracking 1500 ms period, and the remainder of the tracking period during which the items continued to move randomly. All other aspects of the trial were the same as in the previous experiments.

5.3.1. Participants

Neurologically normal participants (17 subjects) from the Eugene, OR community gave informed consent according to procedures approved by the University of Oregon institutional review board. Five subjects were rejected from analysis utilizing the criterion previously stated in Experiment 2.

5.3.2. Stimulus and Procedure

The general procedure for stimulus presentation and parameters as well as EEG recording, measurement and analysis for this experiment was identical to Experiment 2. Figure 5.1. on page 111. This experiment consisted of four conditions: Random, Cluster, Cluster Break, Group in a static cue phase and a dynamic tracking phase. Targets and distractors were placed equidistant from each other on the circumference of a circle of radius of 3degrees centered on a point located 3.5 degrees from the fixation point. The Random condition served as a baseline MOT condition; in this condition participants tracked three items moving randomly among five distractors. In the Cluster condition three items were placed adjacent to each other as in the previous experiment, but not touching each other, forming an apparent dotted line percept. During the tracking phase the items moved together in formation. The Cluster Break condition was identical to the Cluster condition until the tracking phase began, at which point the targets began moving randomly as in the Random condition. Finally, in the Group Move condition targets were placed around the circle randomly and then moved in formation, sharing a common group trajectory as if fixed on the vertices of a randomly generated triangle. In all conditions the distractors moved randomly. In all conditions, in the non-tracked hemifield, the differently (green) distractors moved among blue distractors. Each trial lasted for 3600 ms; for analysis purposes, the EEG data was analyzed for five time windows: 150–250ms, 250–700ms, 800–1200ms, 2700–3100 ms, and 3400–3500 ms. These correspond to the N2pc, CDA, and three tracking period time windows: early tracking (MOT), after the break (BRK), and Late (LT, the last few ms of the tracking period).

5.4. Results

5.4.1. Behavior

Performance was measured by button press, and as can be seen from Figure 5.2. on page 114 , performance was generally high, the average across all conditions was .806, SE=.021. The best behavioral performance was in the Cluster and Group Move conditions (Cluster: M = .84, SE=.018), (Group: M = .90, SE=.02), while the worst performance were in the two conditions which were not grouped during the

MOT phase, (Random: M = .73, SE=.03), (Cluster Break: M = .75, SE=.02). Apparent differences between the means was confirmed with a one-way repeated measures ANOVA, ($F(3,33) = 58.3$, $p < .0001$). Planned comparisons were done to test the performance in the grouping conditions (Cluster, Group Move, Cluster Break) against the Random baseline condition; Cluster vs. Random, ($t(11)=7.45$, $p < .0001$), Group Move vs Random, ($t(11)=9.06$, $p < .0001$), Cluster Break vs Random, ($t(11)=2.22$, $p < .05$).

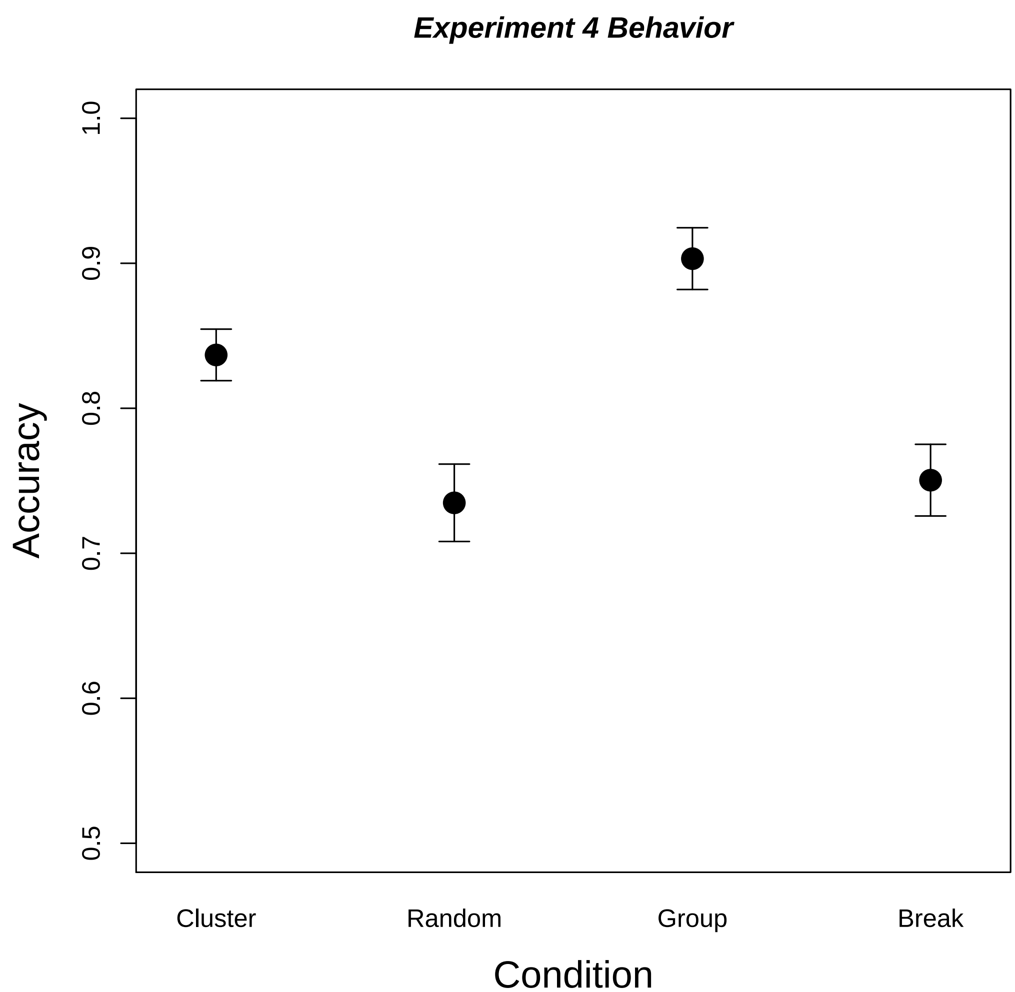

FIGURE 5.2. Experiment 4 Behavior

5.4.2. Electrophysiology

The electrophysiological response in this experiment followed closely that of the two previous MOT experiments. Ipsi-Contra waveforms time locked to tracking array onset show a negative-going waveform beginning about 200 ms after array onset. This difference remained until motion onset, at which point the amplitude increased. See Figure 5.3. on page 116. Difference waves for electrodes F3/F4;C3/C4;P3/P4;O1/O2; OL/OR; T5/T6;PO3/PO4 are presented in Figure 5.4. on page 119 , grand averages for electrodes P3/P4;OL/OR; T5/T6;PO3/PO4 are presented in Figure 5.5. on page 120. Four time windows within each trial, and early cue phase “N2pc”, late cue phase “CDA”, early tracking phase “Group”, late tracking phase subsequent to the break, “Break”, were selected, and the mean of the ERP amplitudes in each time window were averaged. See Figure 5.6. on page 121 for a plot of the mean amplitude in each condition. These mean amplitudes were then compared within each time window of analysis. Repeated measures anova for the N2pc time window ($F(3,33) = 1.52$, $p > .05$) revealed no effect of condition, for CDA window, ($F(3,33) = 1.6$, $p > .05$), or the Grouping window, ($F(3,33) = 2.26$, $p = .09$). However, there was an reliable difference between the means in the Break time window, ($F(3,33) = 2.19$, $p < .05$).

The degree of clustering (clustered or random) did not modulate the N2pc or the CDA during the cue phase, indicating that the items were both selected and represented in memory in similar manner whether the three items were close to each other or widely separated in the cue array. However, during the early tracking phase, when configural information might be expected to convey a benefit in tracking, the Cluster amplitude was reduced compared to the other three conditions, including the identical up to that point Cluster Break condition. Another factor of interest in this

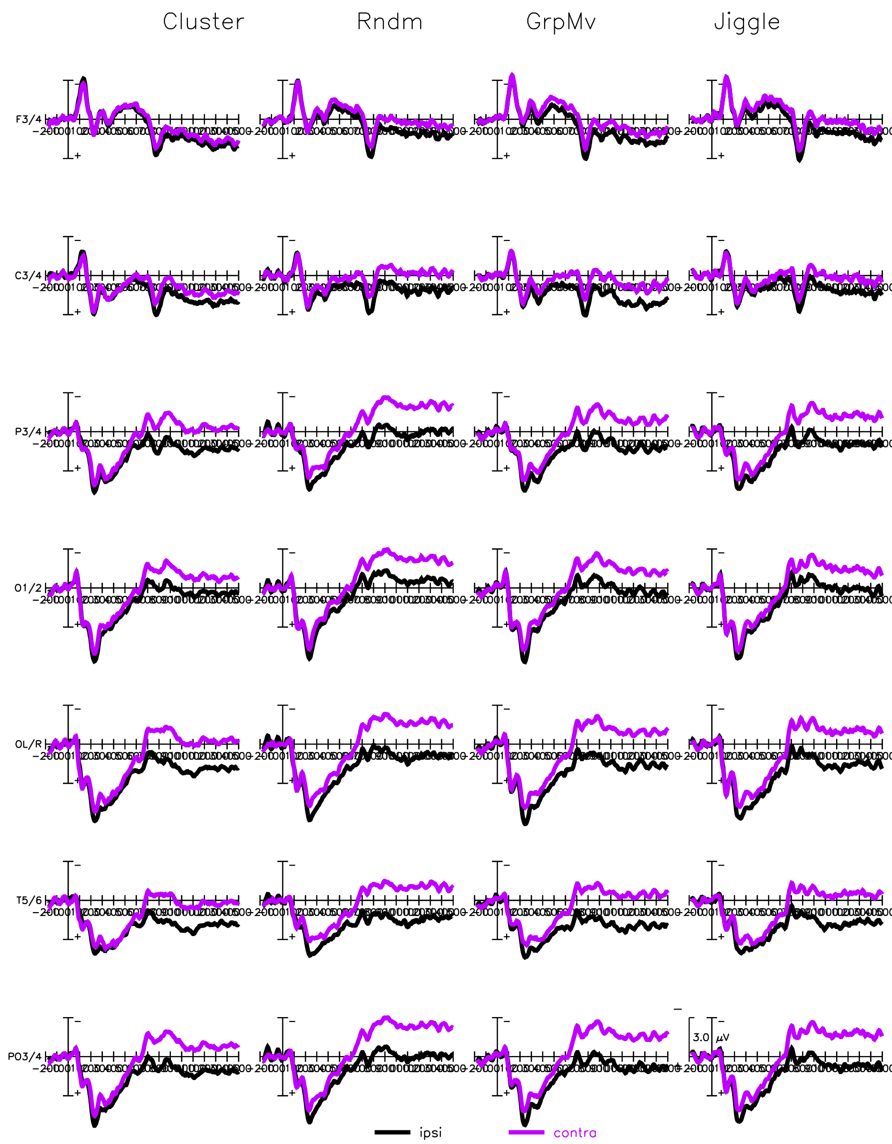

FIGURE 5.3. Experiment 4 Contra-Ipsi Waveforms

experiment was to compare the Cluster and Cluster Break conditions at the transition between CDA and Grouping windows in order to determine if there was a significant rise in amplitude of the items, if those items had been associated at the beginning of the cue phase, but not having moved together. A two-way repeated measures anova with factors of Condition (Cluster, Cluster Break) and Window (CDA, Grouping) was performed and revealed no effect of condition ($p > .05$, but reliable effect of window ($F(1,11) = 56.4$, $p < .0001$). A marginally significant interaction was also seen ($F(1,11) = 3.74$, $p = .08$). Similar analysis for the other conditions showed similar results. Another factor of interest in this experiment was the change in amplitude within a single condition when transitioning from a grouped state to an ungrouped state. There were two conditions and two time windows in which this happened. That is, the comparison within the Cluster Break condition going from the CDA window to the Grouping window, and the comparison between the Cluster condition from Grouping to Break. Since the major factor of interest in this experiment was to what degree grouping influence the amplitude of the measured ERPs as compared to the baseline condition, difference variables were constructed by subtracting the mean amplitude of the grouping condition (Cluster, Cluster Break, or Group Move) from the baseline Random condition. See Figure 5.7. on page 122. The subtractions were then compared with in each time window of interest to determine whether reliable differences existed between the conditions. Another factor of interest was the randomization of the Cluster condition at the Break window. A two-way ANOVA with factors of Condition and Window revealed significant interaction ($F(1,11) = 15.3$, $p < .002$) between the baseline condition, Random, and the Cluster condition across these time points. A similar analysis also revealed that the apparent drop in tracking activity amplitude in the Random condition compared to the Group Move condition was also performed. The Group Move condition was not reduced compared to the Random condition, in fact the opposite. The Group Move condition maintained an amplitude as large as the baseline condition throughout the first three phases, and then maintained a greater amplitude during the Break window the Random condition, a main effect of window ($F(1,11) = 7.61$, $p < .05$), but also a reliable interaction ($F(1,11) = 6.14$, $p < .05$), indicating that the Random condition decreased more than the Group Move condition across the tracking analysis windows. As in the previous experiments, a correlational analysis was conducted in order to determine whether the differences observed in the ERP waveforms were linked with behavioral outcomes. No significant correlations between behavior and amplitude differences between baseline and grouping conditions for each time window, except for the Random/Group Move subtraction and the Cluster Break and Random conditions There was a marginally significant correlation between the Cluster condition behavior and ERP amplitude ($t(10)=1.7$, $p =.06$) as well as the reliable correlation between Cluster amplitude difference and Random condition behavior ($t(10)=2.8$, $p <.05$), and the Cluster Break condition ($t(10)=1.70$, $p =.06$).

5.5. Discussion

The experiments so far have demonstrated that perceptual grouping cues can be used to enhance the efficiency of visually encoded information. Evidence for this includes the increased behavioral performance for items which are perceptually grouped, as well as the reduction in the electrophysiological indexes of active visual representations. This experiment extend these data by contrasting proximity and motion cues to determine the conjoint or disjunctive effects on both early and late ERP indexes of object perception. Particularly the question of whether early

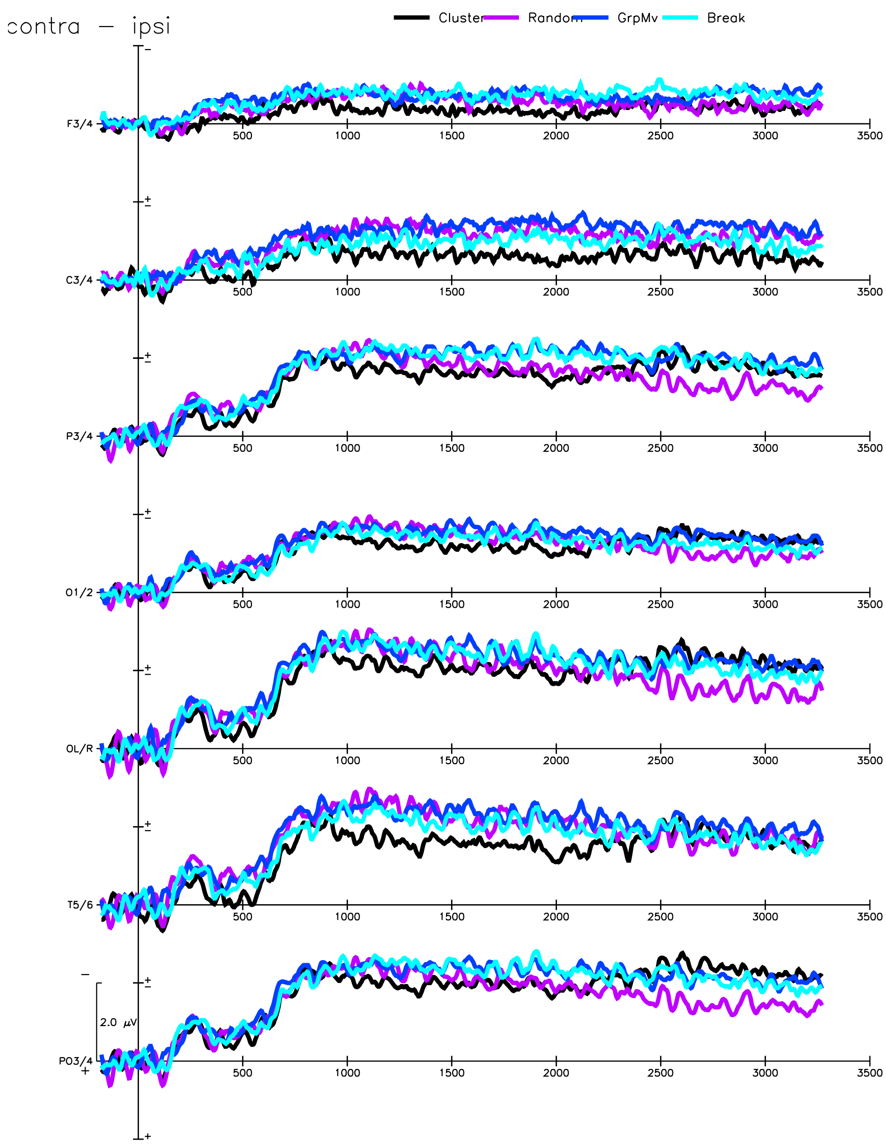

FIGURE 5.4. Experiment 4 Difference Waves

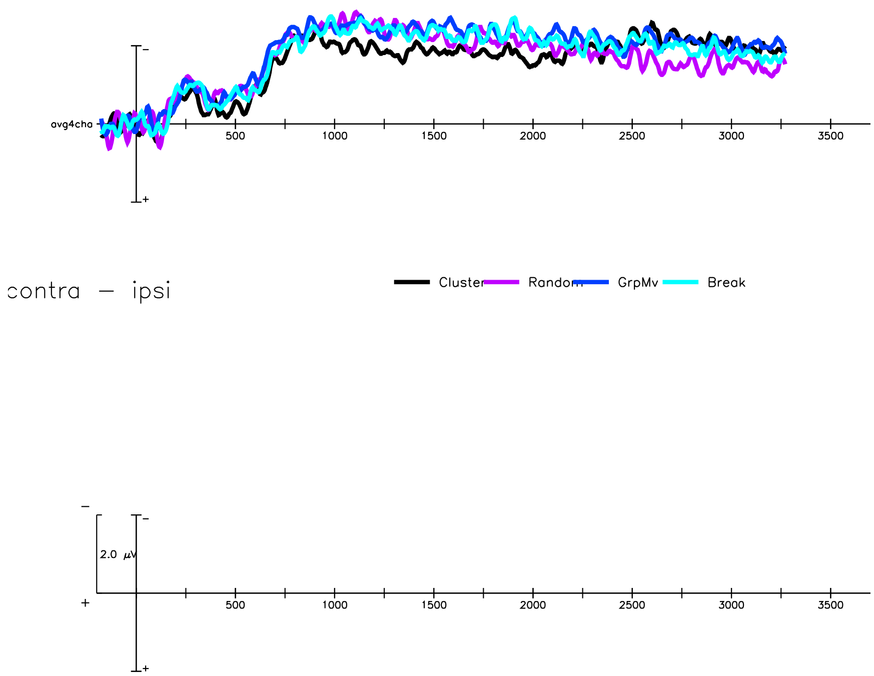

FIGURE 5.5. Experiment 4 Grand Average Difference Waves

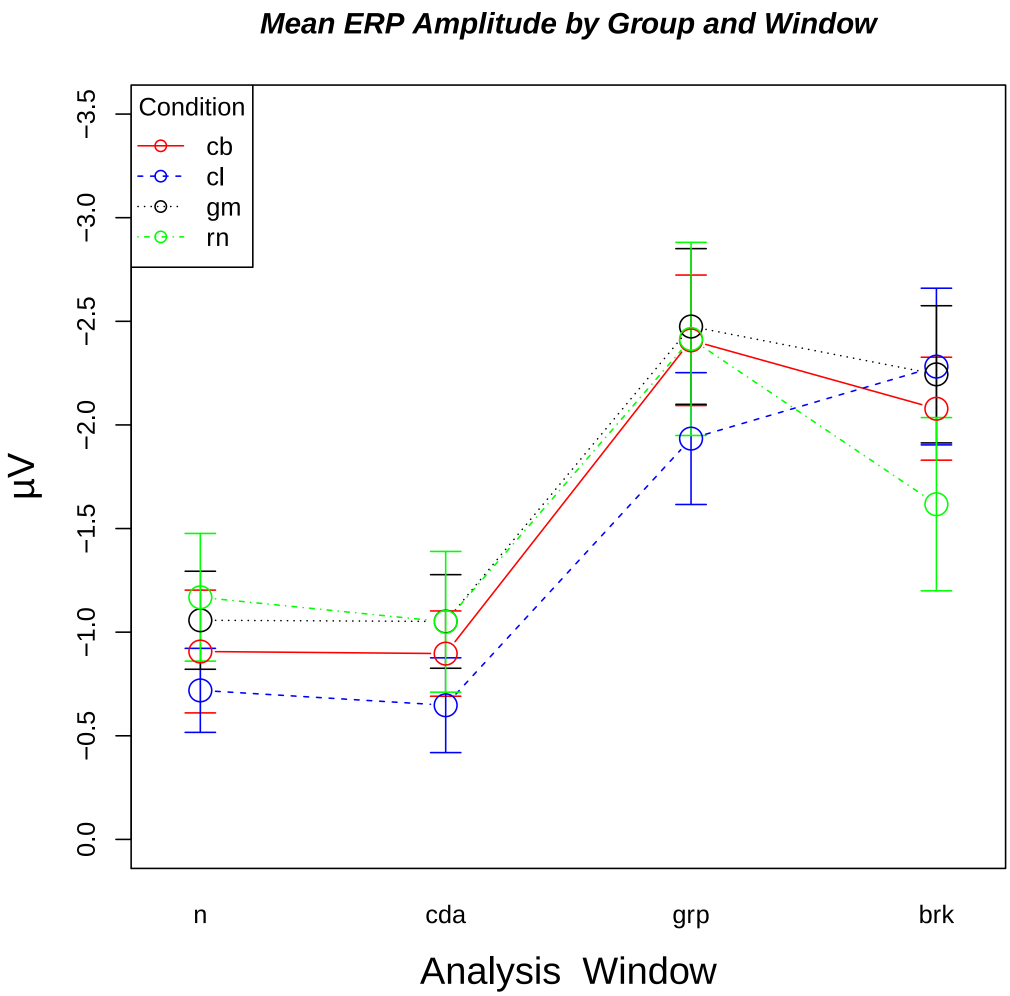

FIGURE 5.6. Experiment 4 Mean Amplitudes

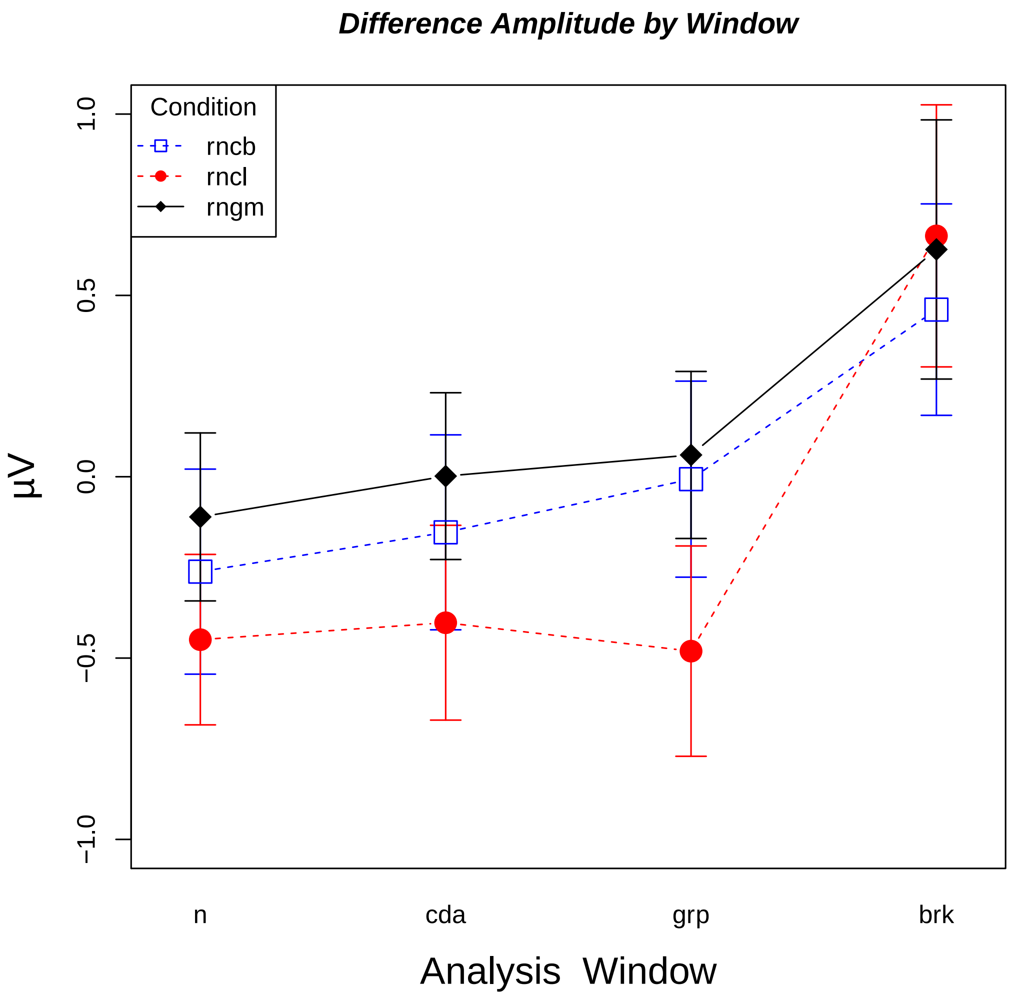

FIGURE 5.7. Experiment 4 Mean Amplitude Differences

N2pc component was sensitive to the number of elements or the subjective percept, and whether early grouping, prior to motion onset, may still reduce tracking load. Furthermore, motion and proximity cues were contrasted across the tracking period.

In this experiment, we attempt to further test these hypothesis by manipulating the strength of the proximity and motion grouping cues in a MOT experiment. That is, is it the case that merely grouping items together at some stage of the task provides tracking enhancement, or does the timing and duration of the grouping cues play a critical role? Here, three types of target grouping were contrasted with each other and with ungrouped targets. We found reliable modulations in both the amplitude of the online tracking activity and the behavioral performance which varied depending on the strength of the grouping cues and the presence or absence of ongoing perceptual support throughout the duration of the trial.

In all the grouping conditions behavioral performance was enhanced compared to random items, indicating that grouping cues, no matter when perceived, may improve performance. These data are consistent with prior results both in this dissertation and Yantis (1992). The electrophysiological response varied according to the type and timing of the grouping cues and component of interest. Earlier components, the N2pc and CDA, were sensitive to the proximity of the targets. That is, the targets in the proximity and proximity-break conditions demonstrated a reduction in component amplitude in comparison to the random or motion groups. However, during the tracking phase, only the proximity group showed reduce tracking load as indexed by the tracking activity and increased behavioral accuracy for those conditions. Therefore, the data support the hypothesis that early components such as the N2pc and CDA are sensitive to the subjective percept. Distance between elements in this experiment were typical for previous MOT experiments.

As in the first experiment, we observed the N2pc for items during the cue phase. We observed an effect of condition on the amplitude such that the N2pc was smaller for the cluster condition than the the other three conditions, indicating that the items were being selected as a single item. In the later cue phase, we observed the same component as previously, the CDA, which was modulated by proximity such that amplitude in the cluster condition was lower than amplitude in the other two conditions. In the early tracking phase, after motion onset, we again observed an increase in the amplitude of the CDA consistent with previous results in Experiment 1, but again a reduction in tracking load for the cluster condition compared to the other two conditions. After 1500ms of tracking the items in the cluster condition broke apart and began moving randomly, while the items in move together or random condition continued moving as previously. Approximately 500 ms after the items in the cluster condition began moving randomly we observed an increase in the amplitude of the CDA for the cluster condition until it exceed the amplitude for the other conditions. However, this amplitude decreased until it was equivalent to the other two movement conditions by the end of the tracking period.

Interestingly, the group motion activity showed no reduction component amplitude. This can be taken as evidence that despite increased behavioral performance, elements of the grouped were individuated during tracking rather than perceptually grouped. However, amplitude for the common motion grouped items was initially indistinguishable from the random condition. Differences in tracking activity only emerged over time. This may best be explained by the concept of perceptual support, rather than perceptual grouping. Consider the fate of items which are dropped in the random condition: those items cannot be recovered and the subject either begins tracking a random item or simply holds on to the remaining items. On the other hand, in the common motion condition if an item is dropped it can be efficiently recovered, since there are strong motion cues segregating the tracked items from distractors. However, the common motion items were nonetheless not represented as a single item, at least insofar as the tracking activity indicates.

Finally, early proximity grouping had only a small behavioral affect on tracking and the ERP tracking activity. Interestingly, the tracking activity for these "break" items did not differ from random items during the first half of the tracking period, and only barely above the random items in the second half. This can be taken as evidence that perceptual grouping happens on a moment-by-moment manner in which the history of the objects, at least in this experiment, does not seem to matter. As soon as the items began to move independently they were immediately individuated and tracked. This is also supported by the increase in the tracking activity of the proximity grouped items, which was initially reduced compared to the other conditions, but at the "break" immediately increased in amplitude.

CHAPTER VI

CONCLUSION

Many researchers have studied grouping, memory, and tracking tasks over the past ten decades of research on the topic, for the most part focusing on effects in performance which highlight which items may be selected from maintenance in memory, rather than specifically on the representation itself. In ERP research, while some investigators have examined how Gestalt processing or subject figures modulate early ERP components, none save these present experiments have specifically examined the effect of illusory figures on active, online representations of visual items. The present dissertation was concerned with understanding the effects of modal completion In a visual working memory task, and how attention or task demand creates top-down influences on illusory items, as well as examining gestalt grouping effects on tracking multiple items simultaneously. A complete explanation of the interaction of these effects in producing items in memory has not yet been proposed. The general aim of this thesis was to explore the influence of early grouping and completion mechanisms on online, active visual object representations, using behavioral accuracy and ERP indexes of memory load to gain insight into the representation and processing. Specific questions addressed here were: Does modal completion alter visual working memory representations? Are these effects obligate or modulate by attention? How do gestalt cues alter dynamic visual representations?

6.1. Chapter Summaries

Chapter I briefly covered the topics of visual working memory and perceptual grouping and described the framework and assumptions that were used in developing these experiments. The dissertation began with discussion of the current understanding and controversies in the cognitive construct of visual working memory, primarily the contrasting views of primary units of visual working memory as discreet, coherent, bound objects or as general, finely-divisible resource, as in the signal-detection model. Also reviewed was literature relevant to multiple object tracking, the proposed methods by which this system may operate and the neural indexes of the same. In addition to a discussion of the primary measures indexing actively maintained, visually attended objects in both static (working memory) and dynamic (tracking) displays the fundamental grouping principles which underlie the formation of object percepts were also discussed. Gestalt grouping principles and the corollary modal and amodal completion phenomena were reviewed, as well as current controversies in the literature concerning the neural origins, consequences, developmental time course, and clinical disease models. finally, this chapter discussed known and hypothesized interactions between visual memory and tracking, and the grouping or illusory contour processes motivating the subsequent experiments.

In Chapter II a paradigm for studying visual working memory, the change detection task, was applied to the study of perception in the service of understanding how apparently low-level, early mechanisms of vision may influence higher level cognition, specifically, the representation of items in visual working memory. This chapter described the use of the hybrid perceptual grouping/change detection methodology to test the hypothesis that top-down attentional control can influence the nature of item representations in memory. Specifically, the experiment compared the allocation of memory resources as indexed by the CDA when the to-be-remembered feature of the objects was congruent with the grouping mechanism, or incongruent. The data suggested that the identical visual stimulus can be represented in memory differently depending on task demand.

Chapter III described the extension of this research from static displays to dynamic displays of motion in order to investigate another more recently defined grouping principle, that of connectedness. Here, the presence or absence of connecting lines between moving targets in displays increased the accuracy while simultaneously decreasing the amount of resources allocated online.

Chapter IV described the extension of this research to other dynamic displays of motion in order to investigate another common grouping principle, that of common fate. The results demonstrated that the neural index was a more sensitive measure of the affect of perceptual grouping on memory representations than were behavioral measures. Furthermore, an effect of grouping was found not only on the sustained tracking activity but also on earlier ERPs, indicating that perceptual grouping most certainly occurs early in the processing stream.

Finally, in Chapter V the differential effects of common fate and proximity on active visual representations were tested. The results demonstrated that the neural index of active representations were sensitive to the grouping principle employed.

6.2. General Conclusion

Overall, the results have shown the utility of using ERPs to examine these kinds of questions. By taking a waveform with known behavior in a well-defined task, and applying these tools to a new questions and phenomena, our understanding of the mechanisms of both perceptual grouping and visual working memory has been deepened. We have extended our knowledge of when perceptual grouping occurs and its reciprocal effects on memory and attention. Further, these chapters have demonstrated that the influence of perceptual grouping or Gestalt grouping principles on memory, is not a singular processing event, but rather a dynamic and active process which is influenced in turn by the allocation of attentional resources and task demand. Overall, we have shown that grouping may reduce online visual working memory requirements and have demonstrated that the effects of perceptual grouping on visual memory are not obligatory but can be influenced by attention. The result encompasses not only visual representations of static items, but also dynamic stimuli, showing that that grouping can modulate both ERPs associated with tracking and performance. In addition, evidence was presented in to support the hypothesis that the grouping principle of element connectedness can modulate both behavior, by increasing performance on the task, and ERPs, by dynamically modulating the amplitude of an online, continuous measure of an object ensemble. Clearly, the common viewpoint of perceptual grouping as a static, unidirectional event in the visual system is erroneous, and if we are to continue to develop our understanding of visual processing, of the parsing of the visual world as well as the internal representations of that external world, we need to further our understanding of the how perceptual grouping shapes our perception and in turn is shaped by our apperception. Taken together, these studies address the question of the influence of Gestalt grouping and illusory completion processes on object representations in both static and dynamic tasks involving the maintenance of visual information in an immediately accessible state, as well as examine whether individual differences in memory capacity may contribute to the active maintenance of unified object representations. In sum, grouping alters the percept of the visual stimulus and reduces resource requirements, moreover, these changes can be tracked dynamically using electrophysiological measures of visual representations.

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