2017

Do multiple conditions elicit the visual redundant signals effect in simple response times?

Ada Mishler
University of Central Florida

STARS Citation

Mishler, Ada, "Do multiple conditions elicit the visual redundant signals effect in simple response times?" (2017). *Electronic Theses and Dissertations, 2004-2019*. 5717.
https://stars.library.ucf.edu/etd/5717

DO MULTIPLE CONDITIONS ELICIT THE VISUAL REDUNDANT SIGNALS EFFECT IN SIMPLE RESPONSE TIMES?

by

ADA DVORAH MISHLER
B.S. Colorado State University, 2012
M.A. University of Central Florida, 2016

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the College of Sciences
at the University of Central Florida
Orlando, Florida

Fall Term
2017

Major Professor: Mark B. Neider

ABSTRACT

The redundant signals effect, or redundancy gain, is an increase in human processing efficiency when target redundancy is introduced into a display. An advantage for two visual signals over one has been found in a wide variety of speeded response time tasks, but does not always occur and may be weakened by some task parameters. These disparate results suggest that visual redundancy gain is not a unitary effect, but is instead based on different underlying mechanisms in different tasks. The current study synthesizes previous theories applied to redundancy gain into the three-conditions hypothesis, which states that visual redundancy gain depends on the presence of at least one of three factors: visual identicalness between multiple targets, familiarity with multiple similar targets, or prepotentiation for multiple different targets. In a series of four simple response time experiments, participants responded to single targets presented to one side of the visual field, or to bilateral targets presented to both sides of the visual field. The first three experiments each explored one condition, the first experiment by comparing identical to non-identical random shapes to examine visual identicalness, the second by comparing familiar to unfamiliar letters to examine familiarity, and the third by comparing previewed with non-previewed random shapes to examine prepotentiation. Finally, the fourth experiment employed letters that varied in familiarity, identicalness, and preview, to examine whether or not the three hypothesized causes have multiplicative effects on redundancy. Results indicated that participants were able to benefit equally from redundancy regardless of identicalness, familiarity, or prepotentiation, but that they did so by ignoring one target in the redundant-target trials. These results suggest that redundancy gain may need to be even further divided into more than three underlying mechanisms, with a serial processing mechanism that can be used for stimuli that are not familiar, prepotentiated, or identical.

ACKNOWLEDGMENTS

I am deeply grateful for all of the help and support that I have received throughout my work on this dissertation and similar projects. I would like to thank my advisor, Dr. Mark Neider, for his constant support, guidance, and tough-guy attitude (and accent). Dr. Neider has made my scientific work at UCF a profoundly fascinating and often humorous adventure, and his help made this dissertation possible. He has been the best mentor I could possibly have had.

I would also like to thank my dissertation committee, whose collective brilliance helped to refine, focus, and expand this project. My thanks go to Dr. Nichole Lighthall, Dr. James Szalma, and Dr. Dana Joseph for taking the time and making the effort to guide me. I owe my gratitude to my current and former labmates as well. Joanna Lewis, Dawn Sarno, and Dr. Alyssa Hess have taken the time- frequently- to sit with me and discuss my research questions, approaches, and results. Their help has been invaluable on all of my research projects. Thanks also to all of the research assistants in our lab, who made the effort to make the lab run smoothly, and thanks to Dr. Joseph Schmidt, whose insight has improved multiple projects, including this dissertation.

Finally, I owe an enormous debt of gratitude to my family and fiancée. My sister, Oriana, and my brother, Alan, are constant and inspiring examples of hard work and of loving support. My parents and stepparents, Jonathan, Tammie, Reed, and Doug, have all uniformly refused to believe that graduate school was too much for me. Lastly, I would like to thank my fiancée, Mary, for her encouragement and patience. Her love and the love of my family have been foundational to my success as a graduate student.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION TO THE VISUAL REDUNDANT SIGNALS EFFECT

In a variety of experimental tasks, people are instructed to respond as quickly and accurately as they can to a particular signal. For example, people may be asked to press a button as quickly as possible any time an asterisk appears on a computer screen; or, in a more applied context, drivers may need to brake as quickly as possible if they find themselves rapidly approaching a vehicle in front of them. Given the existence of a variety of speeded response tasks, a considerable body of research has been devoted to determining what means researchers and designers can use to enhance the efficiency with which people process the targets in such tasks. One means that has been frequently and successfully employed is signal redundancy; when participants are required to respond to a particular signal or one of a group of signals, then multiple target signals can be incorporated into a single display in order to enhance participants' performance (e.g., Duncan, 1980; Miller, 1982; Raab, 1962), a phenomenon often referred to as the *redundant signals effect* or *redundancy gain*. Specifically, the redundant signals effect occurs when a display contains two or more signals that are associated with the same response (Grice & Reed, 1992). For example, when participants are instructed to respond every time they see the letter A in a display, they respond more quickly when there are two A's than when there is only one (Miller, 1982).

Most of the original redundant signals effect studies employed multimodal redundancy such as a flash of light paired with a burst of noise (e.g., Todd, 1912; Diederich, 1995; Diederich & Colonius, 1987; Miller, 1982, 1986), but many studies have also demonstrated that the redundant signals effect occurs even with multiple visual stimuli (e.g., Forster, Cavina-Pratesi, Aglioti, & Berlucchi, 2002; Grice & Gwynne, 1987; Murray, Foxe, Higgins, Javitt, & Schroeder, 2001; Savazzi & Marzi, 2008; Schwarz & Ischebeck, 1994) or with one visual stimulus that contains multiple target signals (e.g., Feintuch & Cohen, 2002; Krummenacher, Müller, & Heller, 2001, 2002). The current study is specifically concerned with redundancy gain for multiple visual stimuli.

As this introduction will discuss, the redundant signals effect occurs in a surprisingly large range of tasks and stimuli; however, the strength of the effect often varies with task and stimulus characteristics. Additionally, some tasks show no evidence of the redundant signals effect, or seem to show that the effect is attributable to factors other than the presence of redundancy. The broad range of tasks subject to redundancy gain suggest that the effect may not have a unitary cause, while the weakness or absence of the effect in some cases suggests that there must be a limited number of causes. The purpose of the current experiments is to explore the possibility that there are three different causes of the redundant signals effect; namely, basic visual identicalness, familiarity of multiple similar stimuli, and short-term potentiation of feature processing; as well as to determine if at least one of these three factors is necessary to elicit redundancy gain.

The redundancy-related increase in processing efficiency is manifested in a variety of performance measures. Often, redundant visual signals shorten response time (RT) compared to a single signal (e.g., Egeth, Folk, & Mullin, 1989; Forster et al., 2002; Girard, Pelland, Lepore, & Collignon, 2013; Grice & Gwynne, 1987; Grice & Reed, 1992; Krummenacher et al., 2001, 2002; Mohr, Endrass, Hauk, & Pulvermüller, 2007; Murray et al., 2001; Savazzi & Marzi, 2008; Townsend & Nozawa, 1995; Zehetleitner, Krummenacher, & Müller, 2009), but redundant signals can also increase accuracy (e.g., Egeth et al., 1989; Hellige & Adamson, 2007; Hellige, Jonsson, & Michimata, 1988; Hellige & Marks, 2001; Hellige, Taylor, & Eng, 1989; Marks &

Hellige, 1999, 2003; Mohr et al., 2007; Mohr, Pulvermüller, & Zaidel, 1994; Shepherdson & Miller, 2014) and can increase response force (Giray & Ulrich, 1993) or shorten the latency of peak response force (Plat, Praamstra, & Horstink, 2000). Thus, the redundant signals effect appears to be a general increase in processing efficiency associated with an increase in the number of signals available for processing.

The current state of the literature indicates that there are a wide variety of tasks under which visual signal redundancy enhances participants' performance. First, simple reaction time tasks are subject to the redundant signals effect. In a simple reaction time task, participants are asked to make a response to the occurrence of any signal, without distinguishing between different signals in the task. For example, Savazzi and Marzi (2008) asked participants to press a button in response to any stimulus on a computer screen; either one or two small squares appeared in each display. RT was shorter when two squares were presented compared to one square. Forster et al. (2002) also found that participants responded more quickly when two LED lights were lit than when only one light was lit. Additionally, participants respond more quickly when two letter-like symbols are displayed on a computer screen than when only one is displayed (Murray et al., 2001), and when two parallel or orthogonal lines are displayed compared to only one line (Schwarz & Ischebeck, 1994).

The visual redundant signals effect also occurs in tasks that require the participant to recognize or discriminate between objects. In two alternative forced choice tasks, participants are asked to make one of two responses depending on what target is present; these responses can be speeded by providing redundant signals. For example, participants who must search for a visual singleton target (a target that differs in a particular feature from all other members of an array) respond more quickly to two singletons or to one singleton that differs from all other items by two features (Krummenacher et al., 2001, 2002). Additionally, participants who must respond to one letter with one hand and to another letter with the other hand respond more quickly to two instances of a letter than to only one instance (Eriksen & Lapin, 1965; Grice, Canham, & Boroughs, 1984); and participants who must respond to the presence or absence of a target letter in a small search array respond much more quickly when multiple target letters are present compared one target letter, and somewhat more quickly to nontarget displays that contain multiple copies of the same nontarget letters compared to displays in which all nontarget letters are different (Holmgren, Juola, & Atkinson, 1974). A similar effect occurs for go/no-go tasks, in which participants must respond to some stimuli while withholding responses to other stimuli; in fact, the redundant signals effect appears to be more robust in go/no-go than in forced-choice paradigms (Grice & Canham, 1990; Grice & Reed, 1992). For example, participants who are asked to respond only to one particular letter respond more quickly to two instances of that letter than to a single instance (e.g., Allen, Madden, Groth, & Crozier, 1992; Allen, Weber, & Madden, 1994; Grice & Gwynne, 1987).

Finally, the visual redundant signals effect occurs for higher-level processing tasks such as stimulus categorization and lexical processing. In categorization tasks, participants who are asked to categorize facial expression respond more quickly to two images of the same facial expression than to one image (Tamietto, Adenzato, Geminiani, & de Gelder, 2007; Tamietto, Latini Corazzini, de Gelder, & Geminiani, 2005); participants who are asked to categorize faces as famous or non-famous respond more quickly to two famous faces than to one (Baird & Burton, 2008); participants who are asked to categorize letters and digits respond more quickly to two letters or to two digits than to one (Duncan, 1980; Egeth et al., 1989; Mishler & Neider, in preparation); and participants more accurately report brief letter and number trigrams when two copies are presented, even if the two copies are in different formats (Marks & Hellige, 2003). Categorical processing of redundant, visually-presented words also shows redundancy gain; participants respond more quickly and accurately to two words that belong to a target category than to one (Shepherdson & Miller, 2014; but see Mullin & Egeth, 1989). Other types of word processing also show redundancy gain for visually-presented words. In lexical decision tasks, in which participants must decide whether or not a string of letters forms a word, participants respond more quickly to the presence of two words than to only one (Egeth et al., 1989; Mohr et al., 2007; Mohr, Pulvermüller, Mittelstädt, & Rayman, 1996; Mullin & Egeth, 1989; but see Zaidel & Rayman, 1994), and may make faster rhyme judgments when two words rhyme with a probe compared to when one word rhymes with a probe, at least when word repetition is high across trials (Banich & Karol, 1992). They also respond more quickly to a word that belongs to two target categories than to a word that belongs to one target category (Fiedler, Schröter, & Ulrich, 2013; Schröter, Bratzke, Fiedler, & Birngruber, 2015). Given that redundant signals exist within a single object in these last two studies, redundancy gain in higher-level cognitive tasks is not attributable, or not always attributable, to the fact that redundant signals occupy a larger amount of the display than single signals.

It is evident that multiple visual signals associated with a single response can enhance processing efficiency in a wide variety of tasks, from simple responses to recognition and discrimination tasks to categorization and semantic processing tasks. However, the visual redundant signals effect does not occur for all tasks and is not equally robust for all tasks.

Limitations on the Visual Redundant Signals Effect

Display Configuration

Although the redundant signals effect occurs for a wide variety of visually-presented signals, there are some cases in which it seems to break down or to become less robust, suggesting that there are limits on the conditions under which visual redundancy can enhance processing efficiency. One manipulation that seems to change redundancy effects is display configuration. Specifically, when redundant targets are displayed as two separate objects, a bilateral configuration showing one target to the left visual hemifield and one target to the right visual hemifield is often the configuration that leads to the greatest redundancy gain. Although Murray et al. (2001) and Ouimet et al. (2009) found no difference in redundancy gain between display configurations, bilateral displays sometimes show a greater redundancy gain than displays in which redundant signals are both displayed to one visual hemifield (Corballis, Hamm, Barnett, & Corballis, 2002; Girard et al., 2013; Schulte, Pfefferbaum, & Sullivan, 2004), and stimuli that do not elicit a significant redundancy gain in unilateral displays can elicit a redundancy gain when displayed bilaterally (Mishler & Neider, in preparation). Additionally, experiments in which redundant stimuli are arrayed along the vertical midline of vision tend to either show a redundancy loss (Mishler & Neider, in preparation), or show that the redundant signals effect is mostly or entirely attributable to noise reduction (e.g., Grice et al., 1984; Grice & Canham, 1990; Grice & Gwynne, 1987; Grice & Reed, 1992; Mishler & Neider, submitted; but see Allen et al., 1994). In other words, redundant signal (target + target) trials may elicit faster RTs than single signal (target + noise) trials. However, no-noise single-signal trials (target only) tend to elicit RTs that are at least as fast as redundant signal (target + target) trials. What is interpreted as redundancy gain in these cases may not be a true speed-up due to the presence of multiple targets, but instead a speed-up due to the absence of noise stimuli.

Why would bilateral displays be a special case for redundancy gain? The general belief is that it is advantageous to rely on a different hemisphere to process each stimulus (e.g., Barr & Corballis, 2003; Corballis, 1998; de Gelder, Pourtois, van Raamsdonk, Vroomen, & Weiskrantz, 2001; Iacoboni & Zaidel, 2003; Miller, 2004; Mohr et al., 1994; Roser & Corballis, 2002; Savazzi & Marzi, 2004; Schweinberger, Baird, Blümler, Kaufmann, & Mohr, 2003; Zaidel & Rayman, 1994, but see Ouimet et al., 2009). By contrast, relying mostly on a single hemisphere to process two different stimuli leads to interference if the stimuli are in a similar format, perhaps due to a high amount of overlap between neurons needed to process each stimulus (Patel & Hellige, 2007). Such interference would be expected according to the biased-competition model of selective attention, which states that closely-spaced objects compete with each other for neural processing to prevent multiple objects from being conflated with each other (Desimone & Duncan, 1995). This indicates a possible neural mechanism for the interhemispheric advantage in multiple-item processing. In separate hemispheres, visual processing of similar-format items can begin in separate populations of neurons, so that the items will not be competing for neural resources in early visual processing. Because interference between similar-format items may occur for unilateral stimuli, and centrally-presented stimuli may be difficult to process due to the need to coordinate object processing between both hemispheres (Abrams, Nizam, & Carrasco, 2012), the current experiments all employed a bilateral display configuration.

Different Features

Often, the redundant signals effect is greater when redundant objects are identical than when they are two different objects. For example, two letters presented in different cases (e.g., A/a) lead to redundancy gain, but the gain is not as great as for two letters presented in the same case (Grice & Reed, 1992), and redundancy gain is weaker when responding to two different target letters than to two identical target letters (Mordkoff & Miller, 1993). In a line detection task, redundancy gain is weaker when responding to two orthogonal lines compared to two parallel lines (Schwarz & Ischebeck, 1994). Redundancy gain is also weaker in a rhyming task if two different words are presented in the same font compared to identical words in the same font (Banich & Karol, 1992). Redundancy loss, instead of gain, occurred in a lexical decision task with two non-identical words, even though identical words led to redundancy gain in the same task (Mullin & Egeth, 1989). Finally, redundancy gain is weaker when responding to two different images of a familiar face than when responding to two copies of the same image (Baird & Burton, 2008). These effects suggest that having duplicate copies of visual features enhances the redundant signals effect.

However, not all studies show a weaker redundant signals effect for non-identical signals; processing of emotional facial expressions seems to benefit equally from two photographs of the same actor or from two photographs of different actors making the same expression (Tamietto et al., 2005). Accuracy in reading letter trigrams may also benefit from non-identical redundancy (the same trigram in different cases) slightly more than from identical redundancy (two identical trigrams), although the benefit is small (Marks & Hellige, 2003). These results, combined with the fact that non-identical targets often show a significant redundancy gain in spite of its weakness compared to identical targets, suggests that identical visual features are not strictly necessary for redundancy gain. This is one indication that there may be multiple causes of the visual redundant signals effect.

Higher-level tasks

As discussed earlier in the introduction, the redundant signals effect occurs in a broad range of tasks employing visual stimuli, including tasks that require higher-level cognitive functions such as stimulus categorization, familiarity judgments, emotion recognition, and lexical processing. However, the redundant signals effect breaks down under some interesting circumstances in some higher-level cognitive tasks.

Reinholz and Pollman (2007) claimed that redundancy gain occurs in a categorization task using photographs of faces and buildings. Because they did not describe the faces and buildings as “famous” or “familiar,” the stimuli were presumably not familiar to the participants. Participants completed a go/no-go task in which they responded to one category while withholding responses to the other category. The target category switched between blocks. In single target trials, the target stimulus was paired with either a stimulus from the opposite category, or a scrambled stimulus. Participants responded more quickly to redundant targets than to single targets paired with a member of the opposite category, but did not respond more quickly to redundant targets than to single targets paired with a scrambled stimulus. This may indicate that the effect was due not to the presence of multiple signals, but to the absence of a distracting stimulus that had previously been defined as a target. Thus, Reinholz and Pollman’s redundant signals effect for faces and buildings may not have been a true effect of redundancy.

Why would Reinholz and Pollman fail to find a redundancy-related improvement in categorization performance, when other researchers have found redundancy gain for similar categorization tasks? Familiarity appears to play an important role in the redundant signals effect for complex stimuli. In a familiarity judgment task, familiar faces show redundancy gain when unfamiliar faces do not (Mohr, Landgrebe, & Schweinberger, 2002; Schweinberger et al., 2003), and unfamiliar faces do not always show redundancy gain even when the task is to judge emotional expressions rather than familiarity (Schweinberger et al., 2003; but see Tamietto et al, 2005, 2007). Additionally, in a lexical decision task, a redundant signals effect occurs for words but not for plausible pseudowords (Mohr et al., 1994, 1996, 2007; Zaidel & Rayman, 1994), although pseudowords show a redundant signals effect when participants are shown prime words before seeing the pseudowords (Hasbrooke & Chiarello, 1998). Lack of familiarity evidently prevents the redundant signals effect in some experiments, although priming may mitigate the loss.

The results reviewed in the current section suggest that the redundant signals effect for visual stimuli does not occur in all types of tasks or for all types of stimuli. Unilateral or central displays, non-identical targets, and unfamiliar targets can all reduce or eliminate redundancy gain in some tasks. Why would these factors affect the ability of participants to capitalize on visual redundancy? The answer may lie in the way that redundant visual information is combined during processing.

The Role of Coactivation and Statistical Facilitation in Redundancy Gain

As mentioned previously, there is an advantage for presenting one stimulus to the left visual hemifield and one to the right, compared to presenting both to one hemifield, when stimuli are in a similar format. Patel and Hellige (2007) assumed that this was due to reduced competition for neural resources when different hemispheres are used to process each stimulus.

This would suggest that redundancy gain begins with processing in different populations of neurons; however, this section will show that information from the two populations of neurons is sometimes summated afterwards for further processing.

Traditionally, two major classes of information processing models are proposed to explain how the existing processing architectures lead to a redundant signals effect; both classes assume parallel processing of multiple targets, which was confirmed by Townsend & Nozawa (1995). The first class is known as *statistical facilitation* or *independent race models*. In these models, processing of two or more targets is not combined in any way; instead, each target is processed separately and independently, and the target that first reaches a threshold point in processing is responsible for triggering a response; the other target does not contribute to the response (e.g., Raab, 1962). Because there is random variation in the amount of time it takes to process an object, the presence of multiple objects increases the chance that there will be a quickly-processed object; hence, these models are known as statistical facilitation models.

The other class of models will be called coactivation models. In traditional coactivation models, the redundant targets all contribute to the same processing stream; when that process is completed or enough information has been gathered to satisfy a decision criterion, a response is triggered (e.g., Miller, 1982; Miller & Ulrich, 2003). Some models suggest that multiple targets are processed separately with their own decision criteria, but that there is information leakage or crosstalk between the channels, so that the presence of one target facilitates the processing of another target (e.g., Mordkoff & Yantis, 1991; Townsend & Wenger, 2004). The terminology varies somewhat here; some articles do not include interchannel crosstalk under the umbrella of coactivation models. For the purposes of the current experiments, the term *coactivation models* will include all models in which information from multiple targets contributes to a final response, including traditional coactivation and crosstalk models.

Statistical facilitation and coactivation models predict different mathematical distributions of response times. Miller (1982) defined the race model inequality:

$$P(RT < t|AB) \leq P(RT < t|A) + P(RT < t|B), \qquad (1)$$

where $P(RT < t|AB)$ refers to the probability that a response has occurred before time *t* given that two signals (A and B) are both present, $P(RT < t|A)$ refers to the probability that a response has occurred before time *t* given that only signal *A* is present, and $P(RT < t|B)$ refers to the probability that a response has occurred before time *t* given that only signal *B* is present. The race model inequality states that, if the redundant signals effect is due to statistical facilitation of response times, then the probability of having made a response by time *t*, given redundant signals, will nowhere be greater than the probability of having made a response by time *t* given one single signal plus the probability of having made a response given the other single signal. If this inequality is violated, it suggests that there must be some form of coactivation, such that processing time in redundant signal trials has decreased entirely or partly because information about both signals has been combined during processing.

Although research employing Miller's race model inequality has often shown evidence of coactivation for multiple targets (e.g., Miniussi, Girelli, & Marzi, 1998; Savazzi & Marzi, 2008; Krummenacher et al., 2001, 2002; Mordkoff & Miller, 1993; Schulte et al., 2004; Tamietto et al., 2005; Tamietto et al., 2007), some research has suggested that coactivation only occurs for redundancy that occurs within a single target; e.g., a target color and a target orientation occur within the same stimulus (Feintuch & Cohen, 2002; Mordkoff & Danek, 2011). However, the race model inequality, while it can rule out race models by showing violation of the inequality, cannot rule out coactivation models by failing to show violation of the inequality. Another method, known as the double factorial design (Townsend & Nozawa, 1995, 1997), can distinguish between multiple models of redundant target processing. In the double factorial design, one factor is the presence or absence of a target on either of two channels, and the other factor is a stimulus quality factor such as intensity, which varies independently for each of the two possible stimuli. For redundant target trials (i.e., trials on which there is a stimulus present in both channels), the mean interaction contrast (mean interaction of stimulus quality on the two different channels) and survivor interaction contrast (interaction of stimulus quality on the two different channels as a function of time) are calculated. The mathematical definitions of these interaction contrasts are presented in the *Interaction Contrasts* subsection of Chapter 2. Mean interaction contrast is applied to the overall mean RT, and survivor interaction contrast is applied to survivor functions. An interaction contrast of 0 indicates that two factors are additive; a negative interaction contrast indicates underadditivity, and a positive interaction contrast indicates overadditivity. Underadditivity suggests, in essence, that reducing the quality of one target reduces the effect of quality in the other target, whereas overadditivity suggests that reducing the quality of one target increases the effect of quality in the other target. As demonstrated by Townsend and Nozawa (1995), race models predict that both mean and survivor interaction contrasts will be overadditive. By contrast, a common class of coactivation models known as Poisson counter channel summation models predict that mean interaction contrasts are overadditive, whereas survivor interaction contrasts are underadditive for small RTs and overadditive for large RTs (Townsend & Nozawa, 1995). The double factorial method can also distinguish between these parallel models, parallel exhaustive models in which all stimuli are completely processed before a response, and serial models in which stimuli are processed one at a time. Townsend and Nozawa (1995) disconfirmed serial and exhaustive models, and showed coactivation in one task and statistical facilitation in another task. Thus, coactivation and race models appear to each be correct depending on the type of task.

In terms of neurological mechanisms, is often assumed that statistical facilitation takes the form of processing in different neurons, whereas coactivation takes the form of neural summation, with multiple inputs enhancing the activation of numerous individual neurons (e.g., Barr & Corballis, 2003; Corballis, 1998; Corballis et al., 2002; de Gelder et al., 2001; Iacoboni, Ptito, Weekes, & Zaidel, 2000; Marzi et al., 1996; Mohr et al., 1996; Roser & Corballis, 2002, 2003; Savazzi & Marzi, 2002, 2004). The superior colliculus is sometimes cited as a likely locus of neural summation for visual information. This is because patients who lack a corpus callosum show evidence of the redundant signals effect (e.g., Corballis, 1998; Corballis et al., 2002; Ouimet et al., 2009; Savazzi & Marzi, 2004), suggesting that neural summation occurs at the subcortical level, and the effect is greatly reduced when stimuli are equiluminant with the background (Corballis, 1998), an effect that would be expected given that the superior colliculus may not be as sensitive to color information as other visual areas (Livingstone & Hubel, 1987). Purple stimuli also lead to a redundant signals effect that does not show evidence of coactivation, whereas red and white stimuli do show coactivation; because the superior colliculus receives very little input from short wave cones (e.g., de Monasterio, 1978), summation would be expected to fail for purple stimuli if it occurs in the superior colliculus (Savazzi & Marzi, 2004). Additionally, hemispherectomy patients can exhibit a redundant signals effect for bilateral stimuli (Tomaiuolo, Ptito, Marzi, Paus, & Ptito, 1997), suggesting again that neural summation must be able to occur in a subcortical location, because the patients only have one hemisphere in which cortical processing can occur. As Savazzi and Marzi (2002) also pointed out, the large redundancy gains associated with multimodal stimuli are also consistent with summation within the superior colliculus, given that the superior colliculus contains neurons that are sensitive to multimodal inputs (Stein, 1998). Finally, the extrastriate cortex, which is richly connected to the superior colliculus (Stein, 1998), shows evidence of activation when acallosal patients violate the race model inequality in a bilateral redundant signals task, but no evidence of such activity when acallosal patients do not violate the race model inequality (Iacoboni et al., 2000). The authors concluded that neural summation likely occurs at the superior colliculus, but may be dependent on interactions with the extrastriate cortex. Turatto, Mazza, Savazzi, & Marzi (2004) suggested that the magnocellular visual pathway, which includes the superior colliculus, is responsible for neural summation, whereas stimuli that must rely on the parvocellular pathway only adhere to a probabilistic race model. However, Turatto et al. employed only the race model inequality to test for neural coactivation, and therefore their results do not necessarily rule out coactivation for stimuli that are processed in the parvocellular pathway.

Moreover, not all studies show that the superior colliculus is a likely location of visual redundant signals summation. Redundant target coactivation does not depend on targets occurring in symmetrical locations (Roser & Corballis, 2002), suggesting that the retinotopically organized superior colliculus may not be involved, or may not be the only location at which summation occurs. One possibility is that summation in the normal brain occurs within the extrastriate cortex itself rather than through its connections with the superior colliculus; ERP evidence pointed to the extrastriate cortex as a likely location for coactivation in one study (Miniussi et al., 1998), given that P1 and N1 latencies in response to redundant stimuli violated the race model inequality. Further, fMRI evidence from Reinholz and Pollman (2007) may have shown coactivation within the fusiform face area for face images and within the parahippocampal place area for building images; neural activation in those areas was stronger for two-target displays than for one-target displays, indicating that information from both targets was being combined within those areas. Finally, FMRI evidence suggests that the redundant signals effect can be associated with activation levels in visual association cortex areas known to be involved with size, color, and motion processing (Schulte, Chen, Müller-Oehring, Adalsteinsson, & Pfefferbaum, 2006). Given that hemispherectomy patients exhibit a redundant signals effect in spite of lacking half of their visual cortex, perhaps the redundant signals effect occurs either within the superior colliculus or within relevant visual areas, depending on the task. Regardless of the exact location of the visual redundant signals effect, the results of these studies suggest that information from both hemispheres converges on neurons somewhere within the visual system, and that this convergence is responsible for the redundant signals effect in a large variety of redundant target paradigms. However, coactivation is not evident in all redundant signals experiments, suggesting that neural summation is not responsible for redundancy gain in all cases.

Multiple Conditions for the Visual Redundant Signals Effect

The previous section demonstrates that neural summation is frequently responsible for the redundant signals effect with two visual signals, and suggests possible locations within visual sensory and perceptual areas that may be responsible for neural summation. It also suggests that neural summation is not always the apparent cause of redundancy gain; sometimes two targets appear to be processed separately. The section before that demonstrates that the redundant signals effect can be weakened or eliminated by not allowing participants to rely on separate hemispheres to process the two stimuli, by using unfamiliar stimuli as the targets, or by using two non-identical targets in the redundant target condition. It is possible to account for all of these results if redundancy gain can be induced by any of the three different task conditions outline below. This will be referred to as the *three-conditions hypothesis.*

Visual Identicalness

Visually identical stimuli lead to a larger redundant signals effect than visually different stimuli, suggesting that identical visual information may be one causative factor in the redundant signals effect. If interhemispheric neural summation is sometimes responsible for the visual redundant signals effect, it would be reasonable to expect that areas of the visual cortex associated with responding to particular features would benefit from the presence of identical features in both visual hemispheres. For example, Baird and Burton (2008) found that redundancy gain was weaker for two different images of the same face than for two identical images of the same face. This result could have been due to enhanced responding in extrastriate areas such as V4, which is sensitive to color information (e.g., Bartels & Zeki, 2000) as well as other types of object information such as length and orientation (e.g., Desimone, Schein, Moran, & Ungerleider, 1985); and inferior temporal cortex, which has neurons that are selective for shape (e.g., Schacter et al., 1995) and color (e.g., Desimone et al., 1985). Given that neurons in the inferior temporal cortex are known to have large receptive fields that cross over into the opposite visual hemifield (at least when objects are presented on a plain background rather than in natural scenes; Rolls, Aggelopolous, & Zheng, 2003), the inferior temporal cortex may be a likely location for redundant, identical features to summate.

If feature identicalness is sufficient to cause coactivation, then redundant objects that share identical features should elicit a redundant signals effect; objects that are completely identical should share the most features and therefore elicit the strongest redundant signals effect. These predictions are often supported in the literature, as discussed previously. Additionally, feature identicalness should contribute to redundant signals processing in an entirely bottom-up fashion. Evidence for this comes from Savazzi and Marzi (2008) who used simple square targets to show that factors that affect visible persistence (the tendency for the sensation of a visual stimulus to last longer than its physical presence) also affect the strength of the redundant signals effect. Assuming that visible persistence is the result of perceptual and not cognitive processing, a redundant signals effect at the level of visible persistence would not be subject to cognitive control manipulations. As a result, identical objects should elicit a redundant signals effect regardless of a participant’s ability to anticipate the presence of particular objects or object features.

The tendency for people to process identical objects more quickly than non-identical objects was also noticed by Posner (1969, 1978) who demonstrated that participants can match letters more quickly if they are visually identical (e.g., AA) than if they only share a name (e.g., Aa) or are semantically related (e.g., two vowels, Ae). Posner interpreted this in terms of levels of processing; AA can be matched by physical comparison only, whereas Aa must be matched by naming the objects, which requires a higher level of processing; and Ae must be matched by determining whether or not both letters belong to the same semantic category, which requires an even higher level of processing. However, Posner (1978) acknowledged that it is possible for the effect to be attributed not to levels of processing, but to simple physical characteristics; perhaps the high number of feature matches between two identical letters leads to faster processing. This interpretation would be consistent with a redundancy gain interpretation based on neural overlap between identical features in visual processing. Additionally, as discussed in the next section, a neural overlap interpretation could be applied to the tendency for Aa (name) matches to be accomplished more quickly than Ae (semantic) matches. Thus, Posner's levels of processing effect could instead be a neural overlap effect.

Familiarity with Multiple Similar Targets

Unfamiliarity tends to reduce or eliminate the redundant signals effect compared to familiar items. Previous researchers (e.g., Mohr et al., 1994, 1996, 2002; Schweinberger et al., 2003) have generally interpreted this result in terms of Hebb's (1949) transcortical cell assembly (TCA) theory. Hebb's theory is based on the assumption that synapses are potentiated through repeated activation of both neurons. According to his theory, repeated stimulation of specific receptors in specific patterns leads to assemblies of neurons that fire together in response to that pattern of stimulation. A familiar item, such as a celebrity's face or a common word, is therefore stored in memory as a widely distributed group of neurons that fire together when the item is encountered again (Hebb, 1949). Previous redundant target researchers have used a TCA interpretation in the following way. If cell assemblies include neurons in both hemispheres, then stimulation of receptors in both hemispheres should lead to summation of activation (i.e., coactivation) within the cell assembly (Pulvermüller & Mohr, 1996). Given that many words activate both hemispheres of the brain (e.g., Neville, Mills, & Lawson, 1992), it is not surprising that lexical processing of words presented in both hemifields would lead to a redundant signals effect, while pseudowords, which participants should not have stored in any cell assembly, do not reliably lead to a redundant signals effect.

The studies that have been interpreted in terms of transcortical cell assembly theory have been performed with complex stimuli (faces or words). Given that a semantic categorization task shows a redundant signals effect with non-identical words (Shepherdson & Miller, 2014), that semantic categorization and lexical decision tasks presumably require non-visual semantic processing of the words, and that the familiarity judgment task used with the face stimuli also requires semantic judgment, it is possible that redundancy gain had nothing to do with visual processing in these cases. However, much of the evidence discussed above indicates that at least part of the redundant signals effect for spatial stimuli is located somewhere within the visual-perceptual processing stream, possibly even for complex stimuli such as faces and buildings. If it is assumed that transcortical cell assemblies for visual stimuli include at least some of the more complex visual information associated with a category, then categorically similar but non-identical stimuli should lead to coactivation within visual processing areas, such as the visual association areas shown to activate by Schulte et al. (2006). This is because the transcortical cell assemblies associated with the categorically similar stimuli should partially overlap, such that the two different stimuli will serve as two different inputs to the transcortical cell assemblies. As discussed above, non-identical faces and buildings may enhance activity in higher-level visual areas associated with processing faces and buildings, a result that is consistent with transcortical cell assembly theory.

Given that two similar visual stimuli necessarily contain some identical features, visual identicalness is likely to play a role in the redundant signals effect even when stimuli are not completely identical. For example, black Arial font letters will contain similar lines and colors even when two different letters are presented. However, if two stimuli have some identical features and overlapping transcortical cell assemblies, and both factors contribute to a redundant signals effect, then there should be multiplicative effects of both visually identical features and familiarity. This could explain why the redundant signals effect was stronger for identical images of a famous face than for non-identical images (Baird & Burton, 2008). It may also explain why the redundant signals effect is sometimes found even for unfamiliar stimuli such as nonwords (Hasbrooke & Chiarello, 1998) and false-font stimuli (Murray et al, 2001).

Finally, transcortical cell assemblies could explain why Posner (1969) found that name letter matches are accomplished more quickly than semantic letter matches. If letters that share the same name and pronunciation are more closely related than letters that only share a semantic category, then their cell assemblies should overlap more, and coactivation should therefore be stronger. Thus, Posner's levels of processing effect could be an effect of neural overlap relatively early on in processing, rather than effect of the level of processing required to complete a task.

Prepotentiation of Target Processing

Neural summation may explain the redundant signals effect with two visually identical stimuli or two familiar stimuli that are somewhat similar. However, redundancy gain may also occur for two stimuli that are neither familiar nor identical. For example, Tamietto et al. (2005, 2007) found redundancy gain for unfamiliar, non-identical faces, in contrast to other research that suggested only redundancy gain for familiar faces (Schweinberger et al., 2003). What is the difference between the experiments that found unfamiliar redundancy gain and the experiments that did not? Tamietto and colleagues had a high rate of face repetition throughout the experiment, whereas Schweinberger et al. had only a few repetitions of each face. It may be that processing of unfamiliar faces was potentiated by prior exposures in the studies by Tamietto and colleagues; this would suggest that prepotentiation is a third possible cause of redundancy gain.

How might prepotentiation elicit redundancy gain? Krummenacher et al. (2002) found that redundancy gain in pop-out visual search is consistent with the dimension-weighting account of unknown singleton search (Found & Müller, 1996; Müller, Heller, & Zeigler, 1995). In singleton search, participants search for an item that differs in some feature or features from everything else in the display; in unknown singleton search, it is not known what the exact difference will be. According to the dimension-weighting account, observers who know or suspect in what feature dimension (e.g., color, orientation) a target will occur can weight target-relevant feature dimensions (e.g., color, orientation) prior to beginning a search task. A map of saliency is created for each dimension; sampling of the dimension-specific saliency maps is biased toward the heavily weighted dimension or dimensions. A master map of saliency is also created from each dimension-specific saliency map. According to Krummenacher et al. (2002), two separate targets will lead to statistical facilitation because two locations will be salient on the master map of saliency; by contrast, one target defined in two dimensions will lead to coactivation, because two different feature dimensions will contribute to saliency within one location on the master map. Consistent with this prediction, Krummenacher et al. (2002) found that a single target defined in two different dimensions violated the race model inequality, whereas two separate targets defined in the same dimension did not. Additionally, two targets defined within separate dimensions only showed evidence of coactivation if they were close in space; this is also consistent with the notion of a location-based map of saliency.

However, participants in a singleton search experiment such as that employed by Krummenacher et al. (2001, 2002) only need to know which feature dimension (e.g., color) defines a target, rather than which specific feature (e.g., red) defines a target. It does appear that participants can weight entire feature dimensions (e.g., Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Found & Müller, 1996; Müller et al., 1995; Zehetleitner, Goschy, & Müller, 2012), but electrophysiological evidence also supports the notion that people can selectively attend to specific features and that feature-selective attention biases early visual processing (e.g., Hillyard & Anllo-Vento, 1998; Müller et al., 2006). Given that visual processing can be biased toward feature dimensions or specific features depending on the task, the dimension-weighting account may need to be combined with the guided search model to explain the results of different visual search paradigms. Wolfe and colleagues' guided search model (Cave & Wolfe, 1990; Wolfe, 1994, 2007; Wolfe, Cave, & Franzel, 1989), early versions of which inspired the dimension-weighting account, suggests that participants are able to use a broad form of feature weighting (e.g., participants looking for a horizontal line might weight a "shallow orientation" feature channel; Wolfe, 2007) in order to constrain search. Weighted feature channels will contribute more strongly to the master map of saliency than unweighted feature channels.

Dimension-weighting and guided search were both developed to explain visual search phenomena. However, assuming that early visual processing operates in similar ways for other types of visual detection paradigms, then a combination of these models can explain redundancy gain as well. If target-relevant features are known beforehand, then visual processing should still be biased towards the relevant features, and those features should be able to contribute strongly to later processing. Guided search assumes that observers rely on the overall master map of saliency, but Found and Müller (1996) and Müller et al. (1995) showed that switching target dimensions between trials degrades performance, suggesting that participants may be sampling from dimension-specific saliency maps instead of a master map. If the correct feature dimension is not sampled first, then other dimensions must be serially searched for the dimension that defines the target. Assuming that the same is true when processing is biased for specific features instead of feature dimension, then the presence of targets with expected features allows participants to process those features in parallel, allowing targets to be selected quickly and in parallel, and leading to a processing race between the targets. By contrast, not knowing what features to expect may require participants to serially search for features.

Krummenacher et al. (2002) argued that a likely neural mechanism of dimension-weighting is the potentiation of areas in the striate or extrastriate cortex associated with processing the relevant dimensions. Evidence that prior attentional settings can affect the visual cortex comes from a PET study showing that attention to a changing feature increases sensitivity to such changes, and is also associated with increased activity in the extrastriate cortex (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991). Mangun and colleagues also utilized long delays between spatial cues and the relevant stimulus to show that both spatial and feature-based visual attention activate both a frontoparietal network and the striate and extrastriate cortex contralateral to the attended hemifield (Giesbrecht, Woldorff, Song, & Mangun, 2003; Hopfinger, Buonocore, & Mangun, 2000), although Fannon, Saron, and Mangun (2008) found that the increase in activation associated with feature-based attention did not predict changes in behavioral performance. They suggested that the baseline increase may not be the mechanism by which feature-based attention enhances performance; instead, some other effect such as increased synchronization in neural firing, or increased activation only within small networks of neurons, might be responsible for changes in behavior. Prepotentation therefore may not take the form of an increase in individual neurons' activation, but an increase in the likelihood that relevant neurons will fire together.

Top-down attentional control or priming may be partially responsible for a wide range of results in the existing literature on redundant signals. Most redundant signals studies have employed one stimulus or a few very specific stimuli, and participants would very quickly have developed expectations about what targets would occur, or would be primed by previous encounters with the target. Even for some categorically-defined targets, priming could have had an effect, considering that large numbers of familiar stimuli, at least 36, can be primed simultaneously, and that priming can last for a considerable length of time, at least 10 minutes (Forbach, Stanners, & Hochaus, 1974). Some studies employing categorically-defined targets had small set sizes and numerous repetitions of target stimuli (e.g., Banich & Karol, 1992; Egeth et al., 1989; de Gelder et al., 2001), so that the redundant signals effect may have been enhanced by target repetition.

Testing the Three-Conditions Hypothesis

The purpose of the current study was to determine whether or not the visual redundant signals effect can in fact be attributed to any one of the three factors listed above (visual identicalness, familiarity, and prepotentiation). Toward that end, a series of four experiments were conducted to attempt to isolate the three factors. All experiments employed a simple RT paradigm, in which participants respond as quickly as possible to the presence of any stimulus on the computer screen, without distinguishing between different stimuli. The purpose of employing simple RT rather than choice RT or go/no-go was to minimize the need for high-level cognitive processing of the stimuli, to reduce the likelihood that the redundant signals effect could be attributable to semantic rather than perceptual processing. This allowed the exploration of the redundant signals effect to be limited to visual processing in the proposed experiments. In a simple RT paradigm, participants do not need to make a choice about which of multiple responses to make, and do not need to choose whether to make or withhold a response based on the identity of the stimulus.

Experiment 1 employed unfamiliar and unexpected stimuli to determine whether or not visual identicalness alone can induce a redundancy gain. Experiment 2 employed familiar vs unfamiliar stimuli to determine whether or not familiarity can induce redundancy gain; Experiment 3 employed preview vs no-preview conditions to determine whether or not prepotentiation is responsible for redundancy gain in unfamiliar, non-identical targets. Finally, Experiment 4 employed identical vs non-identical stimuli, preview vs no-preview conditions, and familiar vs unfamiliar stimuli to test the possibility that all three conditions have multiplicative effects on redundancy gain.

Hypotheses

In line with the three-conditions hypothesis, the following outcomes were expected.

1. Experiment 1: In the absence of familiarity or prepotentiation, two targets must have visually identical features in order to elicit a redundant signals effect. Thus, only identical targets were expected to show a redundant signals effect, and the redundant signals effect was expected to be attributable to coactivation.
2. Experiment 2: In the absence of visual identicalness or prepotentiation, two categorically similar stimuli can elicit a redundant signals effect if they are familiar to the participant. Thus, familiar stimuli were expected to show greater redundancy gain

than unfamiliar stimuli. Unfamiliar stimuli were expected to show a slight redundant signals effect due to target repetition in Experiment 2, but it was expected to be smaller than the effect for familiar stimuli. The redundant signals effect was expected to be attributable to coactivation, because the stimuli should activate overlapping transcortical cell assemblies.

3. Experiment 3: In the absence of familiarity, two visually different stimuli can elicit a redundant signals effect, but only if they have been previewed beforehand. Non-previewed stimuli were not expected to show redundancy gain. Because the two targets were separated in space, the redundant signals effect was expected to be attributable to statistical facilitation.
4. Experiment 5: Identicalness, familiarity, and prepotentation were all expected to have multiplicative effects, such that redundancy gain would be greatest for familiar, identical targets preceded by a target preview.

CHAPTER TWO: EXPERIMENT 1

The purpose of Experiment 1 was to determine whether or not visual identicalness alone is sufficient to induce a redundant signals effect. This is a question that is not answerable from any of the previous research; simple visual RT experiments, as well as most go/no-go and choice RT experiments, have employed one or a few specific stimuli, and often stimuli such as basic squares (e.g., Savazzi & Marzi, 2008) that were presumably highly familiar to participants. Thus, any interaction between identicalness and redundancy could possibly have been attributable to a further interaction between identicalness, redundancy, and one or both of the other hypothesized factors, identicalness and familiarity.

To prevent familiarity, a fractal generator was employed to create 3D fractals from a variety of color schemes and fractal sets and at a variety of angles and distances from the fractal. Even if they were familiar with fractals in general, participants would not have seen the exact combination of fractal set, color set, and viewing angle represented in these images. These stimuli should therefore have been highly unfamiliar and should have no transcortical cell assemblies devoted to them. This minimized stimulus familiarity, but prepotentiation of stimulus features also needed to be minimized. This was accomplished through two approaches. First, each fractal was cropped to fit a randomly generated polygon with a random number of sides. Without any particular shape defining the edges of the fractals, participants should not have been able to develop a strategy based on the boundaries of the stimuli. Second each fractal was presented in only one trial, to prevent priming of a response based on previous exposure to a particular fractal. Random fractals and random shapes should also have reduced the problem of increasing familiarity as a function of the number of trials completed.

Participants responded to targets presented to the left visual field, the right visual field, or both visual fields simultaneously. Half of redundant targets were visually identical, while the other half were non-identical. With familiarity and prepotentiation minimized, the visual identicalness hypothesis predicts that redundancy gain will occur only for identical redundant targets, and not for non-identical redundant targets. Finding redundancy gain in neither case would suggest that visual identicalness alone cannot induce a redundant signals effect. Finding an equal redundancy gain for identical and non-identical stimuli may suggest that identicalness is not always important for redundancy gain, whereas finding a stronger redundancy gain for non-identical than for identical stimuli would suggest that too much sensory overlap leads to interference between bilateral stimuli rather than facilitation.

Finally, stimuli were presented in original or in desaturated format. Saturation level served as the second factor in the double factorial design outlined by Townsend and Nozawa (1995). In line with previous research employing identical redundant signals, it was expected that identical redundant fractals would show evidence of coactivation using Townsend and Nozawa's interaction contrasts.

Method

Participants

Sixteen undergraduates (6 female, mean age = 20.12) from the University of Central Florida participated for partial course credit. All participants had normal or corrected-to-normal vision as determined by near and far Snellen charts and Ishihara plates. One participant was excluded from data analysis due to an extremely high proportion of anticipatory responses (7.59%). In all four experiments, participants were excluded if their proportions of anticipatory or delayed responses were more than 3 standard deviations above the mean, or if their accuracy on catch trials was more than 3 standard deviations below the mean. Fifteen participants were included in data analysis.

Because the purpose of these experiments was to detect possibly small multiplicative effects, the number of participants was chosen based on an analysis in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) to provide a high level of power to detect redundancy gain in all experiments. The Generic F test function was employed because it allows for power analysis of interaction terms for within-subjects designs. In previous redundancy gain experiments in our lab, effect sizes have ranged widely, but were often approximately $\eta_p^2 = .20$, which was therefore chosen as the effect size for the power analysis. Because previous studies also often exhibited a significant violation of sphericity in some interactions, the nonsphericity parameter was specified as .75. Finally, the default repeated measures correlation coefficient of .5 was employed. Given those parameters, the power analyses indicated that 15 participants should provide a power value of approximately .95 for the interaction terms for all of the proposed studies.

Apparatus and Stimuli

Targets were 3D fractals generated in Mandelbulber (Marczak, 2016) from multiple fractal sets, distances, and camera angles, with color set randomized. Each fractal was cropped to a randomly generated polygon containing between 5 and 15 sides and subtending 2° x 2° visual angle from the outermost corners.

Stimuli were presented on a white background 6° to the left and right of the visual vertical meridian, and 3° above the visual horizontal meridian. This placement was suggested by previous research indicating a more reliable redundant signals effect for the upper visual field than for the lower visual field (Mishler & Neider, in preparation) and by a pilot study indicating a more reliable redundant signals effect for the upper visual field than for the horizontal meridian. Such search asymmetries have occurred in other studies (de Gelder et al., 2001; Miniussi et al., 1998), although the effect in these studies has been the opposite, such that the lower visual field had a greater redundant signals effect than the upper visual field. Sample stimuli are presented in Figure 1.

The display monitor was a Samsung SyncMaster 2233 22-inch LCD monitor connected to a Windows 7 Pro computer with a GeForce GT 440 graphics card (NVIDIA, Santa Clara, California). An Eyelink 1000 eye tracker (SR Research, Ottawa, Ontario) with a standard desktop headmount was employed to ensure that participants were fixating the center of the screen at the start of every trial. The eye tracker host computer was a Windows 7 Pro computer with an Intel HD Graphics 2500 graphics driver (Intel, Santa Clara, California). Participants made their responses on a Microsoft Sidewinder game controller.

Participants also completed the paper-and-pencil letter comparison test and pattern comparison test for perceptual speed (Salthouse & Babcock, 1991). In the letter comparison test, participants compare two strings of letters side-by-side. Half of the strings are identical, and half of the strings differ by one letter. If the strings are identical, participants write “S” on a line between the strings; if they are different, participants write “D.” Participants complete as many comparisons as possible in 30 seconds on one page, and then do the same on a second page. The pattern comparison test is the same, except that participants compare abstract line drawings that are identical or differ by one feature. The purpose of the letter and pattern comparison tests was to account for the possibility that only participants with high perceptual speed were able to distinguish between two non-identical targets.

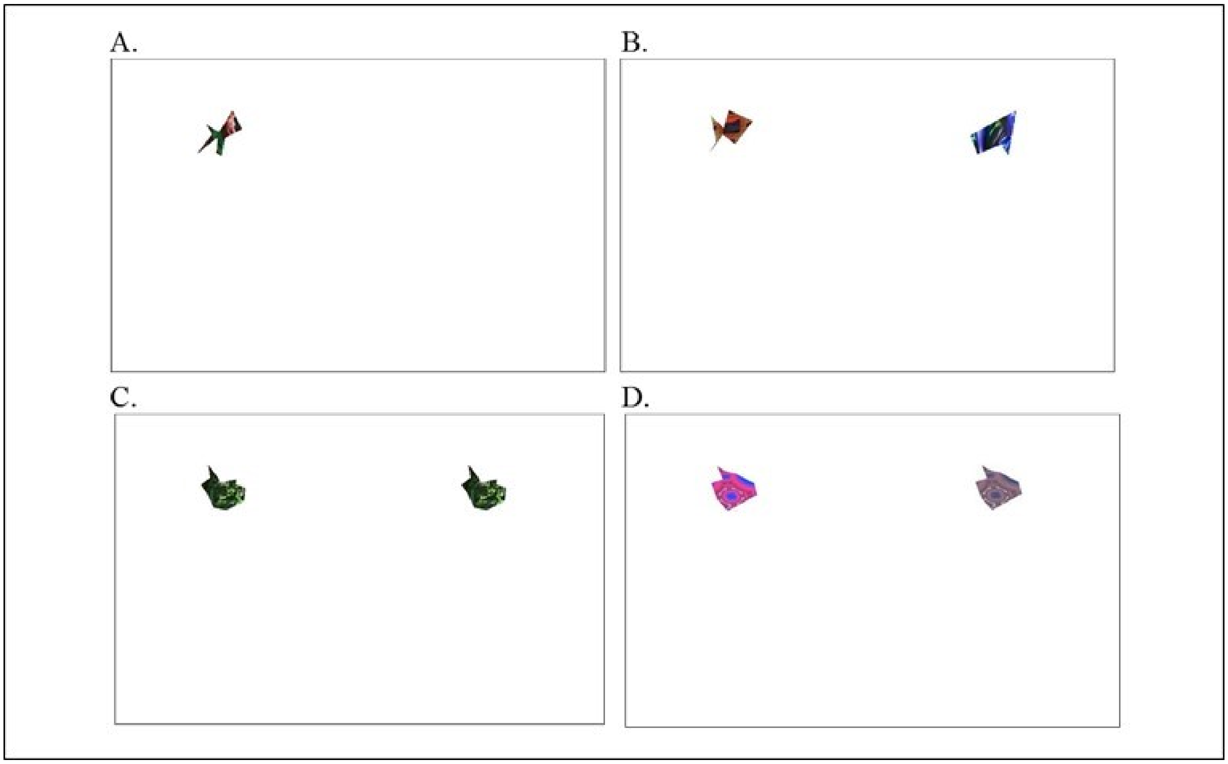


Figure 1. Sample Stimuli from Experiment 1

A) Single left target with original saturation. B) Redundant non-identical targets with original saturation. C) Redundant identical targets with original saturation. D) Redundant identical targets; the left target is at original saturation and the right target is desaturated by 200 points in Irfanview. Stimuli in either location (left or right) may be in either original or desaturated format in all presentation types.

Design

Design of Trials

There were a total of 540 experimental trials, 120 each of left visual field targets, right visual field targets, identical redundant targets, and non-identical redundant targets; plus 60 catch trials in which no targets were present. Catch trials were included to discourage responses made in anticipation of a target before any target had appeared. The trials adhered to a 4-level (presentation type, single left vs single right vs redundant non-identical vs redundant identical) one-way within-subjects design. However, not all levels of all factors were employed in data analysis, as explained in the Results section.

Design of Stimuli within Trials

Targets in each location were presented equally often in original format or with color saturation reduced by 200 points in Irfanview (Skiljan, 2016). Thus, each location adhered to the double-factorial design discussed by Townsend and Nozawa (1995, 1997). For each stimulus location, the stimulus adhered to a 2 (presence; present or absent) x 2 (format; original or desaturated) factorial design.

Procedure

Participants were screened for normal or corrected-to-normal vision, and then completed a demographic questionnaire. They were then instructed to press the right trigger on their game controller as quickly as possible if they saw any stimulus flash to the left of center, right of center, or in both locations at once. Thus, the experiment employed a simple RT paradigm. After instructions, participants placed their chins in the headmount of the eye tracker, and the eye tracker was calibrated to the participant.

Participants completed one block of 27 practice trials, followed by 6 experimental blocks of 90 trials each. All conditions were randomly intermixed within the blocks. Each trial began with drift correction, in which participants focused on a small circle in the center of the display screen while pressing a button. Drift correction corrects for changes in the calculation of fixation positions, but was primarily used in the current study to ensure that participants were focused on the center of the display at the beginning of every trial. Following drift correction, a fixation cross appeared and remained on the screen for an interval randomly varying between 350 and 850 ms. The fixation cross was then replaced by a target display lasting for 100 ms, followed by a blank screen lasting 900 ms or until response. In the case of catch trials, the fixation cross was replaced by a blank screen lasting 1000 ms or until response. Participants were allowed to respond any time from the onset of the target display to the offset of the blank screen.

Participants were provided with a 500-ms feedback screen at the end of every trial. Feedback was presented in 30-point Arial font in the center of a white screen. If participants correctly made a response to targets, the feedback stated, “Response time: *X* ms” in blue letters. If they failed to respond to targets, the feedback stated, “Too slow” in red letters. If they correctly avoided responding on catch trials, the feedback stated, “Correct! There was no target” in blue letters. Finally, if they incorrectly responded on a catch trial, the feedback stated, “There was no target!” in red letters. The feedback screen was followed by the drift correction screen for the next trial. Feedback was included to discourage participants from attempting to finish the experiment quickly without any concern for accuracy, and it has been used in past redundancy gain experiments (e.g., Grice & Reed, 1992; Miller, 1982). After the experiment, participants completed the letter comparison test, followed by the pattern comparison test.

The procedure was designed to be similar to previous research, with the exception that eye tracking is not usually used to enforce center fixation at the beginning of trials. Although display design and procedural details vary widely in redundancy gain research, the general method usually involves asking participants to fixate on the center of a display at the beginning of a trial and to monitor a few specific display locations at which targets may appear. Targets appear after an interval that may be either fixed or variable, and participants usually respond by pressing a button, key, or trigger. Variable intervals were used in the current studies to minimize any effects of being able to anticipate precisely when targets would appear. Although tachistoscopes are sometimes used to ensure that the visual fields remain completely separated from one another (e.g., Townsend & Nozawa, 1995), they more often are not employed (e.g., Baird & Burton, 2008; Barr & Corballis, 2003; Corballis, 1998; Savazzi & Marzi, 2004, 2008), and were not used for the current experiments. Participants also usually place their chins in a chin rest to maintain a constant distance from the display screen; this is similar to the eye tracking headmount employed in the current study (e.g., Baird & Burton, 2008; Barr & Corballis, 2003; Corballis, 1998; Savazzi & Marzi, 2004, 2008).

Results

Data analysis was based on RT for accurate target-present trials, and on accuracy for target-present trials. In these trials, "accuracy" refers to responding to the presence of a target; inaccurate trials were those in which no response was made. Accuracy on catch trials (i.e., not responding when no targets were present) was 66.33%, *SD* = 19.01%.

Redundancy Gain

Response Times

Similar to Savazzi and Marzi (2004), RTs under 100 ms and above 650 ms were discarded; responses under 100 ms are likely to be anticipatory responses, and responses over 650 ms are likely to be delayed responses. Anticipatory and delayed responses were a negligible proportion of trials for participants included in data analysis (anticipatory *M* = .016, *SD* = .012, delayed *M* = .006, *SD* = .005). RTs for single-target trials were calculated for each participant in accordance with a method suggested by Miller and Lopes (1988). RT for the two single-target locations is compared using a two-sample *t*-test with a generous alpha level of .10. If a participant has a significant difference in RT between the two single-target locations, then the mean RT for the faster single-target location is employed to test for a redundant signals effect. However, if the participant does not have a significant difference between the two single-target locations, then the mean RT for both locations is employed to test for a redundant signals effect. This differs from Biederman and Checkosky's (1970) method, which always uses the faster single signal to test for redundancy gain, and is intended to account for the possibility that participants favor one single signal. In the current experiments, a "favored single signal" is the faster of two single-target locations. If one single signal is favored, then redundant-signal responses will be faster than the average single-signal response because the redundant-signal trials always contain the favored signal, whereas single-signal trials only contain the favored signal some of the time. However, Miller and Lopes (1988) demonstrated that consistently using the fastest location will consistently lead to underestimated single-signal RTs, reducing the likelihood of correctly concluding that there is a redundancy gain. Miller and Lopes's estimate corrects for this bias by only using the faster single signal if there is evidence that the signal is truly favored. In Experiment 1, 3 participants showed evidence of a location preference and 12 exhibited no preference.

Per Schneider, Avivi-Reich, and Mozuraitis (2015), ANCOVAs should only be used for within-subjects designs to determine whether or not there are interactions between covariates and within-subjects independent variables. When examining the effects of the within-subjects independent variables themselves, an ANOVA should be used to avoid Type I error inflation. Thus, RT and accuracy in the current study were examined with both an ANOVA, which is used to report the effects of within-subjects variables, and an ANCOVA, which is used to report any interactions between within-subjects variables and covariates. All ANOVAs and ANCOVAs reported in the current study were conducted using SPSS 23 for Windows with default settings, and an alpha level of .05 was used for all.

RTs were subjected to a one-way within-subjects ANOVA with presentation type (single, redundant identical, and redundant non-identical) as the independent variable. Mean RTs are presented in Figure H. In line with Townsend and Nozawa (1995), RT was collapsed across color saturation levels, and saturation level was only employed to test for coactivation.

The effect of presentation type was significant, $F(2,28) = 13.78$, $p < .001$, $\eta_p^2 = .50$. Bonferroni-corrected post-hoc tests indicated that participants responded significantly more slowly to single-target trials than to either type of redundant-target trial ($p < .003$ for both), but that redundant identical trials did not significantly differ from redundant non-identical trials ($p = .520$; $M_{\text{single}} = 241$ ms, $M_{\text{identical}} = 230$ ms, $M_{\text{non-identical}} = 228$ ms). Thus, redundant-target trials did elicit redundancy gain, but the effect was not dependent on identicalness of the targets.

Perceptual speed was then calculated as the total number of correct responses to the letter and pattern comparison tests, and centered by subtracting the mean processing speed score for all participants from each participant's score. RT was subjected to a one-way within-subjects ANCOVA with presentation type as the independent variable and centered processing speed as a covariate. There was no significant interaction between perceptual speed and presentation type, $F(2,26) = 0.82$, $p = .450$, $\eta_p^2 = .06$. Thus, perceptual speed did not affect the pattern of response times to different presentation types.

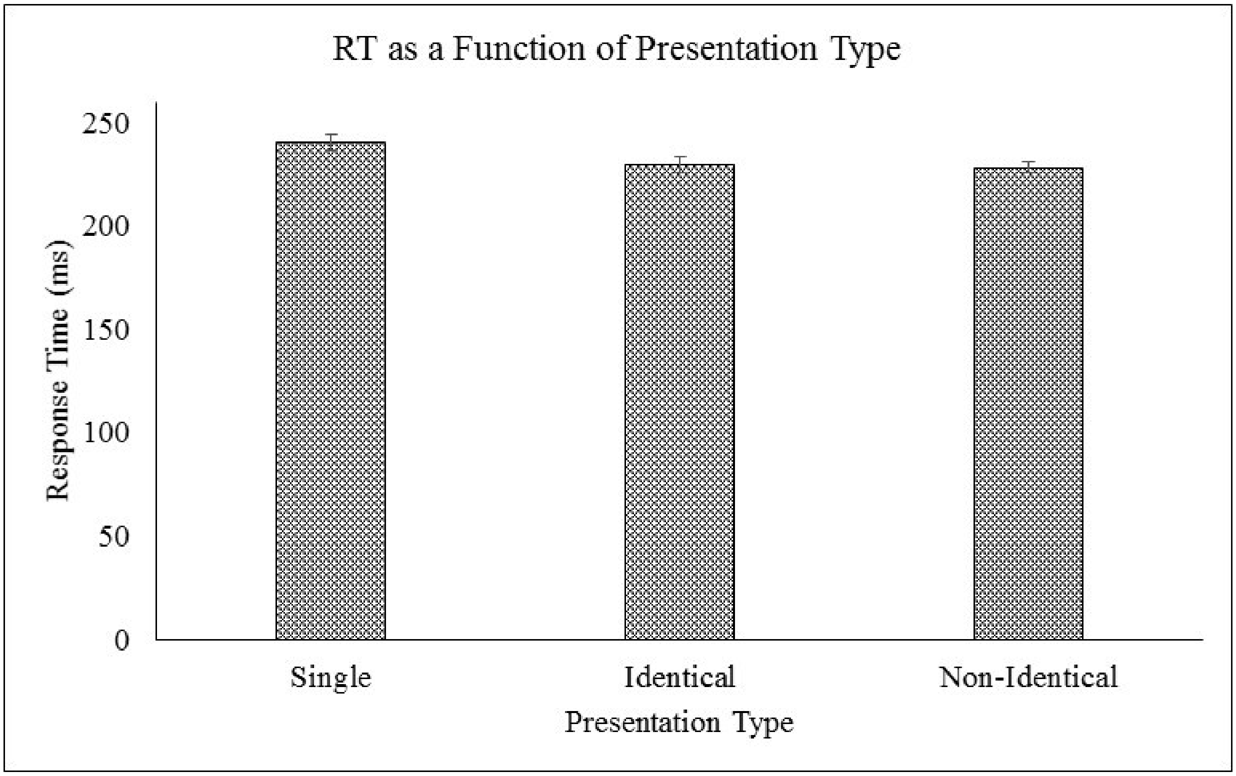


Figure 2. RT as a Function of Presentation Type for Experiment 1

Error bars represent 2 within-subjects standard errors above and below the mean, based on the correction to Cousineau (2005) outlined in Morey (2008). Single-target RTs are slightly slower than either type of redundant-target RT.

Accuracy

Mean accuracy was high overall, M = 98.42%, SD = 1.82%. Accuracy was analyzed with a one-way, within-subjects ANOVA with presentation type as the independent variable. The effect of presentation type was significant, $F(2, 28) = 6.05$, $p = .007$, $\eta_p^2 = .30$. Bonferroni-corrected post-hoc tests indicated that participants were significantly more accurate on single-target trials than on either type of redundant-target trials, $p < .004$ for both, but redundant identical trials did not differ from each other, $p = .379$. Thus, redundancy gain in RT seems to be accompanied by a slight redundancy loss in accuracy, although the differences in accuracy are tiny, $M_{\text{single-identical}}$ = 0.67%, $M_{\text{single-nonidentical}}$ = 0.97%. When centered perceptual speed was added as a covariate, the interaction between perceptual speed and presentation type was not significant, $F(2,26) = 0.99$, $p = .385$, $\eta_p^2 = .07$.

Coactivation analyses

Because there was evidence of redundancy gain, the data were further examined for evidence of coactivation. Two different analyses were employed to search for evidence of coactivation, including Miller's (1982) race model inequality, and Townsend and Nozawa's (1995, 1997) interaction contrasts.

Race Model Inequality

The race model inequality was analyzed separately for redundant identical and redundant non-identical trials, using the technique outlined by Ulrich, Miller and Schröter (2007). For redundant signals trials, the cumulative distribution function describing the probability of having made a response by a given time were estimated in 1-ms time bins. For the upper bound of Miller's race model inequality (Equation 1), the cumulative distribution function for each single target location was estimated and the two locations summed, again using 1-ms time bins. These distributions were used to estimate the time, in ms, associated with a 10, 15, 20, and 25% probability of having responded to redundant signals, and the times associated with the same probability for the race model bound. Because coactivation models are expected to violate the race model inequality early in the distribution, Kiesel, Miller, and Ulrich (2007) suggested testing for violations only in the 10-25% range as a way of minimizing familywise Type I error. If the race model inequality is violated at any percentile, i.e., if the redundant-target distribution is significantly faster than the race model bound at any percentile, it is taken as evidence that coactivation has occurred.

The redundant-targets response time distributions and the race model bound are shown in Figure A. For all quantiles (10%, 15%, 20%, and 25%), both the redundant identical and the redundant non-identical distributions were slower than the race model bound; therefore, no statistical tests were performed on these distributions. There was no evidence of coactivation in either type of redundant-target trials.

However, as mentioned in the introduction, satisfying the race model inequality does not necessarily indicate an absence of coactivation; thus interaction contrasts were also calculated, as discussed in the next subsection.

Interaction Contrasts

The use of original vs desaturated stimuli was intended to enable the use of interaction contrasts as outlined by Townsend & Nozawa (1995). This technique examines the relationship between redundant target trials with different configurations of (in this experiment) original and desaturated stimuli. For original stimuli *o* and desaturated stimuli *d*, the mean interaction contrast is given by the formula,

$$IC = RT(d,d) - RT(d,o) - RT(o,d) + RT(o,o), \tag{2}$$

where each RT is the mean RT for a redundant signals condition. For example, *RT(d,d)* is the mean RT for redundant signals trials in which the left stimulus and the right stimulus are both desaturated.

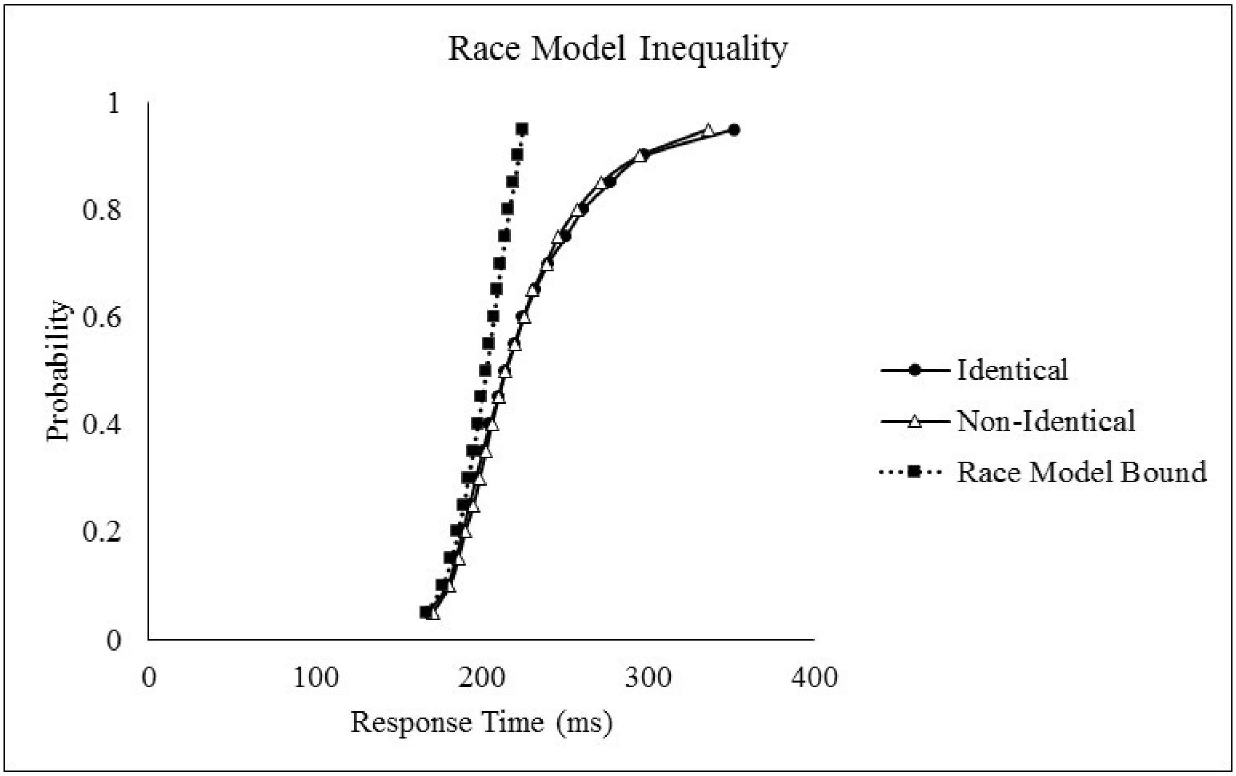


Figure 3. Race Model Inequality for Experiment 1

The cumulative distribution functions for the race model bound (dashed line with squares), redundant identical trials (solid line with circles), and redundant non-identical trials (solid line with triangles) for Experiment 1. Nowhere in the distribution is the probability of having responded by time *t*, given redundant targets, greater than the race model bound (i.e., the race model bound is always to the left of the redundant-target distributions). Thus, there is no evidence for coactivation in the race model inequality.

Survivor interaction contrasts are based on survivor functions, which are estimated from the cumulative distribution functions of each redundant signals condition. Unlike mean interaction contrasts, they are calculated for every time bin for which the cumulative distribution functions are estimated, as follows:

$$IC(t) = S_{dd}(t) - S_{do}(t) - S_{od}(t) + S_{oo}(t), \qquad (3)$$

where t is the given time bin, S is the estimated value of a survivor function at time t, o is an original stimulus, and d is a desaturated stimulus. Survivor interaction contrasts are calculated separately for each participant, because coactivation models predict a small negative dip in $IC(t)$ towards the beginning of the function. Because the function begins at different time bins depending on a participant's overall speed, the small dip occurs at different time bins for different participants and is smoothed over when the functions are averaged across participants.

Race models and coactivation models both predict that $IC > 0$, but race models also predict that $IC(t) > 0$ across the entire distribution, whereas coactivation models predict that $IC(t) < 0$ for a small period at the beginning of the distribution before becoming positive. If $IC \leq 0$, then the assumption of parallel processing is disconfirmed, and neither race nor coactivation models can account for the redundant signals effect.

Mean interaction contrasts and survivor interaction contrasts were calculated separately for redundant identical and redundant non-identical trials. Calculations were completed in R (R Core Team, 2013) using the sft package (Houpt, Blaha, McIntire, Havig, & Townsend, 2014). For each participant, this package computes IC and $IC(t)$, conducts an ANOVA to determine whether or not MIC significantly differs from 0, and conducts two Kolmogorov-Smirnoff tests on $IC(t)$ to determine whether or not it has significantly negative portions and significantly positive portions (using the Kolmogorov-Smirnoff test adaptation described in Houpt & Townsend, 2010).

For redundant identical trials, all participants presented with IC not significantly different from 0, $p > .089$ for all, and $IC(t)$ showing no significantly positive or negative portions, all Ds < 0.49, $p > .082$ for all. This pattern of results is consistent with a serial minimum-time processing architecture (Townsend & Nozawa, 1995). In serial minimum-time processing, participants process targets one at a time, but do not need to complete processing of both targets before they make a response; whichever target is processed first elicits a response. Thus, the results obtained from redundant identical trials are not consistent with any form of parallel processing, instead indicating that participants based their responses to redundant identical trials on the presence of only one of the targets.

For redundant non-identical trials, the results were somewhat less consistent, but still generally consistent with serial minimum-time processing. Twelve of the fifteen participants presented with IC not significantly different from 0, $p > .054$ for all, and no significantly positive or negative portions of $IC(t)$, $D < 0.46$ for all, $p > .052$ for all. One participant presented with a mean interaction contrast that did not significantly differ from 0, $IC = 10.50$, $p = .109$, a significantly negative portion of $IC(\mathrm{t})$, $D = 0.49$, $p = .033$, and no positive portion of $IC(\mathrm{t})$, $D = 0.21$, $p = .542$. One participant presented with $IC = 77.35$, $p = .290$, a positive portion of $IC(t)$, $D = 0.48$, $p = .040$, and no negative portion of $IC(t)$, $D = 0.17$, $p = .675$. Finally, one participant presented with $IC = -35.72$, $p = .045$, and no significant positive or negative portion of $IC(t)$, Ds < 0.44, ps $> .06$. The results from these three participants are inconclusive in that they are not predicted by any known processing architecture. No results from any participant are clearly indicative of parallel processing, either of a race model or of coactivation. Sample survivor interaction contrasts from one participant are presented in Figures B and C.

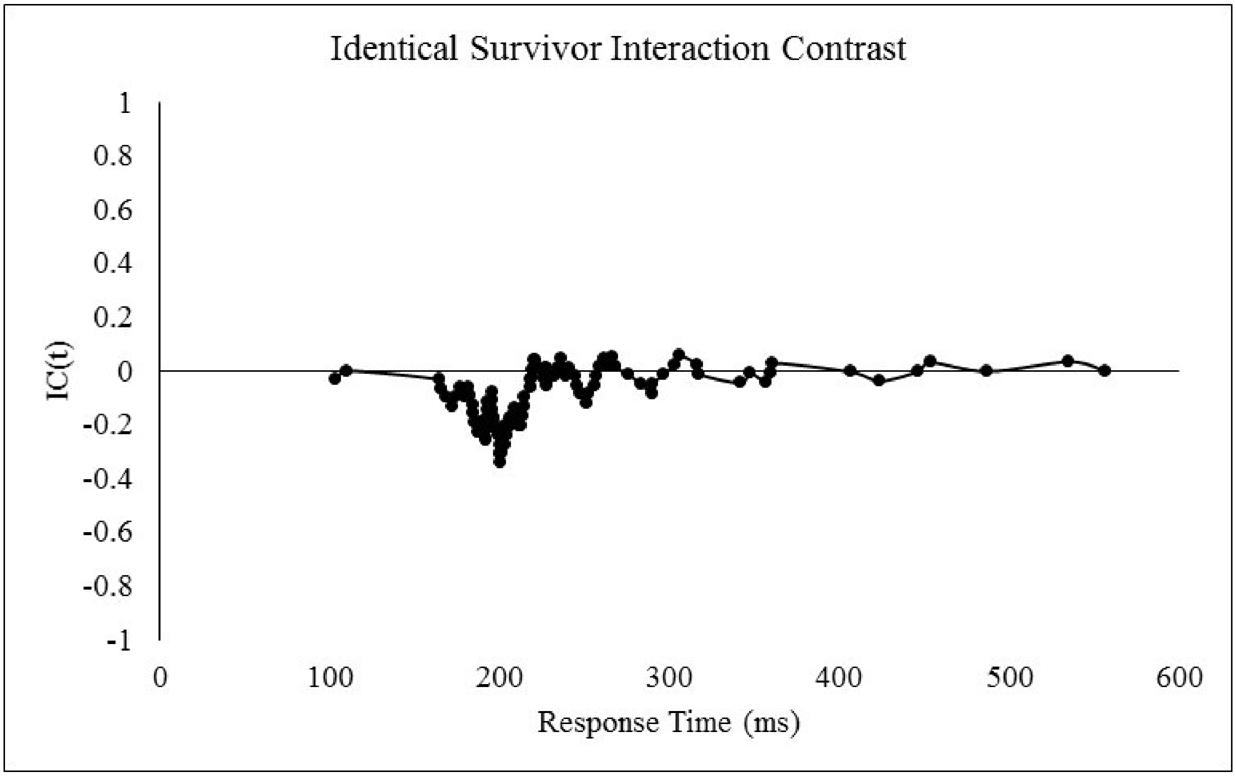


Figure 4. Survivor Interaction Contrast for Redundant Identical Trials in Experiment 1

Sample survivor interaction contrast for redundant identical trials in Experiment 1. The survivor interaction contrast has no significantly positive or negative portions, consistent with a serial minimum-time processing architecture.

Discussion

Experiment 1 was conducted to test the effect of identicalness on redundancy gain, in the absence of familiarity or of expectations about the appearance of upcoming targets. The results indicated that redundancy gain can occur in the absence of familiarity and expectations, but can do equally well for identical and non-identical stimuli. This result is surprising, given previous studies that suggest a benefit of identical stimuli for redundancy gain (e.g., Baird & Burton, 2008; Banich & Karol, 1992; Grice & Reed, 1992; Mordkoff & Miller, 1993; Mullin & Egeth, 1989; Schwarz & Ischebeck, 1994). One possible explanation for this is that the nature of the simple RT task allowed for attentional tuning that is even broader than that suggested by Wolfe (2007). Because all targets were random shapes edged by straight lines, it is possible that participants came to expect straight lines in general, regardless of other factors such as orientation, length, or color.

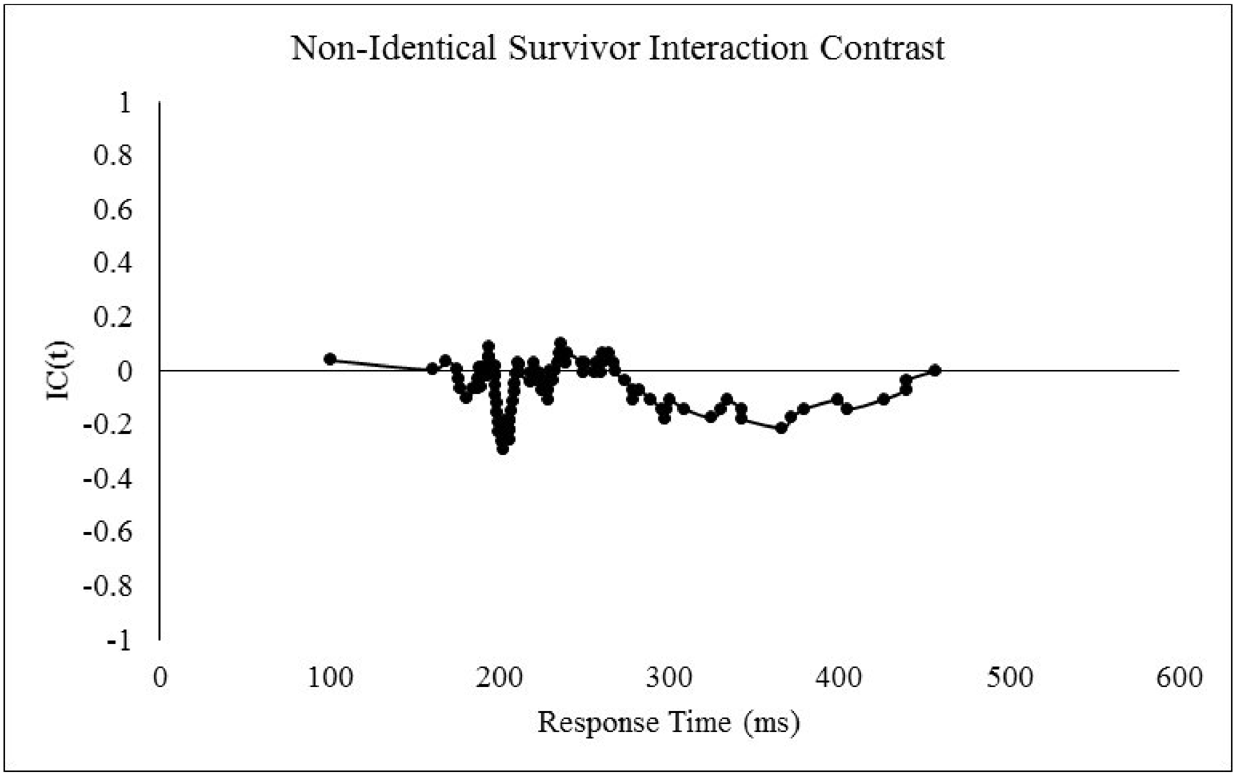


Figure 5. Survivor Interaction Contrast for Redundant Non-Identical Trials in Experiment 1

Sample survivor interaction contrast for redundant non-identical trials in Experiment 1. The survivor interaction contrast has no significantly positive or negative portions, consistent with a serial minimum-time processing architecture.

However, this possibility seems unlikely, given that Schwarz and Ischebeck found a disadvantage for two orthogonal lines compared to two parallel lines in a similar task; the only feature difference between the lines in their study was orientation. A different possibility presents itself in the results of the processing architecture analyses. In spite of Townsend and Nozawa's (1995) strong disconfirmation of serial processing in favor of parallel processing models in a set of simple RT redundancy gain experiments, the current study showed evidence of serial minimum-time processing, in which the first target that is processed elicits a response without input from the second target. This result may suggest that participants can strategically choose between parallel and serial processing styles, depending on the parameters of the task. For experiments with regularly repeated stimuli, such as Townsend and Nozawa's (1995) illuminated dots and most of the redundancy gain experiments conducted in the past, participants might choose to engage in parallel processing that can benefit from familiarity and prior exposures to the repetitive stimuli. By contrast, in an experiment such as the current one, when familiarity and prepotentiation are not available, parallel processing might be less advantageous, and participants might choose serial processing instead.

It is interesting to note that, in spite of serial processing, redundancy gain still occurred. This suggests that participants attended to one location or the other at the beginning of every trial. For single-target trials, this would slow participants down, as the first-attended location would not always contain a target, necessitating a switch of attention to the target's location. Redundant-target trials, on the other hand, would always contain a target in the first-attended location.

However, one result does suggest that not all processing of the redundant targets occurred serially. Accuracy (i.e., pressing the trigger in response to a target or targets) was slightly lower for redundant-target trials than for single-target trials. None of the previous redundancy gain literature indicates that participants are less likely to detect two targets than to detect one target, but the result does suggest that the presence of one target that cannot enhance processing of the other may instead slightly inhibit processing of the other target. This may indicate that selective attention to one location has a disadvantage in that the presence of a target in the other location can distract the participant and reduce the likelihood of detecting what is present in the attended location.

On a final note, accuracy on catch trials was well below ceiling, at 66.33%. Because previous redundancy gain studies employing catch trials (e.g., Savazzi & Marzi, 2008) did not report accuracy on these trials, no comparison can be made to the previous studies. However, catch trials were relatively rare, constituting only 11.11% of all trials. Participants may therefore have been biased to respond as if a target was present instead of withholding responses, given that this would reflect an optimal strategy (e.g., Wickens, 2001). The purpose of catch trials was to prevent participants from responding indiscriminately in every trial and encourage them instead to wait for a target to appear; given that participants withheld responses more often than not on catch trials, but almost always responded on target-present trials, it appears that they did make an effort not to respond unless they had seen a target.

Regardless of the exact mechanisms of attention and distraction, Experiment 1 indicates that redundancy gain can occur even in the absence of identicalness, familiarity, or prepotentiation, but that it is not attributable to either of the parallel processing architectures usually seen in redundancy gain experiments. Thus, the hypotheses for Experiment 1 were not supported; non-identical targets elicited redundancy gain, and redundancy gain for identical targets was not attributable to coactivation. The presence of familiarity and/or prepotentiation in the three following experiments may still show an advantage over unfamiliarity or unexpectedness, if participants were engaged in more typical parallel processing strategies.

CHAPTER THREE: EXPERIMENT 2

Experiment 1 examined the effect of identicalness on redundancy gain. Experiment 2 examined the effect of the second cause in the three-conditions hypothesis, familiarity. Previous experiments have shown that unfamiliarity can eliminate redundancy gain for faces (Mohr et al., 2002; Schweinberger et al., 2003) and words (Mohr et al., 1994, 1996, 2007; Zaidel & Rayman, 1994). Experiment 2 was an attempt to confirm that result using another, simpler type of stimulus. Toward that end, participants who were naïve to Japanese were presented with letters from the English alphabet and Katakana characters. In previous studies, and in the current experiment, familiarity has been operationalized as individually identifiable instances of a category; for example, familiar faces are those with which participants have enough prior experience that they recognize the face from previous encounters. In the current study, participants should have been able to recognize that they have encountered English letters (familiar alphabetical characters), but not Katakana characters (unfamiliar alphabetical characters). Because the English alphabet is limited to 26 characters, there may have been some prepotentiation due to target repetition. However, if two familiar stimuli can enhance processing efficiency through overlapping transcortical cell assemblies, then familiar stimuli should induce a redundant signals effect that exceeds the effect for unfamiliar stimuli. If two familiar stimuli do not have overlapping cell assemblies, or if interference between two overlapping cell assemblies suppresses any effect of signal enhancement, then the familiar redundancy gain should not exceed the unfamiliar redundancy gain.

Method

Participants

Fifteen undergraduates (9 female, mean age = 20.21, with one participant declining to report their age) from the University of Central Florida participated for partial course credit. All participants had normal or corrected-to-normal vision as assessed by near and far Snellen charts and Ishihara plates. Additionally, all participants self-reported that they were not familiar with Japanese alphabetical characters.

Apparatus and Stimuli

Experiment 2 employed the same computers, eye tracking system, and game controller as Experiment 1. Stimuli were letters presented on a white background, place 6° to the left or right of the vertical meridian and 3° above the horizontal meridian of the display. Familiar stimuli were English letters written in Arial font and subtending approximately 1° visual angle, and unfamiliar stimuli were Katakana monographs of the same size, in Kazuka Gothic Pr6N font. Stimuli were presented in black (high contrast; hex code 000000) or gray (low contrast; hex code 707070). This differs from Experiment 1, which employed saturated vs desaturated colors. However, the double-factorial design does not require experiments to manipulate saturation level specifically; it only requires that some factor of stimulus quality be manipulated. Stimuli with a high vs low contrast to the background were employed in this experiment because they are analogous to the high- vs low-intensity lights employed by Townsend and Nozawa (1995).

Because there are 26 English letters, only 26 Katakana monographs were employed to equate the number of target repetitions across familiar and unfamiliar targets. All redundant-target trials contained two non-identical stimuli to control for visual identicalness. Sample stimuli are presented in Figure 2.

Design

Design of Trials

There were a total of 540 experimental trials, 160 each of left visual field targets, right visual field targets, and redundant targets, plus 60 catch trials in which there was no target. Half of all targets in each configuration were English letters, and half were Katakana monographs. The stimulus presentation adhered to a 3 (presentation type, single left vs single right vs redundant) x 2 (familiarity, English vs Katakana) within-subjects factorial design. Data analysis did not include all levels of presentation type, as explained in the Results section.

Design of Stimuli within Trials

Half of all targets in each location were black, and half were gray. Thus, the targets adhered to the double factorial design, with each location following a 2 (presence; present vs absent) x 2 (contrast; gray vs black) factorial design.

Procedure

The procedure was the same as Experiment 1, with the exception of the type of stimuli employed and the number of blocks. Participants completed one practice block of 27 trials, followed by 10 experimental blocks of 54 trials each. Participants pressed the right trigger on their game controller in response to any character, regardless of familiarity. All conditions were randomly intermixed within blocks. Participants completed the letter and pattern comparison tests at the end of the experiment.

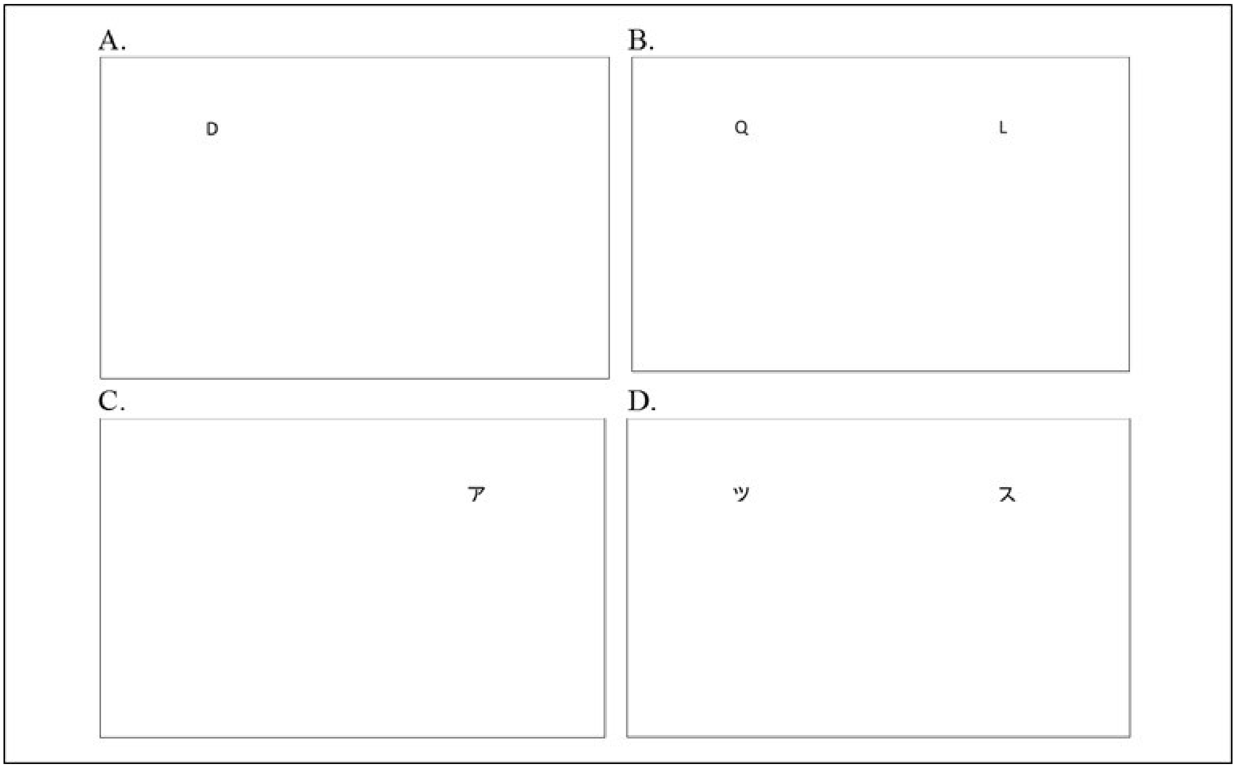


Figure 6. Sample Black Stimuli from Experiment 2

A) Single left target, English (familiar). B) Redundant targets, English. C) Single right target, Katakana (unfamiliar). D) Redundant targets, Katakana. Stimuli in either location (left or right) were either high-contrast (black) or low-contrast (gray).

Results

As with Experiment 1, results were based on RT for accurate target-present responses, and on accuracy for target-present trials, with accuracy defined as responding to the presence of a target. Mean accuracy on catch trials was 67.78%, *SD* = 17.52%.

Redundancy Gain

Response Times

As with Experiment 1, responses times under 100 ms and over 650 ms were discarded. These represented a small proportion of RTs (anticipatory M = .019, SD = .021, delayed M = .007, SD = .006). Single-target RTs were calculated using the method suggested by Miller and Lopes (1988); 2 participants exhibited a location preference and 13 exhibited no location preference. RTs were then subjected to a 2 x 2 within-subjects factorial ANOVA with number of targets (single vs redundant) as one independent variable and familiarity (familiar vs unfamiliar) as the other independent variable. RTs are presented in Figure I. The effect of number of targets was significant, $F(1,14) = 91.51$, $p < .001$, $\eta_p^2 = .867$, such that participants responded more quickly to redundant targets (M = 237 ms) than to single targets (M = 253 ms). The main effect of familiarity and the interaction of familiarity and number of targets were not significant, $p > .705$ for both.

The total number of correct responses to the letter and pattern comparison tests was then centered to obtain the processing speed score, and added as a covariate, as in Experiment 1. There were no significant interactions with processing speed, $p > .860$ for all.

Finally, it is possible that redundancy gain did not differ between familiar and unfamiliar conditions because participants became familiar with the Katakana monographs over the course of the experiment. To test that possibility, RTs were split between the first third, second third, and final third of the experiment, and analyzed with a 2 (familiarity) x 2 (number of targets) x 3 (time) within-subjects factorial ANOVA. The effect of time was not significant, $F(2,28) = 1.48$, $p = .246$, $\eta_p^2 = .10$, and none of the interactions with time were significant, $p > .324$ for all. Thus, increasing familiarity of Katakana characters was not responsible for the similarity in redundancy gain between familiar and unfamiliar stimuli.

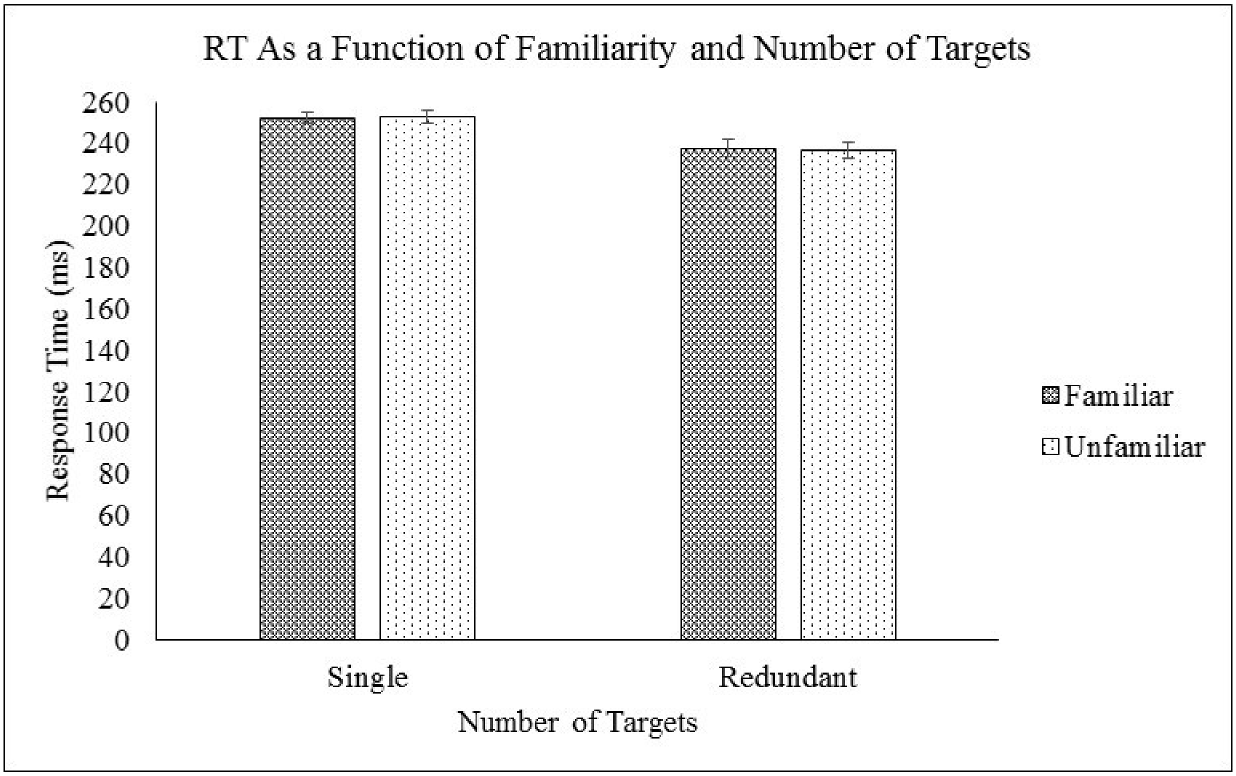


Figure 7. RT as a Function of Familiarity and Number of Targets in Experiment 2

Error bars represent 2 within-subjects standard errors above and below the mean. Redundant-target RTs were faster than single-target RTs, regardless of familiarity.

Accuracy

Mean accuracy was high overall, *M* = 97.50%, *SD* = 3.43%. Accuracy was also subjected to a 2 (number of targets) x 2 (familiarity) within-subjects factorial ANOVA. There were no significant effects, $p > .197$ for all. When processing speed was added as a covariate, there were no significant interactions with processing speed, $p > .162$ for all. Thus, the redundancy gain evident in RTs was not accompanied by any redundancy loss in accuracy.

Coactivation Analyses

Race Model Inequality

Redundant-target response time distributions were compared to the race model bound separately for familiar and unfamiliar targets, using the same method outlined in Experiment 1. The cumulative distribution functions for familiar targets are displayed in Figure D, and the cumulative distribution functions for unfamiliar targets are displayed in Figure E. Comparisons were made of redundant signals RTs and race model bound RTs associated with a 10%, 15%, 20% and 25% probability of having responded. For both familiar and unfamiliar targets, the redundant signals RT was slower than the race model bound for all four quantiles; therefore, no statistical tests were performed. The race model inequality provided no evidence of coactivation for Experiment 2, regardless of familiarity.

Interaction Contrasts

Redundant-target response times were analyzed using the same interaction contrast method as Experiment 1, except that the stimulus quality factor was contrast rather than saturation level. Thus, the mean interaction contrast for Experiment 2 was calculated as

$$IC = RT(g,g) - RT(g,b) - RT(b,g) + RT(b,b), \tag{4}$$

where g indicates gray (low-contrast) targets and b indicates black (high-contrast) targets.

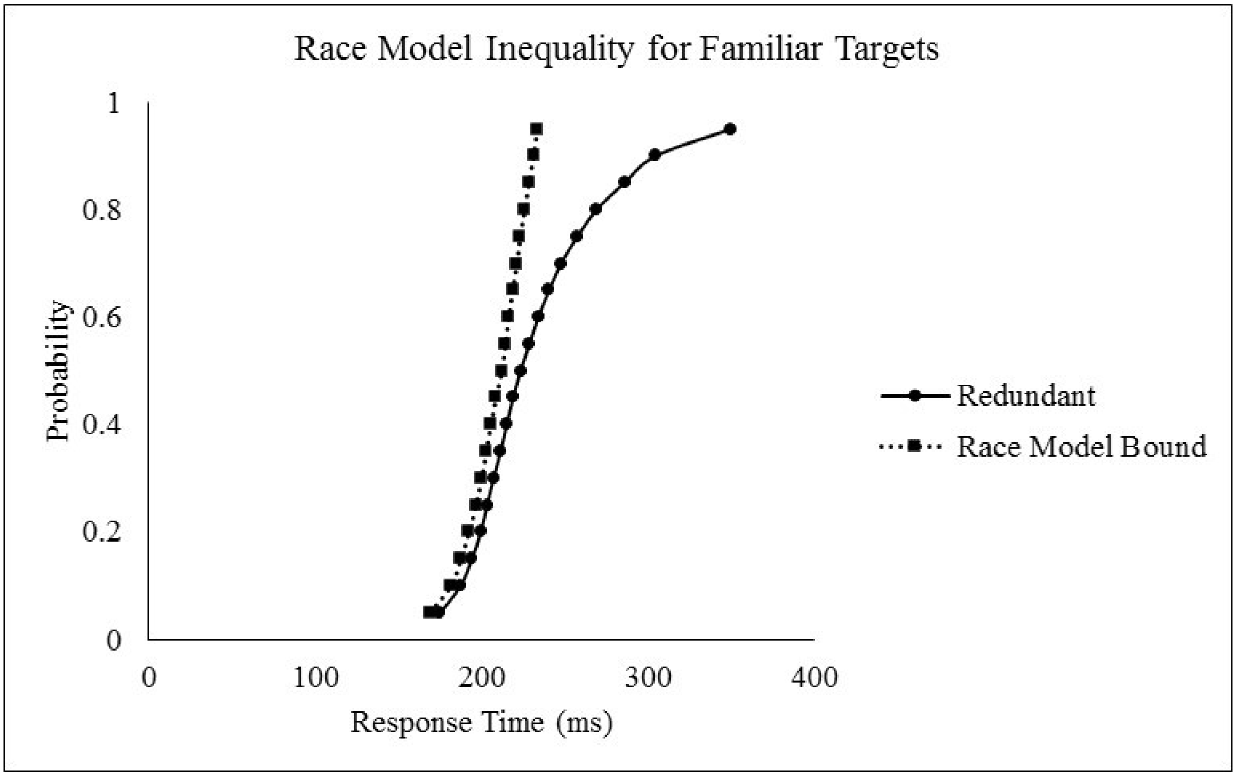


Figure 8. Race Model Inequality for Familiar Trials in Experiment 2

Cumulative distribution functions for familiar redundant-target trials and the corresponding race model bound in Experiment 2. The redundant-target distribution is nowhere to the left of the race model bound, indicating no violations of the race model inequality.

For familiar targets, 13 participants conformed to a serial minimum-time processing architecture, with *IC* not significantly different from 0, $p > .254$ for all, and $IC(t)$ containing no significantly positive or negative portions, $p > .189$ for all. The other participants did not conform to any known processing architecture, with *IC* not significantly different from 0, $p > .093$ for both, a positive portion in $IC(t)$, $D > 0.57$, $p < .048$ for both, and no negative portion of $IC(t)$, $D < 0.22$, $p > .644$ for both.

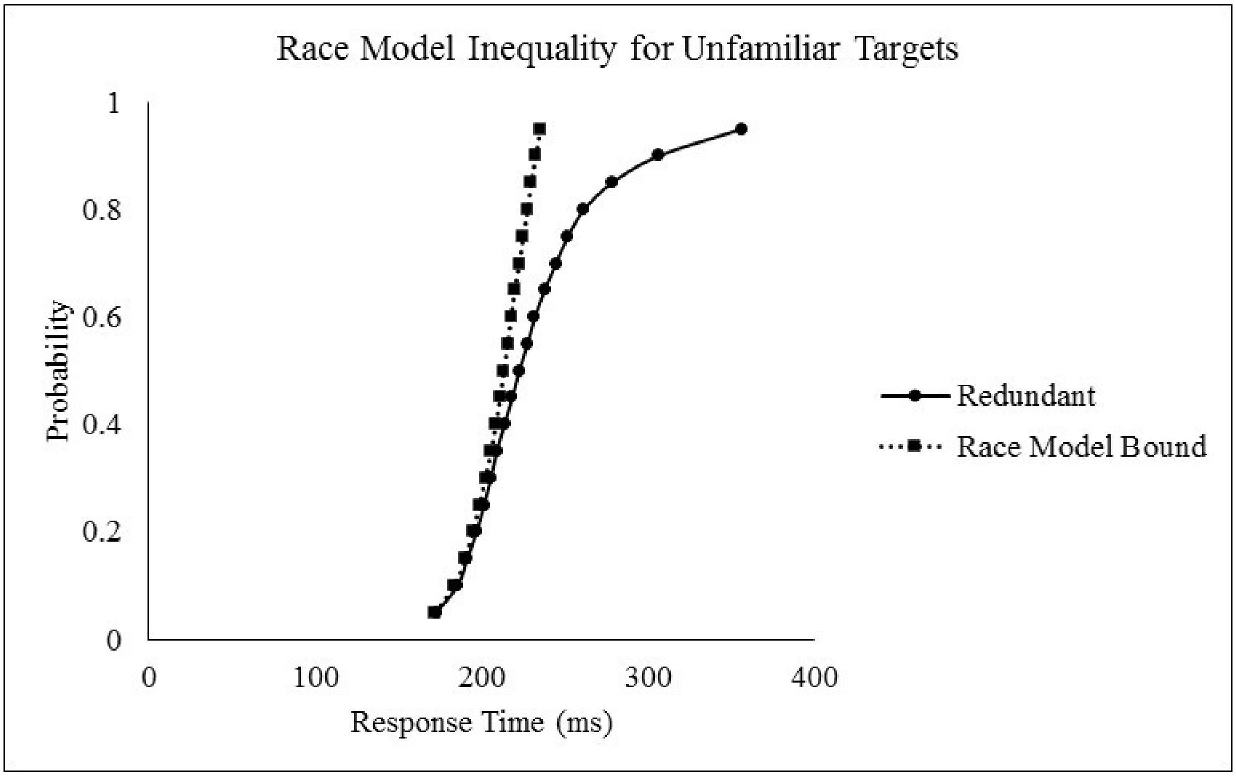


Figure 9. Race Model Inequality for Unfamiliar Trials in Experiment 2

Cumulative distribution functions for unfamiliar redundant-target trials and the corresponding race model bound in Experiment 2. The redundant-target distribution is nowhere to the left of the race model bound, indicating no violations of the race model inequality.

For unfamiliar targets, 13 participants also conformed to a serial minimum-time processing architecture, with *IC* not significantly different from 0, $p > .134$ for all, and $IC(t)$ containing no positive or negative portions, $D < 0.54$, $p > .068$ for all. One participant conformed to a race model, with $IC = 49.63$, $p = .049$, a significantly positive portion of $IC(t)$, $D = 0.59$, $p = .046$, and no significantly negative portion of $IC(t)$, $D = 0.06$, $p = .970$. Finally, one participant did not conform to any known processing architecture, with $IC = 12.39$, $p = .409$, a significantly positive portion of $IC(t)$, $D = 0.55$, $p = .049$, and no significantly negative portion of

IC(*t*), $D = 0.10$, $p = .905$. Overall, the bulk of the evidence was in favor of serial minimum-time processing.

Discussion

Experiment 2 was conducted to test the possibility that familiarity of categorically similar items enables or enhances redundancy gain. The results indicated that familiarity is not necessary for redundancy gain when targets are non-identical and unexpected, and that familiarity does not enhance redundancy gain compared to trials with unfamiliar stimuli. Thus, the hypotheses for Experiment 2 were not supported. This is inconsistent with evidence suggesting coactivation-related redundancy gain for familiar faces (Mohr, Landgrebe, & Schweinberger, 2002; Schweinberger et al., 2003), or for words but not pseudowords (Mohr et al., 1994, 1996, 2007; Zaidel & Rayman, 1994). One possibility is that the failure to find an effect of familiarity here is due to the choice of stimuli. Although participants reported that they were not familiar with Japanese alphabetical characters, they may have enough casual exposure to Katakana monographs through normal interactions with media to have some familiarity with their appearance, even if they were unable to assign any specific linguistic meaning to any of the characters. Alternatively, the fact that all of the stimuli belonged to the category of alphabetical characters may have led participants to develop broad feature expectations, such as expectations for black lines and 90° angles. Another possibility, as previously mentioned, is that overlapping transcortical cell assemblies interfered with each other as much as they enhanced signal strength.

However, as in Experiment 1, most participants seemed to be engaged in serial rather than parallel processing, which makes it unlikely that overlapping transcortical cell assemblies occurred, or that prepotentiation of likely features would have a chance to benefit redundant-target responses. Instead, it appears that, regardless of familiarity, most participants chose to select one of two targets for processing. This result negates the possibility from Experiment 1 that participants chose to conduct serial processing only with stimuli that are both unfamiliar and unexpected. Rather, other task parameters may lead participants to use serial processing. Given that similar simple RT tasks, involving similar visual angles and stimulus durations, have shown consistent evidence of parallel processing (e.g., Savazzi & Marzi, 2004, 2008), it seems unlikely that the duration or location of the stimuli forced participants to attend to a single stimulus location. Another possibility, which Experiments 3 can address, is that participants chose serial processing because of the presence in both Experiments 1 and Experiments 2, of unfamiliar stimuli that were not strongly prepotentiated. Experiments 3 addresses this possibility because it included trials in which the upcoming targets were previewed, giving participants the opportunity to develop expectations about what they would see in some of the trials. If Experiment 3 also elicited serial minimum-time processing, then some other task factor must affect whether participants use serial or parallel processing.

CHAPTER FOUR: EXPERIMENT 3

Experiments 1 and 2 each examined a condition of the three-condition hypothesis, identicalness and familiarity. Both experiments showed that familiarity and identicalness are neither necessary for redundancy gain, nor sufficient to induce parallel race or coactive processing. Experiment 3 examined the third hypothesized condition for redundancy gain, prepotentiation. The purpose of Experiment 3 was to determine whether or not prepotentiation can induce a redundant signals effect in the absence of familiarity or visual identicalness. Toward that end, Experiment 3 employed the same fractal stimuli as Experiment 1 to minimize familiarity. Each trial began with a preview screen that either showed a preview of the targets, or only showed asterisks in the target locations. As with Experiment 2, all redundant images were non-identical to minimize visual identicalness.

Method

Participants

Sixteen undergraduates (10 female, mean age = 18.44 years) from the University of Central Florida participated for partial course credit. All participants had normal or corrected-to-normal vision as measured by near and far Snellen charts and Ishihara color plates. One participant had an extremely high proportion of anticipatory responses (more than 3 standard deviations above the mean) and was excluded from data analysis; 15 participants were included in data analysis.

Apparatus and Stimuli

Experiment 3 employed the same computer, eye tracking system, and game controller as the previous two experiments. Stimuli were the same fractal images employed in Experiment 1, placed on a white background, 6° to the left and right of the vertical meridian and 3° above the horizontal meridian. All redundant stimuli were non-identical. As in Experiment 1, fractals were presented either in original format, or desaturated by 200 points in Irfanview. No fractal was used in more than one trial. After the experiment, participants completed the letter and pattern comparison tests described in Experiment 1.

Participants also completed a version of the flanker task (Eriksen & Eriksen 1974), in which participants must respond to either a square or a diamond presented in one of a set of circles, while ignoring a large square or diamond off to the side of the circles. Participants responded on a keyboard by pressing the “Q” key for a square and the “P” key for a diamond. The large stimulus was sometimes the same as the target stimulus (congruent condition; e.g., a large square off to the side and a small square in one of the circles) and sometimes the opposite (incongruent condition; e.g., a large diamond off to the side and a small square in one of the circles). The main score in a flanker task is the difference between incongruent and congruent RTs, with smaller differences indicating better performance, i.e., a smaller cost associated with incongruency between the target stimulus and distractor stimulus. The Flanker task is employed to test executive function, and was included in Experiments 3 and 4 to account for the possibility that people with high executive function scores might be better than others at taking advantage of target previews to enhance performance.

Design

Design of Trials

There were a total of 540 experimental trials, 160 each of left visual field targets, right visual field targets, and redundant targets, plus 60 catch trials in which no targets were present. Half of all trials began with a target preview, while the other half began with a location-only preview screen. The stimuli adhered to a 3 (presentation type, single left vs single right vs redundant) x 2 (preview condition, preview vs no preview) within-subjects factorial design. Data analysis did not include all levels of presentation type, as explained in the results section.

Design of Stimuli within Trials

As in the previous experiments, each location also followed a 2 (presence; present vs absent) x 2 (format; original vs desaturated) factorial design. Thus, Experiment 3 employed the double factorial design.

Procedure

The procedure was similar to Experiment 2, with the exception that each trial began with a 200-ms target preview screen. Each preview screen contained a red fixation cross at the center of the display to differentiate it from the actual target display. In the preview condition, the screen contained two fractals, one in each possible target location. For redundant target trials, preview fractals were identical to the target fractals. For single-target trials, the target display contained only one of the two previewed fractals, but it was always identical to the previewed fractal in the corresponding target location. This prevented participants from receiving foreknowledge about the number of targets that would occur in the target display.

In the no-preview condition, the same preview screen was presented at the beginning of each trial, but each possible target location contained a black asterisk instead of a fractal. Thus, no-preview trials were the same design and duration as preview trials.

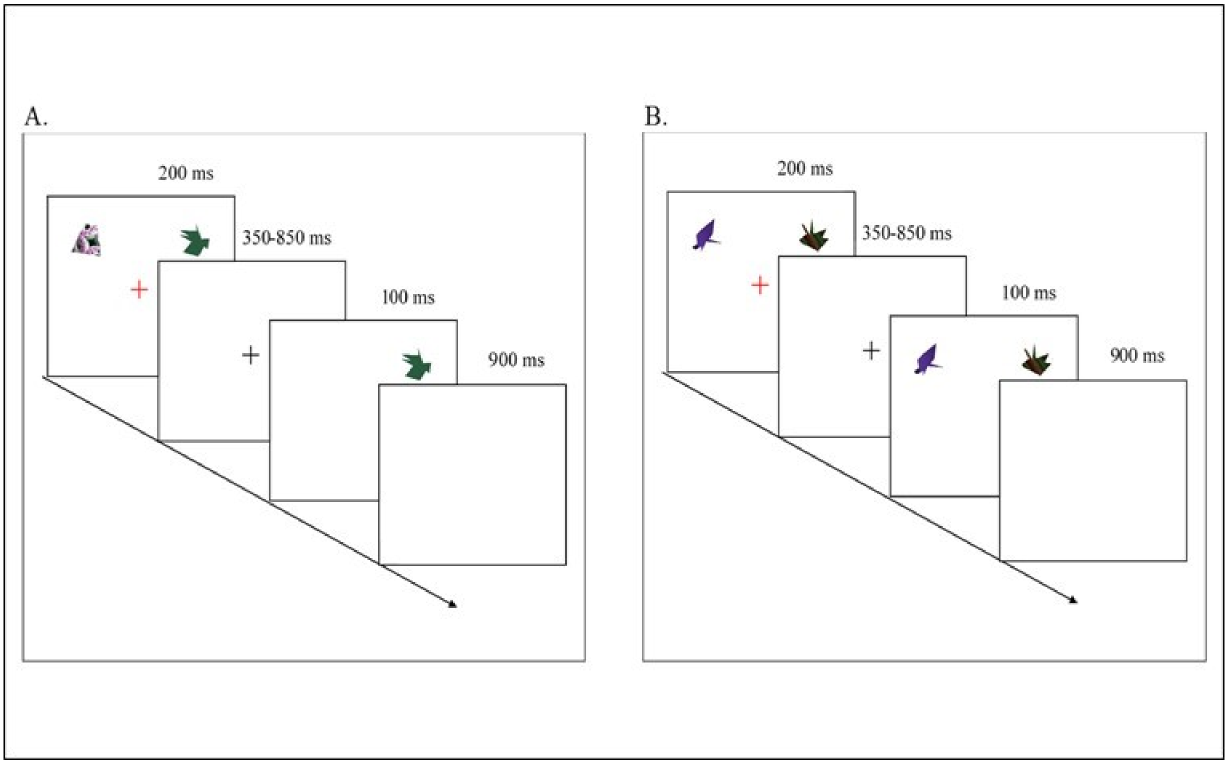


Figure 10. Sample preview trials from Experiment 3.

Trials began with a 200 ms preview screen, followed by a variable-duration fixation cross, followed by the target display and a blank screen that lasted until a response was made. A) Single right target. B) Redundant targets. Stimuli in either location (left or right) could be in original or desaturated format.

The procedure for each trial was as follows. Each trial began with drift correction, followed immediately by the 200-ms preview screen. The preview screen was replaced by a black fixation cross with a duration randomly varying between 350 and 850 ms. The fixation cross was then replaced by a 100-ms target display, which was then replaced by a blank screen that lasted 900 ms or until response. Feedback was presented in the same manner as Experiments 1 and 2. Sample preview trials are presented in Figure 3, and sample no-preview trials are presented in Figure 4.

After the experiment, participants completed the letter and pattern comparison tests and then the flanker task.

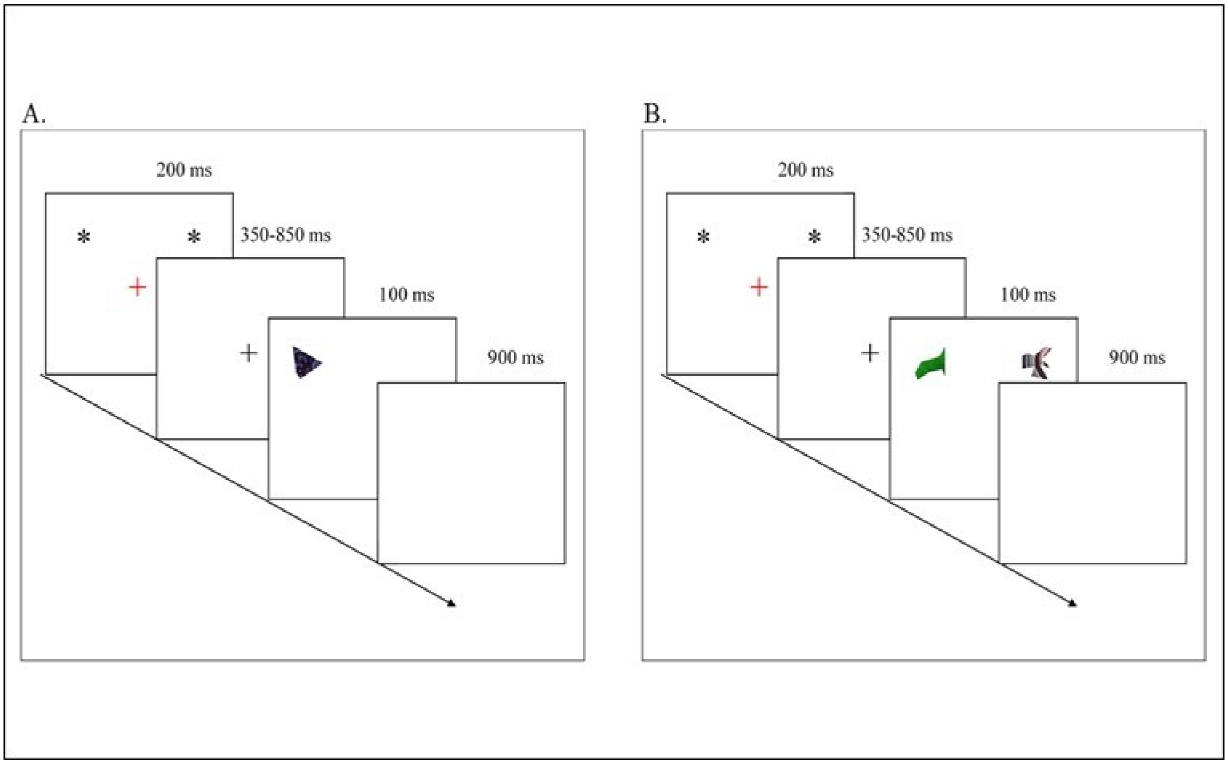


Figure 11. Sample no-preview trials from Experiment 3.

Trials began with a 200 ms preview screen containing asterisks in both target locations, followed by a variable-duration fixation cross, followed by the target display and a blank screen that lasted until a response was made. A) Single left target. B) Redundant targets. Stimuli in either location (left or right) could be in original or desaturated format.

Results

Data analysis was based on response times for accurate target-present responses, and on accuracy for target-present trials. Mean catch accuracy was 56.89%, *SD* = 18.95%.

Redundancy Gain

Response Times

Response times under 100 ms (*M* = 3.47% of responses, *SD* = 2.87%) and over 650 ms (*M* = 1.36% of responses, *SD* = 1.58%) were discarded, and single-target RTs were calculated using the method suggested by Miller and Lopes (1988); 4 participants exhibited a preference for one location over the other, and 11 participants exhibited no preference. Mean RTs were then analyzed with a 2 x 2 within-subjects factorial ANOVA, with number of targets (single vs redundant) as one independent variable and preview condition (preview vs no-preview) as the other independent variable. Mean RTs are displayed in Figure J. The main effect of number of targets was significant, $F(1,14) = 11.19$, $p = .005$, $\eta_p^2 = .44$, such that participants responded more quickly to redundant-target trials (*M* = 236 ms) than to single-target trials (*M* = 245 ms). Thus, redundancy gain occurred in Experiment 3. The main effect of preview condition was also significant, $F(1,14) = 9.82$, $p = .007$, $\eta_p^2 = .41$, such that participants responded significantly more quickly to targets that occurred after a preview (*M* = 235 ms) than to targets that occurred after no preview (*M* = 246 ms). However, the interaction of number of targets and preview condition was not significant, $F(1,14) < 0.01$, $p = .974$, $\eta_p^2 < .01$, such that the presence or absence of a target preview did not affect redundancy gain.

Centered processing speed scores were calculated as in Experiment 1. Flanker scores were also calculated by subtracting the mean RT for congruent trials from the mean RT for incongruent trials; and then centered by subtracting the mean score across all participants from each participant's score. Centered processing speed and flanker scores were then included as covariates in a 2 (number of targets) x 2 (preview condition) within-subjects factorial ANCOVA. There were no significant interactions between the within-subjects variables and either covariate, $p > .250$ for all. One participant had an extreme score on the flanker test ($Z = 3.06$, $p = .002$). When the ANCOVA was conducted without that participant, all interactions with the covariates remained non-significant, $p > .347$ for all.

Accuracy

Accuracy in Experiment 3 was somewhat lower than the first two experiments, M = 92.90%, SD = 5.50%. Accuracy was also analyzed with a 2 (number of targets) x 2 (preview condition) within-subjects factorial ANOVA. The main effect of preview condition was significant, $F(1,14) = 6.49$, $p = .023$, $\eta_p^2 = .32$, such that participants were more accurate in the no-preview condition ($M = .94$) than in the preview condition ($M = .92$). The main effect of number of targets, and the interaction between number of targets and preview condition, were not significant, $p > .521$ for both.

Centered processing speed and flanker scores were then included as covariates in a 2 (number of targets) x 2 (preview condition) within-subjects factorial ANCOVA. There was a significant interaction between preview condition and flanker scores, $F(1,12) = 9.13$, $p = .011$, $\eta_p^2 = .43$. No other interaction with covariates was significant, although the interaction between preview condition and processing speed approached significance, $F(1,12) = 4.42$, $p = .057$, η_p^2 =

.27, all other *p*s > .177. Thus, redundancy gain and the relationship between redundancy gain and target previews were not affected by a participant's processing speed or executive function.

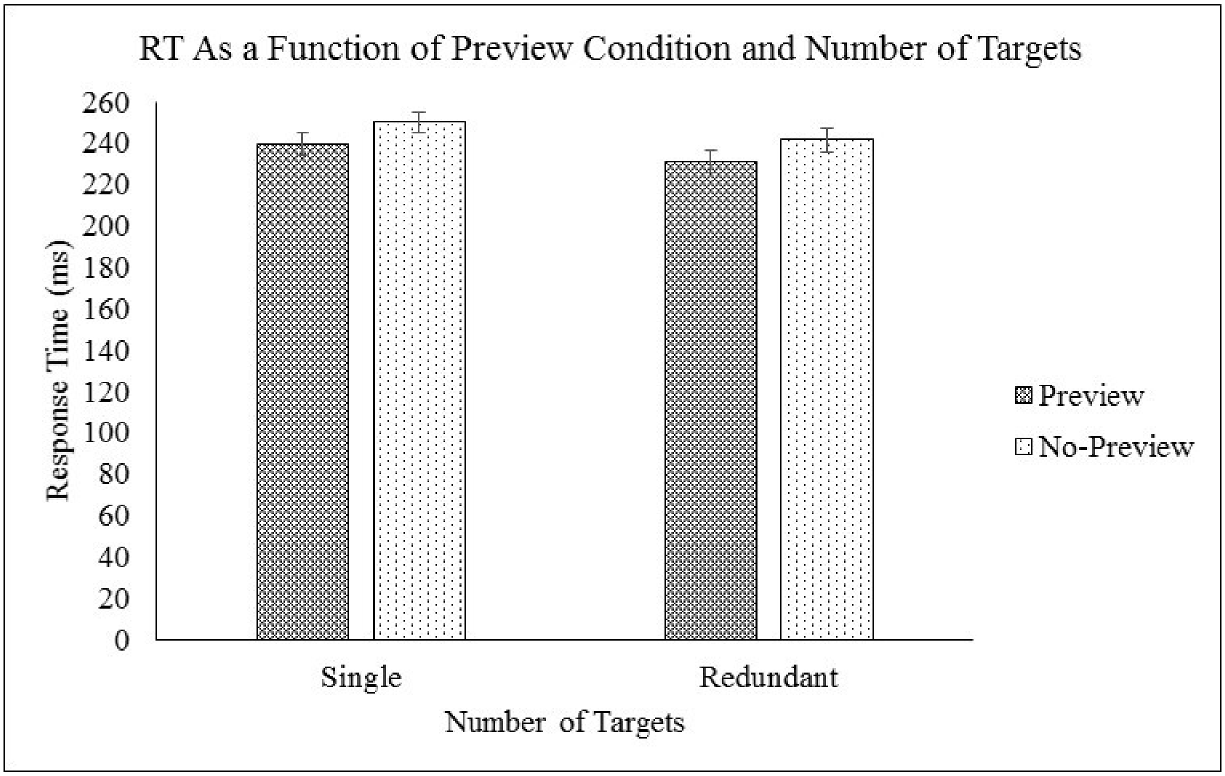


Figure 12. RT as a Function of Preview Condition and Number of Targets for Experiment 3

Error bars represent 2 within-subjects standard errors above and below the mean. Responses to redundant targets were slightly faster than to single targets, regardless of preview condition; and responses to previewed targets were slightly faster than responses to non-previewed targets.

To further explore the relationship between flanker scores and preview conditions, accuracy on preview trials was subtracted from accuracy on no-preview trials to form a difference score. This difference score was then regressed onto centered flanker scores, using linear regression in SPSS 23 for Windows with default settings. The regression model was significant, $R^2 = .34$, $R^2_{adj} = .29$, $F(1,13) = 6.72$, $\beta_{\text{flanker}} = .58$, $p = .022$. Thus, higher flanker scores (worse executive function performance) were associated with larger differences in accuracy between preview and no-preview conditions.

However, when the participant with an outlying flanker score was removed from the ANCOVA, the interaction between preview condition and flanker scores was no longer significant, $F(1,12) = 3.99$, $p = .071$, $\eta_p^2 = .266$; and the regression of accuracy differences onto centered flanker scores was no longer significant, $R^2 = .096$, $R_{adj}^2 = .020$, $F(1,12) = 1.27$, $\beta_{\text{flanker}} = .31$, $p = .282$.

Coactivation Analyses

Race Model Inequality

The cumulative distribution functions for redundant-target trials and the race model bound were calculated separately for preview and no-preview trials, and the RTs for the 10%, 15%, 20%, and 25% quantiles compared for each condition. The redundant-target RT was slower than the race model bound for all quantiles for both conditions, so no statistical tests were conducted. The redundant-target and race model bound distributions for previewed targets are displayed in Figure F, and the distributions for no-preview targets are displayed in Figure G.

Interaction Contrasts

Interaction contrasts were calculated separately for preview and no-preview trials, using the same method discussed in Experiment 1. For preview trials, 14 participants adhered to a serial minimum-time processing architecture, with *IC* not significantly different from 0, $p > .197$ for all, and no significantly positive or negative portions of $IC(t)$, $D < .58$, $p > .076$ for all. One participant did not adhere to any known processing architecture, with $IC = -72.96$, $p = .080$, a significantly negative portion of *IC*(*t*), *D* = 0.57, *p* = .044, and no significantly positive portion of *IC*(*t*), *D* = 0.11, *p* = .898.

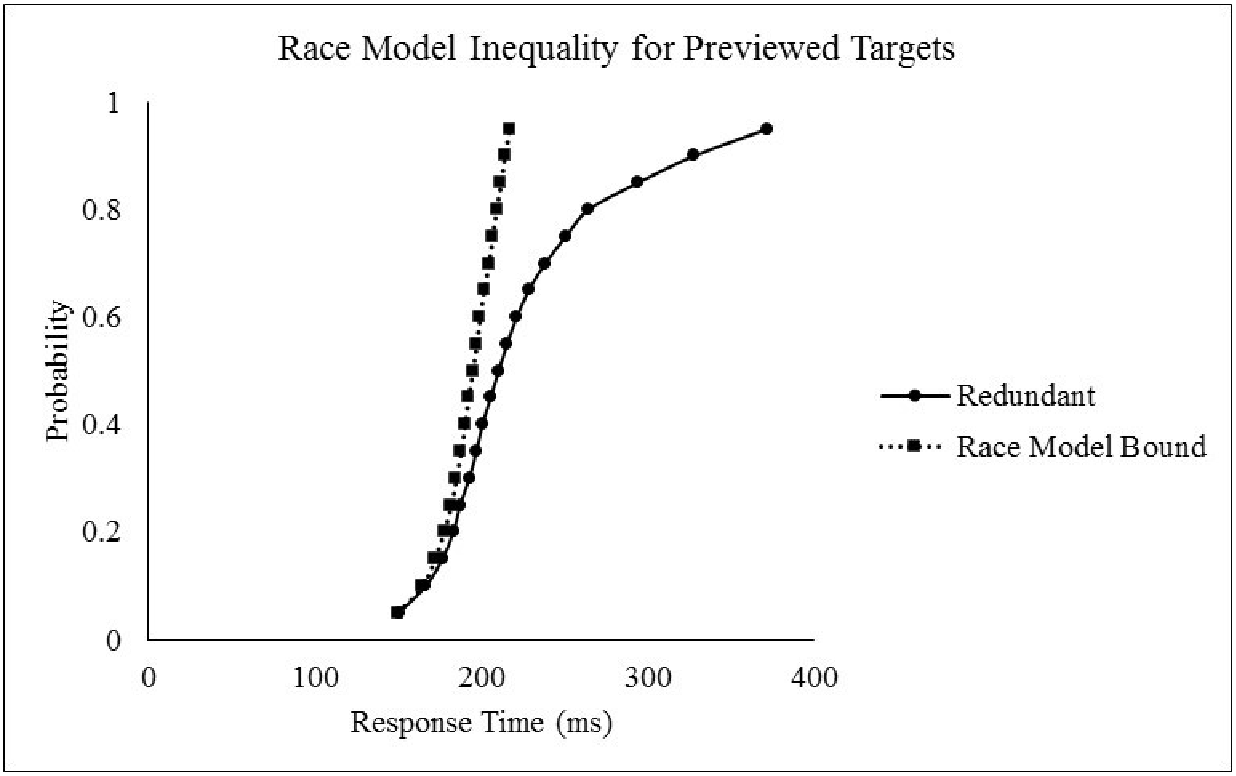


Figure 13. Race Model Inequality for Previewed Trials in Experiment 3

Cumulative distribution functions for previewed redundant-target trials and the corresponding race model bound in Experiment 3. The redundant-target distribution is nowhere to the left of the race model bound, indicating no violations of the race model inequality.

For no-preview trials, all participants adhered to a serial minimum-time processing architecture, with no *IC* significantly differing from 0, *p* > .257 for all, and no significantly positive or negative portions of *IC*(*t*), *D* < 0.49, *p* > .114 for all. Thus, the bulk of the evidence was in favor of serial minimum-time processing.

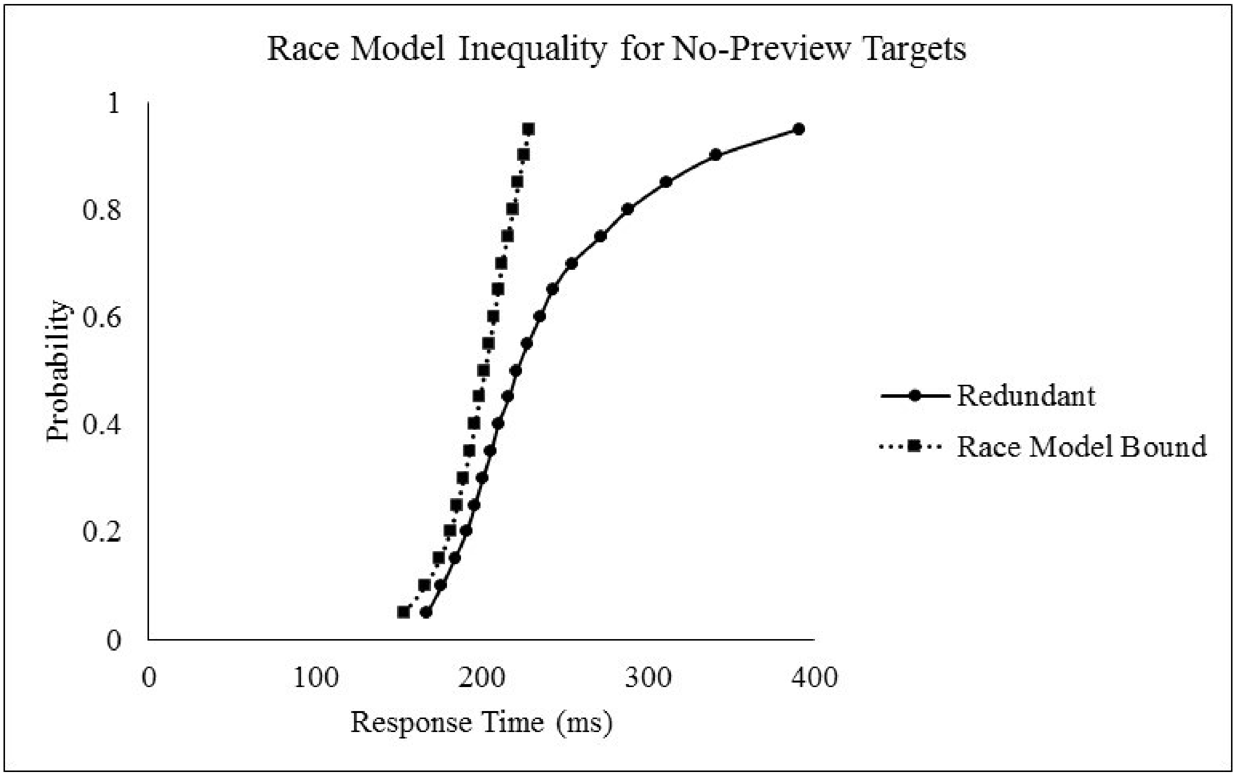


Figure 14. Race Model Inequality for No-Preview Trials in Experiment 3

Cumulative distribution functions for no-preview redundant-target trials and the corresponding race model bound in Experiment 3. The redundant-target distribution is nowhere to the left of the race model bound, indicating no violations of the race model inequality.

Discussion

Experiment 3 was designed to test whether or not prepotentiation, in the form of a target preview, can enhance redundancy gain. The results suggest that prepotentiation has no effect on redundancy gain, with participants responding more quickly to redundant targets than to single targets, regardless of the presence or absence of a target preview. Additionally, the advantage of redundant-target trials was not attributable to either a race between two stimuli, or coactive processing of two stimuli. Instead, as in the first two experiments, participants appeared to be engaged in serial processing, with redundancy gain attributable to the fact that redundant-target trials always contained a target in the location that participants chose to attend first. The combined results from Experiments 1 through 3 indicate that, even though most previous research suggests parallel processing of redundant targets in simple redundant-target tasks, some redundant-target tasks are accomplished by ignoring the extra target and treating redundant-target trials as a single-target trial. When the processing strategy is to ignore one target and process the other target, participants do not have an opportunity to capitalize on multiple copies of simple features, on overlapping transcortical cell assemblies, or on prior expectations about target features to enhance redundant-target processing; thus, none of the three hypothesized conditions would have an effect on redundancy gain.

One result from Experiment 3 seems strange; participants were less likely to respond to the presence of a target after a preview than after no preview, and this was especially true for people with relatively poor executive function as measured by a flanker task. However, this result appears to be an artifact of the way the experiment was programmed. Each preview screen was followed by a fixation cross and then by the target display. If participants pressed the right trigger during the fixation cross, the program did not record a response, instead giving participants the opportunity to make a correct response after the targets were displayed. Participants, however, may not have responded again after they saw the targets. After a preview, they may have found it difficult to inhibit their response long enough to wait for targets to appear; and this may have been especially true of participants with relatively poor executive control.

However, no interaction was found between preview condition and number of targets, suggesting that this difficulty with preview conditions did not differentially affect single- vs redundant-target trials. Thus, the hypotheses for Experiment 3 were not confirmed, and the results from Experiments 1 through 3 appear to disconfirm the three-conditions hypothesis. Nonetheless, it is possible that combinations of three conditions might interact with each other to affect redundancy gain, a possibility that was explored in Experiment 4.

CHAPTER FIVE: EXPERIMENT 4

Experiments 1-3 each examine whether or not one of the three hypothesized conditions for the redundant signals effect (identicalness, familiarity, and prepotentiation) actually does contribute to the redundant signals effect. The three experiments demonstrated no effect of including or excluding any of the three conditions. As a final exploration of the three-conditions hypothesis, Experiment 4 was conducted to determine if combinations of the three conditions can have an effect on redundancy gain. If no combination of identicalness, familiarity, and prepotentiation has an effect on redundancy gain, then it suggests that, at least for some tasks, none of the three conditions affect the mechanisms through which redundancy gain occurs. By contrast, if some combinations, or a combination of all three, have an effect on redundancy gain, then it may suggest that the hypothesized conditions do not operate in isolation, but can operate in conjunction with each other to enhance processing of multiple signals.

Such a result could be somewhat consistent with the previous literature on redundancy gain. As mentioned in Chapter 1, many of the previous studies that demonstrated redundancy gain have employed stimuli that were familiar to participants and highly repetitive (i.e., a conjunction of familiarity and prepotentiation). Additionally, many of the studies that employed unfamiliar stimuli, such as Murray et al. (2001) or Tamietto et al. (2005), employed a combination of small stimulus pools (possibly leading to prepotentiation through frequent repetition) and identicalness. Finally, some of the simplest stimuli in redundancy gain experiments were both highly repetitive and likely familiar shapes to participants (e.g., simple squares and circles). It is possible, then, that including at least two of the three hypothesized conditions leads to enhancements in redundancy gain over the basic serial minimum-time effect found in the current Experiments 1 through 3. Given the prevalence of coactivation in previous studies of redundancy gain, it is also possible that the presence of multiple conditions could encourage parallel coactive processing as well.

Method

Participants

Seventeen undergraduates (11 female, mean age = 20.65) from the University of Central Florida participated for partial course credit. All participants had normal or corrected-to-normal vision as determined by near and far Snellen charts and Ishihara color plates. Additionally, all participants were unfamiliar with Japanese alphabetical characters, as indicated by self-report. One participant was excluded from data analysis because the experiment program crashed before the end of the experiment; another participant was excluded due to an extremely high proportion of anticipatory responses. Fifteen participants were included in data analysis.

Apparatus and Stimuli

Experiment 4 employed the English alphabet and Katakana monographs from Experiment 2. All characters were presented in black on a white background, in the same configuration as Experiment 2.

Design

There were a total of 540 experimental trials, 160 each of left visual field targets, right visual field targets, redundant identical trials, and redundant non-identical trials, plus 60 catch trials containing no target. The number of trials was split evenly between familiar and unfamiliar targets, and split evenly between preview and no-preview trials. Stimulus presentation adhered to a 4 (presentation type, single left vs single right vs redundant identical vs redundant non-identical) x 2 (familiarity, English vs Katakana) x 2 (preview condition, preview vs no-preview) within-subjects factorial design. As with previous experiments, not all levels of presentation type were employed in data analysis, as single-target RTs were estimated in the same manner as previous experiments.

Procedure

The procedure was similar to Experiment 3, except that participants completed a practice block of 36 trials, followed by 6 blocks of 90 trials each. Preview trials contained the exact characters that were in the trial display, whereas no-preview trials contained an asterisk in each target location. Two sample trials are presented in Figure 9. As an analogue to the identical and non-identical redundant target previews, half of the single-target previews contained identical characters, and half contained non-identical characters. This prevented participants from anticipating the number of targets based on the identicalness of preview items. Participants completed the letter and pattern comparison tests and the flanker task after the experiment.

Results

Data analysis was again based on RTs for accurate target-present responses, and on accuracy for target-present responses. Mean accuracy on the catch trials was 71.67%, *SD* = 8.36%.

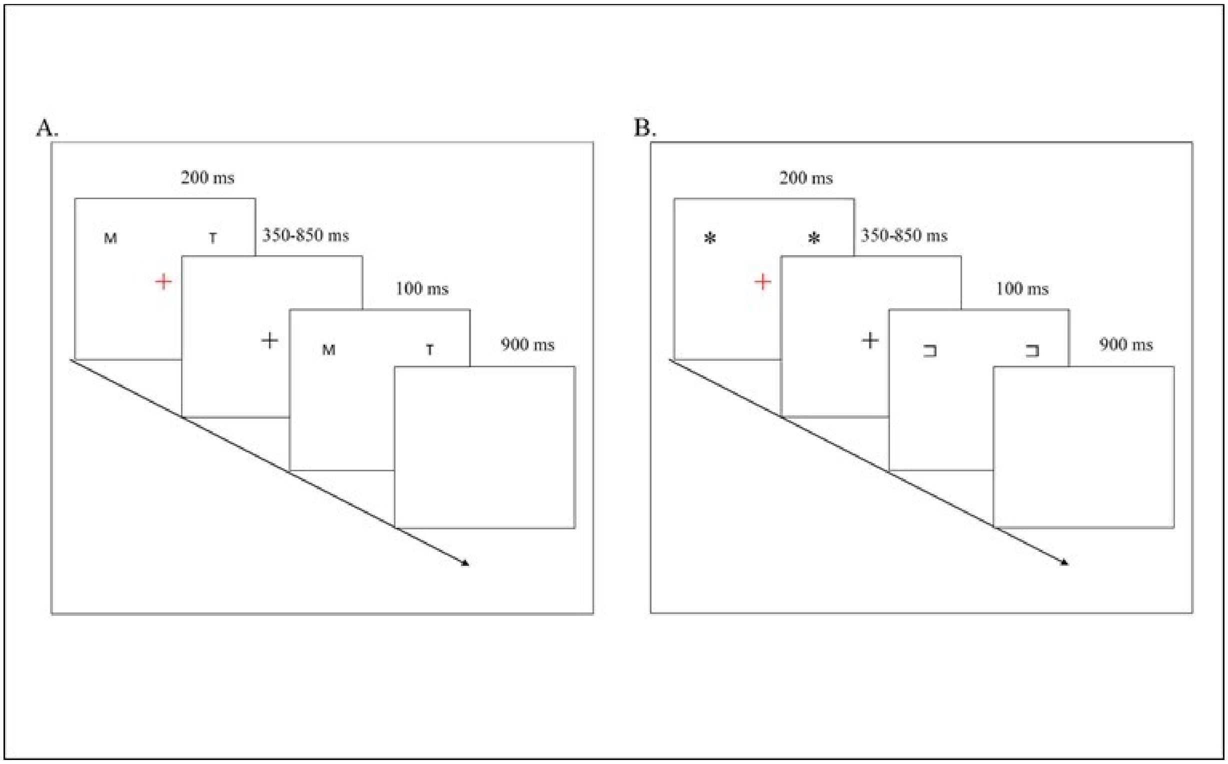


Figure 15. Sample Stimuli for Experiment 4

Trials began with a 200 ms preview screen containing asterisks in both target locations, followed by a variable-duration fixation cross, followed by the target display and a blank screen that lasted 900 ms or until a response. A) Preview trial with redundant, familiar, non-identical targets. B) No-preview trial with redundant, unfamiliar, identical targets.

Redundancy Gain

Response Times

Response times under 100 ms (*M* = 2.02% of responses, *SD* = 1.31%) and over 650 ms (*M* = 1.05% of responses, *SD* = 0.97%) were discarded. Single-target RTs were calculated using the method suggested by Miller and Lopes (1988); 6 participants exhibited a preference for one location, while 9 participants exhibited no preference. RTs were then analyzed with a 2 x 2 x 3 within-subjects factorial ANOVA, with familiarity (familiar vs unfamiliar), preview (preview vs no-preview), and presentation type (single vs redundant identical vs redundant non-identical) as the independent variables. Mean RTs are presented in Figure K. Mauchly's test of sphericity indicated a significant violation of the sphericity assumption for presentation type, $\chi^2(2) = 6.09$, $p = .048$; accordingly, the Greenhouse-Geisser correction for degrees of freedom was employed for the main effect of presentation type.

The main effect of presentation type was significant, $F(1.46,20.38) = 22.23$, $p < .001$, $\eta_p^2 = .61$, $M_{\text{single}} = 257$ ms, $M_{\text{identical}} = 244$ ms, $M_{\text{non-identical}} = 242$ ms. Bonferroni-corrected post-hoc tests indicated that participants responded significantly more quickly to both redundant identical and redundant non-identical trials than to single-target trials, $p < .001$ for both. However, the two redundant-target conditions did not significantly differ from each other, $p = .438$. The main effects of familiarity and preview condition were not significant, $p > .535$ for both.

The two-way interaction of familiarity x preview condition was significant, $F(1,14) = 9.34$, $p = .009$, $\eta_p^2 = .40$. Bonferroni-corrected post-hoc tests of the simple main effect of preview condition indicated that participants responded significantly more slowly to preview trials than to no-preview trials when the targets were familiar, $p = .020$, but not when the targets were unfamiliar, $p = .197$. Additionally, Bonferroni-corrected post-hoc tests of the simple main effect of familiarity indicated that participants responded more slowly to familiar targets than to unfamiliar targets, but only when they had a preview, $p = .023$, and not when they had no preview, $p = .181$. The other two-way interactions and the three-way interaction of presentation type x familiarity x preview condition were not significant, $p > .072$ for all.

Centered processing speed and flanker scores were then added as covariates to conduct a 2 (familiarity) x 2 (preview condition) x 2 (presentation type) within-subjects factorial ANCOVA. The 2-way interaction of familiarity x flanker score was significant, $F(1,12) = 7.72$,

p = .017, η_p^2 = .39. To further explore the interaction, RTs for familiar trials were subtracted from RTs for unfamiliar trials, and the difference score was regressed onto flanker scores using linear regression. The resulting model was not significant, R^2 = .25, R_{adj}^2 = .19, F(1,13) = 4.36, p = .057. However, the trend was similar to the trend in accuracy for Experiment 3, with higher flanker scores (i.e., worse executive control) associated with responding more quickly to familiar targets than to unfamiliar targets and lower flanker scores associated with responding more quickly to unfamiliar than to familiar targets, constant B = -.89, flanker B = .04, flanker β = .50.

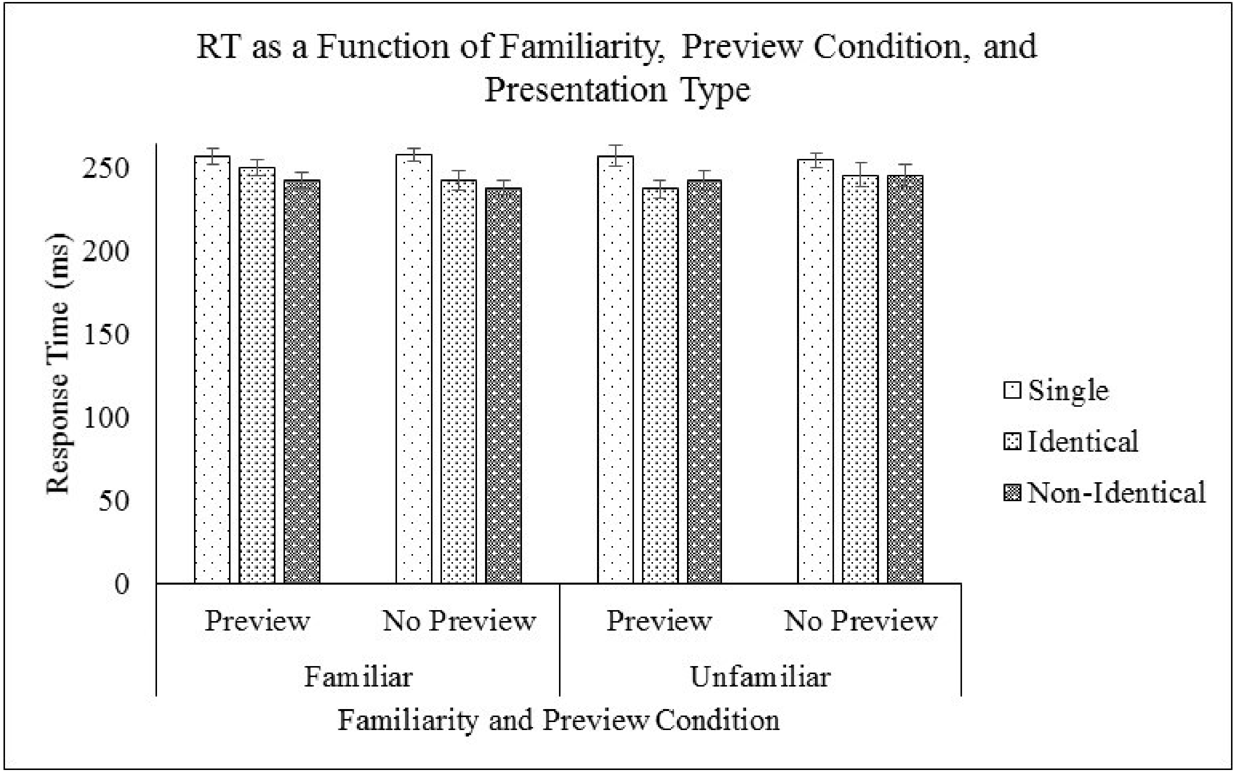


Figure 16. RT as a function of the Three Hypothesized Conditions in Experiment 4

RT as a function of familiarity, preview condition, and presentation type in Experiment 4. Error bars represent 2 within-subjects standard errors above and below the mean. Response times to single-target trials were slightly slower than response times to either type of redundant-target trial.

The 2-way interaction of presentation type x perceptual speed was also significant, $F(2,24) = 3.83$, $p = .036$, $\eta_p^2 = .24$. To further explore the effect, RT for each presentation type was regressed onto perceptual speed using linear regression. None of the models were significant, $R^2 < .183$, $R_{adj}^2 < .119$, $p > .070$ for all. Regression coefficients were negative for all models, indicating a trend towards faster responses with higher perceptual speed, $\beta_{\text{single}} = -.43$, $\beta_{\text{identical}} = -.40$, $\beta_{\text{non-identical}} = -.264$.

Finally, the 3-way interaction of familiarity x presentation type x flanker score was significant, $F(2,24) = 3.55$, $p = .044$, $\eta_p^2 = .23$. To further explore the interaction, response times for redundant identical trials and for redundant non-identical trials were subtracted from response times for single-target trials, and the difference scores were regressed onto flanker scores separately for familiar and unfamiliar targets, using linear regression. None of the four models was significant, $R^2 < .209$, $R_{adj}^2 < .148$, $p > .088$ for all.

Additionally, response times to familiar RTs were subtracted from response times to unfamiliar RTs separately for each level of presentation type, and the difference scores were regressed onto flanker scores using linear regression. The regression model was significant for redundant identical trials, $R^2 = .39$, $R_{adj}^2 = .34$, $F(1,13) = 8.23$, $p = .013$. The regression coefficient was positive, $\beta = .62$, indicating that higher (worse) flanker scores were associated with a larger difference between familiar and unfamiliar targets. The regression model was not significant for single-target trials, $R^2 = .13$, $R_{adj}^2 = .06$, $F(1,13) = 1.88$, $p = .193$, $\beta = .36$; or for redundant non-identical trials, $R^2 = .08$, $R_{adj}^2 = .01$, $F(1,13) = 1.15$, $p = .303$, $\beta = -.29$. Thus, people with relatively poor executive function scores appeared to suffer a reduction in performance for familiar targets, but particularly when there were two identical targets in the display. No other interactions with the covariates were significant, $p > .111$ for all.

Finally, to test the possibility that participants became familiar with Katakana monographs over the course of the experiment, RTs were collapsed across preview condition and analyzed with a 2 (familiarity) x 3 (presentation type) x 3 (time; first third vs second third vs final third) within-subjects factorial ANOVA. The main effect of time was significant, $F(2,28) = 4.53$, $p = .020$, $\eta_p^2 = .24$. Bonferroni-corrected post-hoc tests indicated no significant differences between times, although there was a trend towards participants responding more slowly during the first third of the experiment than during the second third, $p = .036$, or the final third, $p = .033$. The 2-way interaction of presentation type x time was also significant, $F(4,56) = 2.58$, $p = .047$, $\eta_p^2 = .16$. To examine the possibility that redundancy gain was affected by time on task, Bonferroni-corrected post-hoc tests were conducted on the simple main effect of trial type. The tests indicated that single-target trials were slower than both redundant identical and redundant non-identical trials, but only for the first two-thirds of the experiment, $p < .005$ for all; the difference between presentation types was not significant for the final third, $p > .095$ for all. The other interactions with time were not significant, $p > .503$ for both, indicating no difference in redundancy gain between familiar and unfamiliar trials as a function of time.

Accuracy

Accuracy was again fairly high, $M = 96.70\%$, $SD = 3.65\%$. Accuracy was analyzed with a 2 (familiarity) x 2 (preview condition) x 3 (presentation type) within-subjects factorial ANOVA. The main effect of trial type was significant, $F(2,28) = 5.37$, $p = .011$, $\eta_p^2 = .28$. Bonferroni-corrected post-hoc tests indicated that accuracy for redundant identical trials was significantly lower than accuracy for redundant non-identical trials, $p = .014$; single-target trials did not significantly differ from either type of redundant-target trial, $p > .033$ for both. The main effects of familiarity and preview condition were not significant, $p > .421$ for both.

The 2-way interaction of preview condition x presentation type was also significant, $F(2,28) = 6.58$, $p = .005$, $\eta_p^2 = .32$. Bonferroni-corrected post-hoc tests of the simple main effect of preview condition indicated that accuracy was lower for previewed targets than for no-preview targets in redundant non-identical trials, $p = .010$, but accuracy did not differ between preview and no-preview targets for single or redundant identical trials, $p > .123$ for both. Bonferroni-corrected post-hoc tests of the simple main effect of presentation type indicated no difference between presentation types for preview trials, $p > .500$ for all; but, for no-preview trials, participants responded less accurately to redundant identical targets than to single or redundant non-identical targets, $p < .006$ for both. Single targets and redundant non-identical targets did not differ from each other, $p = .100$. The other two-way interactions and the three-way interaction of familiarity x preview condition x presentation type were not significant, $p > .139$ for all.

Centered processing speed and flanker scores were then added as covariates to conduct a 2 (familiarity) x 2 (preview condition) x 3 (presentation type) within-subjects factorial ANCOVA. None of the interactions with covariates were significant, although the interaction of presentation type x perceptual speed approached significance, $F(2,24) = 3.37$, $p = .051$, $\eta_p^2 = .22$; $p > .152$ for all others.

Coactivation Analyses

For each combination of identicalness, familiarity, and preview condition, cumulative distribution functions were calculated for redundant-target response times and for the race model bound. The redundant-target distributions were compared to their respective race model bounds at the 10%, 15%, 20% and 25% quantiles. For all but three quantiles, the redundant-target distribution was slower than its race model bound, and no statistical test was performed. For the three quantiles at which the redundant-target distribution was faster than its race model bound (the 10% quantile for no-preview, familiar, non-identical targets; and the 10% and 20% quantile for preview, unfamiliar, non-identical targets), one-way, paired-sample *t*-tests were performed to determine whether or not the difference was statistically significant. None of the *t*-tests were significant, $t(14) < 0.30$ for all, $p > .310$ for all. Thus, consistent with Experiments 1-3, no coactivation was evident in any condition in Experiment 4.

Discussion

Experiment 4 was conducted to test the possibility that the presence of more than one of the three hypothesized conditions (identicalness, familiarity, and prepotentiation) could enhance redundancy gain, possibly by encouraging parallel coactive processing instead of serial minimum-time processing. The results did not support this possibility or any of the original hypotheses for Experiment 4; no combination of the three conditions led to reliably stronger redundancy gain than any other combination, and no coactivation was evident for any combination.

The double factorial paradigm was not employed in Experiment 4, and therefore processing architecture could not be directly tested through survivor interaction contrasts;

however, given that the results of Experiments 1 through 3 overwhelmingly support serial minimum-time processing, and that no set of conditions in Experiment 4 led to stronger redundancy gain than any other set, it seems probable that participants in Experiment 4 also employed a serial minimum-time processing strategy.

These results disconfirm the current version of three-conditions hypothesis. It is apparent not only that redundancy gain does not disappear in the absence of identicalness, familiarity, or prepotentiation, but that redundancy gain also is not necessarily enhanced by any combination of identicalness, familiarity, and prepotentiation. It appears instead that the nature of the task can encourage a serial processing strategy that leads to redundancy gain without taking advantage of any signal enhancement due to target redundancy.

CHAPTER SIX: GENERAL DISCUSSION

The redundant signals effect, or redundancy gain, has been demonstrated for a diverse range of target types and tasks. Even focusing only on situations in which redundancy is manifested as two separate visual targets, there seem to be a multitude of situations in which extra signals can enhance the efficiency with which a task is completed. However, redundant visual targets do not always enhance efficiency; sometimes, the effect is weakened, eliminated, or even reversed. Moreover, the effect is often attributable to coactive processing in which information from both targets is combined, but is sometimes attributable entirely to statistical facilitation. Given the diversity of tasks that show a redundant signals effect, the presence of occasional failures in the effect, and the satisfaction of contradictory predictions from different mathematical models of processing architectures, it seems unlikely that it is a unitary effect based on a single underlying mechanism.

Because of this diversity in the redundant signals effect, the current study was designed to test a three-conditions hypothesis, which states that different tasks may have one or more of three conditions that make redundancy helpful. The three-conditions hypothesis was intended to be a unifying framework that could explain the previous disparate results on redundancy gain. The first experiment tested the possibility that visual identicalness can allow for coactive processing; i.e., multiple copies of the same features might cause neural summation in visual areas associated with processing those features. The second experiment, based on Hebb's (1949) transcortical cell assembly theory, tested whether or not familiarity can contribute to coactive redundancy gain; i.e., two similar, familiar items might lead to neural summation in overlapping transcortical cell assemblies. The third experiment, based on the guided search model (Cave &

Wolfe, 1990; Wolfe, 1994, 2007; Wolfe, Cave, & Franzel, 1989) and the dimension-weighting account inspired by guided search (Found & Müller, 1996; Müller et al., 1995), tested the possibility that prepotentiation of relevant features provides the opportunity for parallel processing of two different targets, leading to a statistical facilitation-based redundancy gain. Finally, the fourth experiment tested whether or the three hypothesized causes might have multiplicative effects of redundancy gain.

However, the three-conditions hypothesis was not confirmed in the current study. Participants responded more quickly to redundant targets than to single targets, but the effect did not depend on identicalness, familiarity, prepotentiation, or any combination of the three conditions. This result is somewhat surprising, given that previous research has suggested an important role for familiarity (e.g., Mohr et al., 1994, 1996, 2002, 2007; Schweinberger et al. 2003; Zaidel & Rayman, 1994) and identicalness (e.g., Baird & Burton, 2008; Banich & Karol, 1992; Grice & Reed, 1992; Mordkoff & Miller, 1993; Schwarz & Ischebeck, 1994); and that the disadvantage for unfamiliar and non-identical items sometimes does not occur in studies with highly repetitive targets (e.g., Tamietto et al., 2005, 2007) or when targets are primed (Hasbrooke & Chiarello, 1998), indicating a role for prepotentiation as well. What occurred in the current study to enable a redundant signals effect even for unfamiliar, non-previewed, and non-identical targets?

The answer may lie in the mean interaction contrasts and survivor interaction contrasts from the first three experiments. In each condition, all or most of the participants showed mean interaction contrasts and survivor interaction contrasts that did not significantly differ from 0, indicating additivity in both. This is consistent with the predictions of a serial minimum-time processing architecture (Townsend & Nozawa, 1995), in which processing of targets occurs one at a time, and the target that is first processed elicits a response; in other words, only a single target is processed, regardless of the number of targets present in the display. Given serial minimum-time target processing, none of the three conditions in the three-condition hypothesis have an opportunity to affect redundancy gain. If a second target is not being processed at all, then signal enhancement cannot occur due to multiple copies of identical features (identicalness) or due to overlapping transcortical cell assemblies of multiple targets (familiarity), and parallel selection of relevant features in multiple previewed targets cannot occur either (prepotentiation).

How did redundancy gain occur at all, if only one target was processed in each trial? Given that only two locations were possible for targets, it may be that participants attended to one of the two locations at the beginning of every trial. In redundant-target trials, the attended location would always contain a target, which the participant could then select for processing. By contrast, in single-target trials, participants would sometimes be attending to the wrong location, and need to switch attention to the correct location. If, as in Chiu and Yantis (2009), the switch cost is about 26 ms, then needing to switch attention half of the time would lead to an average increase in RT of about 13 ms, close to the 9- to 15-ms increase evident in the four current experiments. This form of redundancy gain would not be an advantage of having multiple targets per se, but only an advantage of always having a target in the first-attended location.

The question remains why participants would need or choose to attend to only a single location instead of attending to both locations in parallel. A serial minimum-time model is inconsistent with previous work showing coactive or parallel race processing of two redundant targets (e.g., Barr & Corballis, 2003; Corballis, Hamm, Barnett, & Corballis, 2002; Colonius & Townsend, 1997; Corballis, 2002; Grice & Reed, 1992; Grice et al., 1984; Miller, 1982, 1986, 2004; Mordkoff & Yantis, 1993; Savazzi & Marzi, 2002, 2004, 2008; Schwarz & Ischebeck, 1994; Townsend & Nozawa, 1995; Townsend & Wenger, 2004). Some of the previous studies have had task parameters similar to the parameters in the current study. For example, some of the studies that have found evidence in favor of race or coactivation models have employed simple RT tasks with stimuli of similar sizes and durations to the current study, that occurred at distances from the fovea similar to the 6° distance employed in the current study, and that were intermixed with catch trials containing no targets at all (e.g., Barr & Corballis, 2003; Corballis, 2002; Corballis et al., 2002; Savazzi & Marzi, 2002, 2004, 2008). Accordingly, basic mechanical considerations of visual angles and target durations seem unlikely to be the cause of a serial processing strategy; and considerations about the type of decision required in the task (here, a simple decision about whether or not any item appeared in the display) also seem to be an unlikely cause. The presence of occasional catch trials also did not prevent parallel processing in previous studies. In addition, complexity of the stimuli was not likely the cause of serial processing, because parallel coactive processing has been found in other research employing letters (e.g., Grice & Reed, 1992) and in studies employing highly complex stimuli such as faces (e.g., Tamietto et al., 2005, 2007). Finally, the need to withhold a response during the fixation cross period probably was not the cause either, considering that previous studies such as those by Savazzi and Marzi (2002,2004,2008) employed variable intervals between the onset of a trial and the onset of targets within a trial. In short, the target locations, sizes, onset variability, durations, and types of decisions employed in the current study are similar to those in previous studies that have elicited parallel processing strategies.

In spite of overwhelming support for parallel processing in typical redundancy gain tasks, two variations on the typical task have been shown to elicit serial minimum-time processing in at least some participants. In one study, one of two target locations was cued before the targets were displayed. For single-target trials, the validity of the cues was manipulated, either cueing the true location of the target 50% of the time, or cueing the location of the target 100% of the time. A typical, parallel processing architecture was found for the 50% validity condition, but all participants employed serial minimum-time processing for the 100% validity condition, a strategy that makes sense if a selectively attended location is certain to have the target and one that suggests the ability to choose a useful processing strategy in a top-down manner (Yang, Little, & Hsu, 2014). However, 100% cue validity did not exist in the current four studies; participants did not know which of two locations would contain the target, and they demonstrated a cost associated with selectively attending to the wrong location.

In a later study, Chang, Little, and Yang (2016) examined the effect of target location probability, i.e., the probability that a single target would occur to the left or to the right, on processing architecture. They found that some participants switched to serial minimum-time processing when the target was more likely to occur in one location than in the other, and all participants switched to serial minimum-time processing when they were explicitly informed that the target was more likely to occur in one location, again demonstrating top-down control of the type of processing architecture used to complete a redundant signals task. However, their results cannot explain the current study any better than Yang et al. (2014); single targets in all four experiments were equally likely to appear to the left or right of center.

Thus, it appears that participants generally choose parallel minimum-time (race model) or parallel coactive processing architectures for redundant signals tasks, but are capable of strategically choosing a serial minimum-time processing architecture if they know which location is likely to contain a target. Nevertheless, the question as to why participants in the current study chose to engage in serial minimum-time processing remains unanswered, given that they had no informative location cues and no difference in probability between single-target locations. One possibility is that the three-conditions hypothesis is partially correct in that familiarity, identicalness, or prepotentiation is necessary for parallel processing to either enhance signal strength (coactivation) or occur without interference between two targets (statistical facilitation). Because unfamiliar, non-identical, or no-preview trials were intermixed with the familiar, identical, or preview trials, participants may have chosen to adopt the processing strategy that was optimal for unfamiliar, non-identical, and non-previewed targets.

This suggests a future direction for redundancy gain research. If participants are able, as Chang et al. (2016) and Yang et al. (2014) suggested, to flexibly choose strategies to complete a block of trials, then they should be able to choose parallel processing for blocks of trials in which parallel processing is useful. Future research should therefore include experiments similar to the current set, but with conditions blocked rather than randomly intermixed. If participants use a parallel processing strategy for blocks in which targets are familiar, previewed, or identical; but a serial processing strategy for other blocks, it would provide support for a modified three-conditions hypothesis. According to the modified version, redundancy gain without familiarity, prepotentiation, or identicalness is merely an effect of spatial certainty; the first-attended location always contains a target in redundant-target trials. In such conditions, parallel processing of targets is either not possible, or would lead to signal interference rather than signal enhancement. However, in the presence of familiarity, prepotentiation, or identicalness, participants are able to take advantage of parallel processing to enhance redundancy gain beyond the effect of spatial certainty.

Future research also needs to examine the reason that a spatial certainty-based redundancy gain occurred in the current study, when it has not always occurred in other studies, e.g., studies of unfamiliar face processing (Mohr et al., 2002; Schweinberger et al., 2003) and studies of plausible psuedowords (Mohr et al., 1994, 1996, 2007; Zaidel & Rayman, 1994). Perhaps these studies that failed to find any form of redundancy somehow encouraged participants to engage in parallel processing of targets even though that was not the optimal strategy for dealing with unfamiliar stimuli. The nature of the stimuli may have affected participants' ability to ignore one of the targets, given that distractor faces are harder to ignore than other types of distractor objects (Jenkins, Lavie, & Driver, 2003) and that distractor words are processed all the way to the point of semantic recognition before being ignored (Yee, 1990). In the cases that failed to show any redundancy gain, even a small one due to serial object selection, it is possible that the additional target interfered with processing of the target chosen for selection, due to involuntary parallel processing. Future research might examine different types of stimuli in redundant signals tasks to determine if some of them necessarily elicit parallel processing.

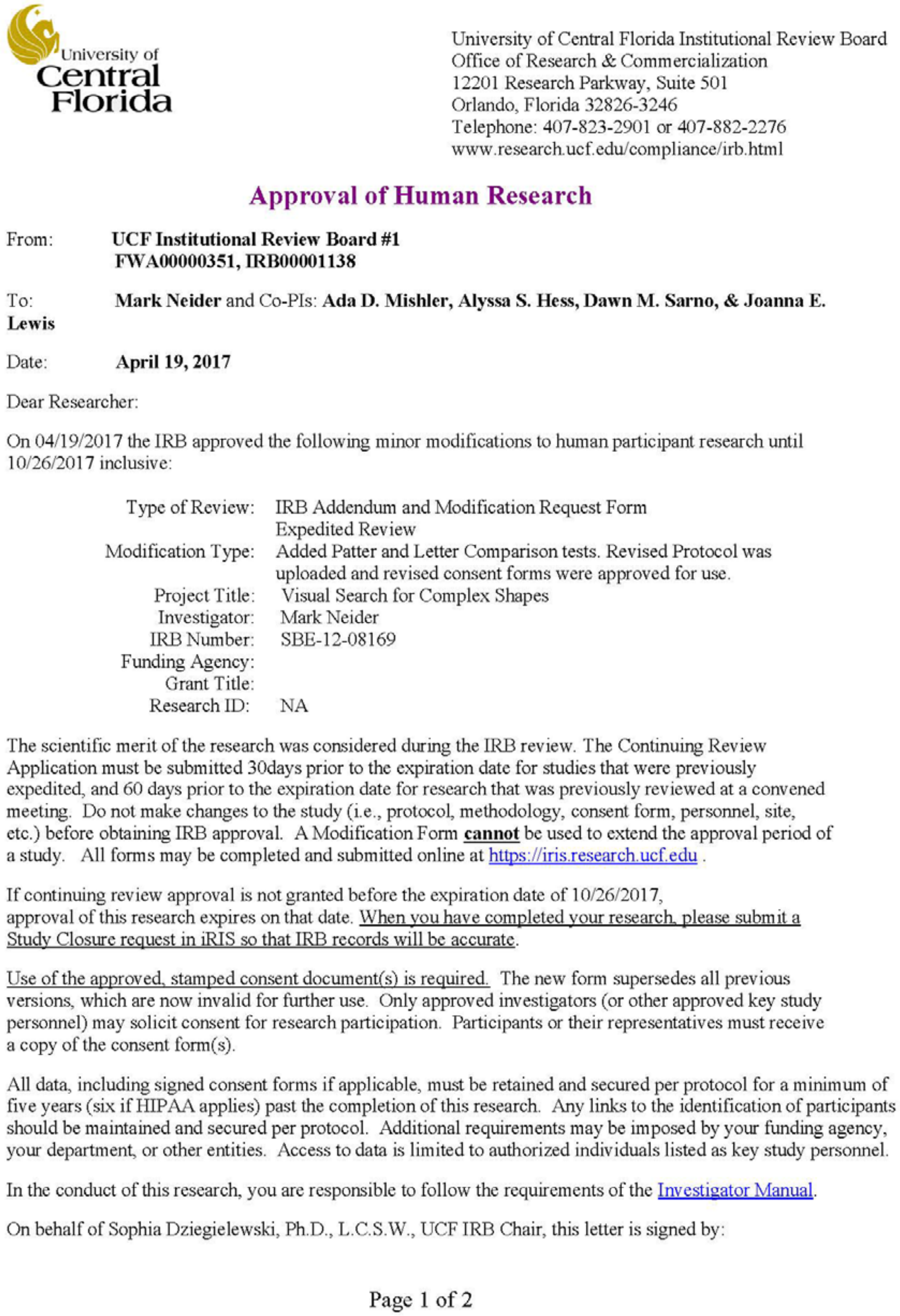
Another possible explanation for serial minimum-time processing in the current study is that the use of eye tracking changed participants' behavior. Previous studies requested that participants focus on the center of a display at the start of each trial (e.g., Barr & Corballis, 2003; Baird & Burton, 2008; Corballis, 1998; Savazzi & Marzi, 2004, 2008), but did not use eye tracking to ensure that central focus occurred. It is possible that participants did not make a strong effort to maintain central fixation in previous studies, and that the requirement to make such an effort was treated as a secondary task in the current experiment. If so, then attention was divided between two tasks, which could have made it more difficult to process multiple targets simultaneously. Future research may be needed to explore the utility of redundancy in multi-tasking contexts.

Future research should also examine the role of covert attentional shifts in redundancy gain. In the current experiments, it is apparent that participants were shifting attention to one of two target locations, although the majority of participants were not shifting attention to the same location on every trial, given that the majority of participants did not show a preference for one location in response times. These participants showed evidence of serial processing, but it is possible that covert attentional shifts have occurred even in research that showed evidence of parallel processing. Such shifts could affect the strength of redundancy gain, for example, by weakening but not eliminating the contribution of the unattended target to processing. Designs that encourage or discourage attentional shifts through rewards could be employed to explore their effects on redundancy gain.

On a final note, it was expected that some weak form of prepotentiation might lead to redundancy gain for unfamiliar and non-previewed stimuli, simply due to repetition of letters in Experiments 2 and 4, and possibly repetition of general features of the fractal stimuli (e.g., straight lines) in Experiments 1 and 3. In Experiment 2, letters would be repeated on average approximately once every 40 trials; in Experiment 5, the frequency of repetition would be a little higher, approximately once every 30 trials, due to two-target previews even for single-target trials. If participants could be expected to use the typical parallel processing architectures for prepotentiated target features, as they have in the past (e.g., Krummenacher et al., 2001, 2002), then prepotentiation of all stimuli should lead participants to routinely use parallel processing instead of serial processing. That participants did not employ parallel processing therefore may indicate that previews or primes must be more recent than 30 trials back in order to cause detectable prepotentiation of target processing. Future research could examine the frequency of target repetition necessary to affect redundancy gain. Familiarity also apparently needs to be stronger than that caused by a few repetitions within a single experiment, as the relationship between familiar and unfamiliar stimuli did not change over time in Experiments 2 and 4. This result is to be expected if familiarity-based redundancy gain is due to overlapping transcortical cell assemblies, given that such assemblies take time to develop.

The current study was designed to test the three-conditions hypothesis, that identicalness of target features, familiarity of similar targets, or prepotentiation of target-relevant feature processing is necessary to elicit redundancy gain in visual redundant signals tasks employing two separate visual targets. The results appear to disconfirm the hypothesis; redundancy gain is possible regardless of familiarity, identicalness, or target previews. However, participants unexpectedly engaged in serial minimum-time processing rather than parallel processing of the targets, a strategy in which none of the three hypothesized conditions would be useful. This suggests that a benefit for redundant targets can be based solely on spatial certainty when a serial processing architecture is used. Further work is necessary to determine whether or not identicalness, familiarity, or prepotentiation is necessary to elicit stronger redundancy gain through parallel processing architectures. Regardless, visual target redundancy appears to speed up processing even in the absence of any of the conditions named in the three-conditions hypothesis. It is thus apparent that, as long as participants are able to ignore the second target, redundancy will be useful for speeded processing of an enormous variety of stimuli.

APPENDIX: APPROVAL LETTER



University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Mark Neider** and Co-PIs: **Ada D. Mishler, Alyssa S. Hess, Dawn M. Sarno, & Joanna E. Lewis**

Date: **April 19, 2017**

Dear Researcher:

On 04/19/2017 the IRB approved the following minor modifications to human participant research until 10/26/2017 inclusive:

Type of Review:	IRB Addendum and Modification Request Form Expedited Review
Modification Type:	Added Patter and Letter Comparison tests. Revised Protocol was uploaded and revised consent forms were approved for use.
Project Title:	Visual Search for Complex Shapes
Investigator:	Mark Neider
IRB Number:	SBE-12-08169
Funding Agency:	
Grant Title:	
Research ID:	NA

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 10/26/2017, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Kamille Chap

Signature applied by Kamille Chaparro on 04/19/2017 09:00:18 AM EDT

IRB Coordinator

REFERENCES

Abrams, J., Nizam, A., & Carrasco, M. (2012). Isoeccentric locations are not equivalent: The extent of the vertical meridian asymmetry. *Vision Research, 52*, 70-78. doi: 10.1016/j.visres.2011.10.016

Allen, P. A., Madden, D. J., Groth, K. E., & Crozier, L. C. (1992). Impact of age, redundancy, and perceptual noise on visual search. *Journal of Gerontology, 47,* P69-P74. doi: 10.1093/geronj/47.2.P69

Allen, P. A., Weber, T. A., & Madden, D. J. (1994). Adult age differences in attention: Filtering or selection? *Journal of Gerontology: PSYCHOLOGICAL SCIENCES, 49,* P213-P222. doi: 10.1093/geronj/49.5.P213

Baird, L. M., & Burton, A. M. (2008). The bilateral advantage for famous faces: Interhemispheric communication or competition? *Neuropsychologia, 46,* 1581-1587. doi: 10.1016/j.neuropsychologia.2008.01.001

Banich, M. T., & Karol, D. L. (1992). The sum of the parts does not equal the whole: Evidence from bihemispheric processing. *Journal of Experiment Psychology: Human Perception and Performance, 18,* 763-784. doi: 10.1037/0096-1523.18.3.763

Barr, M. S., & Corballis, M. C. (2003). Redundancy gain in the acallosal brain. *Neuropsychology, 17,* 213-220. doi: 10.1037/0894-4105.17.2.213

Bartels, A., & Zeki, S. (2000). The architecture of the colour centre in the human visual brain: New results and a review. *European Journal of Neuroscience, 12,* 172-193. doi: 10.1046/j.1460-9568.2000.00905.x

Biederman, I., & Checkosky, S. F. (1970). Processing redundant information. *Journal of Experimental Psychology, 83,* 486-490. doi: 10.1037/h0028841

Cave, K. R., & Wolfe, J. M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology, 22,* 225-271. doi: 10.1016/0010-0285(90)90017-X

Chang, T. Y., Little, D. R., & Yang, C. T. (2016). Selective attention modulates the effect of target location probability on redundant signal processing. *Attention, Perception, & Psychophysics, 78,* 1603-1624. doi: 10.3758/s13414-016-1127-2

Chiu, Y. C., & Yantis, S. (2009). A domain-independent source of cognitive control for task sets: Shifting spatial attention and switching categorization rules. *Journal of Neuroscience, 29*(12): 3930. doi: 10.1523/JNEUROSCI.5737-08.2009

Colonius, H., & Townsend, J. T. (1997). Activation-state representation of models for the redundant-signals-effect. In A. A. J. Marley (Ed.), *Choice, decision, and measurement* (pp 245- 254). Mahwah, NJ: Lawrence Erlbaum Associates.

Corballis, M. C. (1998). Interhemispheric neural summation in the absence of the corpus callosum. *Brain, 121,* 1795-1807. doi: 10.1093/brain/121.9.1795

Corballis, M. C. (2002). Hemispheric interactions in simple reaction time. *Neuropsychologia, 40,* 423-434. doi: 10.1016/S0028-3932(01)00097-5

Corballis, M. C., Hamm, J. P., Barnett, K. J., & Corballis, P. M. (2002). Paradoxical interhemispheric summation in the split brain. *Journal of Cognitive Neuroscience, 14,* 1151-1157. doi: 10.1162/089892902760807168

Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1991). Selective and divided attention during visual discriminations of shape, color, and speed: Functional anatomy by positron emission tomography. *The Journal of Neuroscience, 11,* 2383-2402.

Cousineau, D. (2005). Confidence intervals in within-subjects designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology, 1,* 42-45.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18,* 193-222. doi: 10.1146/annurev.ne.18.030195.001205

Desimone, R., Schein, S. J., Moran, J., & Ungerleider, L. G. (1985). Contour, color and shape analysis beyond the striate cortex. *Vision Research, 25,* 441-452. doi: 10.1016/0042-6989(85)90069-0

Diederich, A. (1995). Intersensory facilitation of reaction time: Evaluation of counter and diffusion coactivation models. *Journal of Mathematical Psychology, 39,* 197-215. doi: 10.1006/jmps.1995.1020

Diederich, A., & Colonius, H. (1987). Intersensory facilitation in the motor component? *Psychological Research, 49,* 23-29. 10.1007/BF00309199

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review, 87,* 272-300. doi: 10.1037/0033-295X.87.3.272

Egeth, H. E., Folk, C. L., & Mullin, P. A. (1989). Spatial parallelism in the processing of lines, letters, and lexicality. In B. E. Shepp & S. Ballesteros (Eds.), *Object perception: Structure and process* (pp. 19-52). Hillsdale, NJ: Lawrence Erlbaum Associates.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143-149. doi: 10.3758/BF03203267

Eriksen, C. W., & Lapin, J. S. (1965). Internal perceptual system noise and redundancy in simultaneous inputs in form identification. *Psychonomic Science, 2*(12), 35-352. doi: 10.3758/BF03343493

Fannon, S. P., Saron, C. D., & Mangun, G. R. (2008). Baseline shifts do not predict attentional modulation of target processing during feature-based visual attention. *Frontiers in Human Neuroscience, 1*(7): 1-14. doi: 10.3389/neuro.09.007.2007

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175-191. doi: 10.3758/BF03193146

Feintuch, U., & Cohen, A. (2002). Visual attention and coactivation of response decisions for features from different dimensions. *Psychological Science, 13,* 361-369. doi: 10.1111/1467-9280.00465

Fiedler, A., Schröter, H., & Ulrich, R. (2013). Redundancy gain for semantic features. *Psychonomic Bulletin & Review, 20,* 474-480. doi: 10.3758/s13423-012-0362-3

Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 847-858. doi: 10.1037/0096-1523.24.3.847

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control setting. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1030-1044. doi: 10.1037/0096-1523.18.4.1030

Forbach, G. B., Stanners, R. F., & Hochaus, L. (1974). Repetition and practice effects in a lexical decision task. *Memory & Cognition, 2,* 337-339. doi: 10.3758/BF03209005

Forster, B., Cavina-Pratesi, C., Aglioti, S. M., & Berluchhi, G. (2002). Redundant target effect and intersensory facilitation from visual-tactile interactions in simple reaction times. *Experimental Brain Research, 143,* 480-487. doi: 10.1007/s00221-002-1017-9

Found, A., & Müller, H. J. (1996). Searching for unknown feature targets on more than one dimension: Investigating a "dimension-weighting" account. *Perception & Psychophysics, 58,* 88-101. doi: 10.3758/BF03205479

de Gelder, B., Pourtois, G., van Raamsdonk, M., Vroomen, J. & Weiskrantz, L. (2001). Unseen stimuli modulate conscious visual experience: Evidence from interhemispheric summation. *Neuroreport, 12,* 385-391. doi: 10.1097/00001756-200102120-00040

Giesbrecht, B., Woldorff, M. C., Song, A. W., & Mangun, G. R. (2003). Neural mechanisms of top-down control during spatial and feature attention. *NeuroImage, 19,* 496-512. doi: 10.1016/S1053-8119(03)00162-9

Girard, S., Pelland, M., Lepore, F., & Collignon, O. (2013). Impact of the spatial congruence of redundant targets on within-modal and cross-modal integration. *Experimental Brain Research, 224,* 275-285. doi: 10.1007/s00221-012-3308-0

Giray, M., & Ulrich, R. (1993). Motor coactivation revealed by response force in divided and focused attention. *Journal of Experiment Psychology: Human Perception and Performance, 19,* 1278-1291. doi: 10.1037/0096-1523.19.6.1278

Grice, G. R., & Canham, L. (1990). Redundancy phenomena are affected by response requirements. *Perception & Psychophysics, 48,* 209-213. doi: 10.3758/BF03211520

Grice, G. R., Canham, L., & Boroughs, J. M. (1984). Combination rule for redundant information in reaction time tasks with divided attention. *Perception & Psychophysics, 35,* 451-463. doi: 10.3758/BF03203922

Grice, G. R., & Gwynne, J. W. (1987). Dependence of target redundancy effects on noise conditions and number of targets. *Perception & Psychophysics, 42,* 29-36. doi: 10.3758/BF03211511

Grice, G. R., & Reed, J. M. (1992). What makes targets redundant? *Perception & Psychophysics, 51,* 437-442. doi: 10.3758/BF03211639

Hasbrooke, R. E., & Chiarello, C. (1998). Bihemispheric processing of redundant bilateral lexical information. *Neuropsychology, 12,* 78-94. doi: 10.1037/0894-4105.12.1.78

Hebb, D. O. (1949). *The organization of behavior: A neuropsychological theory.* New York, NY: John Wiley & Sons.

Hellige, J. B., & Adamson, M. M. (2007). Hemispheric differences in processing handwritten cursive. *Brain and Language, 102,* 215-227. doi: 10.1016/j.bandl.2006.11.003

Hellige, J. B., Jonsson, J. E., & Michimata, C. (1988). Processing from LVF, RVF, and BILATERAL presentations: Examinations of metacontrol and interhemispheric interaction. *Brain and Cognition, 7,* 39-53. doi: 10.1016/0278-2626(88)90020-6

Hellige, J. B., & Marks, N. L. (2001). Are hemispheric strategy differences independent of the level of performance? *Neuropsychology, 15,* 380-395. doi: 10.1037//0894-4105.15.3.380

Hellige, J. B., & Michimata, C. (1989). Visual laterality for letter comparison: Effects of stimulus factors, response factors, and metacontrol. *Bulletin of the Psychonomic Society, 27,* 441-444. doi: 10.3758/BF03334650

Hellige, J. B., Taylor, A. K., & Eng, T. L. (1989). Interhemispheric interaction when both hemispheres have access to the same stimulus information. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 711-722. doi: 10.1037/0096-1523.15.4.711

Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences, 95,* 781-787. doi: 10.1073/pnas.95.3.781

Holmgren, J. E., Juola, J. F., & Atkinson, R. C. (1974). Response latency in visual search with redundancy in the visual display. *Perception & Psychophysics*, *16,* 123-128. doi: 10.3758/BF03203264

Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience, 3,* 284-291. doi: 10.1038/72999

Houpt, J. T., Blaha, L. M., McIntire, J. P., Havig, P. R., & Townsend, J. T. (2014). Systems factorial technology with R. *Behavioral Research Methods*, *46,* 307-330. doi: 10.3758/s13428-013-0377-3.

Houpt, J. W., & Townsend, J. T. (2010). The statistical properties of the survivor interaction contrast. *Journal of Mathematical Psychology, 54,* 446-453. doi: 10.1016/j.jmp.2010.06.006

Iacoboni, M., Ptito, A., Weekes, N. Y., & Zaidel, E. (2000). Parallel visuomotor processing in the split brain: Cortico-subcortical interactions. *Brain, 123,* 759-769. doi: 10.1093/brain/123.4.759

Iacoboni, M., & Zaidel, E. (2003). Interhemispheric visuo-motor integration in humans: The effect of redundant targets. *European Journal of Neuroscience, 17,* 1981-1986. doi: 10.1046/j.1460-9568.2003.02602.x

Jenkins, R., Lavie, N., & Driver, J. (2003). Ignoring famous faces: Category-specific dilution of distractor interference. *Perception & Psychophysics, 65,* 298-309. doi: 10.3758/BF03194801

Karayanidis, F., Andrews, S., Ward, P. B., & McConaghy, N. (1993). Event-related potentials and repetition priming in young, middle-aged and elderly normal subjects. *Cognitive Brain Research, 1,* 123-134. doi: 10.1016/0926-6410(93)90017-Y

Kiesel, A., Miller, J., & Ulrich, R. (2007). Systematic biases and Type I error accumulation in tests of the race model inequality. *Behavior Research Methods, 39,* 539-551. doi: 10.3758/BF03193024

Krummenacher, J., Müller, H. J., & Heller, D. (2001). Visual search for dimensionally redundant pop-out targets: Evidence for parallel-coactive processing of dimensions. *Perception & Psychophysics, 63,* 901-917. doi: 10.3758/BF03194446

Krummenacher, J., Müller, H. J., & Heller, D. (2002). Visual search for dimensionally redundant pop-out targets: Parallel-coactive processing of dimensions is location specific. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1303-1322. doi: 10.1037//0096-1523.28.6.1303

Livingstone, M. S., & Hubel, D. H. (1987). Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. *The Journal of Neuroscience, 7,* 3416-3468.

Marczak, K. (2016). Mandelbulber [Computer software]. Retrieved from http://www.mandelbulber.com/

Marks, N. L., & Hellige, J. B. (1999). Effects of bilateral stimulation and stimulus redundancy on interhemispheric interaction. *Neuropsychology, 13,* 475-487. doi: 10.1037/0894-4105.13.4.475

Marks, N. L., & Hellige, J. B. (2003). Interhemispheric interaction in bilateral redundancy gain: Effects of stimulus format. *Neuropsychology, 17,* 578-593. doi: 10.1037/0894-4105.17.4.578

Marzi, C. A., Smania, N., Martini, M. C., Gambina, G., Tomelleri, G., Palamara, A., … Prior, M. (1996). Implicit redundant-targets effect in visual extinction. *Neuropsychologia, 34,* 9-22. doi: 10.1016/0028-3932(95)00059-3

Miller, J. (1982). Divided attention: Evidence for coactivation with redundant signals. *Cognitive Psychology, 14,* 247-279. doi: 10.1016/0010-0285(82)90010-X

Miller, J. (1986). Timecourse of coactivation in bimodal divided attention. *Perception & Psychophysics, 40,* 331-343. doi: 10.3758/BF03203025

Miller, J. (2004). Exaggerated redundancy gain in the split brain: A hemispheric coactivation account. *Cognitive Psychology, 49,* 118-154. doi: 10.1016/j.cogpsych.2003.12.003

Miller, J., & Lopes, A. (1988). Testing race models by estimating the smaller of two true mean or true median reaction times: An analysis of estimation bias. *Perception & Psychophysics, 44,* 513-524. doi: 10.3758/BF03207485

Miller, J., & Ulrich, R. (2003). Simple reaction time and statistical facilitation: A parallel grains model. *Cognitive psychology, 46,* 101-151. doi: 10.1016/S0010-0285(02)00517-0

Miniussi, C., Girelli, M., & Marzi, C. A. (1998). Neural site of the redundant target effect: Electrophysiological evidence. *Journal of Cognitive Neuroscience, 10,* 216-230. doi: 10.1162/089892998562663

Mishler, A. D., & Neider, M. B. (in preparation). Redundancy gain for categorical targets depends on display configuration and duration.

Mishler, A. D., & Neider, M. B. (submitted). Noise reduction explains the redundant signals effect for a centrally presented categorization task.

Mohr, B., Endrass, T., Hauk, O., & Pulvermüller, F. (2007). ERP correlates of the bilateral redundancy gain for words. *Neuropsychologia, 45*, 2114-2124. doi: 10.1016/j.neuropsychologia.2007.01.015

Mohr, B., Landgrebe, A., & Schweinberger, S. R. (2002). Interhemispheric cooperation for familiar but not unfamiliar face processing. *Neuropsychologia, 40,* 1841-1848. doi: 10.1016/S0028-3932(02)00040-4

Mohr, B., Pulvermüller, F., Mittelstädt, K., & Rayman, J. (1996). Multiple simultaneous stimulus presentation facilitates lexical processing. *Neuropsychologia, 34*, 1003-1013. doi: 10.1016/0028-3932(96)00006-1

Mohr, B., Pulvermüller, F., & Zaidel, E. (1994). Lexical decision after left, right, and bilateral presentation of function words, content words and non-words: Evidence for interhemispheric interaction. *Neuropsychologia, 32*, 105-124. doi: 10.1016/0028-3932(94)90073-6

de Monasterio, F. M. (1978). Properties of ganglion cells with atypical receptive-field organisation in retina of macaques. *Journal of Neurophysiology, 41,* 1435-1449.

Mordkoff, J. T., & Danek, R. H. (2011). Dividing attention between color and shape revisited: Redundant targets coactivate only when parts of the same perceptual object. *Attention, Perception, & Psychophysics, 73,* 103-112. doi: 10.3758/s13414-010-0025-2

Mordkoff, J. T., & Miller, J. (1993). Redundancy gains and coactivation with two different targets: The problem of target preferences and the effects of display frequency. *Perception & Psychophysics, 53,* 527-535. doi: 10.3758/BF03205201

Mordkoff, J. T., & Yantis, S. (1991). An interactive race model of divided attention. *Journal of Experiment Psychology: Human Perception and Performance, 17,* 520-538. doi: 10.1037/0096-1523.17.2.520

Mordkoff, J. T., & Yantis, S. (1993). Dividing attention between color and shape: Evidence of coactivation. *Perception& Psychophysics, 53,* 357-366. doi: 10.3758/BF03206778

Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorials in Quantitative Methods for Psychology, 4,* 61-64.

Müller, M. M., Andersen, S., Trujillo, N. J., Valdes-Sosa, P., Malinowski, P., & Hillyard, S. A. (2006). Feature-selective attention enhances color signals in early visual areas of the human brain. *Proceedings of the National Academy of Sciences, 103,* 14250-14253. doi: 10.1073/pnas.0606668103

Müller, H. J., Heller, D., & Ziegler, J. (1995). Visual search for singleton feature targets within and across feature dimensions. *Perception & Psychophysics, 57,* 1-17. doi: 10.3758/BF03211845

Mullin, P. A., & Egeth, H. E. (1989). Capacity limitations in visual word processing. *Journal of Experiment Psychology: Human Perception and Performance, 15,* 111-123. doi: 10.1037/0096-1523.15.1.111

Murray, M. M., Foxe, J. F., Higgins, B. A., Javitt, D. C., & Schroeder, C. E. (2001). Visuo-spatial neural response interactions in early cortical processing during a simple reaction time task: A high-density electrical mapping study. *Neuropsychologia, 39,* 828-844. doi: 10.1016/S0028-3932(01)00004-5

Neville, H. J., Mills, D. L., & Lawson, D. S. (1992). Fractionating language: Different neural subsystems with different sensitive periods. *Cerebral Cortex, 2,* 244-258. doi: 10.1093/cercor/2.3.244

Ouimet, C., Jolicœur, P., Miller, J., Ptito, A., Paggi, A., Foschi, N., … Lassonde, M. (2009). Sensory and motor involvement in the enhanced redundant target effect: A study comparing anterior- and totally split-brain individuals. *Neuropsychologia, 47,* 684-692. doi: 10.1016/j.neuropsychologia.2008.11.023

Patel, U. J., & Hellige, J. B. (2007). Benefits of interhemispheric collaboration can be eliminated by mixing stimulus formats that involve different cortical access routes. *Brain and Cognition, 63,* 145-158. doi: 10.1016/j.bandc.2006.10.007

Plat, F. M., Praamstra, P., & Horstink, M. W. I. M. (2000). Redundant-signals effects on reaction time, response force, and movement-related potentials in Parkinson's disease. *Experimental Brain Research, 130,* 533-539. doi: 10.1007/s002219900276

Pulvermüller, F., & Mohr, B. (1996). The concept of transcortical cell assemblies: A key to the understanding of cortical lateralization and interhemispheric interaction. *Neuroscience and Biobehavioral Reviews, 20,* 557-566. doi: 10.1016/0149-7634(95)00068-2

Raab, D. H. (1962). Statistical facilitation of simple reaction times. *Transactions of the New York Academy of Sciences, 24,* 574-590. doi: 10.1111/j.2164-0947.1962.tb01433.x

R Core Team. (2013). R: A language and environment for statistical computing [Computer software]. R Foundation for Statistical Computing, Vienna, Austria.

Reinholz, J., & Pollman, S. (2007). Neural basis of redundancy effects in visual object categorization. *Neuroscience Letters, 412,* 123-128. doi: 10.1016/j.neulet.2006.11.004

Rolls, E. T., Aggelopoulous, N. C., & Zheng, F. (2003). The receptive fields of inferior temporal cortex neurons in natural scenes. *The Journal of Neuroscience, 23,* 339-348. doi:

Roser, M., & Corballis, M. C. (2002). Interhemispheric neural summation in the split brain with symmetrical and asymmetrical displays. *Neuropsychologia, 40,* 1300-1312. doi: 10.1016/S0028-3932(01)00219-6

Roser, M., & Corballis, M. C. (2003). Interhemispheric neural summation in the split brain: Effects of stimulus colour and task. *Neuropsychologia, 41,* 830-846. doi: 10.1016/S0028-3932(02)00290-7

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27,* 763-776. doi: 10.1037/0012-1649.27.5.763

Savazzi, S., & Marzi, C. A. (2002). Speeding up reaction time with invisible stimuli. *Current Biology, 12,* 403-407. doi: 10.1016/S0960-9822(02)00688-7

Savazzi, S., & Marzi, C. A. (2004). The superior colliculus subserves interhemispheric neural summation in both normal and patients with a total section or agenesis of the corpus callosum. *Neuropsychologia, 42,* 1608-1618. doi: 10.1016/j.neuropsychologia.2004.04.011

Savazzi, S., & Marzi, C. A. (2008). Does the redundant signal effect occur at an early visual stage? *Experimental Brain Research, 184,* 275-281. doi: 10.1007/s00221-007-1182-y

Schacter, D. L., Relman, E., Uecker, A., Polster, M. I., Yun, L. S., & Cooper, L. A. (1995). Brain regions associated with retrieval of structurally coherent visual information. *Nature, 376,* 587-590.

Schneider, B. A., Avivi-Reich, M., & Mozuraitis, M. (2015). A cautionary note on the use of Analysis of Covariance (ANCOVA) in classification designs with and without within-subjects factors. *Frontiers in Psychology, 6*, 474. doi: 10.3389/fpsyg.2015.00474

Schröter, H., Bratzke, D., Fiedler, A., & Birngruber, T. (2015). Does semantic redundancy gain result from multiple semantic priming? *Acta Psychologica, 161,* 79-85. doi: 10.1016/j.actpsy.2015.08.001

Schulte, T., Chen, S. H. A., Müller-Oehring, E. M., Adalsteinsson, E., Pfefferbaum, A., & Sullivan, E. V. (2006). fMRI evidence for individual differences in premotor modulation of extrastriatal visual-perceptual processing of redundant targets. *NeuroImage, 20,* 973-982. doi: 10.1016/j.neuroimage.2005.10.023

Schulte, T., Pfefferbaum, A., & Sullivan, E. V. (2004). Parallel interhemispheric processing in aging and alcoholism: Relation to corpus callosum size. *Neuropsychologia, 42,* 257-271. doi: 10.1016/S0028-3932(03)00155-6

Schwarz, W., & Ischebeck, A. (1994). Coactivation and statistical facilitation in the detection of lines. *Perception, 23,* 157-168. doi: 10.1068/p230157

Schweinberger, S. R., Baird, L. M., Blümler, M., Kaufmann, J. M., & Mohr, B. (2003). Interhemispheric cooperation for face recognition but not for affective facial expressions. *Neuropsychologia, 41,* 407-414. doi: 10.1016/S0028-3932(02)00173-2

Shepherdson, P., & Miller, J. (2014). Redundancy gain in semantic categorization. *Acta Psychologica, 148,* 96-106. doi: 10.1016/j.actpsy.2014.01.011

Skiljan, I. (2016). Irfanview (Version 4.42) [Computer software]. Retrieved from http://www.irfanview.com/

Stein, B. E. (1998). Neural mechanisms for synthesizing sensory information and producing adaptive behaviors. *Experimental Brain Research, 123,* 124-135. doi: 10.1007/s002210050553

Tamietto, M., Adenzato, M., Geminiani, G., & de Gelder, B. (2007). Fast recognition of social emotions takes the whole brain: Interhemispheric cooperation in the absence of cerebral asymmetry. *Neuropsychologia, 45,* 836-843. doi: 0.1016/j.neuropsychologia.2006.08.012

Tamietto, M., Latini Corazzini, L., de Gelder, B., & Geminiani, G. (2005). Functional asymmetry and interhemispheric cooperation in the perception of emotions from facial expressions. *Experimental Brain Research, 171,* 389-404. doi: 10.1007/s00221-005-0279-4

Todd, J. W. (1912). Reaction to multiple stimuli. *Archives of Psychology, 3*(25), 1- 65. doi: 10.1037/13053-000

Tomaiuolo, F., Ptito, M., Marzi, C. A., Paus, T., & Ptito, A. (1997). Blindsight in hemispherectomized patients as revealed by spatial summation across the vertical meridian. *Brain, 120,* 141-150. doi: 10.1093/brain/120.5.795

Townsend, J. T., & Nozawa, G. (1995). Spatio-temporal properties of elementary perception: An investigation of parallel, serial, and coactive theories. *Journal of Mathematical Psychology, 39,* 321-359. doi: 10.1006/jmps.1995.1033

Townsend, J. T., & Nozawa, G. (1997). Serial exhaustive models can violate the race model inequality: Implications for architecture and capacity. *Psychological Review, 104,* 595-602. doi: 10.1037/0033-295X.104.3.595

Townsend, J. T., & Wenger, M. J. (2004). A theory of interactive parallel processing: New capacity measures and predictions for a response time inequality series. *Psychological Review, 111*, 1003-1035. doi: 10.1037/0033-295X.111.4.1003

Turatto, M., Mazza, V., Savazzi, S., & Marzi, C. A. (2004). The role of the magnocellular and parvocellular systems in the redundant target effect. *Experimental Brain Research, 158,* 141-150. doi: 10.1007/s00221-004-1884-3

Ulrich, R., Miller, J., & Schröter, H. (2007). Testing the race model inequality: An algorithm and computer programs. *Behavior Research Methods, 39,* 291-302. doi: 10.1037/0096-1523.4.3.423 10.3758/BF03193160

Wickens, T. D. (2001). *Elementary signal detection theory*. New York, NY: Oxford University Press.

Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review, 1,* 202-238. doi: 10.3758/BF03200774

Wolfe, J. M. (2007). Guided search 4.0: Current progress with a model of visual search. In W. D. Gray (Ed.), *Integrated Models of Cognitive Systems* (pp. 99-119). New York, NY: Oxford University Press.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 419-433. doi: 10.1037/0096-1523.15.3.419

Yang, C. T., Little, D. R., & Hsu, C. C. (2014). The influence of cueing on attentional focus in perceptual decision making. *Attention, Perception, & Psychophysics, 76,* 2256-2275. doi: 10.3758/s13414-014-0709-0

Yee, P. L. (1990). Semantic inhibition of ignored words during a figure classification task. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 43,* 127-153. doi: 10.1080/14640749108401002

Zaidel, E., & Rayman, J. (1994). Interhemispheric control in the normal brain: Evidence from redundant bilateral presentations. In C. Umiltà & M. Moscovitch (Eds.), *Attention and Performance XV: Conscious and Nonconscious Information Processing* (pp. 477-504) Cambridge, MA: MIT Press.

Zehetleitner, M., Goschy, H., & Müller, H. J. (2012). Top-down control of attention: It's gradual, practice-dependent, and hierarchically organized. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 941-957. doi: 10.1037/a0027629

Zehetleitner, M., Krummenacher, J., & Müller, H. J. (2009). The detection of feature singletons defined in two dimensions is based on salience summation, rather than on serial exhaustive or interactive race architectures. *Attention, Perception, & Psychophysics, 71,* 1739-1759. doi: 10.3758/APP.71.8.1739