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Effect of Attentional Capture and Cross-Modal Interference in Multisensory Cognitive Processing

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Walden University
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Abstract

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MS, University of Pittsburgh, 1994

MA, University of Dayton, 1977

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Dissertation Submitted in Partial Fulfillment

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General Research Psychology

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Abstract

Despite considerable research, the effects of common types of noise on verbal and spatial information processing are still relatively unknown. Three experiments, using convenience sampling were conducted to investigate the effect of auditory interference on the cognitive performance of 24 adult men and women during the Stroop test, perception of object recognition and spatial location tasks, and the perception of object size, shape, and spatial location tasks. The data were analyzed using univariate analysis of variance and 1-way multivariate analysis of variance. The Experiment 1 findings indicated reaction time performance for gender and age group was affected by auditory interference between experimental conditions, and recognition accuracy was affected only by experimental condition. The Experiment 2a results showed reaction time performance for recognizing object features was affected by auditory interference between age groups, and recognition accuracy by experimental condition. The Experiment 2b results demonstrated reaction time performance for detecting the spatial location of objects was affected by auditory interference between age groups. In addition, reaction time was affected by the type of interference and spatial location. Further, recognition accuracy was affected by interference condition and spatial location. The Experiment 3 findings suggested reaction time performance for assessing part-whole relationships was affected by auditory interference between age groups. Further, recognition accuracy was affected by interference condition between experimental groups. This study may create social change by affecting the design of learning and workplace environments, the neurological correlates of auditory and visual stimuli, and the pathologies of adults such as attention deficit hyperactivity disorder.

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Dedication

I would like to dedicate this dissertation to my mother, Dorothy F. Jennings, and my father, James H. Jennings, both of whom passed away before they could witness the completion of my doctoral studies and this great academic achievement. I also dedicate this dissertation to my wife, Kriza A. Jennings who unselfishly provided solace when needed, her compassion and commitment to listening to my cogitations and pontifications, while completing this great work.

I also dedicate this work to my sister, Brenda who inspired me to seek and pursue academic excellence by setting the example and serving as a role model in my early years of education. Through the years, I have remembered this example and strived to continue the pursuit of higher education and lifelong learning.

With continued love for you all, I am proud to have achieved this academic honor, and it is your faith and belief in me that kept me going for all of these years to complete my doctoral studies.

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Chapter 1: Introduction to the Study

Introduction

Technology has enriched our lives with devices that stimulate our senses. The environment we interact with daily contains an array of stimuli that can have a beneficial or detrimental effect depending on the context through which the multisensory events take place, individual differences, the task at hand (Lavie, 2010). Our world is filled with stimuli that are omnipresent whether humans are in a state of consciousness or unconsciousness, when actively engaged in mental activity, meditating, asleep or in a state of deep relaxation (Shams & Seitz, 2008)

It has been suggested that low-level noise distraction affects the learning and memory performance of children with anxiety and attention issues, and low or barely perceptible sounds that constantly turn on and off may increase stress and interfere with memory and learning in the classroom (Sparks, 2015). Whether low or high, noise and noise levels are of interest to scientists and teachers, and as technological devices such as smartphones and media players become ubiquitous, and have entered the workplace and learning environments, and our personal spaces, we must continue to investigate their impact. In our daily lives, the use of technological products is becoming an obtrusive distractor, becoming commonplace, often ignored events that may exacerbate and produce unwanted auditory stimuli in our environment.

During any cognitive or learning process, there are both relevant and irrelevant stimuli that require some level of attentional resources to be allocated. My focus in this study was on the degree to which auditory stimuli draw on attentional resources during verbal and spatial tasks.

Auditory Interference

The phenomenon of auditory interference on cognitive processing has been the focus of research for several decades (Davis, 1939; Eriksen & Hoffman, 1973). Several authors have documented the effects of music on cognitive processing, and it has been determined to be a mediator of cognitive performance (Mammarella, Fairfield, & Cornoldi, 2007; Newman, Rosenbach, Burns, Latimer, Matocha, & Vogt, 1995; Schellenberg & Hallam, 2005). It has been shown that classical music enhanced the cognitive performance and working memory of healthy older adults. The Vivaldi effect (Mammarella et al., 2007) and the Mozart effect (Newman et al., 1995) improved spatial ability, and cognitive abilities in preadolescent youth were enhanced by the blur effect (Schellenberg & Hallam, 2005). Other examples of auditory stimuli as a mediator have been demonstrated through a phenomenon called *brain entrainment* whereby a pulsing sound, light, or electromagnetic field is used to stimulate the brain into a specific state, causing brainwaves to align to the frequency of a given beat (Baker, & Holding, 1993; Will & Berg, 2007).

Brainwave entrainment has been shown to help adults with attention deficit hyperactivity disorder (ADHD) concentrate better; relieve stress and anxiety; and improve memory, attention, general intelligence, and general cognitive functions in individuals without neural pathologies (Baker, & Holding, 1993; Will & Berg, 2007).

Researchers in the scientific community continue to investigate the role of auditory interference on cognitive functioning and the cortical mapping involved, and whether deficits in cognitive performance is the consequence of capacity limitations in visual working memory (Luck & Vogel, 2013; Oberauer, Farrell, Jarrold, & Lewandowsky, 2016). Research has shown that white noise acts as a moderator of cognitive performance and improves verbal free recall performance in inattentive school children (Söderlund, Sikstrom, Loftesnes, & Barke, 2007, 2010). The effects of speech interference as it relates to the cocktail party effect has also been shown to increase reaction times in numerosity judgment tasks, but in such paradigms the effect of multiple simultaneous sounds has rarely been studied (Kawashima & Sato, 2015).

Cortical Mapping and Cognitive Performance

Researchers have advocated theories and memory models (such as the Baddeley multicomponent model) to explain the human memory processes of the brain, the roles of cortical areas, and the functioning of its primary visual and auditory systems (Baddeley & Hitch, 1974; Gazzaniga, Ivry, & Mangun, 2009). The literature has provided spurious results and conclusions 1) when it comes to how verbal and spatial information or objects are processed under different levels of stimulus degradation, and 2) the impact of degraded stimuli and auditory distraction on the binding of object features (Baddeley, 2012; MacLeod, 1981). In the pursuit of further broadening our knowledge of multisensory cognitive processing, it is also important to align the cortical areas responsible for information processing in verbal and visuo-spatial tasks with the areas of the visual field for which stimuli are projected Chen, Bickford, & Hirsch, 2016).

The primary visual cortex (Area 17 – V1), secondary visual cortex (Area 18 – V2), and secondary visual cortex (Area 19 – V3) of the occipital lobe, all have a well-defined map of the spatial information in vision that conforms to a transformation of the visual image from the retina into V1, termed retinotopic mapping. (Trans Cranial Technologies, Ltd, 2012). Images displayed in the fovea have a specific mapping to Area 17. As images are displayed further away from foveal vision and subsume peripheral vision, Areas 18 and 19 are involved in the processing (Trans Cranial Technologies, Ldt, 2012).

Stroop Effect Paradigm

The original Stroop color-word test (also referred to as the serial color-word test) is a procedure whereby participants perform a color-naming task using words that are congruent or incongruent with the ink color of the words and control color patches (Stroop, 1935b). The Stroop effect has been highly researched with over 700 studies, and there are many variations of the original Stroop test, such as the music Stroop (Gregoire & Perruchet, & Poulin-Charronnat, 2013), emotional Stroop (Kappes & Bermeitinger, 2016), auditory Stroop (Cohen & Martin, 1975; Hamers, 1973), spatial Stroop (Luo, & Proctor, 2016), semantic Stroop (White, Risko, & Besner, 2016), numerical Stroop (Kawashima & Sato, 2015), and the reverse Stroop *(*Durgin, 2000).

Variations in the Stroop test have to do with the number of colors used (3, 4, 5, or 6), the background color (white or black), type of color patches (circular dots, unspecified, colored Xs, rectangular shapes, colored asterisks, achromatic words, geometric shapes), different card sizes (unspecified, 9 ¼” x 9 ¼”, 18” x 25”, 17 ¾” x 25

¼”), word type (font types, warped, curved), number of practice items (7, 10), practice method (continuous short or long verbalizations prior to test), and methodology (traditional, hybrid) (Jensen & Rohwer, 1966, MacLeod, 1991). Due to variances in either the materials used in the test, how the test was administered or scored, and the lack of using neutral-word control conditions, there is no standard version of the Stroop test (Jensen & Rohwer, 1966). Researchers investigating interference and facilitation have produced spurious results, making interpretation complicated and inconclusive (Dyer, 1973c; MacLeod, 1991).

While auditory inference has been studied in Stroop paradigms, its effect on the processing of verbal and spatial information and cortical mappings of cognitive performance has remained less conclusive. However, Stroop researchers has explored the auditory dimension more as an outcome variable (such as note naming (Grégoire, Perruchet & Poulin-Charronnat, 2013, 2014) or a stimulus characteristic (Hamers, 1973) than as an independent variable. Gier, Kreiner, Solso and Cox (2010) provided the first variation of the original Stroop test to investigate whether interference effects were different for the properties of words and shapes when displayed in different visual fields.

Problem Statement

Research that further advances our knowledge of how the brain allocates attentional resources and processes multisensory information between the two hemispheres continues to be of interest in cognitive psychology as well as the neurosciences (Banich & Shenker, 1994; Bergman et al. 2013; Gier et al., 2010; Lisman, 2015; Matusz et al., 2015; Proulx et al., 2014). Stroop (1935) and Stroop-like studies have increased our understanding of verbal and spatial information processing, while hemispheric lateralization studies have contributed to insights regarding how individuals process stimuli in the environment in everyday life. Over centuries of cognitive research, the scientific community has learned of the benefits and shortfalls of the effects of sonification, attentional resource conflicts, and various types of sensory interference on cognitive performance. What is not known are the effects of irrelevant auditory interference (such as speech, music, and noise) on the reaction times and recognition accuracy scores for the processing of verbal and spatial information in Stroop and Stroop-like paradigms.

Beamon (2005) suggested that stricter attention to the effects of auditory interference may improve cognitive performance. It is still controversial as to whether spatial information is subject to interference effects during shape and object feature-binding and perception (Treisman & Gelade, 1980).

The central question of my study was: does auditory interference disrupt the perception of shapes or objects (e.g. part-whole matching) under conditions of stimulus degradation? Research by Gier et al (2010) was the first study that produced the first variation of the original Stroop test to investigate whether interference effects were different for the properties of words and shapes when displayed in different visual fields. This study extends the Gier et al. 2010 study by introducing different types of auditory interference as an independent variable under more visuo-spatial field positions; and its effect on part-whole matching of geometric shapes (Jennings, 1977; Nebes, 1971a, b).

Purpose of the Study

My intent with this quantitative study was to examine: a) the effects of auditory and visual distractors on selective attention and working memory, under conditions of attentional capture and interference during the performance of Stroop- and Stroop like recall and recognition tasks; and b) resource limitations and cross-modal effects on selective attention during the performance of Stroop- and Stroop like recall and recognition tasks. I focused on a) Stroop and Stroop-like verbal and spatial task performance at additional and different fixation points than those presented in research by Gier et al. 2010), b) the issues and roles of feature binding in multisensory perceptual processing congruent with working memory research of Allen, Baddeley and Hitch (2014); Allen, Baddeley, and Hitch (2006); Baddeley (2012), and Treisman and Gelade (1980), c) a new variation of the original Stroop test (Stroop, 1935b), and d) the effects of visual and auditory interference on information processing as posited by Beaman (2005), Roberts & Besner (2005), Elliott, Morey, Morey, Eaves, Shelton, & Lutfi-Proctor (2014), Gamble and Luck (2011), and Golumb (2015).

Nature of the Study

I used a quantitative, true experimental within-subjects design which is consistent with investigations of differences in reaction times and recognition accuracy for displayed word and shape stimuli as well as effects due to different types of interference and stimulus degradation in immediate serial recall tasks.

The sample population that I used for this study was English-speaking adult men and women between the ages of 18 and 60 years, with a high school diploma or equivalent, who are right-handed, and possess a visual acuity of normal (20/20) or corrected or near normal vision (between 20/32 and 20/63), normal color vision, and no hearing loss. A version of the Snellen eye chart was used to assess hyperopia (nearsightedness) and visual acuity.

I selected the adult participants based on the verification of hand dominance and normal visual acuity and color vision. I used the multivariate analysis of variance (MANOVA), a multivariate extension of analysis of variance (ANOVA) to explore the effect of two independent variables (auditory interference and stimulus degradation) have on the patterning of response on the dependent variables (recognition accuracy and reaction time scores), and whether there were any interactions among the dependent variables and the independent variables.

I used a power analysis to determine the total number of participants needed for the study, with the goal of achieving no less than 80% statistical power, at an alpha level of .05. Using GPower settings with Test family = *F* tests, Statistical tests = MANOVA: Global effects, Effect size $F^2(V) = 0.35$, alpha (α) = 0.05, Power = 0.80, Number of groups = 2, and Response variables = 2, the total sample size = 24, for Experiment 1. The results of the GPower analysis were interpreted as requiring six participants per group. For Experiments 2 and 3, with the same GPower settings, however with number of groups = 2, The total sample size = 24. The results of the GPower analysis were interpreted as requiring 12 participants per group. I recruited a total $N = 40$, during the recruitment process to allow for attrition. Estimates were based on G Power calculations, with small effect size = 0.10, medium effect size = 0.25, and large effect size = 0.40 (Faul et al., 2013).

A within-subjects design afforded an assessment of differences in mean reaction times and recognition accuracy scores of two or more groups of participants. The independent variables were auditory distraction, Stroop dilution (degraded stimulus representations) and spatial location; and the dependent variables were reaction time and recognition accuracy.

I used reaction time and recognition accuracy measures, spatial locations around a center fixation point, assessments of the congruency-incongruency effect in previous Stroop studies (MacLeod, 1991), and specifically by Gier et al. 2010, and different types of auditory distraction than Beamon (2005), Roberts & Besner (2005), and Elliott et al. (2014). I used a univariate analysis of variance (ANOVA) and one-way multivariate analysis of variance (MANOVA) in this investigation. For the experimental design, presentation and recording of responses and reaction time measures, I used a Windows-based software product called ePrime by Professional Software Tools, Inc. To determine the participant's hand dominance, I used the Edinburgh handedness inventory (Oldfield, 1971).

The sources of all data were primary, and collected from each participant meeting the inclusion/exclusion criteria:

1. An assessment of the handedness of study participants.
2. An assessment of the visual acuity of participants using a Snellen chart.

3. An assessment of hearing ability of participants using percentage of correct responses using the free online hearing test.
4. An evaluation of color vision using a color matching task.
5. Reaction time measures of word and color stimuli across panoramic visual fields.
6. Reaction time measures of shape stimuli across panoramic visual fields.
7. Reaction time measures of word and color stimuli based on auditory distraction.
8. Reaction time measures of shape stimuli based on auditory distraction.
9. Recognition accuracy measures of word and color stimuli across panoramic visual fields.
10. Recognition accuracy measures of shape stimuli across panoramic visual fields.
11. Recognition accuracy measures of word and color stimuli based on auditory distraction.
12. Recognition accuracy measures of shape stimuli based on auditory distraction.

Handedness, and visual acuity data were gathered through questionnaires, and visual observation prior to the conduct of experimental test sessions, during screening and selection procedures.

For each of the alternative hypotheses stated below, I analyzed the data with SPSS, using univariate ANOVA and one-way MANOVA procedures to detect significant differences between mean correct responses and reaction times to word and shape stimuli as a result of levels of auditory interference, stimulus degradation based on panoramic visual field presentations. For evaluating main effects and interactions between variables, I used *F* tests, contrast analysis, and post hoc pairwise comparisons. (Creswell, 2009; Green & Salkind, 2014).

Research Questions and Hypotheses

RQ1: What is the effect of auditory interference and stimulus degradation on the reaction times and recognition accuracy of adult men and women, for verbal information processing in working memory?

H_{01a}: Auditory interference does not affect reaction times and recognition accuracy for verbal information processing.

H_{a1a}: Auditory interference affects reaction times and recognition accuracy for verbal information processing.

H_{01b}: Auditory interference does not affect reaction times and recognition accuracy for degraded verbal information.

H_{a1b}: Auditory interference affects the reaction times and recognition accuracy for degraded verbal information.

RQ2: To what extent is spatial location information processed differentially than structural object features in working memory, for adult men and women?

H_{02}: Spatial location information is not processed differentially than structural object features for adult men and women.

H_{a2}: Spatial location information is processed differentially than structural object features for adult men and women.

RQ3: To what extent are there speed-accuracy tradeoff differences in spatial information processing in working memory, for adult men and women, under conditions of auditory interference-based on visual field presentation?

H_{03}: There are no speed-accuracy tradeoff differences in spatial information processing in working memory, under condition of auditory interference based on visual field presentation.

H_{a3}: There are speed-accuracy tradeoff differences in spatial information processing in working memory, under conditions of auditory interference based on visual field presentation.

RQ4: Does auditory interference affect the speed-accuracy of detecting the spatial location of degraded objects based on visual field presentation, for adult men and women?

H_{04}: There are no speed-accuracy tradeoff differences in the detection of the spatial location of degraded objects based on visual field presentation.

H_{a4}: There are speed-accuracy tradeoff differences in in the detection of the spatial location of degraded objects based on visual field presentation.

RQ5: Does cross-modal interference affect the speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point, for adult men and women?

H_{05}: Cross-modal interference does not affect speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point based on visual field presentation.

H_{a5}: Cross-modal interference affects the speed-accuracy of size and shape perception of geometric shapes features and spatial information processing for objects presented in locations peripheral to a central fixation point based on visual field presentation.

Operational Definitions

The following terms are found within the cognitive psychology and cognitive neuroscience literature.

Attention: The process of selectively focusing on one aspect of the environment while ignoring other aspects of the environment through the executive allocation of attentional resources (Kahneman, 1973).

Attentional capture: The unintentional focusing of attention, by a change in a stimulus, which interrupts other processing. Explicit attentional capture refers to when a salient and unattended stimulus draws attention, leading to awareness of its presence; and implicit attentional capture refers to when a salient and irrelevant stimulus affects performance on another task, regardless of whether or not the participant is aware of the stimulus (Simons, 2000).

Attentional control: The central executive ability to maintain attention on one aspect of the environment or shift attention and disengage from an intended aspect of the environment to a new aspect of the environment while ignoring irrelevant information (Derryberry & Reed, 2002; Engle & Kane, 2003).

Blur effect: A differential cognitive performance in the spatial-temporal reasoning of pre-adolescents as a result of listening to the popular music “Blur” than reported from listening to Mozart’s music (Schellenberg & Hallam, 2005).

Cocktail Party Effect: is the ability of the human sound system to extract, localize, and identity a single sound source of interest among mixtures of interfering sound sources (Wood & Cowan, 1995).

Cortical mapping: The use of cortical organizations or collections (areas) of the cerebral cortex that identifies sensory systems and their specific information processing functions through the use of visualizations (texture maps, color maps, contour maps, imaging technology, etc.) (Buonomano & Merzenich, 1998; Perrine, Devinsky, Uysal, Santschi, & Doyle, 2000).

Cross-modal: is normally used to refer to situations in which the presentation of a stimulus in one sensory modality can be shown to exert an influence on our perception of, or ability to respond to, the stimuli presented in another sensory modality (Robinson & Sloutsky, 2013).

Divided attention: Attention which characterizes the efforts to process multiple channels of information or carry out multiple tasks in parallel, the latter being characterized as successful multitasking (Wickens, 2007).

Feature-binding: The process by which different properties of a stimulus are integrated as an object (Jaswal & Logie, 2013; Treisman & Gelade, 1980).

Feature integration theory: A theory of attention that posited that the features of an object are pre-attentive and registered early in an automatic parallel manner, while the object itself is separately identified at a later stage of processing (Treisman & Gelade, 1980).

Focused attention: Attention which characterizes the goal-directed orientation of the spotlight and which breaks down when processing of selected elements is disrupted by unwanted distractions (Eriksen & Eriksen, 1974).

Mozart effect: The result of listening to Mozart's music that may induce improvement in spatial-temporal reasoning tasks (Newman, Rosenbach, Burns, Latimer, Matocha, & Vogt, 1995).

Multiple resource theory: A human factors and applied psychology theory mostly cited as the standard for the design of user interfaces and complex systems that says there are a limited and fixed capacity of resources an individual can use for information processing based on processing stage, code, and sensory modality (Kramer, Wiegmann, & Kirlik, 2007; Wickens, 2007).

Multisensory: A neuron (or neural area) whose activity is influenced by inputs from more than one sensory modality (Allman, Keniston, & Meredith, 2009).

Processing: All the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used (Neisser, 1976).

Retinotopic mapping: A transformation of the visual image from the visual fields of the retina to Area 17 (V1) of the primary visual cortex. The correspondence between a given location in V1 and in the subjective visual field is very precise: even the blind spots are mapped into V1 (Trans Cranial Technologies, Ltd, 2012).

Selective attention: A serial "spotlight" on selected elements of the external world or the mental representations that must switch in series between them (Wickens, 2007).

Sonification: A term used to describe the use of non-speech audio to convey information or the perceptualization of data, using techniques which increase or decrease levels of pitch, amplitude, or tempo of the sound (Kramer, 1994).

Sound pressure level: The sonic effect experienced from the radiated power or intensity that caused a sound, whose loudness is usually expressed as a decibel dB unit on a ratio scale (NIOSH, 2016).

Stimulus degradation: A stimulus, visual or auditory composed of noise that makes it more difficult to perceive (Yeshurun & Marciano, 2013).

Visual: Information that is transmitted to the perceiver by light energy or by differences in light energy and is received by the receptors in the retina of the eye (van der Heijden, 2016).

Vivaldi effect: The result of listening to Vivaldi's music that may induce improvement in cognitive performance in memory tasks for healthy older adults (Mammarella, Fairfield & Cornoldi, 2007).

White noise: Noise that is specified in mathematical models that is used in the production of electronic music, but refers to how the signal power is distributed independently over time and among different frequencies (Baker, & Holding, 1993).

Working memory: A theoretical construct relating to the mechanism for maintaining task relevant information during cognitive task performance (Baddeley & Hitch, 1974).

Working memory capacity: The amount of visual or auditory information that an individual may store and rehearse for later retrieval from a working memory store. Often measured by the reading span task (Daneman & Carpenter, 1980) or the Operation Span Task (Turner & Engle, 1989).

Scope, Assumptions, and Limitations

Scope

This study, I investigated the effects of speech interference as it relates to the cocktail party effect (Kawashima & Sato, 2015), music interference (Hip-hop genre only), and noise interference (white noise only), and stimulus degradation on cognitive performance in reaction time and recognition accuracy tasks in part-whole matching, objection detection and recognition, Stroop and Stroop-like paradigms. The effects of congruence and incongruency of verbal stimuli as documented by Stroop (1935a, b, 1938) I investigated, were in accordance with the influences of stimulus degradation, auditory interference, and spatial location.

The study also extended the work of Gier et al., 2010 and investigated the effects of cross-modal interference and the Stroop effect using panoramic fixation points to assess response latencies in Stroop and Stroop-like task performance. In addition, I focused on the part-whole matching of geometric shapes and the accuracy of their location and size perceptions, as postulated by feature integration theory (Treisman & Gelade, 1980). The scope of the target population is only specific to right-handed adult men and women with normal vision, between the ages of 18 and 60 years of age. For this study, I did not consider other demographics such as generation, socioeconomic status, and marital status. Geographic location was a participant characteristic, but only participants residing in the Greater Washington, D.C. and Northern Virginia areas were considered for the study.

Assumptions

The following assumptions were made in conducting this planned research:

1. Auditory interference can influence cognitive performance depending on the task to be performed.

2. Auditory interference is a distractor of attention stemming from competition for attentional resources between the distractor and target stimuli.

3. Auditory interference influences cognitive performance depending on intensity, duration, and spatial frequency in both children and adults.

4. Object features and parts are perceived after the processing of spatial location.

5. The stimulus projections in the various spatial locations in this study are directly related to the cortical mapping and neural activity in the posterior parietal cortex and primary visual cortex.

6. Spatial location influences reaction time and recognition accuracy scores in the recall of object location and size.

7. Attentional capture from auditory stimuli influences reaction time and recognition accuracy scores in verbal recall tasks.

Limitations

The literature on attention is vast and comprises different types (focused, sustained, selective, alternating, and divided) (Sohlberg & Mateer, 2001). The current study is focused on selective and focused attention as it relates to cognitive performance in reaction time and recognition accuracy tasks in Stroop and Stroop-like paradigms. The effects of different types of auditory interference, I investigated are limited to noise that simulates real-world stimuli, but only in a laboratory environment. Specific intensities and exposure durations are not as variable and obtrusive as they would be experienced in a work or learning environment, but approximated and presented at predetermined frequencies and measurements. A stratification by ethnicity, age, location, music and speech types and other related stimulus and participant characteristics are limited based on the scope of the study as described below.

Significance of the Study

Of the over 400 studies (MacLeod, 1991) on the interference in the Stroop color-word interference test (Stroop, 1935b), limited research investigating the congruency-incongruency effect of word and shape stimuli under conditions of cross-modal resource conflict, attentional capture, and different types of auditory interference has been conducted by researchers over the past 50 years. The study of the Stroop effect has been the platform for examining automatic and controlled processing, and incongruous stimulus conditions for human adults, using executive functions to minimize interference (Stroop, 1935b; Washburn 2016). I explored interference and cognitive control during Stroop tasks, under conditions of stimulus degradation, and compared cognitive performance in adults. Studying how people learn and use spatial information is essential to developing spatial skills, navigating the environment, and detecting the location and proximity of dangerous or friendly targets (Newcombe, 2016). Everyday individuals both consciously and subconsciously interact with and process visual and auditory stimuli in our environment. On a daily basis, our health and livelihood is dependent on how well we attend to, recognize, and process multisensory stimuli. There are many distractors in our workplace, schools, and personal environments that capture our attention, disrupt and limit our ability to ignore irrelevant information during the processing of relevant information.

The pervasiveness of auditory stimuli (such as speech, music, and noise) in our environment and its effect on the processing of verbal and spatial information has not been the primary focus of researchers. Researchers have investigated the effect of irrelevant auditory stimuli as an independent variable as it occurs and impacts auditory perception and working memory (known as the irrelevant sound phenomenon), and has garnered considerable theoretical interests for human factors and cognitive research (Beamon, 2005). Speech and noise has also been of interests as a source of disturbance in the workplace (Landström, Soderberg, Kjellberg, & Nordstrom, 2002), and has been shown to cause deficits in learning when comparing quiet versus noisy workplace and classroom environments (Beaman, 2005; Evans & Johnson, 2000). As media devices become ubiquitous and permeate our day-to-day experiences, work and learning environments, studies by researchers that continue to investigate their impact and disruptive effects on specific populations (i.e., adult learners and millennials) require continuous study. It is believed that reductions in auditory interference would mediate improvements in academic performance in the workplace, school rooms, open offices, group situations, conference meeting areas and produce lesser cognitive errors (Chapplelow (1999) as cited in Beamon, 2005). Results of this study may impact and influence decisions for the creation of separate learning and work environments, where individuals who are sensitive to distraction learn and work in either a noisy or quiet space; and decisions for developing and evaluating procedures for teleworking environments.

Humans during prehistoric times, did not have to deal with the bombardment and ubiquity of visual and auditory stimuli that individuals face today. Distractions by media devices and noise from several sources in the environment have disruptive as well as enhancing effects on cognitive and academic performance. This doctoral research focuses on the effects of attentional capture by three types of auditory interference common in our environment, cross-modal interference, and ecological factors shown to have both a positive and negative influence on brain processing in different task domains. However, our sensitivity to visual and auditory distractions has been shown to affect learning, memory, perception, attention, stress and anxiety levels, and executive functions related to attentional or cognitive control, inhibitory control, working memory, reasoning, planning, and problem-solving (Chan, Shum, Toulopoulou, & Chen, 2008; Diamond, 2013; Washburn, 2016).

Due to advances in neuroimaging technology and methods for visualizing neural activity and communication between cortical areas for specific types of cognitive processing, a resurgence of interests in the higher level cognitive functions of the executive system has emerged. It is believed that most studies by researchers have traditionally focused on the development of executive functions during the lifespan of early childhood to adolescence when neuroplasticity is most evident as abilities peak as the brain matures (Anderson, 2002; De Luca & Leventer, 2008). Limited research has focused on the older adult population, due to the contention that working memory, spatial abilities, cognitive control, and executive function start to decline as human approach the age of 70 (Baddeley, 1986; De Luca & Leventer, 2008). In light of this content, this study focuses on adult men and women between the age of 18 and 60, whom are believed to represent a majority of adult learners, for the study of the attentional control and executive systems. Being a good listener and understanding what a teacher or speaker has said requires working memory, recall, remembering, and attention, and increasing auditory vigilance under conditions of simultaneous auditory interference (Kamourieh et al., 2015). If adults, and by extension adult learners' ability to overcome distractions when reading or performing cognitive tasks increases, the study should show more optimal performance for participants in the control versus the experimental conditions. The study was valuable for understanding the effects of continuous, task irrelevant speech, music, and noise on verbal and spatial learning and perception.

Studies have shown that visual and auditory distractions interfere with short-term memory processing (Banbury & Berry, 2005; Beaman, 2005; Schneider, Daneman, Murphy, & Kwong, 2000; Tun, O'Kane, & Wingfield, 2002), and such results may also have impact for revising the structure of classrooms and workplace environments that can improve academic performance. Throughout our evolutionary history, word, color, time, and shape perception has played a significant role in human survival (Shams & Seitz, 2008), and educational environments and stakeholders can benefit from an understanding of research on verbal, spatial, and multisensory information processing, and conditions under which interference may impact cognitive and academic performance.

A study by Gier et al (2010) is believed to be the first study to examine whether properties of verbal and spatial information differ as a result of different visual field projections. The study utilized the knowledge gained from the work of Gier et al (2010), and further investigated the effects of cross-modal interference and the Stroop effect, using panoramic visual field projections to assess response latencies and recognition accuracy in part-whole matching, Stroop and Stroop-like paradigms. While the Gier et al (2010) was the first of its kind, the current study is believed to be the first study to investigate and compare different and continuous types of interference as an independent variable, with stimulus degradation and additional visual field projections, in the performance of traditional verbal and spatial cognitive tasks. It is also believed that the study provided insights that may inform teachers and educational neuroscience regarding cortical mapping and information processing in the prefrontal, temporal, parietal, and visual cortices.

Summary and Transition

In our multisensory environment, there are multifarious visual and auditory stimuli for which we interact with on both a conscious and subconscious level. Visual and auditory stimuli that can be harmful, but can have both positive and negative influences on our well-being, health, mood, emotional state, and cognitive performance are oftentimes accepted as commonplace. All of these common sounds become dangerous to our auditory system when perceived at sound pressure levels ranging between 60 dBA and 190 dBA. The National Institute of Occupational Safety and Health (NIOSH) has categorized environmental stimuli and the level of sound pressure believed to be harmful, if sustained for a specific duration. The phenomenon of auditory interference has been the focus of research for over 50 years (Davis, 1939; Eriksen & Hoffman, 1973). Auditory interference serves the role of mediator and moderator for improvements in cognitive performance in verbal, spatial, memory and attention-related tasks for young children and older adults alike, persons with ADHD, and individuals without neural pathologies (Baker, & Holding, 1993*;* Will & Berg, 2007).

In the pursuit of further broadening our knowledge of multisensory cognitive processing, it is also important to align the cortical areas responsible for information processing in verbal and visuo-spatial tasks with the areas of the visual field for which stimuli are projected. While the role of cortical areas and their functionality in human memory models have been explored, when it comes to how verbal and spatial information or objects are processed under different levels of stimulus degradation, and the impact of degraded stimuli, and auditory distraction on the binding of object features, the literature has provided spurious results and conclusions (Baddeley, 2012; MacLeod, 1991). The primary visual cortex (Area 17 – V1)(striate), secondary visual cortex (Area 18 – V2)(parastriate), and secondary visual cortex (Area 19 – V3)(peristriate) of the occipital lobe, all have a very well-defined map of the spatial information in vision that conforms to a transformation of the visual image from the retina into V1 (retinotopic mapping)(Trans Cranial Technologies, Ltd, 2012), how verbal and visuo-spatial processing occurs in these area under conditions of auditory interference are of primary interest in the study.

Notwithstanding the known variances in methodology and versions of the original Stroop test, it remains a highly researched topic in cognitive psychology, and the classic paradigm for understanding interference effects in verbal and spatial information processing. Stroop and Stroop-like paradigms continued to provide insights into how attentional resources are allocated, and further research using new and under-researched phenomena that help to clarify the limits and capabilities of multisensory cognitive processing in areas of the primary visual cortex are of significance and value to cognitive psychology and cognitive neuroscience.

The literature review in Chapter 2 establishes the context, relevance, and need for which the current study was conducted, and serves as advocacy for continued research on the influences of stimuli in our environment which impacts cognitive performance in learning and workplace environments. The rationale for use and the relevance of three theoretical frameworks: a) multiple resource theory, b) interference theory, and c) feature-integration theory, for which the dissertation is rooted, and their relevance to this study was discussed in this chapter. In addition, an analysis of the interaction of different modalities and sensory codes and their impact on the processing of verbal and spatial tasks was provided. Throughout the review, the reader can gain an understanding of the significance, conclusions drawn and evidence for focusing on and researching cognitive performance under conditions of auditory interference in cross-modal tasks.

The research methodology presented in Chapter 3 provided the specific details regarding purpose of the study, the structure of the research design, and the setting under which the research was conducted. The chapter provides a description of the sample and sampling methodology, stimuli, test conditions, research apparati and instrumentation, for each of the experiments in the study. Detailed explanation of the procedures that were followed for participant selection, including exclusion and exclusion criteria, instructions for task performance, assignment of participants to experimental and control groups, and the control of extraneous variables were discussed. Data analysis methodology was discussed in regard to its implementation, data gathering and collection procedures, the statistical analysis (including methods, significance levels, tests, and post hoc comparisons), and threats to reliability and validity were provided. Statistical results for all experiments were summarized for the main effects and interactions of all independent and dependent variables in Chapter 4. Summaries, conclusions, and recommendations were provided in Chapter 5.

Chapter 2: Literature Review

Introduction

This literature review established the context, relevance, and need for which the current study was conducted, and served as advocacy for continued research on the influences of stimuli in our environment which impacts cognitive performance in learning and workplace environments. Over the past 80 years, knowledge of cognitive processing has continued to advance and add new constructs and theories of significance and value to the fields of cognitive psychology and neuroscience. Researchers have transitioned from a focus on unisensory processing to research paradigms involving multisensory cognitive processing. A multisensory approach is consistent with the multisensory environment and how humans interact with and process sensory information in our lives on a daily basis. Every day, people are expected to perform cognitive tasks of different complexities for the purpose of survival, manifested through learning, memory, and perceptual processing. Various distractors of a visual, auditory, olfactory, spatial, and psychophysical nature may influence and interfere with the efficacy and proficiency of the executive functions of the brain, also known as cognitive control and the supervisory attentional system (Diamond, 2013).

Search Strategy

This dissertation is rooted in three theoretical frameworks: a) multiple resource theory, b) interference theory, and c) feature-integration theory. This chapter includes an analysis of the interaction of different modalities and sensory codes and their impact on the processing of verbal and spatial tasks. Empirical research related to cognitive functions and performance in verbal and spatial tasks are included in a variety of cognitive, health, and neuroscience journals, retrieved from sources such as PsycINFO, PsycARTICLES, ScienceDirect, GoogleScholar, ProQuest Central, and EBSCOhost Academic Search Complete. The list of search terms that I employed for the literature search included *verbal and spatial learning, cross-modal attention, cross-modal interference, auditory interference, music interference, speech interference, sonification, auditory distraction, visuo-spatial working memory, color naming, Stroop test, word-shape Stroop effect, size and shape perception, noise and serial verbal recall, hemispheric lateralization, human visual cortex, retinotopic mapping, attentional capture,* and *multisensory processing.* I downloaded and reviewed all articles for the study digitally, and seminal articles were manually printed. Articles that were not available for digital storage or printing were obtained using the Walden University document delivery service. I obtained several books to explore research topics more in-depth and gain knowledge from overviews and meta-analyses.

This chapter includes an overview of workload, attention, and memory models as they relate to the processing of multisensory stimuli and their relevance to interference and modalities involved in cognitive tasks associated with verbal and spatial information. The chapter also includes a discussion of different sources of interference and how they either mediate or modulate cognitive performance. To support the contention of whole-brain information processing and the sensory processing that is the purview of the primary and secondary cortices of the occipital lobe, I provided a discussion of the retinotopic mapping of visual field projections to these areas.

Limited research has explored the perception of geometric shapes and stimulus degradation in Stroop paradigms, as well as metrics related to the cognitive performance due to cross-modal interference in part-whole matching tasks. How cognitive performance is influenced under conditions of interference in multisensory tasks is discussed and is the focus of the present study.

In the study of cognitive psychology, a researcher must understand a wealth of information and rationalize, the different perspectives and theories on how the human system processes multisensory information to carry out mental and physical tasks. However, when considering the manner, resources allocated, sensory capacities, cross-modal effects, cerebral processing zones, and models supported, the literature on attention, memory, and cognitive processing is filled with controversy and conflicts (Allen, Baddeley, & Hitch, 2006, 2014; Allen, Hitch , Mate & Baddeley, 2012; Atkinson & Shiffrin, 1968, 1971; Baddeley, 2012; Baddeley & Hitch, 1974; Gamble & Luck, 2011; Gier et al., 2010; Hollingsworth, Matsukura, & Luck, 2013; Jones and Tremblay, 2000; Leonard, Lopez-Calderon, Kreither, & Luck, 2013; Luck & Vogel, 2013; MacLeod, 1991; Morey, Morey, van der Reijden, & Holweg, 2013; Morrison, Burnham, & Morrison, 2015; Neisser, 1976, 1977; Odegaard, 2015; Silverman, 2013; Treisman & Gelade, 1980; Wang, & Wang, 2014; Wickens, 1984; Wickens, 1990).

Considering the voluminous amount of research on these topic areas in cognitive psychology and cognitive neuroscience, the literature review is selective. I found that most studies focused on research that is germane to multisensory cognitive processing as it relates to selective attention, cortical and retinotopic mapping, and interference effects in the processing of verbal and spatial stimuli, in the primary visual cortex and visuo-spatial working memory.

Theoretical Foundation

Multiple Resources Theory

The limits of attention and memory have been the focus of research in cognitive psychology and neuroscience (Baddeley, 2012). Several efficiency, functional localization, cognitive load, memory and attentional models and theories have been prevalent in these studies. I found that these prevailing models emphasize and challenge the contention that there are working memory capacity limits when specific types of cognitive tasks are performed together depending on the sensory modalities that are employed.

The idea that attention is a single pool of resources which are a source of competition between attention and cognitive processing was first proposed by Kahneman (1973). Navon and Gopher (1979) proposed the concept of multiple resources whereby cognitive resources are deployed in combination to perform tasks. Wickens (1984) -- building upon the work of Kahneman (1973) and Navon and Gopher (1979) argued that attention is a multiple resource with different attributes. Multiple resource theory researchers prescribe that there are a limited and fixed capacity of resources an individual can use for information processing based on processing stage, code, and sensory modality (Wickens, 1980, 1984, 1990, 1991, 2002, 2004, 2007; see Figure 1).

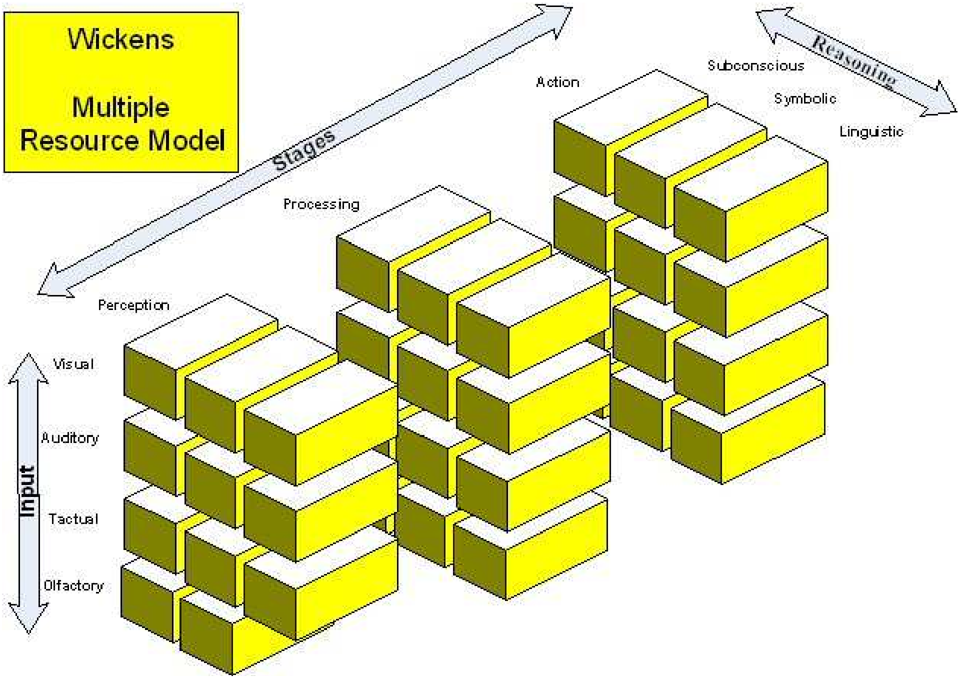


Figure 1. Wickens Multiple Resource Model. This figure illustrates processing stages and types of reasoning associated with sensory input. From "Multiple Resources and Performance Prediction," by C. D. Wickens, 2002, Theoretical Issues in Ergonomics Science, 3(2), p. 163. Copyright 2002, 1984 by Taylor & Francis. Adapted with permission.

According to multiple resource theory, when individuals perform cognitive tasks, there are several factors that influence successful outcomes that play a critical role in explaining task interference whether multiple tasks are being performed all at once, or in the performance of a single task in isolation (Wickens, 1990). Several explanations have been posited for dual task performance such as switching (Moray, 1986), confusion (Navon & Miller, 1987), and cooperation (Fracker & Wickens, 1989) asinformation processing rationale, when more than one task is being performed. As a result, there is a greater resource demand and performance, and one or both of the tasks will deteriorate due to the limited capacity and availability of processing resources (Wickens, 1990). If more effort is expended on a task, such an investment may improve task performance, and more effort is required to maintain a consistent performance level as task difficulty increases (Vidulich & Wickens, 1984, 1986). According to Wickens (1990), less difficult tasks require fewer resources to maintain a high level of performance (e.g., the retention of seven chunks vs. five chunks of information in working memory).

The resource concept is further manifested in the types of task, the input mode, stage of processing, and information processing codes. The Wickens multiple resource model prescribed that information processing efficiency is influenced by compatibilities between perceptual-cognitive activity and response processes. Depending on tasks demands, the efficiency of task performance involving perceptual-cognitive activity or response processes are subject to differences in timesharing. Different resources are assumed by researchers to be used for the processing of spatial and analog information than the processing of verbal and linguistic information and perpetuates a dichotomy applicable to perception, central processing, and response processes, and their input modalities (Wickens, 1990).

Researchers have also identified several dichotomies related to processing codes such as: 1) linguistic-symbolic vs spatial-analog (Baddeley, 1986; Polson, Wickens, Klapp, & Colle, 1989), 2) verbal (text and speech) vs. nonverbal material (spatial orientation, pictures, geometric shapes and symbols); and 3) central processing, and verbal and spatial working memory operations (Baddeley, 1986; Baddeley & Hitch, 1974; Gier et al., 2010; Wickens & Sandry, 1982). In addition, several researchers have shown a dichotomy of speech responses (a verbal code) with manual responses (a spatial code) whereby interference is greater between two manual tasks than between a verbal and a manual task (Martin, 1989; Wickens, 1980; Wickens, Sandry, & Vidulich, 1983). Thus, the multiple resource model researchers prescribed more of an interference effect between two tasks, if they both require spatial or verbal resources across or within a processing stage as opposed to between processing stages (Wickens, 1990; see Figure 2). It is interesting to note that the comparisons of code (verbal and spatial) and stage (perceptual/cognitive and response) includes the spatial code, while the multiple resource model (Wickens,1984) does not mention a spatial code or spatial tasks.

	Perceptual/Cognitive	**Response**
Verbal	Print reading Voice understanding Rehearsal Mental arithmetic Logical reasoning	Speech
Spatial	Velocity flow fields Spatial relations Mental rotation Image transformations	Manual control Keyboard presses

Figure 2. Dichotomization of stage- and code-defined resource by task type. This figure illustrates interference effects between verbal and spatial codes by the task performed cognitive stage and type of output. From "Multiple Resources and Performance Prediction", by C. D. Wickens, 2002, "Theoretical Issues in Ergonomics Science, 3(2), p. 169. Copyright 2002 by Taylor & Francis. Adapted with permission.

Attention, memory, resource allocation, and factors that mediate and modulate them have continued to be of interest and the focus of research in both cognitive psychology and neuroscience. Multiple resource theory is an important framework for this research because it can be used to assess critical concepts that provide insights into why, what, and how verbal and spatial information is sensitive to modes of input, task types, and stages of processing. However, other components and influences based on the environment, cortical regions of processing, and new communications media since its development are of interests for the study.

Since the pioneering works of numerous researchers (Atkinson & Shiffrin, 1968, 1971; Baddeley & Hitch, 1974; Beaman, 2005; Broadbent, 1958; Cattell, 1886; Kahneman, 1973; Miller, 1956; Navon & Gopher, 1979; Neisser, 1967, 1976, 1977; Norman & Bobrow, 1975; Shams & Seitz, 2008; Sperry, 1961; Stroop, 1935; Treisman & Gelade, 1980; Wickens, 1980, 1984, 1990), advances in computer and media technologies have produced additional distractions, interference and inhibitory effects on cognitive and information processing (Shams & Seitz, 2008).

Interference Theory

The research of Anderson (2003) and Muller and Pilzecker (1990) has established interference theory as the basis for understanding human working memory and the effects of interference in verbal and spatial serial recall task performance. When considering the processing of information in memory, Jenkins and Dallenbach (1924) provided evidence that everyday experiences interfere with memory, and that these memory traces decay over time (McGeoch, 1932). Recounting the experiments of Ebbinghaus (1885), Jenkins and Dallenbach (1924) argued that forgetting is a function of time that is initially rapid and gets progressively slower over time. For a series of nonsense syllables measured using the method of savings, researchers have reported that 41.8% is forgotten after an interval of 20 minutes, increasingly decaying over a week to 74%, and after 31 days 78.9% is forgotten (Jenkins & Dallenbach, 1924). The construct of forgetting resulted in researchers positing decay theory, which later became interference theory. Two types of interference defined by researchers were: a) retroactive interference (Muller & Pilzecker, 1990) which occurs when the recall of previously learned information is impeded by newly learned information, and b) proactive interference which occurs when new memories are affected by memory traces of prior learned material (Keppel & Underwood, 1962).

There is support in the literature for a strong connection between auditory interference effects and the level of cognitive performance in job-related and learning environments (Beaman, 2005, Kawashima & Sato, 2015; Murphy, Groeger, & Greene, 2016). Various sources of interference that impact task performance in our everyday lives have been identified by researchers. Beaman (2005) reported that irrelevant sounds in office and other workplaces have direct consequences on cognitive performance of young adults in serial recall tasks. Interference caused by irrelevant sounds in the workplace and other learning environments were believed by researchers to be disruptive and their effects were purported to be involuntary and occurs in a manner that is beyond an individual’s control. Contrary to dual-task cognitive performance where auditory distractions require focusing attention on the auditory stimuli, Cowan (1995) argued that the maintenance of a to-be-remembered verbal series is affected by irrelevant sound, and Salame & Baddeley (1982) contended that the irrelevant sound contaminated encoded material directly. As a practice, researchers have disclosed or informed the participant of the intended effect of extraneous noise that is to be considered irrelevant to the task. It is believed that such disclosures are confounding, but depends on the extent of the disclosure for the subsequent cognitive task performance (Shelton et al., 2009; Van Zoest, Hunt, & Kingstone, 2010).

Irrelevant sound has garnered considerable interest by human factors practitioners conducting applied cognitive research on auditory perception and immediate memory (Beaman, 2005; Cowan, 1995; Kawashima & Sato, 2015; Murphy, Groeger, & Greene, 2016; Salame & Baddeley (1982). The effects of extraneous speed and noise are the most salient and cited sources of disturbance and contributors of aviation accidents due to human error from distraction (Landström, Soderberg, Kjellberg, & Nordstrom, 2002). While empirical evidence regarding decreased responsivity upon repeated exposure to irrelevant speech as an auditory distraction is lacking, it is believed that irrelevant speech effects are impervious to temporal effects (Beaman, 2005). It is important to investigate the effects of irrelevant sound effects using the immediate serial recall paradigm because past research reported that there is little evidence of habituation in the short-term (Jones, Macken & Mosdell, 1997; Tremblay & Jones, 1998) or long-term (Ellermeir & Zimmer, 1997; Hellbruck, Kuwano, & Namba, 1996). However, recently other researchers have reported that foreknowledge reduces auditory distraction caused by irrelevant speech when remembering visually presented digits (Röer, Bell, & Buchner, 2013, 2015); and different magnitudes of disruption and allocations of attentional resources occur, depending on the frequency by which irrelevant words were used (Elliott & Briganti, 2012). Therefore, the type and specificity of knowledge given to participants may determine the short-term and long-term levels of habituation to irrelevant sounds in immediate serial recall paradigms, even if participants are instructed to ignore the sounds (Hughes & Jones, 2001; Page & Norris, 2003; Salame & Baddeley, 1982). A better understanding of interference may be gained by discussing the sources of interference.

Feature Integration Theory

Recently, the role of feature binding as it relates to the integration of different stimulus properties has been of interest by researchers (Bell, Roer, & Buchner, 2013; Delvenne, Cleeremans, & Laloyaux, 2010); DiLillo, 2012; Ecker, Mayberry, & Zimmer, 2013; Hu, Hitch, Baddeley, Zhang, & Allen, 2014).; Jaswal, 2012, 2013; Jaswal & Logie, 2013; Keizer, Hommel, & Lamme, 2015; Wolfe, 2012; Wyatte, Herd, Mingus, & O'Reilly, 2012). Treisman and Gelade (1980) put forth a hypothesis regarding the role of focused attention called the feature integration theory of attention that advocated that attention is a serial process which required the perceiver to separately focus on the conjunctive stimulus elements in a display when multiple features are needed to characterize or distinguish the objects presented. Several research paradigms that included the identification and localization of stimulus dimensions such as shape and color; and part-whole matching tasks involving lines, curves, and parts of objects as features integral to perceiving complex wholes were tested. As Gestalt psychologists (David Hume, Kurt Koffka, Max Wertheimer and Wolfgang Kohler) had previously claimed, Neisser (1976) and Treisman and Gelade (1980) supported the contention that perception of the whole object preceded perception of its parts, and later only if needed does an analysis of the component parts and properties of an object occur. However, this Gestaltist perspective was contrary to and was debated by Associationists (such as Plato, Aristotle, John Locke, John Stuart Mill, Pavlov and others) who believed that the perception of complex wholes was the result of associations between one mental state and its successive states and a combination of multiple elementary sensations (Timberlake, 1994). The feature integration theory further purported that a visual scene is coded based on separate dimensions such as color, orientation, spatial frequency, brightness, and direction of movement. The role of attention was believed to be the glue that integrates the individual features into one object, but as memory decays or is interfered with, the features were believed to persist and recombine into illusory conjunctions (Treisman, 1977).

Conceptual Framework

Unless attention is focused, integration of features is difficult, and the stimulus properties of color, size, brightness, and location are not perceived. However, no hypothesis regarding the temporal order of the stimulus properties or the processing of conjunctions of features were proposed. Are all of these features perceived pre-attentively and processed serially or are specific features, such as location initially the focus of attention, followed by stimulus dimensions? The debate of the process of feature-binding was aimed at understanding which features bind together, and its mechanism(s), and the result of the perception of features, if they are not integrated together (Jaswal, 2013). Jaswal (2012) has also argued that the relevance of features played a significant role in the feature-binding process. Other researchers (Keizer, Hommel, & Lamme, 2015) have emphasized that consciousness is not necessary for visual feature binding, and that features such as orientation and location were processed automatically.

According to Di Lollo (2012), there is not a binding problem that occurs when visual features such as color and orientation which are believed to be coded in separate brain regions, are integrated in a single perceptual experience. Di Lollo argued that when the binding problem was originally formulated, advances in neuroanatomy and neurophysiology had not disconfirmed the problem and that the feature-binding problem was ill-posed. The binding-problem was identified in 1981 by von der Malsburg based on the discovery of neurons in the primary visual cortex that responded selectively to color or orientation features. Di Lollo (2012) argued that since it is now known that the primary visual cortex performs coding for multiple features and not single features, the binding question has been rendered a moot point. Wolfe (2012), however disagreed with the contention of Di Lollo (2012), and argued that the binding problem is a real problem that is solved by selective attention in the visual system, and the error was how the binding problem was mapped onto the brain. Wolfe (2012) argued that it does not matter whether color or orientation are processed in separate parts of the brain, and depends on selective attention to accurately distinguish between them. Delvenne, Cleeremans, and Laloyaux (2010) have questioned the adequacy of attentional processes and investigated whether feature-bindings are maintained in visual short-term memory without the aid of sustained focused attention. In the Delvenne, Cleeremans, and Laloyaux (2010) study, memory for single color or shape features were compared to memory for the binding of color and shape of an object. Using a retro-cue, attention was directed and focused on a subset of memory items. Researchers have hypothesized that if the feature-bindings and not the individual features were maintained in memory through sustained focused attention, the retro-cue would not affect memory performance. The hypothesis was not supported because both memory for feature bindings and memory for individual features were improved, indicating that sustained focused attention is not needed to maintain feature bindings in visual short-term memory (Delvenne, Cleeremans, & Laloyaux, 2010). Understanding the role of interference, feature-binding, and the processing of object features are integral to part-whole matching tasks and the focus of this study.

Sources of Interference

Humans live in a multisensory environment whereby the sources of interference have evolved and grown exponentially since our earliest sensory experiences. Von Helmholtz (1911, 1925) claimed that the richness of our daily perceptual experiences are due to unconscious interference processes that precede retinal stimulation. Based on the state of domain knowledge of the effects of interference on information in several modalities, it could be argued that these unconscious interference processes are omnipresent in our environment and are applied prior to and subsequent to retinal stimulation (Gibson, 1966; Haber, 1969; Shams & Seitz, 2008).

Speech

Speech has been shown by researchers to be an auditory distractor with disruptive effects in tasks involving the serial-recall of verbal and spatial stimuli that are critical to air-traffic controllers and pilots when discerning identity or spatial location of air-traffic

(Colle, 1980; Tremblay, Parmentier, Hodgetts, Hughes, & Jones, 2012); an impairment in proofreading (Halin, Marsh, Haga, Homgren, & Sorqvist, 2013); reading comprehension (Oswald, Tremblay, & Jones, 2000); prose memory (Bell, Buchner, & Mund, 2008), and other job-related tasks (Banbury & Berry, 1997, 1998; Beamon, 2005). According to Colle (1980), speech noise required the recoding and storage of list items in auditory memory as a result of increased serial recall errors and masking by noise, during visual presentations. In everyday life, our environment contains auditory stimuli that is disruptive and often serves the purpose of being distractions rather than being helpful, depending on an individual's low or high working memory capacity (Halin, Marsh, Hellman, Hellstrom, & Sorqvist, 2014).

Further evidence of the effect of speech on cognitive performance supporting the "cocktail party" effect was reported by Kawashima and Sato (2015) which indicated differential reaction times in numerosity judgments. The cocktail party effect is the ability of the human sound system to extract, localize, and identity a single sound source of interest among mixtures of interfering sound sources (Wood & Cowan, 1995). The phenomenon of the cocktail party effect may have visual as well as auditory correlates and the underlying mechanisms for which the effect is manifested are still controversial and have been challenged by the late selection models of attention by Treisman (1969), Deutsch and Deutsch (1963), and Norman (1968). This phenomenon is exemplified by the scenario where an observer is situated at a table with several individuals in a conference room and others are talking while the observer is trying to listen to a presenter. In addition, there are several other tables with several individuals, and everyone is talking. The ability of the listener to process the verbal information provided by the presenter is reduced by auditory interference created by the speech produced in different spatial locations (near and far) by others in the conference room (Kawashima & Sato, 2015; Wood & Cowan, 1995). While this scenario is an example of how speech as an auditory source can have a negative impact on information processing, music as an auditory source has been shown to have a positive impact on the processing of information and on learning (Mammarella et al., 2007; Newman et al., 1995).

Music

Music as a mediator has been revealed as the “Mozart effect” (Newman et al., 1995) and the “Vivaldi effect” (Mammarella et al., 2007). Mammerella et al. (2007) used a repeated measure design using older adults to determine whether listening to Vivaldi’s “Four Seasons” had a positive impact on the cognitive performance of digit span and phonemic fluency under test conditions of classical music, white-noise, and no-music. Working memory performance was shown to increase in the classical music versus the no-music conditions, but no increase was shown as a result of white noise. The benefits of music on learning and health (Bennet, 2000) have been documented and other auditory stimuli such a speech, and various types of noise have been shown to affect cognitive performance in learning and memory tasks. During any cognitive or learning process, there are both relevant and irrelevant stimuli that require some level of attentional resources to be allocated (Wickens, 1984).

Listening to classical music has also been shown to improve spatial abilities in adults (Newman et al., 1995) and the cognitive abilities of 10- and 11-year olds

(Schellenberg & Hallam, 2005). Results researchers from neurobiological and animal studies have supported the positive effect of music on cognitive performance (Richard, Toukhsati, & Field, 2005), the effects of music and white noise on working memory performance in monkeys (Synnove, Rama, Artchakov, & Linnankoski, 1997), and the influence of music as a distractor on the cognitive performance of extroverts and introverts (Furnham & Allass, 1999). Research by Sorqvist (2010) revealed that there are individual differences regarding susceptibility to auditory distraction based on low or high working memory capacity, while Smith, Waters, & Jones (2010) suggested that prior exposure to noise and listening to Mozart produced improvements in spatial reasoning of young adults on a math task. Research has also shown that white noise acts as a moderator of cognitive performance and improves verbal free recall performance in inattentive school children (Söderlund et al., 2007, 2010). In addition to speech and music in workplace and learning environments, research has shown that noise affects the learning and memory performance in various ways (Beaman, 2005; Elliott, Morey, Morey, Eaves, Shelton, & Lutfi-Proctor, 2014; Gamble & Luck, 2011; Golumb, 2015; Roberts & Besner, 2005; Shams & Seitz, 2008).

Noise

Beaman (2005) has suggested that stricter attention to the effects of auditory interference may improve cognitive performance. In this 2005 study, the consequences for learning and the effects of noise in learning and workplace environments was investigated. In addition, the research specifically sought to identify what types of sound were most suitable for auditory warning signals, and assessed the impact of auditory distraction from low-intensity noise. Using the phenomenon known as the ‘irrelevant sound effect’ (Beaman & Jones, 1997, 1998) participants were tested in the performance of an immediate serial recall task and informed of exposure to noise that was irrelevant to the task being performed (Beaman, 2005). The participant’s control of the disruptive effects of the irrelevant sound was limited, but they were asked to try to ignore it. Banbury and Berry (2005), Beaman (2005), Beaman and Jones (1997, 1998), Elliott et al. (2014), Sparks (2015), Yeshurun and Marciano (2013) have also reported deficits in cognitive performance in immediate serial recall tasks as a consequence of the irrelevant sound effect. As Shams and Seitz (2008) has pointed out, studies of learning and specifically perceptual learning has had a unisensory focus, but our day-to-day perceptual experiences are multisensory. Since auditory distraction affects cognitive performance in unisensory as well as multisensory tasks, presets of a stimulus can be shown to exert influence on our perception of, or ability to respond to, the stimuli presented in another sensory modal (cross-modal) (Robinson & Sloutsky, 2013).

Auditory interference of various types has been documented to affect cognitive performance both positively and negatively. Recent research on the effects of noise has focused on the distracting effects of cellphones (Roer, Bell, & Buchner, 2013; Shelton, Elliott, Eaves, & Exner, 2009), noise effects in children (Klatte, Bergstrom, & Lachman, 2013), the consequences of prior exposure to office noise and music on working memory (Smith, Waters, & Jones 2010; Sorqvist, 2010), cultural differences and potential dangers for portable music player users (Levy, Fligor. Cutler, & Harushimana, 2013), and noise-induced hearing loss in call centers (Beyan, Demiral, Hikmet, & Ergor, 2016).

In the Roer et al. (2013) study, the disruptive effects of a ringing cell phone on short-term memory in a serial recall tasks were investigated. The 51 participants (31 women, 20 men) were asked to recall in serial order a list of numbers presented at different onsets under auditory distractor conditions (quiet, other ringtone, or their own ringtone). When a ringing phone was required to be ignored recall performance was worse, but gradually improved as compared to quiet conditions. The auditory distraction of a cell phone ringing captured the participant's attention and drew their attention away for the current task being performed. Shelton et al. (2009) also investigated the distracting effects of different types of noise (ringing cell phone, tones, and music (an instrumental song) on accuracy scores on a surprise quiz in a college classroom setting during a lecture with 158 psychology students. Results from the study revealed equally distracting effects on mean accuracy scores for each type of noise compared to controls in the quiet condition. These results have been corroborated with similar effects of exposure to music and office noise on working memory for math tasks (Smith, Waters, & Jones 2010) and the recall of individual elements of a sound sequence (Sorqvist, 2010). Our sensory experiences can be both unisensory under controlled conditions, but multisensory in everyday life. In the real-world environment in which we live, information is processed simultaneously by more than one sensory modality, and subjected to conditions of cross-modal attention and the division of attentional resources. The influence of cross-modal interference was also a focus for this research.

Cross-modal Attention

When tasks require the participant to attend to two or more types of sensory information simultaneously causing an unequal division of attentional resources, it is characterized as cross-modal attention (Chen, 2012). Deficits caused by cross-modal attention result in significant delays in reactions when distractions are cross-modal, and may result in dangerous situations such as what occurs when trying to use a cellphone while driving, endangering the driver, passengers, pedestrians, and other drivers (Gherri & Eimer, 2011). Research has indicated that attention is a limited resource that cannot be divided and tends to degrade the quality of attention during multitasking and divided attention (MacAluso, Frith, & Driver, 2002). When stimuli are presented in different sensory modalities and observed at the cellular level, neurophysiologists have argued that cross-modal processing may be an inappropriate term, in favor of "multisensory integration" (Driver & Noesselt, 2008; Morgan, DeAngelis, & Angelaki, 2008; Odgaard, Arieh, & Marks, 2003).

Our understanding of cross-modal attention facilitates better understanding of how we think and utilize our attention, and research has shown that reinforcing information in multiple modalities improved learning (Robinson & Sloutsky, 2013). Understanding the rules of cross-modal information processing and the integration of sensory information and its benefits have been promulgated and studied recently by several researchers (Ferris & Sarter, 2008; Marsh & Jones, 2010; Shams & Seitz, 2008; Spence and Ho, 2008; Spence, Senkowski, & Röder, 2009). Evidence from both multisensory and unisensory experiments (Bizley, Nodal, Bajo, Nelken, & King, 2007;

Ghazanfar, Maier, Hoffman, & Logothetis, 2005; Kayser, Logothetis, & Panzeri, 2010; Meyer, Salimpoor, Wu, Geary, & Menon, 2010) has shown that areas in the sensory cortices are sensitive to more than one modality, and may involve other cerebral zones as well. For example, during visual-only lip reading, the primary auditory cortex responds to lip position, and during auditory-only speech, responses are observed in visual face-sensitive areas (Kayser et al., 2010; Meyer et al., 2010; Schall, Kiebel, Maess & von Kriegstein, 2013). The literature also revealed similar effects on cognitive performance under conditions where the stimulus is degraded and perceptual load is low or high.

Stimulus Degradation

In a study by Yeshurun and Marcino (2013), the effects of perceptual load on distractor interference was investigated. The 18 participants were asked to respond as quickly and accurately as possible regarding the presence of a target letter in a circle of letters was either an X or an N, by clicking the letter using a keyboard. The luminance level of a gray letter on a black background defined the low-load-target-degraded (LLTD) and low-load-distractor-degraded (LLDD) conditions. A third low-load-both-degraded (LLBD) consisted of both the target and distractor displayed at the lowest luminance level (2 cd/m^2). The high-load-no-degradation (HLND) consisted of eight evenly spaced locations whereby the target letter was presented with several other letters, or alone. The study revealed that the degree of distractor interference is not dependent on task difficulty, and were apparent under all low load conditions despite stimulus degradation. Other researchers (Lavie & Fockert, 2003) have also found the same results, which seem to be prevalent in older adults during cognitive decline (Humes & Young, 2016).

In another study, Jennings (1977) conducted two experiments using solid and degraded hemi-circle stimuli to investigate the effects of stimulus degradation on the part-whole matching of geometric shapes, using fourteen female undergraduate psychology students. The 60 participants were asked to view a series of cards containing hemi-circles of different sizes that were degraded (solid, dotted, dashed) and to judge from the half-circle presented tachistoscopically, the whole circle in which they thought the half-circle was a part of. All stimuli were presented to the left or right of a center fixation point. The results of the study revealed that solid arcs produced better recognition accuracy than broken and dotted arcs, and a right visual field advantage for all stimulus types and sizes. This finding was contrary to the cerebral dominance literature (Nebes, 1971a, b) that geometric shapes and/or spatial stimuli should indicate a left visual field advantage. In addition, participants viewed the same stimuli under a masked ad non-masked condition. Again, a right visual field advantage was revealed for all stimulus types and sizes, although the overall performance was lower. The effects were explained as being due to a destructive effect of a post-exposure mask, and difficulty of stimulus processing as a result of a dark pre-exposure field followed by a bright flash which stopped or disrupted stimulus processing.

Other researchers have reported visual field contradictions manifested by a phenomenon where participants do not respond to an auditory stimulus when a visual stimulus is simultaneously presented, referred to the Colavita visual dominance effect (Colavita, 1982; Yue, Jiang, Li, Wang, & Chen, 2015).

Priming and Prior Knowledge in Visual Tasks

The results of cognitive performance measured by reaction time and accuracy has been shown to be affected by the timing of sensory input during cross-modal processing of visual and auditory information and has the effect of producing large effects when the irrelevant distractor occurs prior to an attended target (Donohue, Appelbaum, Park, Roberts, & Woldorff, 2013); during priming of task relevant and task-irrelevant shape or color feature information when the prime and target do not share the same spatial location (Michael, De Gardelle, & Summerfield, 2014); during semantic priming at various prime-target stimulus intervals (Dehaene, Naccache, Le Clec'H, Koechlin, Mueller, Dehaene-Lambertz, G., van de Moortele, & Le Bihan, 1998; Kristjánsson, & Jóhannesson, 2014; Schooler, Shiffrin, & Raaijmakers, 2001) and as a result of practice (MacLeod, 1991).

Van Zoest, Hunt, & Kingstone (2010) investigated representations of visual information based on the speed of stimulus presentation and reported that visual cognition relied on the dynamic or changing representations of visual information, and performance was impacted not only by the point in time that responses were measured, but the prior knowledge of specific aspects of the stimulus dramatically produced behavioral changes over time and salience of the stimuli in the visual field. Shelton et al. (2009) investigated the distracting effects of a ringing cell phone on cognitive performance, using different types of sound, including irrelevant tones and music commonly encountered by participants. When participants were warned that they would be distracted by a specific type of stimuli, participants recovered from the distraction more quickly, indicating that there was some benefit of prior knowledge on cognitive performance. The researchers concluded that their findings offered insight into top-down cognitive processing that moderated involuntary orienting responses that were commonly encountered in the classroom environment (Shelton et al., 2009).

It is believed that differences in cognitive performance in verbal tasks is the result of words being more readily recognized and named because humans have had more practice recognizing (or reading) word colors than the names of colors for the same words (Brown, 1915; Cattell, 1886; Stroop, 1935a, b, 1938), and has been demonstrated by researchers in the several studies (Durgin, 2000*;* Gregoire & Perruchet, & Poulin-Charronnat, 2013; Hamers, 1973; Kappes & Bermeitinger, 2016; Kawashima & Sato, 2015; Luo, & Proctor, 2016), auditory Stroop (Cohen & Martin, 1975; Hamers, 1973), spatial Stroop (Luo, & Proctor, 2016; MacLeod, 1991; White, Risko, & Besner, 2016). The framework for which verbal and spatial information processing occurs can be explained by the multicomponent memory model (Baddeley, 2000).

Multicomponent Memory Model

One of the most well-known models of memory is the Baddeley multi-component model. Its theoretical framework was derived from the Atkinson-Shiffrin memory model (Atkinson & Shiffrin, 1968, 1971), also known as the “modal model” asserted that human memory had three separate components: sensory register, short-term store, also called working memory or short-term memory, and a long-term store. (see Figure 3).

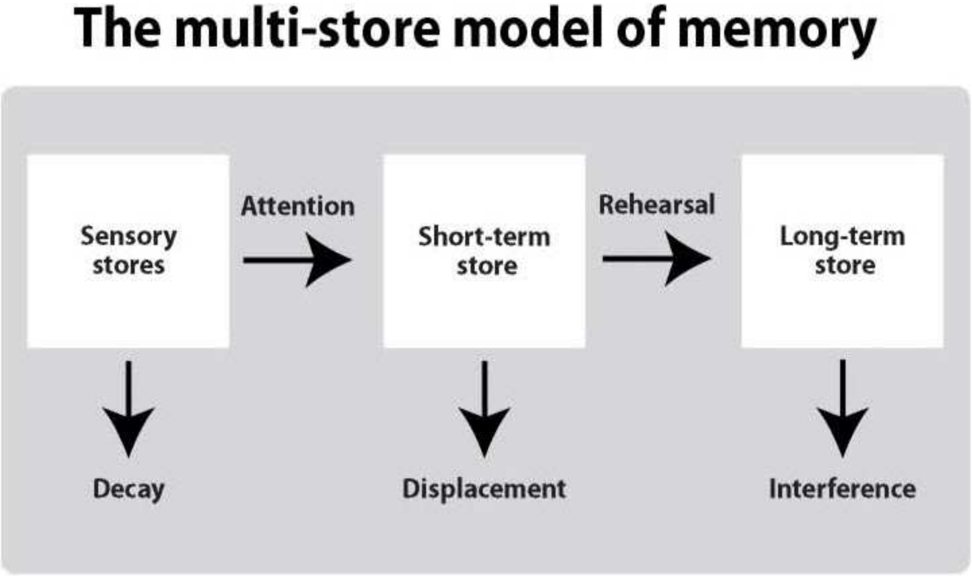


Figure 3. Atkinson-Shiffrin Memory Model. This figure illustrates the stages of information processing between human memory components. From “Working Memory: Theories, Models, and Controversies,” by A. Baddeley, 2000, Annual Review of Psychology, 63(1), p.18. Copyright 2012 by Annual Reviews. Reprinted with permission.

The Atkinson-Shiffrin memory model provided the context and theoretical framework used by the Baddeley multi-component model for how verbal and spatial information is encoded, interpreted, processed, stored, and retrieved. I have discussed that the Wickens multiple resource model prescribed that there was a limited and fixed capacity of resources an individual can use for information processing based on processing stage, code, and sensory modality (Wickens, 1984). According to Baddeley (2003), short-term or working memory stores and maintains information for a limited period of time, in support of thought processes involving long-term memory, perception and action (p. 829).

Over the period from 1974 to 2012, the Baddeley multi-component model evolved from a three-component model consisting of the egg-shaped central executive, visuo-spatial sketchpad, and phonological loop (see Figure 4) to a model that included long-term memory, or crystallized systems and fluid systems (see Figure 5), and finally a model that subsequently included a fourth component, the episodic buffer, which included a speculation of how information flowed from perception to working memory, executive functions, sensory modalities, and processes related to long-term memory (Baddeley, 2012).

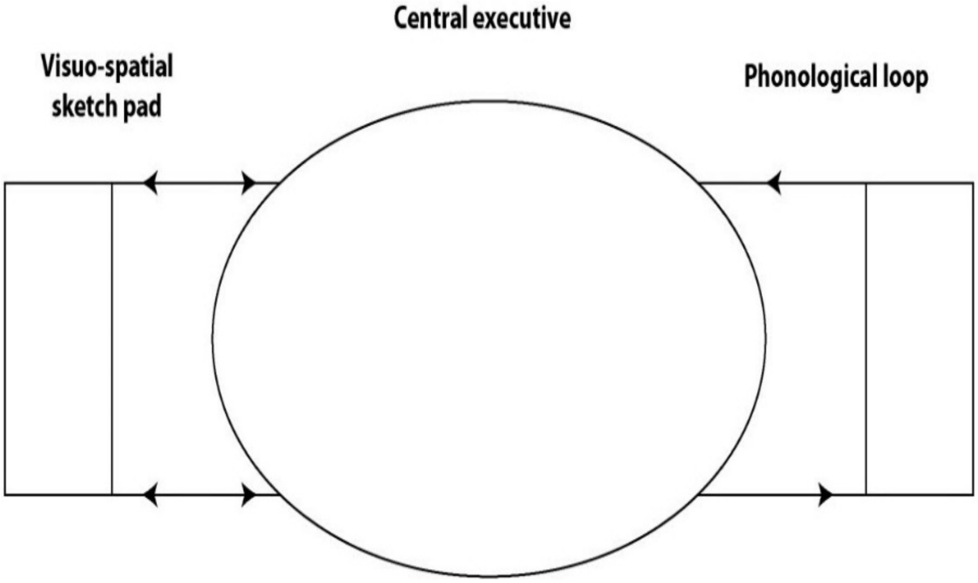


Figure 4. Original Baddeley & Hitch Working Memory Model. This figure illustrates the original three memory components of the model. From “Working Memory: Theories, Models, and Controversies,” by A. Baddeley, 2012, Annual Review of Psychology, 63(1), p.6. Copyright 2012 by Annual Reviews. Reprinted with permission.

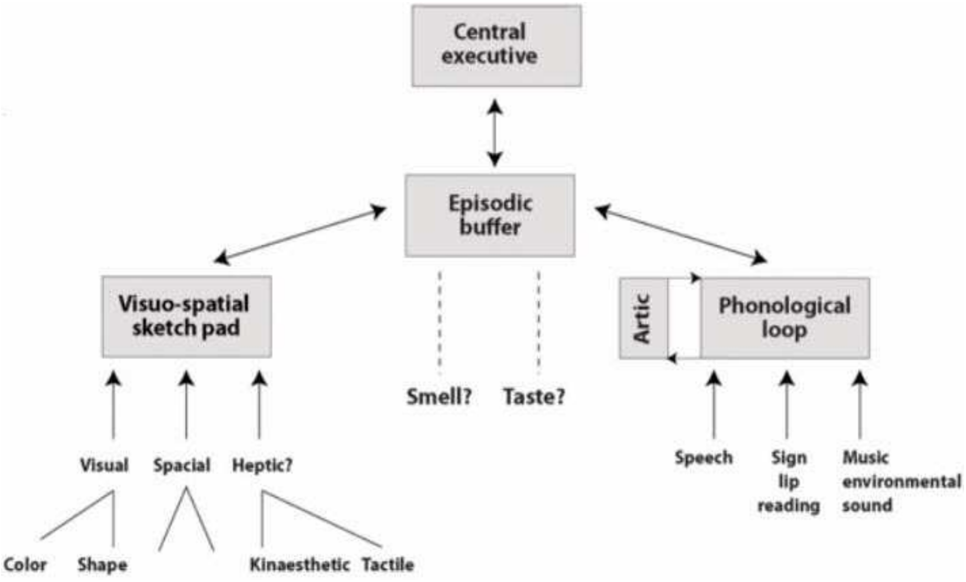


Figure 5. Revised Baddeley Multi-Component Model. This figure illustrates the addition of the episodic buffer as the fourth component of the memory model. From “Working Memory: Theories, Models, and Controversies,” by A. Baddeley, 2012, Annual Review of Psychology, 63(1), p.23. Copyright 2012 by Annual Reviews. Reprinted with permission.

The memory research of Alan Baddeley and his collaborators has been critical to our understanding of human cognition and memory processing, and this topic area continues to be of interest to the research community. What the evolution of memory and cognitive information processing models point out is that our basic knowledge of factors that governs our interactions with sensory modalities and information continues to change and most continue to be studied as new and more complex stimuli permeates our environment and influences how we sense, think, and process information.

In the study of mental processes, memory and attention are two of the most researched areas of cognitive psychology whose contributions have been integrated into various disciplines of psychology. The research of many psychologists has contributed to the body of knowledge on working memory, but a few are noteworthy to discuss. The concept of short-term and long-term memory was the idea of William James (Schultz, & Schultz, 2012). Research to quantify memory capacity was first attributed to the work of George Miller in 1956, whereby tasks related to immediate memory required participants to recall a set of digits, or labels for a stimulus, or to count a limited group of items rapidly to test attention span. These studies by researchers of memory capacity yielded a common metric of “seven plus or minus two”, and the concept of the “chunking” of information in order to efficiently process information in short-term memory (Miller, 1956).

The levels-of-processing theory of memory (Craik, & Lockhart, 1972) came into being in part as an answer to the Atkinson-Shiffrin memory model and the Baddeley multi-component model. Rather than focusing on the notions of storage and rehearsal, Craik and Lockhart emphasized the role of process in the development of long-term memory. The levels of processing model of memory claimed that deep levels of encoding of new material during learning process that is associated with previously learned material produces a greater ability to remember the new material when subsequently recalled (Craik & Lockhart, 1972). The Craik and Lockhart framework for memory encoding advocated a non-structured approach to memory, contrary to the structured, and the memory was not a uniform process, and in opposition to the Atkinson-Shiffrin memory model declared no difference between short-term and long-term memory (Craik & Lockhart, 1972).

Past research has provided many insights into how verbal, spatial, and auditory information has been processed in working memory, and has expounded upon its components and functioning. Allen, Baddeley, & Hitch (2006) focused on whether the binding of visual features is resource-demanding in working memory. Golomb (2015) showed that spatial attention played a critical role in feature binding, and when perceiving multiple objects or locations in our environment, attention was shifted or split between them resulting in various types of feature-binding errors.

Research by Allen, Baddeley and Hitch (2014) offered evidence for the existence of two attentional components related to early and later stage processing in visual working memory. Johnson, Hollingsworth, and Luck (2008) examined the role of attention in the maintenance of feature bindings in visual short-term memory, where participants attempted to detect changes in the colors and orientations of multiple colored geometric shapes. Li and Saiki (2015) investigated how feature- and location-based selection influenced visual working memory (VWM) encoding and maintenance, and found that color cues played a spatial role in the encoding of feature bindings. Nees and Walker (2013) showed the differences that occur in the executive function of working memory for encoding in a picture-sound verification task. The auditory interference variable has been shown to cause delays in the processing of visual information as well as verbal information similar to Beaman (2005). Nees and Walker (2014) showed that there were differences in the processing of verbal and spatial information in verbal, visuo-spatial, and auditory interference tasks. However, new evidence has shown that there are two (a language-based and an attention-based) mechanisms involved in the storage of verbal information in working memory, contrary to dichotomies promoted in the 1970's for short-term versus long-term maintenance by Baddeley and Hitch (1974).

Research has shown that visual and auditory distractions interfere with short-term memory processing (Banbury & Berry, 2005; Beaman, 2005; Schneider, Daneman, Murphy, & Kwong, 2000; Tun, O'Kane, & Wingfield, 2002) and has impacted plans to revise the structure of classroom and workplace environments and is believed to improve academic performance. Zhang and Luck (2011) explored the influence of the number and quality of representations in working memory. Similar to Luck and Vogel (2013), it was found that working memory capacity could be characterized as the limit of the number of items stored and is not based on the number and quality of the representation of stimulus attributes. All of these studies by scientists reflect the diversity of cognitive research, the contributions made to our basic understanding of working memory, and the relationships and processing that occurs in the prefrontal, parietal, and temporal cortices (D'Esposito, & Postle, 2015).

Hemispheric Lateralization and Cortical Mapping

Our continued research and understanding of the cognitive processing and neurological correlates of perceptual processes are critical and vital to the human genome itself. Advances in neuroscience has changed the way cognitive psychologists think about the structure of the brain and the underlying functionality of its cortical zones (Kosslyn & Miller, 2013). The past viewpoint of hemispheric lateralization still is a prominent philosophy of the mapping (Kosslyn & Miller, 2013) of brain function and the relationship between hemispheres, but recent research and efforts have now been promoted that emphasize cross-modal interaction and information-sharing between cortical zones due to advances in research methodologies in cognitive neuroscience. No longer is the left-brain, right-brain perspective of brain function as prominent as it was, and some researchers (Kosslyn & Miller, 2013; Lisman, 2015; Proulx, Brown, Pasqualotto, & Meijer, 2014) have published supporting documentation. In addition, recent efforts such as the $30 million NIH Blueprint: The human connectome project (NIH, 2010) to map the long-distance pathways of the brain in order to show how brain networks are organized; and the $46 million investment in neurotechnology by the Obama Administration, "The BRAIN Initiative" seeks to develop new technologies for studying the brain, and emphasize the continued importance and interests in cognitive research (Office of Science and Technology Policy (OSTP), 2015).

Hemispheric Differences

Traditional research in cognitive psychology has been based on the contention that the left and right hemispheres of the brain specialize and manifest unique abilities that are different from each other, also referred to as the lateralization of brain function. Early research on lateralization began with the research of Pierre Paul Broca in 1861, who noticed that damage to the left frontal lobe area of the brain (Broca's area) produced speech production deficits. Karl Wernicke later discovered that damage to the left posterior, superior temporal gyrus (Wernicke's area) cause deficits in language comprehension instead of speech production. Split brain patient research in the early 1960's by Michael Gazzaniga and Roger Sperry provided further understanding of lateralization of brain function, showing that reductions in bilateral brain communication occurred when the corpus callosum was severed. The prevailing premise has been that the left hemisphere specialized in verbal information processing, while the right hemisphere specialized in spatial information processing.

Researchers have shown hemispheric differences for language between left-handed and right-handed men and women (Josse & Tzourio-Mazoyer, 2004), recognition of verbal and nonverbal stimuli (Fontenot, 1973; Liederman, 1985). McKeever & Gil, 1972), word recognition (Brysbaert, Vitu, & Schroyens, 1996; Iacoboni & Zaidel, 1996), in Stroop paradigms (MacLeod, 1991), selective attention (Hubner, Steinhauser, & Lehle, 2010; Johnson & Dark, 1986), spatial stimuli (Bradshaw, Gates, & Patterson, 1976; Gross, 1972), and visual search (Madden & Nebes, 1980). Cerebral dominance effects in favor of the left hemisphere for verbal stimuli and the right hemisphere has been well documented in the literature, but recent studies by researchers have shown incongruency effects for the dominant hemisphere for the processing of geometric word-shape combination (Gier et al., 2010; Shomstein & Gottlieb, 2016; Sturz, Edwards & Boyer, 2014), and object feature perception in visual short-term memory (Sheremata, & Shomstein, 2014).

Retinotopic Mapping

Cortical or retinotopic mapping refers to a transformation of the visual image from the visual fields of the retina to Area 17 (V1) of the primary visual cortex. The correspondence between a given location in V1 and in the subjective visual field is very precise: even the blind spots are mapped into V1 (Trans Cranial Technologies, Ltd, 2012). It is notable that most of the studies by researchers on attention and hemispheric lateralization has utilized tasks which have projected verbal, auditory, and spatial stimuli to the left and right of a center fixation point within three to twelve degrees. Limited research using panoramic visual field presentations of verbal and spatial stimuli under conditions of auditory interference, with healthy humans has been uncovered, and was found to be mostly related to design of displays (Furness & Kocian, 1986; Mecklenborg, 1974), robotic vision (Argyros, Bekris, & Orphanoudakis, 2001), in animal studies with birds and insects (Lindemann, Kern, Michaelis, Meyer, Van Hateren, & Egelhaaf, 2003; Martin & Katzir, 1994), visual attention shifts during single and multiple location cueing (Wright, 1994); virtual spaces (Furness & Kocian, 1986; Koenderink, & van Doorn, 2008), and felines (Benedek, Eördegh, Chadaide, & Nagy, 2004; Nagy, Eördegh, & Benedek, 2003).

Anatomy and Limits of the Primary Visual Cortex

According to Dougherty, Koch, Brewer, Fischer, Modersitzki and Wandell (2003), correspondence between specific areas of the brain and the primary visual cortex (V1) are not clearly defined in the parastriate cortex (V2) and the peristriate cortices (V3) of the occipital lobe. While surface areas of V1 and V2 vary across subjects, the surface areas between V1 and V3 tends to diminish across subjects, and are believed to be a consequence of individual differences in the density of ganglion cells (Dougherty et al., 2003). Functional MRI estimates of cortical magnifications between the left and right hemispheres, using Functional MRI have revealed difficulties in measuring specific visual field representations other than those attained from a measure central within the visual field (Crivello, Schormann, Tzourio-Mazoyer, Roland, Zilles & Mazoyer, 2002).

Visual field projections using a cortical mapping of the surface of V1 has been shown to be representative of arcs spanning 2-4 degrees eccentrically to 10-12 degrees around the center fixation point (Dougherty et al., 2003). Stimuli projected 2-4 degrees eccentrically should be processed in area V1, proceeding saggitally to V2, then V3 toward the frontal lobe (see Figure 6) (Connolly & Van Essen, 1984). For visual working memory, it has been found that storage is limited, and the neuroanatomical basis for the limitations were related to cortical size and thickness of the gray matter of the primary visual cortex (Bergmann, Genc, Kohler, Singer, & Pearson, 2016).

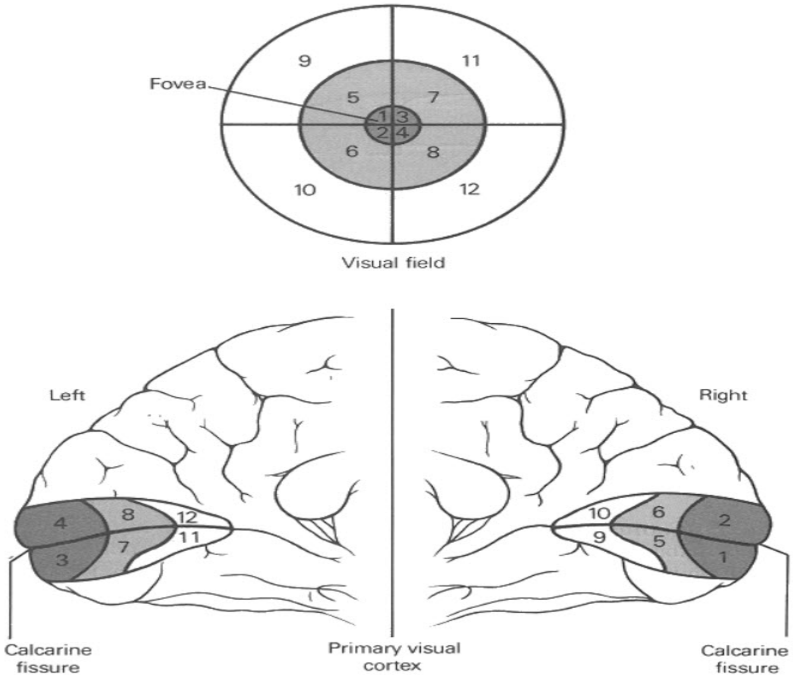


Figure 6. Retinotopic mapping of the left and right hemisphere of the primary visual cortex. This figure illustrates the visual field projections for visual input spanning 2-4 degrees eccentrically to 10-12 degrees around the center fixation point. From “The Representation of the Visual Field in the Parvicellular and Magnocellular Layers of the Lateral Geniculate Nucleus in the Macaque Monkey,” by M. Connolly & D. Van Essen, 1984, *The Journal of Comparative Neurology, 226*(4), p.18. Copyright 1984 by Wiley Online Library. Reprinted with permission.

Visuo-Spatial Working Memory

Visuo-spatial tasks are dependent on visual short-term memory (VSTM). According to several researchers (Baddeley, 1986; Baddeley & Hitch, 1974; Luck & Vogel, 1997), there is a difference between visual-short-term memory and verbal short-term memory. The capacity of verbal short-term memory involves temporary storage of only a few milliseconds (Phillips, 1974; Sperling, 1960, 1963), while VSTM has a temporary storage of a few seconds, and is independent of retinotopic location (Pashler, 1988; Phillips, 1974). Both verbal short-term memory and VSTM storage capacity are limited to about four visual items (Luck & Vogel, 1997; Pashler, 1988). Miller (1956), however Miller (1956) posited that seven items is the limit of our short-term memory capacity. Since Broadbent (1958) presented the notion of a limited-capacity channel, other researchers like Waugh and Norman (1965) favored the storage interpretation of Miller (1956) and the multistore model of Atkinson and Shiffrin (1971). Visual working memory is essential for maintaining the essence of a visual scene, once it disappears (Baddeley, 2003), but temporary storage capacity reflects individual variance and is limited by neuroanatomical differences (Bergmann et al., 2016). Other interpretations of memory capacity advocated the importance of attention, whereby the level of difficulty of a task determined the amount of resources allocated for the processing of stimuli (Lavie, 2010; Lavie, Hirst, de Fockert, & Viding, 2004). While other researchers have argued that individual variances in the size of the V1 surface are associated with visual illusion strength (Schwarzkopf & Rees, 2013), spatial orientation sensitivity (Song, Schwarzkopf, & Rees, 2013), the number of items that can be remembered (Franconeri, Alvarez, & Cavanagh, 2013), memory allocated for representing individual visual patterns, all of the research has been attributed to the presence of larger glia and thicker primary visual cortices in individuals (Han, et al., 2013; Oberheim, Goldman, & Nedergaard, 2012; Elvsåshagen et al., 2014). Over four decades of psychological research conducted to investigate the effects of perceptual load on distractor perception based on early selection and late selection contended that attention prevents processing of irrelevant distractors, or that memory or response selections were only affected in later phases of perceptual processing (Duncan, 1980; Treisman, 1969). Late selection is apparent in the filtering of attention during Stroop tasks where participants process the semantic meaning of word, but cannot ignore irrelevant stimuli during color naming tasks (Stroop, 1935, MacLeod, 1991).

Stroop Paradigms

Original Stroop Effect

The original foundations for the Stroop (1935) test date back the work of Cattell (1886) who reported a longer latency for the naming of objects (and colors) to be spoken aloud than their names took to read aloud. The contention that words can be recognized and named more readily is based on the fact that humans have had more practice recognizing (or reading) the color of words than naming the color of the same word (Brown, 1915; Cattell, 1886). According to Brown (1915) and Lund (1927), differences in speed for word reading and color naming do not rely on practice, but different association processing involved in color naming and the reading of printed words. The studies prior to the Stroop (1935b) study by researchers investigated color naming and word-reading times under different levels of practice, and showed that color-naming performance was a consequence of two processes and benefited from extended practice depending on age (Brown, 1915; Ligon, 1932; and Lund, 1927). Hollingworth (1912, 1915, 1923) refuted the differential-practice hypothesis and claimed different processes were at work such as the requirement for articulation for word reading only, and the need for both articulation and association for color naming. Brown (1915) and Ligon (1932) maintained that both tasks involved two processes but with a different association element for each test. Ligon (1932) developed a three-factor theory (school grade, color naming and word reading), using 638 pupils in school grades 1 to 9 inclusive comparing the results of color naming and the reading of color names. The results from the Ligon (1932) study revealed mean differences between school grades for which time scores were more than twice as great in third grade as in first grade; more than three times as great in fifth grade compared to first grade; and approximately four times as great in the eighth and ninth grade compared to first grade. The Stroop (1935b) study was the first study to combine colors and words and was basically motivated by the need to explain interference between conflicting processes, while still considering the effect of practice, age and gender differences, and the congruency-incongruency phenomenon (MacLeod, 1991). The Stroop (1935) study not only revealed interference effects, but differences and superior performance of women over men and during practice trials. Time scores were significantly lowered as a result of days of practice, and it was concluded that differences in speed in the reading of colors and in color naming could be accounted for by practice effects and the length of training (Stroop, 1935).

The Stroop effect has been used for a variety of applications, but is most utilized to measure selective attention as a diagnostic tool for patients with psychological pathologies, such as schizophrenia, attention deficit hyperactivity disorder, where interference is prevalent due to neurodegenerative diseases or brain injury (Gazzaniga, M., Ivry, R., & Mangun, G, 2009). The Stroop test is also of value for evaluating executive functions, speed of processing and cognitive performance using verbal and spatial stimuli (Dyer, 1972, 1973a-d; Geng, Schnur, & Janssen, 2014; Gier et al., 2010; Guest, Howard, Brown, & Gleeson, 2015; MacLeod, 1991; Van der Heijden, 2016).

Stroop Variations

Since the research of Stroop (1935a, b, 1938), the Stroop effect has been demonstrated in several variations such as the music Stroop (Gregoire & Perruchet, & Poulin-Charronnat, 2013), emotional Stroop (Kappes & Bermeitinger, 2016), auditory Stroop (Cohen & Martin, 1975; Hamers, 1973), spatial Stroop (Luo, & Proctor, 2016), semantic Stroop (White, Risko, & Besner, 2016), numerical Stroop (Kawashima & Sato, 2015), the reverse Stroop (Durgin, 2000), and congruency-incongruency based on cross-attribute matching and correspondence between irrelevant stimuli and combined relevant stimuli (Dyer, 1972, 1973a-d; Treisman & Fearnley, 1969). The findings from these studies and those of Dyer (1972, 1973a-d) and Treisman and Fearnley (1969) documented interference effects mostly in the processing of colors and words, but were extended to different types of stimuli, as indicated above (MacLeod, 1991). While the focus of this research is not the auditory, spatial Stroop, or other Stroop test variations, the research findings from the auditory and spatial Stroop tests may have relevance from a cognitive processing perspective for the use and investigation of the word/shape Stroop; and size and shape perception.

Auditory Stroop

In a study by Cohen and Martin (1975), right-handed participants were required to judge the pitch of pure tones of different frequencies, and congruent and incongruent words at high and low frequencies. The sequence of the stimuli was presented monaurally to the left and right hemispheres non-dichotically. A Stroop effect was produced when the stimuli were presented to the left hemisphere, and was larger for the right ear. However, when the stimuli were presented dichotically with a competing message to the opposite ear, the Stroop effect was larger for the right ear. Cognitive performance measured by reaction time and accuracy has been shown to be affected by the timing of sensory input during cross-modal processing of visual and auditory information and has the effect of producing large effects when the irrelevant distractor occurs prior to an attended target (Donohue, Appelbaum, Park, Roberts, & Woldorff, 2013). Other disparities and differences in the processing of auditory information have been argued to be dependent on age differences (Beamon, 2005; Elliot et al. 2016; Klatte, Lachman, Schlittmeier, & Hellbruck, 2010; Lewandowsky & Oberauer, 2015).

Word/Shape Stroop

Previous research has also revealed incongruency effects when geometric words and shapes were presented in the same visual field, and proposed a greater incongruency effect for stimuli presented to the left-visual field/right hemisphere (LVF/RH) for shapes, and the right-visual field/left hemisphere (RVF/LH) for words (Gier et al., 2010). In the

Weekes and Zaidel's (1996) Stroop-like task, a color patch and a color word was presented either in the same visual field or in separate visual fields. The results showed the strongest Stroop effect when the word and patch were both in the RVF/LH, demonstrating interfering effects of words with color. The performance differences due to stimulus type and visual field presentation, we based on the assumption that responses to words are faster when presented to the dominant right hemisphere. This assumption and finding was found to be consistent with the research of Weekes and Zaidel (1996) and others (David, 1992; Dyer, 1973; Tsao, Feustel, & Soseos, 1979). Researcher have reported that enhanced performance was realized when the processing of word and shape stimuli was divided between the hemispheres (Banich & Belger, 1990; Davis & Schmit, 1971, 1973), while no enhanced performance has been reported by other researchers (Bradshaw, Nettleton, & Patterson, 1973; Liederman, 1985; Liederman, Merola & Martinez, 1985). The Gier et al., (2010) study was the first variation of the original Stroop test to investigate whether interference effects were different for the properties of words and shapes when displayed in different visual fields. However, similar Stroop-like performance under different types of multisensory and cognitive load has yet to be studied. In addition, results of cognitive performance related to spatial dimensions may also be relevant and provide additional insight.

Spatial Stroop

The Simon effect that was obtained with the words left and right as the task-relevant stimulus dimension that has been attributed to the automatic processing of task-irrelevant spatial information. Luo and Proctor (2016) demonstrated that in a two-choice spatial reaction task where there is a one-to-one correspondence between a left and right keypress with a left and right stimulus location, response times tended to be faster and more accurate when the mapping was congruent versus congruent reflecting the Simon effect. Although, there has been inconsistent use of terminology for such tasks, researchers have verified faster responses times and the spatial Stroop effect for task-irrelevant information and color-shape attributes (Georgiou-Karistianis, Akhlaghi, Corben, Delatycki, Storey, Bradshaw, & Egan, 2012; Lu & Proctor, 1995; Simon, 1990). Research investigating the temporal processing order of spatial location versus the object features has also been the subject of spatial information processing. One of the theories related to this study and to the integration of object feature and their attributes is feature integration theory (Treisman and Gelade, 1980).

Part-Whole Matching

A study by Crafts (1932), investigated the part-whole research paradigm in five experiments, exploring whole and part methods with visual spatial material for its value, difficulty, unity, coherence, and impact of the efficiency of learning. Participants (*N* = 305, undergraduate men and women psychology students) were given a diagram of a large number of black points arranged symmetrically on a white background. There were pairs of points connected by black lines vertically, horizontally, or diagonally. After practice was given for a period of 120 second to learn the exact location of each of the lines on the diagram. Before testing, the cardboards containing the diagrams to be learned were concealed. When exposed, the diagrams were presented using three presentation methods: a) as a whole, b) by parts, or c) by a combination of parts. Using methodology described as whole, pure part, combination part, and progressive part, circles, lines and figures were used with different exposure times and sequences of the parts. Results of the study indicated that the whole method was superior to either of the part methods for learning the circles and figures, but were independent of exposure time. None of the part methods were superior to another for circles, lines, or figures. It is of note that only solid circles, lines, and figures were used in the study without any degradation of the stimuli.

Nebes (1971a) investigated the part-whole matching task using patients with cerebral commissurotomy, in order to explore the capacity of the left and right hemispheres to determine which of three sizes of whole circles, a given arc corresponded to. In the study, controls also matched circles to circles and arcs to arcs. The results indicated that left-handed participants were superior to right-handed participants when using their dominant hand to match the arcs to the corresponding size of the circles. However, in the control condition, both left and right hands performed equally, when like stimuli were matched. Commissurotomized patients were not able to cross match the stimuli, which indicated a left-hand advantage and superiority of the right hemisphere for matching a partial shape stimulus to its whole (Nebes, 1971a). Does the right hemisphere superiority still exist for normal participants under auditory interference and cognitive load is the focus of Experiment 3.

Nebes (1971b) further investigated the part-whole matching task and the ability of left and right-handed participants to perceive part-whole relations, but had participants examine an arc haptically, and select visually, the corresponding whole circle from which the arc belonged. The results of the Nebes (1971a) study had revealed a right hemisphere superiority and left-hand advantage, but with split-brains without bilateral communication. The results of the Nebes (1971b) indicated that right-handers with intact brains performed significantly better than left handers. However, the superior performance of right handers was reflected only on the part-whole matching, and not when matching wholes to wholes or parts to parts.

Jennings (1977) extended the Nebes (1971b) study and investigated the part-whole matching task with normal individuals, and presented stimuli tachistoscopically, under conditions of visual backward masking and stimulus degradation. Two experiments were conducted to investigate factors, other than handedness, which might affect the perception and registration of size and curvature in normal dextral subjects. Solid and degraded hemi-circles were presented to the left and right of a fixation point and the subjects were required to match an arc to the appropriate size of circle. In Experiment 1, the proportion of correct responses indicated a RVF advantage for all arc sizes. In Experiment 2, the same arc sizes were combined with three stimulus types (solid, broken and dotted) under two post-mask conditions. Solid arcs produced superior matching performance over broken and dotted arcs. In both the masked and non-masked conditions, again there was a RVF advantage for all stimulus types indicating left hemisphere superiority. Recognition accuracy performance was significantly reduced for all stimulus types, in the masked condition, with visual backward masking. The results corroborated the findings of Nebes (197a, b) and were related to differential hemispheric ability, the processes of metacontrol, and stimulus manipulations. Further investigation of the part-whole matching paradigm using more modern presentation techniques, stimulus manipulations, and interference effects should provide new and interesting constructs for deliberation.

Implications of Past Research

Past literature by researchers has shown that the field of cognitive psychology and cognitive neuroscience has many facets and has continued to evolve and consolidate our understanding of perceptual processes. Research by Wickens (1984) has shown that our attentional and sensory processes are subject to difference factors that determine the efficiency and proficiency for which information is processed. A sensory input in one sensory modality may impact the processing of information in another sensory modality, and depends on task dimensions which may or may not be relevant to the task at hand. The idea that attention is a single pool of resources which are a source of competition between attention and cognitive processing was first proposed by Kahneman (1973). Navon and Gopher (1979) proposed the concept of multiple resources whereby cognitive resources are deployed in combination to perform tasks. Wickens (1984) building upon the work of Kahneman (1973), and Navon and Gopher (1979) suggested that attention is a multiple resource with different attributes. Multiple resource theory prescribed that there are a limited and fixed capacity of resources an individual can use for information processing based on processing stage, code, and sensory modality. Although multiple resource theory is a human factors and applied psychology theory, and has mostly been cited as the standard for the design of user interfaces and complex systems, it has value for understanding that there are a limited and fixed capacity of resources an individual can use for information processing based on processing stage, code, and sensory modality (Kramer, Wiegmann, & Kirlik, 2007; Wickens, 2007).

An understanding of the capacities and properties of working memory and the limits of multimodal information processing has been the continued interests of researchers in neuroscience and cognitive psychology (Reprovs & Baddeley, 2006). Over the period from 1974 to 2012, the Baddeley multi-component model evolved from a three-component model, based on the Atkinson and Shiffrin (1968, 1971) modal model, to a four-component model consisting of the egg-shaped central executive, visuo-spatial sketchpad, and phonological loop. The Baddeley multi-component model has significance for helping to initially explain the capacities and processing of verbal and spatial information in the environment handled by short-term (working) memory and long-term memory processes in the prefrontal, parietal, and association cortices Breedlove, Watson, & Rosenzweig, 2013).

Working memory and attention are processes at the core of what we mean when we say we are "thinking." Understanding the nature of representations held in working memory is of fundamental importance for understanding the limits to conscious cognition. The concept of working memory often includes both the short-term maintenance of task-relevant information and the active rehearsal and manipulation of this information (Cohen et al., 1997; Smith & Jonides, 1999). Much of mental life involves the manipulation of relations and associations within complex entities ranging from perceptual objects and images to abstract propositions. The mechanisms that maintain these associations or bindings within working memory are essential to efficient functioning (Wheeler & Treisman, 2002).

Previous researchers have posited that cognitive processing entails communication from all areas of the brain in a synergism of neural communications "whole-brain processing" (Kosslyn & Miller, 2013), providing insights to spatial processing in the dorsal or "where" stream and object processing in the ventral or "what" stream (Claffey, 2013; Dougherty et al., 2003; Gilbert & Li, 2013) (see Figure 7). The research of these authors used panoramic stimulus presentations and suggested that visual projections to the lower left and right visual fields should process spatial information such as location more readily in the parietal cortex, and visual projections to the upper left and right visual fields should process object features such as color, shape, and size more readily in the frontal cortex. In light of modern day visual display designs, panoramic visual field projections of shape stimuli may provide some answers to the credulity of these assertions, and further insights to verbal and spatial information processing.

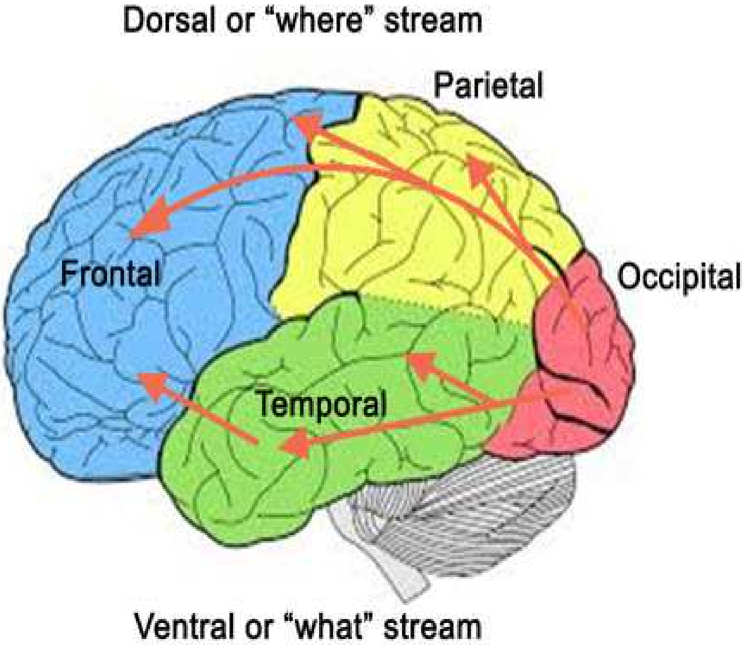


Figure 7. Spatial and object information processing in the dorsal or "where" and ventral or "what" streams in the brain. This figure illustrates the two main channels or "streams" by which visual information exits the occipital lobe.

Past studies by researchers on interference (Ebbinghaus, 1885; Jenkins & Dallenbach, 1924; and McGeoch, 1932) were the basis for proposing interference theory (Anderson, 2003; Muller & Pilzecker, 1990), our continued understanding and interests in the research of human working memory (Baddeley, 2003, 2012), and the effects of interference in verbal and spatial serial recall task performance (MacLeod, 1991, Wickens, 2002, 2004, 2007). Interference has been shown by researchers to influence cognitive performance in verbal tasks and spatial tasks, and research continues to explore the cortical mapping of cognitive functions, multimodal cognitive processing, and what defines the limits of working memory capacity (Oberauer et al., 2016). Studying how people learn and use spatial information is essential to developing spatial skills, navigating the environment, and detecting the location and proximity of dangerous or friendly targets (Newcombe, 2016).

MacLeod (1991) revealed that of the over 400 studies on interference in the Stroop Color-Word Interference Test (Stroop, 1935b), limited research investigating the congruency-incongruency effect of word and shape stimuli under conditions of cross-modal resource conflict, attentional capture, and different types of auditory interference has been conducted over the past 50 years. The pervasiveness of auditory stimuli (such as speech, music, and noise) in our environment and its effect on the processing of verbal and spatial information has not been the primary focus of researchers. Studies have investigated the effect of irrelevant auditory stimuli as an independent as it occurs and impacts auditory perception and working memory (known as the irrelevant sound phenomenon), and has garnered considerable theoretical interests for human factors and cognitive research (Beamon, 2005). Speech and noise has also been of interests of researchers as a source of disturbance in the workplace (Landström, Soderberg, Kjellberg, & Nordstrom, 2002), and has been shown to cause deficits in learning when comparing quiet versus noisy workplace and classroom environments (Beaman, 2005; Evans & Johnson, 2000). It is believed by researchers that reductions in auditory interference would mediate improvements in academic performance in the workplace, school rooms, open offices, group situations, conference meeting area and produce lesser cognitive errors (Chapplelow (1999) as cited in Beamon, 2005).

Summary and Transition

The current doctoral study has been informed by the studies of previous cognitive researchers and will attempt to add value to the literature by addressing several cognitive phenomena in verbal and spatial learning and perception under the confluence of auditory interference. Several areas of research were found to be relevant and related to this study, but studies by researchers that were tangential to the phenomenon under study had to be eliminated. In this study, I explored research in the areas of working memory and capacity, hemispheric lateralization, neuroanatomy of the primary visual cortices, and various sources and influences of auditory interference. Several theoretical frameworks by researchers on multiple resource theory, interference theory, attention and memory models, and various aspects of verbal and spatial information processing provided the context and foundations for building the experimental paradigms for investigation.

I examined studies on the attentional resources of the human brain that suggested our short working memory capacity is limited to around 5 to 7 items (Miller, 1956), can be influenced by both visual and auditory distractors (Beamon, 2005; Kawashima and Sato (2015), depends on unisensory or multisensory task performance (Robinson & Sloutsky, 2013;Shams & Seitz, 2010; Wickens, 1984), prior knowledge and practice effects, and task relevancy (Dehaene et al., 1998; Donohue et al., 2013; Kristjánsson, & Jóhannesson, 2014; Michael, De Gardelle, & Summerfield, 2014; Stroop, 1935), and even the shape and size of the surface of an individual's brain regions (Bergmann, 2016; Claffey, 2013; Dougherty et al., 2003). I designed this doctoral study based upon a review of existing psychological literature in the areas of verbal, auditory, and spatial information processing; and memory and attention.

In Chapter 3, I discussed the research methodology, setting and sample, instrumentation, experimental procedures, data collection and analysis that were used to conduct the study, along with ethical considerations. I summarized the statistical results for all experiments, the main effects and interactions of all independent and dependent variables in Chapter 4. Summaries, conclusions, and recommendations were provided in Chapter 5.

Chapter 3: Research Method

Overview

In this chapter, I provided the foundation of the study, the research design, a description of the target population, the sampling and sampling procedures, apparatus and instruments used, data collection and analysis procedures, and how I addressed ethical concerns. The rationale for the research design and why the design was most appropriate for the study was provided. Three quantitative experiments were conducted.

In Experiment 1, I explored a Stroop variation to examine the effect of different types of auditory interference and stimulus degradation on the cognitive performance (reaction time and recognition accuracy) in a Stroop paradigm. In Experiment 2, I investigated whether the perception of object size and spatial location is influenced by cross-modal interference. In Experiment 3, I examined the effects of different types of auditory interference on the reaction time and recognition accuracy of the perception of the size of degraded geometric shapes, and explored geometric shape sizes projected tachistoscopically and differently than those in the Jennings (1977) study. The results of these three experiments provided insight in the effects of auditory interference on verbal and spatial information for the Stroop test, and the processing of objects and their features in part-whole matching tasks.

Purpose

My intent for this study was to examine: a) the effects of auditory interference on cognitive performance (reaction time and recognition accuracy) for selective attention and working memory, under conditions of attentional capture and cross-modal interference; b) resource limitations and cross-modal effects on selective attention during the performance of Stroop- and Stroop like recall and recognition tasks; and c) the effects of auditory interference and stimulus degradation on cognitive performance for words and geometric shapes.

Research Design

In this study, I sought to understand the effects of common sources of interference for the processing of a) degraded colored-words characteristic of the original Stroop test to demonstrate the Stroop effect; b) features and spatial locations of geometric shapes; and c) the size, shape, and location of part-whole relationships of geometric shapes. I used a quantitative approach that seeks to investigate differences in the mean reaction times and recognition accuracy scores (the dependent variables) of two or more groups. The research design was a within-subjects experimental design consisting of three levels (speech, music, and noise) of auditory interference (independent variable 1) and three levels (solid/none, dashed, or dotted) of stimulus degradation (independent variable 2), using the univariate ANOVA and one-way MANOVA statistical procedures.

The within-subjects experimental design was most appropriate for this study because it allowed me to compare and assess the cognitive performance of different groups of participants based on different sources of auditory interference. For the Stroop effect, researchers have confirmed that there are no differences in performance between men and women (Stroop, 1935b). I deferred an assessment of between-subject factors, due to the need to use convenience sampling. In addition, a within-subjects design allowed testing each participant at each level of the independent variables.

Setting and Sample

Setting. I conducted the research in a private and secure research facility located in Alexandria, Virginia during nonduty work hours, between 6 pm and 9 pm, Monday through Friday. I was the only research personnel for this study. Study participants were escorted to the study location and personally supervised. Permission to use the usability laboratory situated at the United States Patent and Trademark Office in Alexandria, Virginia was received from the Office of the Chief Information Officer to conduct the study with the sample population in accordance with Department of Commerce Order DAO 217-19.

Participants. The target population for the study consisted of 24 adult men and women between the ages of 18 and 60 years, who reside in the Greater Alexandria and Washington, D.C. areas, and I selected participants using convenience sampling. The approximate estimate in the D.C and Alexandria, Virginia area was estimated to be 139,966 (67,262 men, or 48.05% and 72, 704 women, or 51.95%). I selected study participants according to the following inclusion criteria: a) speak English b) reside in the Greater Alexandria and Washington, D. C. areas; c) male or female gender; d) between the ages of 18 and 60 years; e) right-handed; f) possess a visual acuity of normal (20/20) or corrected or near normal vision (between 20/32 and 20/63); g) possess normal color vision; have a high school diploma or equivalent education; and h) not hearing-impaired. Participants not meeting the inclusion criteria were excluded from participation in the study.

Sample Size. I conducted a power analysis to determine the total number of participants needed for the study, with the goal of achieving no less than 80% statistical power, at an alpha level of .05. I used GPower settings with test family = *F* tests, statistical tests = MANOVA: global effects, effect size F^2 (V) = 0. 35, alpha (α) = 0.05, power = 0.80, number of groups = 2, and response variables = 2, the total sample size = 24, for Experiment 1. The results of the GPower analysis were interpreted as requiring 12 participants per group. For Experiments 2 and 3, with the same GPower settings, however with number of groups = two, the total sample size = 24. The results of the GPower analysis were interpreted as requiring 12 participants per group. By recruiting total *N* = 40, the recruitment process allowed for attrition. My estimates were based on G Power calculations, with_small effect = 0.10, medium effect = 0.25, and large effect = 0.40 (Faul et al., 2013).

Selection Procedures. I selected participants based on the verification of the inclusion criteria with specific focus on hand dominance, normal visual acuity and color vision, and hearing. Each participant provided demographic information using the participant approval form (see Appendix A). The participation approval form I used allowed a verbal attestation of vision quality, handedness, hearing, and personal identifiable information by the participant, and informed the participant that their participation was voluntary. I further informed participants that information would be held confidential and used for research purposes only, and a paid incentive would be provided for their participation in the research study. Participants were required to complete and sign an informed consent form for study participation and the mitigation of risks and indemnification.

Prior to experimental trials, each participant was required to stand approximately 10 feet or more away and read letters from a Snellen eye chart (see Appendix D) mounted on a wall, to assess hyperopia (nearsightedness) and visual acuity. Participants were asked to cover one eye and read line eight of the chart for 20/20 vision one time forward, and one time backwards.

Following the vision test, I assessed handedness by using the Edinburgh handedness inventory (Oldfield, 1971) to determine the participants' hand dominance. Upon successful verification of visual acuity and handedness, participants were administered the free online hearing test (a 5-step speech-in-noise test) to fulfill the hearing assessment and requirement (Hear-it.org, 1999). In the original Stroop (1935) test, or any of the 400 studies reviewed by MacLeod (1991), the normality of the participant's color vision was not evaluated. However, in the current study, a simple color evaluation requiring the participant to match the depiction of the 10 colors (red, yellow, blue, green, black, pink, orange, brown, gray, and purple) used in the study to its color name was administered (see Appendix M).

Participants wore Sennheiser HD 380 Pro Headphones to eliminate external ambient noise. The noise level being propagated through the headphones was calibrated using a RadioShack 33-2050 Analog Display Sound Level Meter to ensure a sound pressure level (SPL) of 95 dBA or less, when performing the hearing assessment. Reverification of the participant's eligibility for study participation took less than 30 minutes to complete. Once the participant was screened and approved, the experiments began. At the end of the experiment, I debriefed the participants.

Sample Demographics

Descriptive Data Analysis

For all three experiments, a total of 24 (*N* = 24) participants with a mean age range of 37.63 year (*SD* = 11.65) and age range of 18 to 60 years comprised the sample population. In the study, there were 13 men and 11 women (54.17% and 45.83%, respectively aged 22 to 60 years. Table 1 presents the age and gender of study participants by experimental groups.

Table 1

Age and Gender of Study Participants by Group

Group	Age Bracket (Years)	Female		Male		Total	
		n	%	*n*	%	*n*	%
Experimental	18-28	1	9.09	1	7.69	2	8.33
	29-39	3	27.27	1	7.69	4	16.67
	40-50	2	18.18	2	15.38	4	16.67
	51-60	2	18.18	0	0.00	2	8.33
	> 60	0	0.00	0	0.00	0	0.00
Total		8	72.72	4	30.77	12	50.00
Control	18-28	1	9.09	4	30.77	5	20.83
	29-39	0	0.00	3	23.08	3	12.50
	40-50	1	9.09	2	15.38	3	12.50
	51-60	1	9.09	0	0.00	1	4.17
	>60	0	0.00	0	0.00	0	0.00
Total		3	27.27	9	69.23	12	50.00
Grand Total		11	100.00	13	100.00	24	100.00

Note: The proportion of each gender in each age bracket is represented in the percentages columns. Percentages for Grand Total were rounded to the nearest whole number.

The sample population consisted of various occupations (administrative, managerial, and technical). Table 2 presents the job occupations of participants as stated during the screening sessions, and were representative of federal employees in the convenience sample from the United States Patent and Trademark Office for the Alexandria, Virginia area.

Table 2

Occupation and Gender of Study Participants by Group

Occupation	Female		Male		Total	
	n	%	*n*	%	*n*	%
Experimental						
Budget Analyst	1	9.09	0	0.00	1	4.17
Communications Specialist	1	9.09	0	0.00	1	4.17
Graphic Artist	1	9.09	0	0.00	1	4.17
HR Assistant	1	9.09	0	0.00	1	4.17
Librarian	2	18.18	0	0.00	2	8.33
Mechanic	0	0.00	1	7.69	1	4.17
Program Analyst	1	9.09	2	15.38	3	12.50
Software Developer	0	0.00	1	7.69	1	4.17
Task Order Manager	1	9.09	0	0.00	1	4.17
Total	8	72.73	4	30.77	12	50.00
Control						
Budget Analyst	0	0.00	3	23.08	3	12.50
Communications Specialist	0	0.00	0	0.00	0	0.00
Facilities Specialist	0	0.00	1	7.69	1	4.17
Graphic Artist	0	0.00	0	0.00	0	0.00
HR Assistant	0	0.00	0	0.00	0	0.00
Librarian	0	0.00	0	0.00	0	0.00
Mechanic	0	0.00	0	0.00	0	0.00
Program Analyst	1	9.09	4	30.77	5	20.83

(table continues)

Program Support Specialist	1	9.09	1	7.69	2	8.33
Software Developer	0	0.00	0	0.00	0	0.00
Task Order Manager	0	0.00	0	0.00	0	0.00
User Interface Designer	1	9.09	0	0.00	1	4.17
Total	3	27.27	9	69.23	12	50.00
Grand Total	11	100.00	13	100.00	24	100.00

Note: The proportion of each gender in each occupation is represented in the percentages columns. Percentages were rounded to the nearest whole number.

The ethnicity of the sample consisted of three general ethnic categories (25% or six participants were Black, 41.67% were White, and 33.34% described themselves as Other). Table 3 presents the ethnicity of study participant by gender for the experimental groups. All participants who did not report their ethnicity as White or Black were classified in the category of "Other."

Table 3

Ethnicity and Gender of Study Participants by Group

Group	Female		Male		Total	
	n	%	*n*	%	*n*	%
Experimental						
Black	1	9.09	1	7.69	2	8.33
White	5	45.45	1	7.69	6	25.00
Other	2	18.18	2	15.38	4	16.67
Total	8	72.73	4	30.77	12	50
Control						
Black	1	9.09	3	23.08	4	16.67
White	1	9.09	3	23.08	4	16.67
Other	1	9.09	3	23.08	4	16.67
Total	3	27.27	9	69.23	12	50.00
Grand Total	11	100.00	13	100.00	24	100.00

Note: The proportion of each gender in each age bracket is represented in the percentages columns.

Participant demographic data were obtained via the website, and involved 19 screening questions related to previous participation in a Stroop and reaction time study, handedness, visual acuity, hearing, music preferences, reading difficulty, color vision, mental and physical disabilities. Table 4 provides statistical data regarding participant responses to the 19 screening questions. All 24 study participants were selected based on their responses to these screening questions, and met the inclusion criteria.

However, participant characteristics that may be of interest for subsequent data analysis were: When asked "Do you like Hip-Hop music?" 45.83% or 11 women and 45.83% or11 men responded that they liked Hip-Hop music, while 4.17% or one woman and 4.17% or one man responded that they did not like Hip-Hop music. When asked "Are you easily distracted when performing a reading task? 20..79% or five participants out of 24 responded "Yes."

Coding errors were checked, after the data for all participants were collected, for each experiment. For Experiment 1, I measured recognition accuracy scores as the percent correct made during the test trials. During a trial, if the participant's response was a mispronunciation of a colored word that disrupted the fluidity or cadence of vocalizing the word list, all occurrences were noted as an error. If the participant's response was the misidentification of a colored word (saying "Red", when the word color was "Green"), all occurrences were noted as an error. The number of errors by treatment were scored for each participant and the overall score was tabulated. Recognition accuracy scores for Experiments 2 and 3, and reaction time scores for Experiments 1, 2 and 3, and were performed by the E-Prime software. After the researcher completed data collection and verification, the data was separated, and merged into 3 datasets for importing into the Statistical Package for the Social Sciences (SPSS).

Table 4

Screening Questions by Group

Group	Experimental		Control		Total
Screening questions	Yes	No	Yes	No	No.
1. Have you previously participated in a Stroop test study before?	0	12	0	12	24
1a. Have you previously participated in a Stroop test study within the last six months?	0	12	0	12	24
2. Have you previously participated in a reaction time study before?	0	12	0	12	24
2a. Have you previously participated in a reaction time study within the last six months?	0	12	0	12	24
3. Are you right-handed?	12	0	12	0	24
4. Are you left-handed?	0	12	0	12	24
5. Do you have normal visual acuity (20/20 vision)?	11	1	12	0	24
6. Do you have corrected or near normal vision (Between 20/32 and 20/63 vision)?	12	0	12	0	24
7. Are you near-sighted?	1	11	3	9	24
8. Are you far-sighted?	0	0	0	0	24
9. Do you have normal hearing?	12	0	12	0	24
10. Do you ever experience ringing in your ear(s)?	0	12	0	12	24
11. Do you currently experience ringing in your ear(s)?	0	12	0	12	24
12. Have you ever suffered from hearing loss, in your left or right ear?	0	12	0	12	24
13. Do you like Hip-Hop music?	11	1	11	1	24

(table continues)

14. Do you like classical music?	12	0	12	0	24
15. Are you easily distracted when performing a reading task?	1	11	4	8	24
16. Do you currently have a mental or physical disability?	0	12	0	12	24
17. Do you currently have normal color vision?	12	0	12	0	24

Instrumentation

Demographics. Using the participant approval form, basic information regarding the age, gender, education, ethnicity, location, and how they may be contacted was collected.

Edinburgh Handedness Inventory. In response to twelve questions, participants -placed a “+” in either the “Left” or “Right” column for each activity to indicate their preference for use of hand(s). For absolute handedness (left or right-and use only) for an activity, the participant placed a “++” in the appropriate column. If the participant had no hand preference for an activity, or used either the left or right hand for an activity, the participant placed a “+” in both columns. The Edinburgh handedness inventory (see Appendix C) has an internal consistency (Cronbach coefficient alpha) for both men and women of .96, a test-retest reliability of r = .97 for men and .96 for women, and a correlation of .83 with a behavioral measure of handedness (Chapman & Chapman, 1987; Oldfield, 1971). This instrument was in the public domain, and test content may be reproduced and used for non-commercial research and educational purposes without having to seek the author’s written permission, as long as the source and copyright owner are cited (Oldfield, 1971).

Free Online Hearing Test. The free online hearing test is a 5-step speech-in-noise test) (Hear-it.org, 1999). Participants were initially given three practice trials whereby a set of single digit numbers were spoken aloud during different three (low, medium, high) volume levels of noise. The participant's task was to click the individual numbers spoken using a ten-digit number pad that was displayed on the screen. After the three trials were completed the assessment test began. Twelve trials were conducted and at their conclusion, a percentage of correct responses was provided. For percentages lower than 80%, the assessment recommended improving speech understanding by wearing a hearing device. Percentages 80% or higher informed the participant that the speech understanding was fine and the benefits of wearing a hearing device were limited. The hearing requirement was successfully met, if the participant successfully achieved a percentage correct score of 70% or better for the hearing assessment test. This instrument was in the public domain, and was authorized for use for personal and personal purposes as long as no compensation was charged for the information and the copyright owner was cited (Hear-it.org, 1999).

RadioShack 33-2050 Analog Display Sound Level Meter. The RadioShack 33-2050 Analog Display Sound Level Meter measured sound pressure level for frequencies of 32 Hz to 10,000 Hz over a -10 to +6 dBA or dBC weighting for both slow or fast response rates. It has wide sound measuring abilities which measured from 50 dB to 126 SPL with seven ranges, offering an accuracy of + or – 2 dB. The sound meter weighs 5.8 ounces or approximately 165 grams, with an operating temperature of 32 degrees F to 122 degrees F. The dimensions (H x W X D) of the sound level meter were 6.25 x 2.5 x

1.75 inches. A 9-volt alkaline battery powered an Electret condenser microphone for SPL measurements. This instrument was the researcher’s personal property, so no permission for use was required.

Sennheiser HD 380 Pro Headphones. Closed back headphones commonly known in recording circles as the industry standard. Also considered one of the most popular recording headphones in the world. These headphones provided a circumaural design for excellent passive attenuation of ambient noise (up to 32 dB), an extended frequency response for accurate, reliable sound reproduction, and able to handle sound pressure levels up to 110 dBA. This instrument was the researcher’s personal property, so no permission for use was required.

Snellen Eye Chart. The Snellen eye chart (see Appendix D) consisted of eleven rows of letters, ranged hierarchically, from worse to best, for assessing eight levels of visual acuity. Row 1, contained 1 letter for 20/200, Row 2 has two letters for 20/100, Row 3 has three letters for 20/70, Row 4 has four letters for 20/50, Row 5 has five letters for 20/40, Row 6 has six letters for 20/30, Row 7 has seven letters for 20/25, and Row 8 has eight letters for 20/20 visual acuity. The remaining rows all contained eight letters, each row with different letter sizes for visual acuity better than 20/20 vision. This instrument was in the public domain.

Western Ophthalmics Screw Clamp Type Chin/Head Rest. The WO-219C chin rest/head rest fixture was designed to mount to a table edge and is adjustable from 11.5" to 15” (29 to 38 cm). Double screw clamps accommodated table thickness up to 2.5”. The chin/head rest maintained and consistently positioned the participant’s head during interactions with displayed visual stimuli. This instrument was the researcher's personal property, so no permission for use was required.

Experimental Apparatus. E-Prime professional version 3.0 was the experimental apparatus for the presentation of all stimuli and the recording of responses. E-Prime suite of applications is a Windows-based software product by Professional Software Tools, Inc. which consisted of six (E-Studio, E-Basic, E-Run, E-Merge, E-DataAid, and E-Recovery) components for creating and controlling psychological experiments, using a scripting language similar to the scripting language of Visual Basic for Applications (Psychology Software Tools, Inc., 2016). The stimuli were displayed on a Hewlett-Packard Z24i display with a screen resolution of 1920 by 1200 pixels in a landscape orientation. The E-Studio graphical interface was responsible for the presentation of graphical (verbal and spatial) properties of objects onto procedural time lines. Participants were provided their reaction time responses using a powerful USB-based response and stimulus device called Chronos which featured millisecond accuracy and consistent sound output latencies, directly connected to an ASUS computer via a USB 2.0 or 3.0 port. The recognition accuracy scores and reaction time measurements were captured and analyzed using the components of the E-Prime suite of applications.

Experiment 1: Stroop Test

Experiment 1 was based on the original Stroop (1935b) task, using a congruent and incongruent colored word list. This experimental paradigm produced interference effects and slower time measures, when the color of a word and its color name were incongruent (did not match, e.g., the word green displayed in red text). Multiple resources theory prescribes that there is a limited and fixed amount of cognitive resources an individual can utilize for information processing depending on the processing stage, code, and sensory modality. Interference theory advocates that during the processing of verbal and spatial information in working memory, the memory trace decays over time. If during an immediate verbal serial recall task, using degraded stimuli and the participant also has to process different types auditory stimuli, it is hypothesized from multiple resources theory and Interference theory that cognitive performance would be affected. Research Question 1 was answered by a determination of whether auditory interference during a verbal serial recall task produced slower reaction time and recognition accuracy performance in adult men and women between the ages of 18 and 60.

In Experiment 1, I explored a Stroop variation to examine the effect of different types of auditory interference and stimulus degradation on the cognitive performance (reaction time and recognition accuracy) in a Stroop paradigm by adult men and women. Studies investigating interference effects in various Stroop paradigms have revealed a congruency-incongruency effect between the word name and its color for which interference was characterized as a mediating variable. In addition, deficits in recall performance, recognition accuracy, and reaction time as a result of stimulus degradation also have been shown. This study explored the effects of speech, music, and noise as interference factors for determining the effect of auditory distractions on verbal and spatial information processing.

In Experiment 1, the within-subject variables were auditory interference (by task-irrelevant speech, Hip-Hop music with irregular beat patterns, and white noise, and stimulus degradation during the performance of immediate serial recall tasks). The dependent variables of reaction time provided a performance measure for information processing rate for verbal stimuli, and recognition accuracy provided a performance measure of the percentage of colored-words correctly named and identified during immediate serial recall tasks.

Research Questions and Hypotheses.

RQ1: What is the effect of auditory interference and stimulus degradation on the reaction times and recognition accuracy of adult men and women, for verbal information processing in working memory?

H_{01a}: Auditory interference will not affect the reaction times and recognition accuracy for verbal information processing.

H_{a1a}: Auditory interference will affect the reaction times and recognition accuracy for verbal information processing.

H_{01b}: Auditory interference will not affect the reaction times and recognition accuracy for degraded verbal information.

H_{a1b}: Auditory interference will affect the reaction times and recognition accuracy for degraded verbal information.

Stimuli. In Experiment 1, the stimuli consisted of a 5 by 8 array of colored-degraded words (see Appendix E). The 5 by 8 array of colors contained ten colors (red, yellow, blue, green, black, pink, orange, brown, gray, and purple) display at different frequencies, but totaling a set of 40 colors (see Appendix E). The following RGB color specifications for each of the ten colors are respectively: Red (RGB: 255, 0, 0); yellow

(RGB: 255, 255, 0); blue (RGB: 0, 0, 255); green (RGB: 0, 204, 0); black (RGB: 0, 0, 0); pink (RGB: 255, 102, 204); orange (RGB: 255, 102, 0); brown (RGB: 102, 51, 0); gray (RGB: 119, 119, 119); and purple (RGB: 136, 0, 221). The letters of each word in the array was degraded by slicing the letters seven times horizontally, using a 2-pixel separation between each of the slices. The color of the slices was medium gray (RGB: 153, 153, 153), the same color as the array background. The practice array was congruent colored-words (the color-word name and its exact color). The test array was incongruent colored-words (the color-word name and the wrong color). The 5 by 8 array resided on a medium gray (RGB: 153, 153, 153) background (700 pixels wide by 420 pixels high), and forty light gray (RGB: 221, 221, 221) small rectangles (130-pixels wide by 45-pixel high) with a 4 pixel separation. Each colored-word was displayed in ARIAL 14-point, Bold font and centered on the light gray rectangle.

Auditory interference was created by royalty-free MP3 sounds of task-irrelevant speech and white noise from PacDV free sound effects (2016), and engaging Hip-Hop music with irregular beat patterns from Loopartists (2016), presented continuously at 95 dBA or less, during the performance of the immediate serial recall tasks. Task-irrelevant speech consisted of a recording of party crowd noise (party_crowd_1.mp3). White noise was processed white noise (processed_white_noise.mp3). Hip-Hop music was the Wessup Hip-Hop Mix which has an engaging attention-getting rhythmic pattern. All auditory stimuli were presented binaurally to the left and right ear, for the duration of each experimental trial, beginning with an initial onset of one second and terminating one second after the trial. The volume level of all auditory stimuli used a sound pressure level of 95 dBA and a duration of more than 30 seconds), considered to be the acceptable permissible continuous exposure time of 1 hour before hearing impairment occurs (National Institute of Occupational Safety and Health (NIOSH, 2016).

Procedure. Participants were randomly assigned to each of the experimental and the control conditions. There were a total of twelve participants (*N*=12) for the experimental and control groups, for a total of twenty-four (*N*=24). During each of the auditory interference conditions (speech, music, and noise), participants were presented a list of 40 colored words in a 5 by 8 array. The word color sequence was arranged such that the repetition of a two-color word sequence appeared no more than twice in the 40-item array of colors. The array was centered on the screen. Using an adjustable chinrest, the participant's eyes were positioned at a height approximating the intersection between the horizontal (width) and vertical (height) of the display screen (960 by 600 pixels). Participants were positioned 50.8 cm away from the computer screen. Due to the differential effects of practice, priming, and prior knowledge on cognitive performance in visual and verbal tasks, practice was minimized to one sample (12 trials) of the 40-item list. Each participant in the experimental condition performed a total of six trials for degraded and normal stimuli, for the congruent and incongruent array of colors (36 trials). Participants in the control condition also performed a total of 36 trials. For each trial, the elapsed time and recognition accuracy scores was recorded. A black display screen was displayed for 1000 ms, followed by the 5 by 8 array for 35 seconds (see Appendix F and Appendix G).

Prior to the onset of the experiment, participants were given the following Stroop Word-Color Task instructions:

Stroop Word-Color Task Instructions

In this experiment, you will see a list of 40 colored words. Your task will be to read each word aloud name of each of the colored words, as fast and accurately as possible. When you have read the last word in the list, press the "5th" or "right response key" as fast as you can. A black display with a white fixation point will be displayed for 1 second (1000 ms), followed by a 40-item word list. There will be a total of twelve (12) practice trials to perform. Press the "SPACE BAR" on the keyboard to begin. After a 5-second (5000 ms) rest period, the test phase instructions will be displayed. You will perform the same task for thirty-six (36) test trials. Each test trial will be followed by a black screen with a white fixation point for a 1 second (1000 ms) period. At the end of the last test trial, you will see a white display screen with the words "End of Experiment." Press the "SPACE BAR" on the keyboard to begin.

Experiment 2: Object Recognition and Detection

Experiment 2a investigated the underlying assumption of the feature integration theory (Treisman & Gelade, 1980) which states that features of an object are pre-attentive and registered early in an automatic parallel manner, while the object itself is separately identified at a later stage of processing. Based on the contention of limited and fixed capacity of resources from the multiple resources theory, degradation of cognitive performance in working memory over time from interference theory, and the processing of verbal and spatial information in working memory by the multicomponent memory model, Experiment 2a provided answers to Research Question 2. If feature integration theory is correct, reaction times should be lower and recognition accuracy scores should be higher for naming the object versus the recognition of its spatial location. In addition, Research Question 3 was answered by determining whether the detection of the object's spatial location and color is a factor when required to process numeric information (non-spatial feature). It was hypothesized that the processing of the color of an object is pre-attentive and recall of the number would influence the perceptions of spatial location.

Experiment 2a utilized the same independent and dependent variables in Experiment 1. Whether the perception of object features and their spatial location is influenced by cross-modal interference was investigated. In addition, the contention that features of an object are pre-attentive and registered early in an automatic parallel manner, while the object itself is separately identified at a later stage of processing was investigated (Treisman & Gelade, 1980). As in Experiment 1, the within-subject variable of auditory interference (by task-irrelevant speech, Hip-Hop music with irregular beat patterns, and white noise (95 dBA or less) was used to assess their influence on the perception spatial location and feature-binding in object recognition tasks. The dependent variables were reaction time and recognition accuracy. Cross-modal interference has been shown to be evident when the presentation of a stimulus in one sensory modality exerts influence on the perception of, or ability to respond to a stimulus in another sensory modality. Experiment 2a explored the effects of cross-modal interference during the perception of object features and numbers embedded in colored geometric shapes (circles, triangles, squares) randomly projected to the left visual field (LVF), center visual (CVF), and right visual field (RVF).

Research Questions and Hypotheses.

RQ2: To what extent is spatial location information processed differentially than structural object features in working memory, for adult men and women?

H_{02}: Spatial location information will not be processed differentially than structural object features for adult men and women.

H_{a2}: Spatial location information will be processed differentially than structural object features for adult men and women.

RQ3: To what extent are there speed-accuracy tradeoff differences in spatial information processing in working memory, for adult men and women, under conditions of auditory interference based on visual field presentation?

H_{03}: There will not be any speed-accuracy tradeoff differences in spatial information processing in working memory, under condition of auditory interference based on visual field presentation.

H_{a3}: There will be speed-accuracy tradeoff differences in spatial information processing in working memory, under conditions of auditory interference based on visual field presentation.

Stimuli. In Experiment 2b, the stimuli consisted of colored geometric shapes (filled circles, triangles, and squares) (see Appendix H). The colors of the geometric shapes for the experimental group and the control groups were green, yellow, and light blue. A sequence of numbers from one to eight number appeared above, below, or adjacent to the colored shape in one of four visual field positions panoramically around the center fixation point. For the geometric shapes, the numbers were displayed in black, .64 cm high, and positioned above, below, or adjacent to the geometric shape. The diameter of the circle was be 2.54 cm, the triangle was 2.54 cm wide by 2.54 cm high, and the square was 2.54 cm square (see Appendix H). All stimuli were projected to the left visual field (LVF), center visual (CVF), and right visual field (RVF) panoramically within 2 to 12 degrees around the center fixation point.

Procedure. In Experiment 2b, participants were randomly assigned to each of the experimental and the control conditions. There were a total of twelve participants (*N*=12) for the experimental and control groups, for a total of twenty-four (*N*=24). During each of the auditory interference conditions (speech, music, and noise), participants were presented number and shape stimuli that were randomly projected to the left (LVF), center (CVF), or right (RVF) visual fields. The visual fields projections were consistent with the cortical surface of the primary visual cortex (V1), spanning 2-4 degrees eccentrically to 10-12 degrees around the center fixation point. For the object feature recognition task, the dependent variable of reaction time provided a performance measure for information processing rate for responding to the perception of the geometric shape type and its spatial location while ignoring the shape color; and recognition accuracy provided a performance measure of the percentage of shape types and spatial locations correctly identified. For object detection task, the procedure was similar, except participants responded to the number displayed, and spatial location of the geometric shape, while attending to the shape color. The number appeared above, below, or adjacent to colored shape in one of four visual fields. All stimuli were counterbalanced to be displayed evenly across the left, center, and right visual fields. The order of the object feature recognition and object detection tasks were counterbalanced across participants to reduce order effects.

Using an adjustable chinrest, the participant's eyes were positioned at a height approximating the intersection between the horizontal (width) and vertical (height) of the display screen (960 by 600 pixels). Participants were positioned 50.8 cm away from the computer screen. Due to the differential effects of practice, priming, and prior knowledge on cognitive performance in visuo-spatial and verbal tasks, practice was minimized to three trials for the object feature recognition and object detection tasks. Each participant in the experimental condition performed a total of ten trials for the object feature recognition and object detection tasks combinations (60 trials). Participants in the control condition also performed a total of 60 trials. For each trial, the elapsed time and recognition accuracy scores were recorded. A black display screen was displayed for 2000 ms, followed by the display of a colored shape or shape-number combination for 250 ms (see Appendix I).

Prior to the onset of the experiment, participants were given the following instructions for the object feature recognition task or object detection task:

Object Feature Recognition Task Instructions. When the experiment begins, you will initially see a black display screen with a white fixation point. Please keep your eyes on the fixation point at all times. When prompted, press the left response key to begin the timed practice trials. Using the right response key, respond as quickly and accurately as possible. When finished, a light green screen will be displayed. After 2000 ms, the experiment will begin. Upon the display of the geometric shape, your task will be to say the name of the geometric shape (circle, triangle or square), and press the key corresponding to the displayed location of colored geometric shape as quickly and correctly as possible. After responding, you will again see a light green display screen with a white fixation point, for a period of 2000 ms, or two seconds. At the end of the two seconds, the second test trial will begin, and so on. When the experiment has concluded, you will see a white display screen with the words "End of Test."

Object Detection Task Instructions. When the experiment begins, you will initially see a black display screen with a white fixation point. Please keep your eyes on the fixation point at all times. When prompted, press the left response key to begin the timed practice trials. Using the right response key, respond as quickly and accurately as possible. When finished, a light green screen will be displayed. After 2000 ms, the experiment will begin. Upon the display of the geometric shape, your task will be to say the number displayed, and press the key corresponding to the color of the geometric shape as quickly and correctly as possible. After responding, you will again see a light green display screen with a white fixation point, for a period of 2000 ms, or two seconds. At the end of the two seconds, the second test trial will begin, and so on. When the experiment has concluded, participants viewed a white display screen with the words "End of Test" (see Appendix J).

Experiment 3: Part-Whole Matching

Experiment 3 was based on the work of Nebes (1971b) that indicated that right-handers with intact brains performed significantly better than left handers and tested size and shape perception tasks under three types of auditory interference. Jennings (1977) extended the Nebes (1971b) study and investigated the part-whole matching task with normal individuals, and presented stimuli tachistoscopically, under conditions of visual backward masking and stimulus degradation, and also report a right visual field advantage. Experiment 3 extended the Jennings (1977) study by exploring, interference effects during size, shape, and spatial location perceptions of normal and degraded geometric shapes. Research Question 4 was answered by determining whether differences in reaction time and recognition accuracy scores were revealed as a result of panoramic visual field projections. As with Experiments 2 and 3, the research design was derived from the same theories governing attention, memory, perception, resource allocation, and the reduction of practice effects.

Experiment 3 examined the effects of different types of auditory interference on the reaction time and recognition accuracy of the perception of the size of normal and degraded geometric shapes by adult men and women, in part-whole matching tasks. Interference effects in the perception of geometric shapes has been investigated by several researchers (Dyer, 1973c; Gier et al., 2010; Elliott, Hughes, Briganti, Joseph, Marsh, & Macken, 2016; Jennings, 1977; Lewandowsky & Oberauer, 2015; MacLeod, 1991; Roberts & Besner, 2005). In Experiment 3, the same independent variables used in Experiments 2 and 3 were used during the performance of size and geometric shape perception in part-whole matching tasks. All stimuli were randomly projected to the left visual field (LVF), center visual (CVF), and right visual field (RVF). The dependent variable of recognition accuracy provided a performance measure of the percentage of shapes correctly identified during size and shape perception in part-whole matching tasks. The dependent variable of reaction time provided a performance measure for information processing rate for responding to the perception of the geometric shape type and its spatial location.

Research Questions and Hypotheses.

RQ4: Does auditory interference affect the speed-accuracy of detecting the spatial location of degraded objects based on visual field presentation, for adult men and women?

H_{04}: There will not be any speed-accuracy tradeoff differences in the detection of the spatial location of degraded objects based on visual field presentation.

H_{a4}: There will be speed-accuracy tradeoff differences in the detection of the spatial location of degraded objects based on visual field presentation.

RQ5: Does cross-modal interference affect the speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point, for adult men and women?

H_{05}: Cross-modal interference will not affect the speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point based on visual field presentation.

H_{a5}: Cross-modal interference will affect the speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point based on visual field presentation.

Stimuli. In Experiment 3, the stimuli consisted of three monochromatic geometric shape types (solid, dashed and dotted circles) for four shape sizes. The diameter of the circles was 1.29 cm or ½ inch, and 2.54 cm or 1 inch, 3.81 cm or 1 ½ inches, 5.08 cm or 2 inches (see Appendix K). Degraded stimuli were represented as dashed and dotted circles. All stimuli were projected on a light gray background, to the left visual field (LVF), center visual (CVF), and right visual field (RVF) panoramically within 2 to 12 degrees around the center fixation point.

Procedure. In Experiment 3, participants were randomly assigned to each of the experimental and the control conditions. There were a total of twelve participants (*N*=12) for the experimental and control groups, for a total of twenty-four (*N*=24). During each of the auditory interference conditions (speech, music, and noise), participants were presented normal and degraded geometric shape stimuli that were randomly projected to the left (LVF), center (CVF), or right (RVF) visual fields. The visual fields projections were consistent with the cortical surface of the primary visual cortex (V1), spanning 2-4 degrees eccentrically to 10-12 degrees around the center fixation point. The coordinates for the concentric circles had their zero-degree point at the apex of the circle, and the

180-degree point at its base. All visual field projections of the concentric circles were displayed six degrees from the center fixation point. For the size and shape perception tasks, the dependent variables of reaction time provided a performance measure for information processing rate for responding to the perception of the size and shape; and recognition accuracy provided a performance measure of the percentage of size and shape judgements correctly identified. All stimuli were counterbalanced to be displayed evenly across the left, center, and right visual fields. The order of the degraded and normal stimuli for the size and shape feature perception tasks were counterbalanced across participants to reduce order effects.

Using an adjustable chinrest, the participant's eyes were positioned at a height approximating the intersection between the horizontal (width) and vertical (height) of the display screen resolution of 1920 by 1080 pixels. Participants were positioned 50.8 cm away from the computer screen. Practice was minimized to six trials each for the degraded and normal stimuli for the size and shape feature perception tasks. Each participant in the experimental condition performed eight trials for each of the four geometric shape sizes and three stimulus type combinations, for a total of ninety-six trials. Participants in the control condition also performed a total of ninety-six trials. For each trial, the elapsed time and recognition accuracy scores were recorded. A black display screen was displayed for 2000 ms, followed by the display of the degraded or normal shape stimuli on a white background for 250 ms, followed again by a light green display for 3000 ms, followed by the stimulus for another test trial for 250 ms (see Appendix L).

Prior to the onset of the experiment, participants were given the following instructions:

Part-whole Task Instructions. Welcome to the Experiment. When the experiment begins, you will initially see a black display screen with a white fixation point. Please keep your eyes on the fixation point at all times. A half-circle of one of four sizes will be displayed for 250 milliseconds. Your task will be to select which circle you think the half-circle was a part of as fast and accurately as possible, using the "right" or number "5" response key. After your response, a light green display followed by a black screen with a white fixation point will be displayed, followed by another half-circle. There will be a total of ninety-six (96) test trials. When the experiment has concluded, you will see a white display screen with the words "End of Test" (see Figure 10). "PRESS THE "SPACEBAR" WHEN YOU ARE READY TO BEGIN!"

Data Collection and Analysis

Recruitment Process

For recruitment purposes, a secure socket layer (SSL) web site was designed that described the purpose of the dissertation research being conducted; the inclusion/exclusion criteria; requirements after selection; incentive payment; the research site; how to apply for the study online; and contact information. In addition to the web site, a combination of recruitment methods that included the design and placement of flyers in public areas, solicitations of personal contacts, word of mouth, email and telephone communications were used. When the recruitment method was through the web site, the participant was notified of their inquiry and to expect further communication from the researcher that provided more details of the study.

Upon receipt of the demographic data and the participant's email and telephone number, a follow-up email was sent detailing the logistics of the research site, and available date and time slots for testing sessions.

The recruitment response was better than expected. It was originally planned that a total of 80 participants would be recruited to allow for attrition, however sample size calculations for a power value of .80, and a small effect size of .35, showed that 24 participants was adequate. Moreover, other researchers studying the Stroop test (MacLeod, 1991), irrelevant speech interference (Elliot, 2012), cross-modal interference (Yue et al., 2015), stimulus degradation (Yeshurun & Marciano, 2013), selective attention and cognitive control (Lavie, Hirst, de Fockert, & Viding, 2004), and size and shape perception (Chen et al., 2016) have utilized similar sample sizes. Instead, a total of 40 potential participants were solicited over a two-month period, yielding nine participants in the first month and 15 participants in the second month. Data collection continued over the two-month period, until twenty-four participants were acquired. During the data collection process, there were no adverse events, no withdrawals during the pre-screening process, and no participant withdrawals from the study.

Participant Screening. During the screening process, participants navigated two of three screening stations (see Appendix N). At station one (vision test), participants verified the perception of a red and green colored bar, and read a row of letters from left to right with their left eye, and then their right eye, corresponding to a visual acuity of

20/25 and 20/20, respectively. At station two (hearing test), participants listened to three practice trials, and then 12 test trials. Participants used the keyboard to enter three individual numbers heard at four different of sound levels. The output for the Free Online Hearing Test was the percentage of correct responses for the twelve test trials. In addition, participants provided responses to a handedness questionnaire for a list of motor activities performed with either the left, right, or both hands. All cognitive experiments (see Chapter 3) were conducted at station three (see Appendix O), where an introductory video describing each experiment was provided. Each experiment started with task instructions, followed by twelve practice trials and then the test trials, and concluded with a debriefing and incentive payment.

E-Prime. The experimental design, presentation and recording of responses and reaction time measures were captured using a Windows-based software product called E-Prime by Professional Software Tools, Inc. According to the vendor, "E-Prime is a suite of applications to fulfill all of your computerized experiment needs. Used by more than 5,000 research institutions and laboratories in more than 60 countries, E-Prime provides a truly easy-to-use environment for computerized experiment design, data collection, and analysis. E-Prime provides millisecond precision timing to ensure the accuracy of your data. E-Prime's flexibility to create simple to complex experiments is ideal for both novice and advanced users" (Psychology Software Tools, 2016). E-Prime 3.0 consists of six (E-Studio, E-Basic, E-Run, E-Merge, E-DataAid, and E-Recovery) components. E-Studio is the graphical interface which uses drag and drop functionality for placing a series of objects for which experiments are comprised on a procedural timeline. E-Basic is a Visual Basic-like scripting language which compiles the graphical representation prepared in E-Studio into an E-Basic script. The combined outputs of E-Studio and E-Basic allowed the experiment to be run with millisecond presentation, synchronization and data collection via E-Run. Merging of single and multiple session data, and a history of each data file, their maintenance and tracking are allowed by the E-Merge component. The E-DataAid component managed data, provided data security, and compatibility with function of external statistical packages. E-Recovery provided data recovery functionality of incomplete E-Run data compilations and data file conversions back to an E-Prime data file, as a consequence of program crashes or terminations (Psychology Software Tools, Inc., 2016). The E-Prime software package helped design and run the three psychological experiments in the study, and has been developed to focus on psychological and cognitive science, and to enable data gathering and data analysis (Spape, Verdonschot, van Dantzig, & Steenbergen, 2014).

Data Sources. The sources of all data were primary, and collected from each participant. Reaction time and recognition accuracy scores were recorded using the data collection form (see Appendix B). The types of information provided by participants were:

1. An assessment of the handedness of study participants.
2. An assessment of the visual acuity of participants using a Snellen Chart.
3. An assessment of hearing ability of participants using percentage of correct responses using the Free Online Hearing Test.
4. An evaluation of color vision using a color matching task.

5. Reaction time measures of word and color stimuli across panoramic visual fields.
6. Reaction time measures of shape stimuli across panoramic visual fields.
7. Reaction time measures of word and color stimuli based on conditions of auditory distraction.
8. Reaction time measures of shape stimuli based on conditions of auditory distraction.
9. Recognition accuracy measures of word and color stimuli across panoramic visual fields.
10. Recognition accuracy measures of shape stimuli across panoramic visual fields.
11. Recognition accuracy measures of word and color stimuli based on conditions of auditory distraction.
12. Recognition accuracy measures of the features of shape stimuli based on conditions of auditory distraction.

Handedness and visual acuity data were gathered through questionnaires, visual observation, and verbal report prior to the conduct of experimental test sessions, and during the screening and selection process.

Data Reduction. Data reduction was facilitated by the use of E-Prime and the Statistical Package for the Social Sciences (SPSS). The single participant session data file(s) generated by E-Prime were merged into multiple session data file(s) for export into SPSS. SPSS used the dataset to analyze dataset(s), using the univariate ANOVA and one-way MANOVA procedures to evaluate whether the population means of the dependent variables vary across the levels of the independent variables. Main effects, significance levels, and interactions between variables were evaluated using *F* tests, contrast analysis, and post hoc pairwise comparisons. (Creswell, 2009; Green & Salkind, 2014). Both descriptive and parametric statistics were generated and displayed using SPSS.

Threats to Validity.

Of the nine threats to internal validity (Shadish, Cook, & Campbell, 2002), the possible threats to internal validity considered were related to: a) ambiguous temporal precedence, b) the procedures for selecting participants, c) attrition (mortality), and d) testing. The remaining five threats (history, maturation, regression artifacts, instrumentation, additive and interactive effects of threats to validity) are considered to be non-applicable.

Ambiguous temporal precedence. It was believed that the research design was appropriately structured to allow the ability to discern with reasonable certainty the temporal order for which variables occurred. The independent variable of auditory interference has three levels which are represented as separate treatment groups. The dependent variables were distinct measurements which provided data on participant interactions that were unique, and conclusive for determining cause-effect relationships influenced by test conditions and the levels of the independent variable.

Procedures for Selecting Participants. The type of sampling strategy for the study was convenience sampling whereby the participants were selected based on availability. It was believed that drawing the sample population from a target population of adult men and women that were normally distributed for each of the populations, the variances of the dependent variables were the same for all populations, and each represented a random sample from the population, and scores of the test variable were independent of each other satisfied the assumptions of the one-way analysis of variance (ANOVA) (Green & Salkind, 2014), and mitigated this threat.

Attrition (Mortality). The selection process drew a sample of participants that was consistent with the required number of participants for the effect size, power, and statistical tests for the study. By exceeding the sample size requirement of 40 participants, it was believed that the probability of drop out or failure to complete the treatment/study activities was reduced and helped a sufficient group size to be maintained. Thus, effects may not be a consequence of drop out rather than the treatment, and serve to mitigate this threat.

Testing. For the Free Online Hearing Test, participants were given three practice trials, and the subsequent test trials were unique and were not repeated. For each of the three experiments, practice trials were limited to reduce practice effects. In Experiment 1, practice was minimized to a one trial sequence of the 12-items. In Experiment 2, practice was also minimized to a one trial sequence for the object feature recognition and object detection tasks. In Experiment 3, practice was minimized to a one trial sequence for the degraded and normal stimuli for the size and shape feature perception tasks. In all experiments, the threat of testing through reactivity and influences due to subsequent performance on the same test was mitigated by counterbalancing the order of the tasks across participants to reduce order effects.

Ethical Considerations

The first 13 questions of the Research Ethics Planning Worksheet were valuable for assessing ethical considerations for this study. These questions addressed methodology, data collection and storage, security and privacy, anonymity, potential risks, conflicts of interest, and the use of sites, participant access and permissions to use data. Other ethical considerations associated with these data and their use had to do with the maintenance of privacy, confidentiality, harm, and obtaining informed consent consistent with the American Psychological Association (APA) Ethical principles of psychologists and code of conduct (APA, 2014; Bersoff, 2008; Fisher, 2013).

Ethical concerns for methodology related to potential risks and harm from the use and intensity of auditory stimuli were addressed by verifying and controlling sound pressure levels and the use of quality sound absorption devices (headphones). Acceptable sound pressure levels (less than 95 dBA or less) were verified and calibrated prior to presentation using a sound pressure meter. Sound and noise exposure levels that cause harm or hearing loss were based on exposure time (National Institute for Occupational Safety and Health (NIOSH, 2016). For example, for every 3 dBA less than 100 dBA (the frequent level with music via head phones), the permissible exposure time doubles. A sound pressure level of 100 dBA can be continuously heard for 15 minutes, or 82 dBA can be continuously heard for 16 hours without hearing impairment (NIOSH, 2016). In the study, continuous exposure durations were five seconds or less. In this study, the volume level of all auditory stimuli consisted of a sound pressure level of 95 dBA and a duration of no more than 30 seconds and was well within the acceptable permissible continuous exposure time of 1 hour before hearing impairment occurs (National Institute of Occupational Safety and Health (NIOSH), 2016).

Confidentially, privacy, and anonymity concerns were addressed through the strategy of full disclosure of procedures and the purpose of the study, allowing participants to terminate participation in the study, assuring participants that all information used or collected would be held confidential, the signing of informed consent forms, acquiring permissions for data use and site locations, allowing the participants to ask questions before conducting any testing or administering any treatments, the secure storage of data, and debriefing participants before and after the study. All electronic and physical data was stored on a removable disk and housed in a safe deposit box under lock and key for a period of five years. Research risks and burdens of participants related to personal time was mitigated through the use of incentives paid for study participation. The research study was conducted at a secure, public location that eliminates any risks or conflicts of interests. A letter of cooperation (see Appendix P) for facility use was obtained. No vulnerable populations were utilized for the study. All results from the study were accessible to all participants.

Identification and Acquisition of Participants. While the general inclusion criteria for participation was an adult man or woman, the participants were required to meet handedness, visual acuity, color vision, education, and specific age range, with normal hearing requirements. The handedness requirement was resolved by administering the Edinburgh handedness inventory (see Appendix C) to all participants to determine hand dominance. Color vision was evaluated by a color matching task (see

Appendix H). The visual acuity requirement was resolved by using a Snellen eye chart to determine whether participants had normal vision (20/20), or near normal vision (between 20/32 and 20/63) (Colenbrander, 2002; Schneider, 2002). Participants between the ages of 18 and 60 years of age participated in the study. Auditory perception for the study did not assess hearing loss or the need for a special hearing device. Hearing loss issues or needs must be determined by a trained audiologist. Therefore, the study only needed to determine the participant's ability to hear speech using different levels of background noise. Upon successful verification of visual acuity and handedness, participants were administered the free online hearing test (a 5-step speech-in-noise test) to fulfill the hearing assessment and requirement (Hear-it.org, 1999). The noise level was calibrated using a RadioShack 33-2050 Analog Display Sound Level Meter to ensure a sound pressure level (SPL) of 95 dBA or less, when performing the hearing assessment. The hearing requirement was successfully met, if the participant achieved a percentage correct score of 70% or better for the hearing assessment test.

Acquisition of participants may also be a barrier, in addition to the inclusion criteria. Advertisement of the research study through bulletin boards at local universities, local newspapers, the posting of flyers announcing and describing the study, the need for volunteers and participants for the research study, online websites, and the use of the Walden University Participant Pool (Walden University, 2015) were options for mitigating these barriers.

Acquisition of the Research Site. Another ethical consideration was for the location for which the research study was conducted. There was a need for a site that was local and within the greater Washington, D.C. area, that was safe and secure and allowed no harm to come to participants. Permission to utilize the Usability Laboratory situated at the United States Patent and Trademark Office in Alexandria, Virginia was confirmed by a signed Letter of Cooperation (see Appendix P), through communication with the Office of the Chief Information Officer (OCIO) to conduct the study with the sample population. The research was conducted under IRB approval number 01-10-17-0456602, in this private and secure research facility located in Alexandria, Virginia during non-duty work hours, between 6 pm and 9 pm, Monday through Friday. Research personnel consisted of the experimenter only. The researcher performed all escorting and screening duties. Participants were required to provide identification credentials at the lobby security desk, in order to be escorted to the testing area by the researcher. The participant's credentials were returned, after the experiment, and the escorting of the participant back to the lobby security desk.

Summary and Transition

The current chapter included an overview of the quantitative study which consisted of three experiments investigating the effects of auditory interference on the processing of verbal and spatial information, under conditions of irrelevant speech, music, and noise. The chapter began with an introduction and a description of the research design and its relationship to the research questions, and was followed by detailed explanations and descriptions of the sampling and sampling procedures, including all stimuli, procedures, and instrumentations, along with data collection and analysis methodology that were utilized in the study. Also provided were the operation definitions of variables, a description of data analysis software and statistical tests, and how threats to validity were mitigated. Finally, ethical concerns related to data collection, data storage and usage, and confidentiality were addressed. The chapter provided a precursor to the results of actual data collection and analysis, which is described in detail in the Chapter 4. Summaries, conclusions, and recommendations are provided in Chapter 5.

Chapter 4: Results

Introduction

I conducted this study to (a) examine the effects of auditory interference and stimulus degradation verbal and spatial information processing, (b) determine the effects of attentional capture and cross-modal interference on recognition and detection of object features and spatial location, and (c) determine the effect of auditory interference and stimulus degradation on the perception of size, shape, and location of part-whole relationships of geometric figures. This chapter includes a description of the demographics of the participants; details regarding how data were collected, prepared, and analyzed; and the statistical results for the three experiments.

The independent variables were: three types of auditory interference (task-irrelevant speech, music, and noise) and two types of stimulus degradation (normal and degraded). The dependent variables were reaction time (RT), and recognition accuracy (RA; defined as the number of correctly identified items or responses per trial). The hypotheses tested using univariate ANOVA and one-way MANOVA procedures for the three experiments were as follows:

Hypotheses

Experiment 1: Stroop Test

RQ1: What is the effect of auditory interference and stimulus degradation on the reaction times and recognition accuracy of adult men and women, for verbal information processing in working memory?

H_{01a}: Auditory interference does not affect reaction times and recognition accuracy for verbal information processing.

H_{a1a}: Auditory interference affects the reaction times and recognition accuracy for verbal information processing.

H_{01b}: Auditory interference does not affect reaction times and recognition accuracy for degraded verbal information.

H_{a1b}: Auditory interference affects reaction times and recognition accuracy for degraded verbal information.

Experiment 2: Object Recognition and Detection

RQ2: To what extent is spatial location information processed differentially than structural object features in working memory, for adult men and women?

H_{02}: Spatial location information is not processed differentially than structural object features for adult men and women.

H_{a2}: Spatial location information is processed differentially than structural object features for adult men and women.

RQ3: To what extent are there speed-accuracy tradeoff differences in spatial information processing in working memory, for adult men and women, under conditions of auditory interference-based on visual field presentation?

H_{03}: There are no speed-accuracy tradeoff differences in spatial information processing in working memory, under condition of auditory interference-based on visual field presentation.

H_{a3}: There are speed-accuracy tradeoff differences in spatial information processing in working memory, under conditions of auditory interference-based on visual field presentation.

Experiment 3: Part-Whole Matching

RQ4: Does auditory interference affect the speed-accuracy of detecting the spatial location of degraded objects based on visual field presentation, for adult men and women?

H_{04}: There are no speed-accuracy tradeoff differences in the detection of the spatial location of degraded objects based on visual field presentation.

H_{a4}: There are speed-accuracy tradeoff differences in in the detection of the spatial location of degraded objects based on visual field presentation.

RQ5: Does cross-modal interference affect the speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point, for adult men and women?

H_{05}: Cross-modal interference will not affect speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point based on visual field presentation.

H_{a5}: Cross-modal interference will affect the speed-accuracy of size and shape perception of geometric shapes features and spatial information processing for objects presented in locations peripheral to a central fixation point based on visual field presentation.

Testing Assumptions

The factorial MANOVA procedure was conducted to explore the effect of two independent variables (auditory interference and stimulus degradation) have on the patterning of response on the dependent variables (recognition accuracy and reaction time scores), and whether there were any interactions among the dependent variables and the independent variables. When I evaluated the assumptions and they were not met or violated, one-way MANOVAs and univariate ANOVAs were used.

The MANOVA is considered to be an extension of an ANOVA (Green & Salkind, 2014). Prior to using the MANOVA procedure, I tested and evaluated the following assumptions, for each of the three experiments:

1. Two or more dependent variables measured at the interval or ratio level.
2. Two or more categorical independent groups.
3. Independence of observations. No relationship between the observations in each group or between groups.
4. Adequate sample size.
5. There is multivariate normality.
6. There is homogeneity of variance-covariance matrices.
7. There is no multicollinearity.
8. There is a linear relationship between each pair of dependent variables for all combinations of groups of two independent variables.
9. No univariate or multivariate outliers.

Experiment 1: Stroop Test

Data Preparation

For Experiment 1, the data were found to violate statistical assumptions #6, and #9 for the continuous variable, RT. The data revealed outliers (see Figure 8), which were transformed for both groups overall (see Figure 9), and represented separately for the experimental and the control group (see Figures 10 and 11).

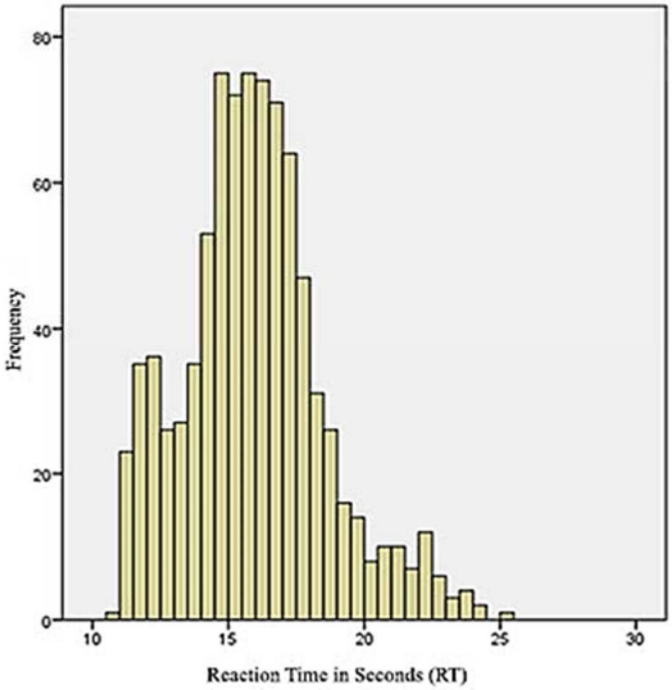


Figure 8. Reaction time (RT) in Experiment 1 for both groups. It illustrates the dispersion of reaction times prior to the elimination of extreme RT data points.

For assumption 6, The Box's M test was not significant *F*(3, 133747920) =6.79, *p* = .08, indicating that equal covariance matrices cannot be assumed and there are differences in the matrices. However, assumption 9 was resolved through recoding, data transformations, and data cleansing with the calculation of Mahalanobis Distance. Examination of RT showed a skewness value of .675 for the experimental group, and

3.44 for the control group. Kurtosis measured .566 for the experimental group, and .245 for the control group.

Initially, 19 RT data points that were identified as multivariate outliers due to participant error, which included one or more errors due to mispronunciations of word name or color name were transformed. After I tranformed these outliers, data cleaning continued with the calculation of Mahalanobis Distance. Mahalanobis Distance values were compared to a Chi Square critical value of 18.46. Statistical assumption 9 was violated after evaluating the Mahalanobus values, resulting in 11 extreme RT data points. The extreme values ranged between 9 and 25 seconds. After transforming these RT data points, the RT data were reexamined and found to be consistent with a normal distribution (see Figure 9).

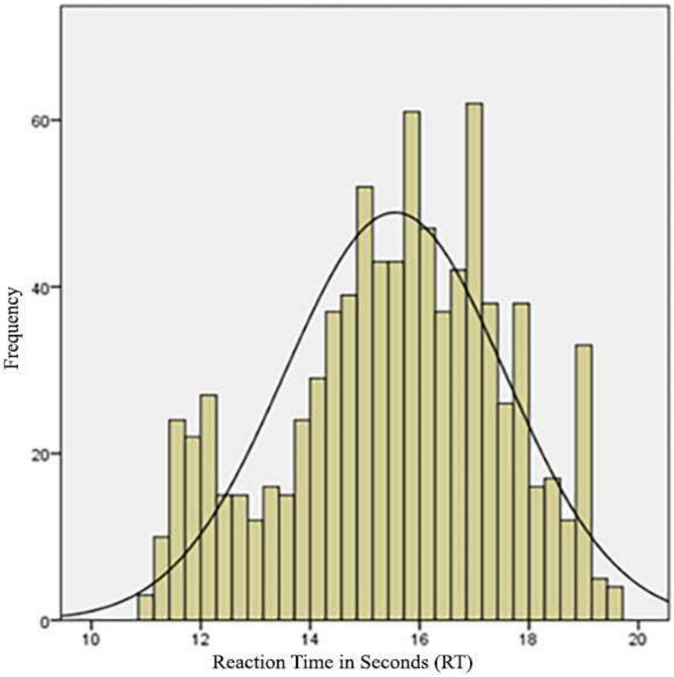


Figure 9. Reaction time (RT) in Experiment 1 for both groups after the removal of extreme RT data points. It illustrates the dispersion of reaction times after the elimination of extreme RT data points greater than Mahalanobis Distance values of 18.46.

Calculation of Median Absolute Deviation

Leys, Ley, Klein, Bernard, and Licata (2013), Whelan (2008), and Ratcliff (1993) suggested several methods for detecting reaction time outliers and the creation of normal distributions that were suitable for statistical analysis and arrived at a consensus in favor of using the median absolute deviation (MAD) method. The MAD method provided a means to avoid problems and difficulties encountered for detecting outliers in small samples associated with the use of the mean and standard deviation for which it is assumed that the RT distribution is normal (Leys et al., 2013).

In this study, I calculated the *MAD* using a conservative value of 3.0 deviations around the median as the cutoff values for RT. The formula I used was the following equation for the threshold of outliers: $M - 3(MAD) < \mathrm{RT} < M + 3(MAD)$. The symbol M

is the median of the RT scores. *MAD* = 1670.00, and *M* = 16000.00, yielding an interval of 10990 < RT < 21010, resulting in the removal of 19 RT data points (2.2% of the original RT data total) excluded.

Whelan (2008) recommended that several transformations of RT should be calculated. Because of the various ways researchers have analyzed reaction time, both transformed RT and Square Root (SQRT) RT have been reported (see Figures 10 for the experimental group and 11 for the control group).

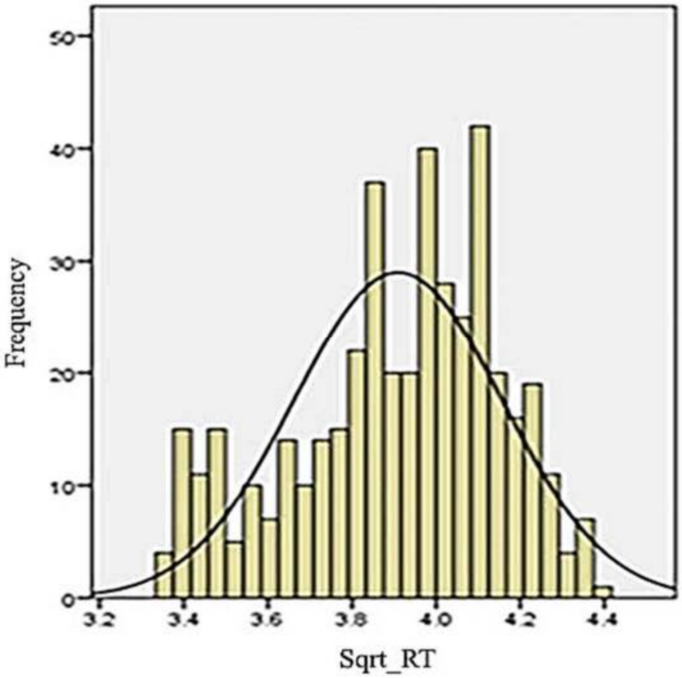


Figure 10. Transformed reaction time (RT) in Stroop test for the experimental group. It illustrates the dispersion of square root reaction times for the experimental group.

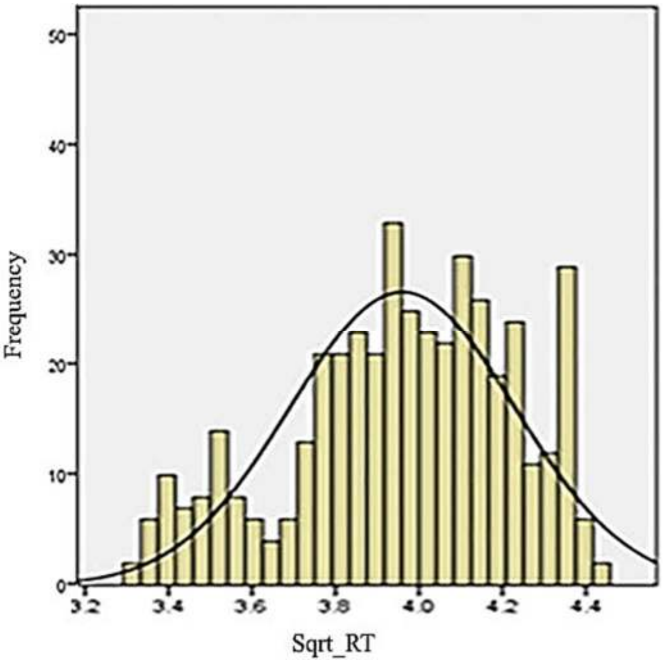


Figure 11. Transformed reaction time (RT) in Stroop test for the control group. It illustrates the dispersion of square root of reaction times for the control group.

For Experiment 1, the data for the second dependent variable, RA was found to violate statistical assumptions #5, #6, and #9. The Wilk's lambda was significant, $F(2, 861) = 7.91$, $p < .01$, indicating that there was multivariate normality, and the Box's M test was not significant $F(3, 133747920) =6.79$, $p = .08$, indicating the equal variances could be assumed. However, the distribution revealed a slight skewness value of -1.05 for the control group and -1.84 for the experimental group; and a kurtosis of 2.11 for the experimental group and 3.22 for the control group. Because of the small sample size, the negative skewness was expected for the RA scores with most score closer to 100%. Therefore, it was decided that transformations of the RA dependent variable were not required.

Data Analysis

I conducted a one-way ANOVA to evaluate the effect of age group on RT (see Table 5). Using the Bonferroni method, the data revealed significant mean differences between all age-groups, $F(3, 863) = 42.67, p < .01, n^2 = 1.3$ (see Figure 12). In addition, there was a significant RT by sex interaction between groups, $F(1, 863) = 60.10, p < .01, n^2 = 6.5$. The Pearson product moment correlation coefficient (r) was conducted to assess the degree the age and RT were linearly related in the sample. The regression analysis indicated that the relationship between age and reaction time were statistically significant, [$R^2 = .118, R^2_{\text{adj}} = .117, F(1, 862) = 115.77, p < .01$]. The results suggested that RT scores were affected by the age of the study participants.

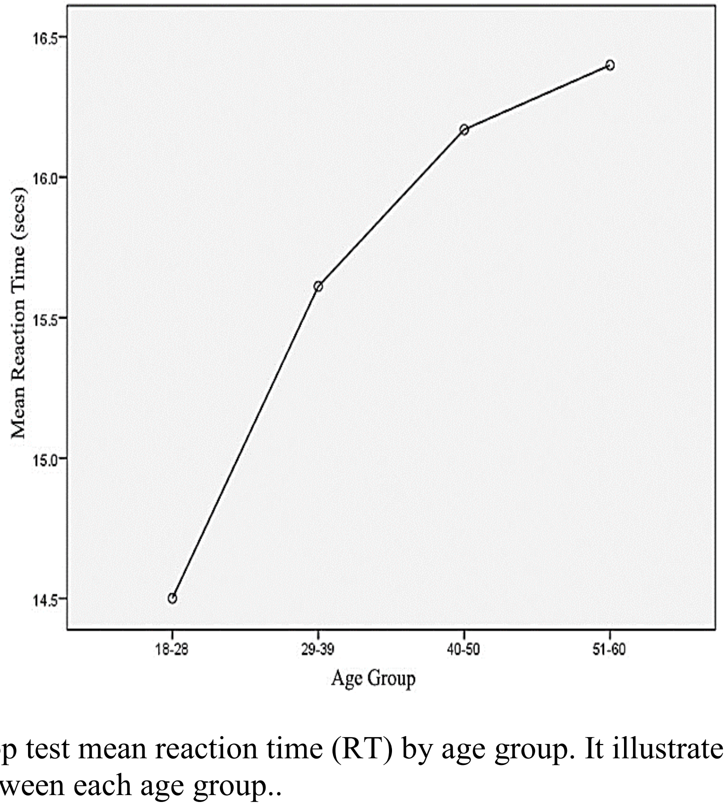


Figure 12. Stroop test mean reaction time (RT) by age group. It illustrates mean RT performance between each age group..

Using a one-way ANOVA, I evaluated the mean differences in RA scores between the experimental and control groups which was found to be significant, *F*(1, 863) = 3.83, *p* = .05 (see Table 5). Table 6 shows RA (Errors) by Ethnicity by Gender and Graphic Type by Group.

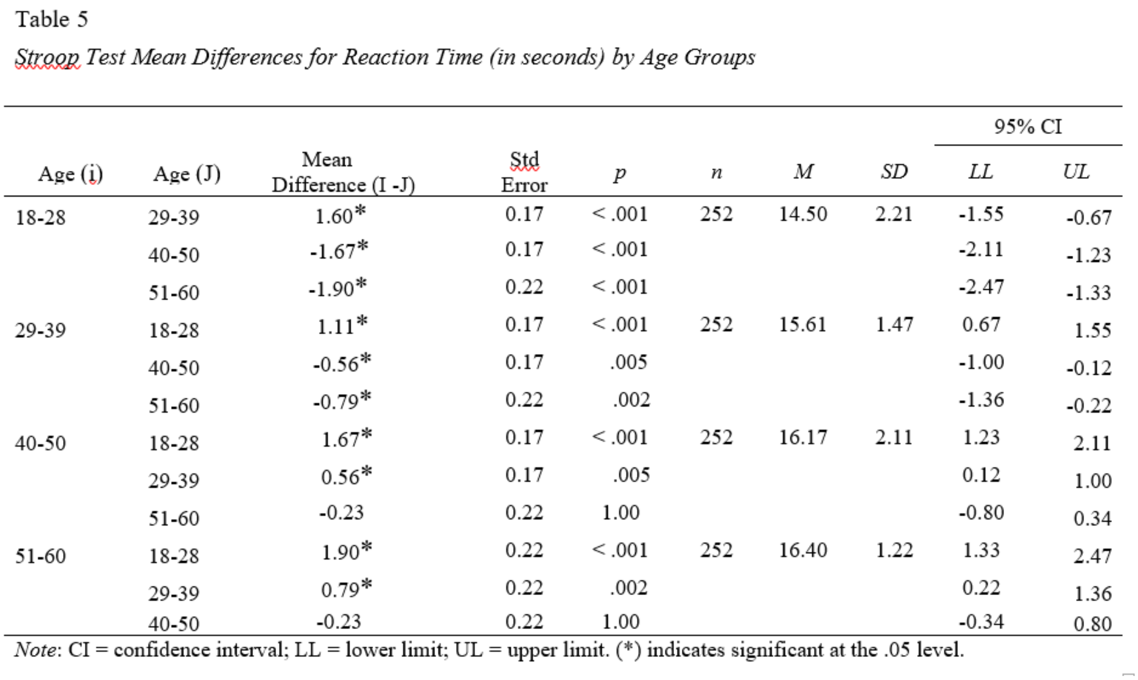


Table 5

Stroop Test Mean Differences for Reaction Time (in seconds) by Age Groups

Age (i)	Age (J)	Mean Difference (I -J)	Std Error	*p*	*n*	*M*	*SD*	95% CI *LL*	95% CI *UL*
18-28	29-39	1.60*	0.17	< .001	252	14.50	2.21	-1.55	-0.67
	40-50	-1.67*	0.17	< .001				-2.11	-1.23
	51-60	-1.90*	0.22	< .001				-2.47	-1.33
29-39	18-28	1.11*	0.17	< .001	252	15.61	1.47	0.67	1.55
	40-50	-0.56*	0.17	.005				-1.00	-0.12
	51-60	-0.79*	0.22	.002				-1.36	-0.22
40-50	18-28	1.67*	0.17	< .001	252	16.17	2.11	1.23	2.11
	29-39	0.56*	0.17	.005				0.12	1.00
	51-60	-0.23	0.22	1.00				-0.80	0.34
51-60	18-28	1.90*	0.22	< .001	252	16.40	1.22	1.33	2.47
	29-39	0.79*	0.22	.002				0.22	1.36
	40-50	-0.23	0.22	1.00				-0.34	0.80

Note: CI = confidence interval; LL = lower limit; UL = upper limit. (*) indicates significant at the .05 level.

Table 6 shows RA (Errors) by Ethnicity by Gender and Graphic Type by Group. The data revealed that the overall effect of interference on RA performance of study participants were less for the control group (no interference) than the experimental group (see Figure 13). These results were consistent with research hypotheses 1a and 1b.

Table 6

Stroop Test Recognition Accuracy (Errors) by Ethnicity by Gender and Graphic Type by Group

Group	Female				Male			
	Normal		Degraded		Normal		Degraded	
	Con	Incon	Con	Incon	Con	Incon	Con	Incon
Experimental								
Black	4	3	1	3	2	0	4	3
White	7	18	15	24	4	4	6	3
Other	12	8	8	22	10	6	6	5
Total	23	29	24	49	16	10	16	11
%	68	85	77	82	47	29	47	23
Mean	7.67*	9.67*	8.00*	16.33*	5.33*	3.33*	5.33*	3.67*
Variance	69.67	132.33	96.67	356.33	40.00	17.33	29.33	14.33
STDev	8.35	11.50	9.83	18.88	6.32	4.16	5.42	3.79
Control								
Black	1	1	0	2	10	4	5	1
White	8	4	4	6	2	11	6	10
Other	2	0	3	3	6	9	7	26
Total	11	5	7	11	18	24	18	37
%	32	15	23	18	53	71	53	77
Mean	3.67	1.67	2.33	3.67	6.00	8.00	6.00	12.33
Variance	23.00	5.67	8.33	16.33	15.56	24.22	12.22	86.33
STDev	4.80	2.38	2.89	4.04	3.94	4.92	3.50	9.29
Grand Total	34	34	31	60	34	34	34	48

Note: The proportion of errors for each gender in each stimulus degradation bracket is represented in the percentages rows. Percentages were rounded to the nearest whole number for the Grand Totals. *Con refers to "Congruent", Incon refers to "Incongruent", and STDev refers to "Standard Deviation." (*) indicates significant at .05 level.*

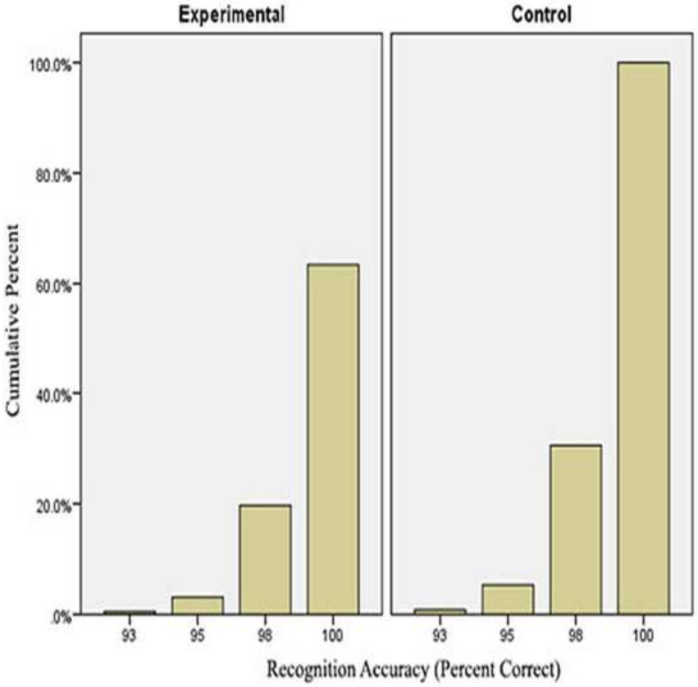


Figure 13. Stroop test recognition accuracy (percent correct) between groups. It illustrates the percent of correct color-naming trials performed by both groups.

In addition, multiple comparisons between interference types (speech, music, and noise) and RA between groups was not significant, *F*(2, 863) = 2.26, *p* = .11 (see Figure 14).

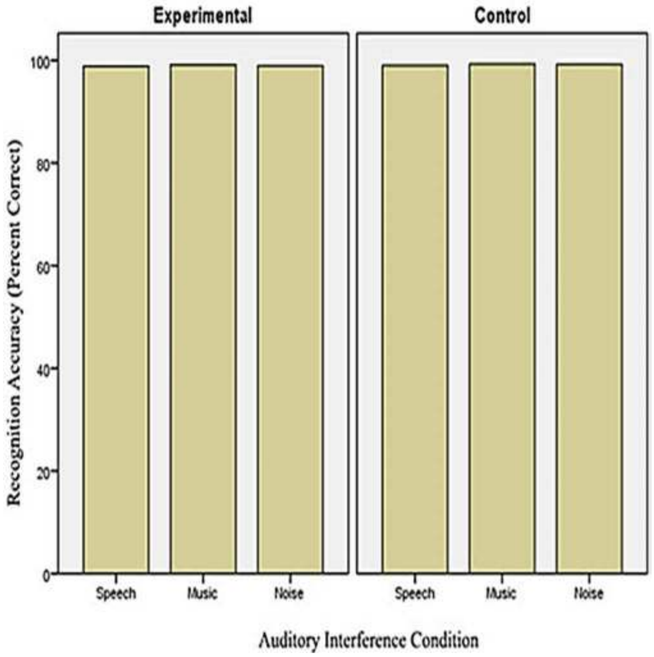


Figure 14. Untransformed recognition accuracy (percent correct) for auditory interference for Stroop test. It illustrates a comparison of recognition accuracy performance between both groups for auditory interference types.

Experiment 2a: Object Recognition

Data Preparation

For Experiment 2a, all assumptions, except #5 and #6 were met. For assumption #5, The Box's M test was not computed due to fewer than two nonsingular cell covariance matrices. The Levene's test of equality of error variances also was not significant *F*(24, 1415) = 3.25, *p* < .001, indicating the equal variances cannot be assumed. However, the distribution revealed a skewness value of 1.17 for the experimental group and 1.31 for the control group; and a kurtosis of 2.51 for the experimental group and 3.50 for the control group. Initially, 44 data points were identified as multivariate outliers (see Figure 15). It is questioned as to whether these data points should be considered as true multivariate outliers caused by participant errors, or the results of delays in spatial information processing. After I transformed these outliers, a more normal distribution was produced (see Figure 16). The extreme values ranged between 88 and 3747 milliseconds. The distribution revealed a skewness value of .44 for the experimental group and .68 for the control group; and a kurtosis of -.35 for the experimental group and -.09 for the control group.

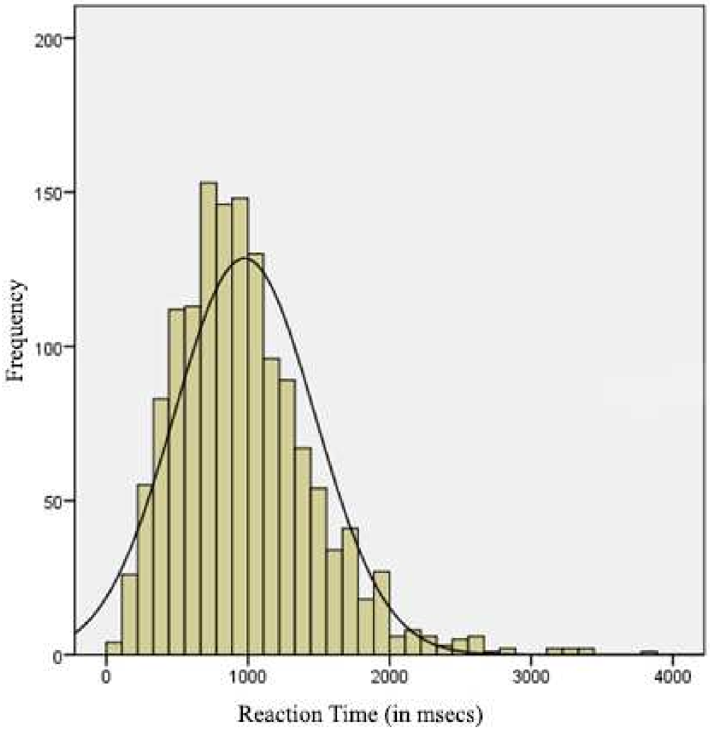


Figure 15. Reaction time (RT) in Experiment 2a for both groups. It illustrates the dispersion of reaction times before outlier transformation.

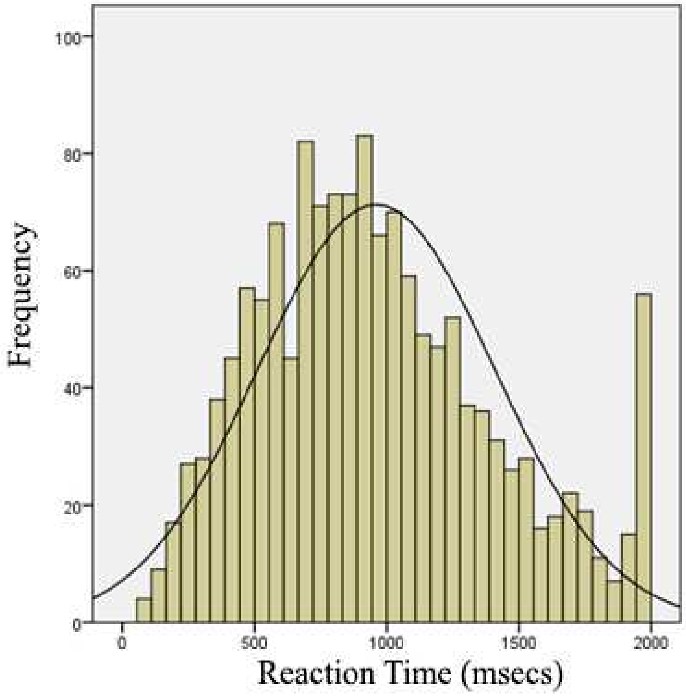


Figure 16. Reaction time (RT) in Experiment 2a for both groups after the transformation of extreme RT data points. It illustrates the dispersion of RT after oulier transformation.

Whelan (2008) recommended several transformations of RT should be calculated. For the previous experiments, both transformed RT and SQRT RT are reported for the experimental group (see Figure 17) and for the control group (see Figure 18).

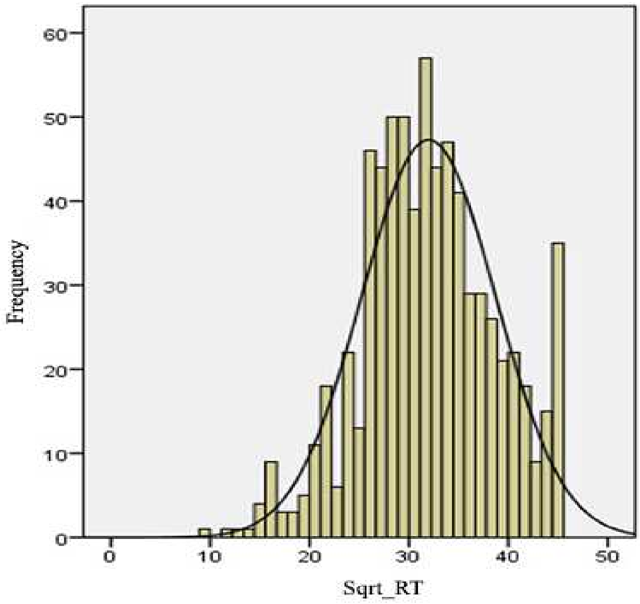


Figure 17. Transformed reaction time (RT) for object recognition for the experimental group. It illustrates the dispersion of square root RT for the experimental group.

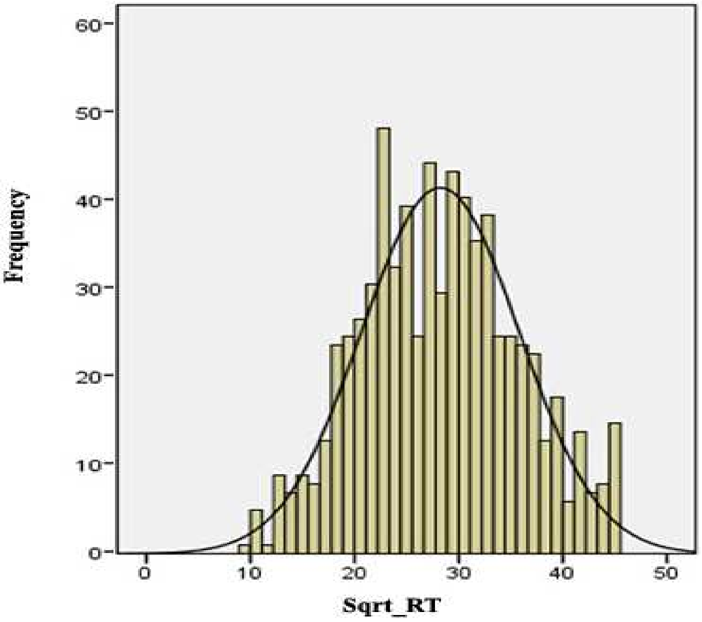


Figure 18. Transformed reaction time (RT) for object recognition for the control group. It illustrates the dispersion of square root of RT for the control group.

Data Analysis

Using a one-way ANOVA, I evaluated the effect of age group on RT. Using the Bonferroni method, the data revealed significant mean differences between all age groups, $F(3, 1438) = 37.70$, $p < .01$, except for between the 18-28 and 29-39 age groups, $p > .05$ (see Figure 19).

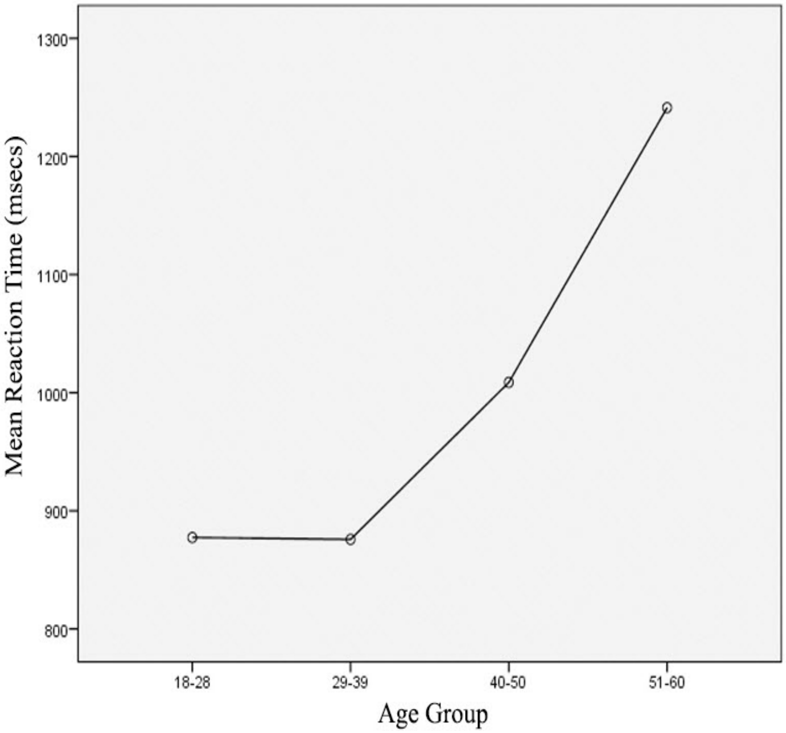
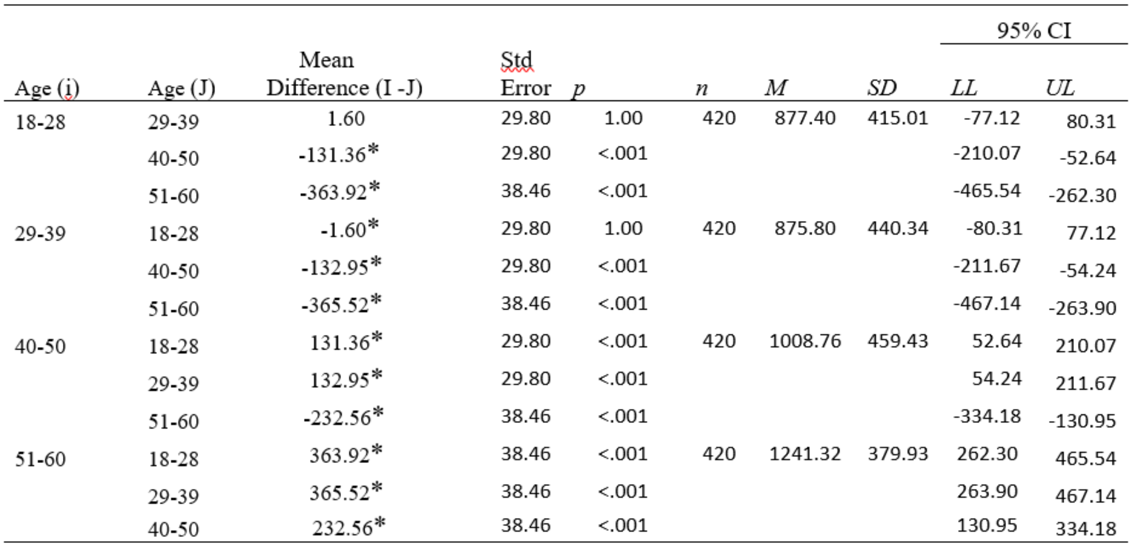


Figure 19. Object recognition mean reaction time (RT) by age group in Experiment 2a. It illustrates mean RT performance between each age group..

I conducted a Pearson product moment correlation coefficient (r) to assess the degree that age group and RT were linearly related in the sample. The regression analysis indicated that the relationship between age and reaction time were statistically significant, [$R^2 = .240$, $R^2_{\text{adj}} = .057$, $F(1, 862) = 87.66$, $p < .01$]. Table 7 shows the mean differences for RT between age groups. The results suggested that RT scores were affected by the age of the study participants.

Table 7

Object Recognition Mean Differences for Reaction Time Between Age Groups



								95% CI	
Age (i)	Age (J)	Mean Difference (I -J)	Std Error	*p*	*n*	*M*	*SD*	*LL*	*UL*
18-28	29-39	1.60	29.80	1.00	420	877.40	415.01	-77.12	80.31
	40-50	-131.36*	29.80	<.001				-210.07	-52.64
	51-60	-363.92*	38.46	<.001				-465.54	-262.30
29-39	18-28	-1.60*	29.80	1.00	420	875.80	440.34	-80.31	77.12
	40-50	-132.95*	29.80	<.001				-211.67	-54.24
	51-60	-365.52*	38.46	<.001				-467.14	-263.90
40-50	18-28	131.36*	29.80	<.001	420	1008.76	459.43	52.64	210.07
	29-39	132.95*	29.80	<.001				54.24	211.67
	51-60	-232.56*	38.46	<.001				-334.18	-130.95
51-60	18-28	363.92*	38.46	<.001	420	1241.32	379.93	262.30	465.54
	29-39	365.52*	38.46	<.001				263.90	467.14
	40-50	232.56*	38.46	<.001				130.95	334.18

Note: CI = confidence interval; LL = lower limit; UL = upper limit. (*) indicates significant at the .05 level.

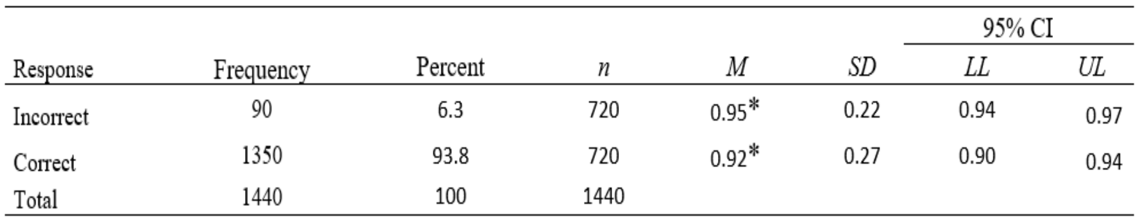
For Experiment 2a, a one-way univariate ANOVA was conducted on the data for the second dependent variable, and the Levene's test of equality of error variances also was not significant, $F(22, 1417) = .49$, $p = .98$, indicating the equal variances can be assumed for RA (percent correct) across groups. The univariate tests for between-subjects effects were not significant for the main effects of group and gender, $F(1, 1750) = .01$, $p = .99$, graphic type, $F(2, 1750) = .35$, $p = .71$. In addition, no two-way and three-way interactions were found to be significant.

Using a one-way ANOVA, I evaluated the effects of sex, age-range, and interference conditions on RA which was not significant for sex, $F(1, 1417) = .01$, $p = .99$; age-range, $F(3, 1417) = .004$, $p = 1.0$; and interference, $F(2, 1417) = 1.43$, $p = .23$.

A one-way ANOVA, I conducted to evaluate the mean differences in RA scores between the experimental and control groups was found to be significant, *F*(1, 1440) = 9.44, *p* <.01. In addition, an independent samples *t*-test for mean differences in RA between the experimental and control groups was significant, *t*(1438) = 38.64, *p* = .002). Table 8 shows RA (percent correct) for both groups. The data revealed that for the overall effect of interference on RA performance of study participants was less for the control group (no interference) (*M* = .92, *SD* = .266) than the experimental group (*M* = .88, *SD* = .331) (see Figure 20). These results were consistent with research hypothesis 2b.

Table 8

Object Detection Recognition Accuracy (Percent Correct) for Both Groups



						95% CI	
Response	Frequency	Percent	*n*	*M*	*SD*	*LL*	*UL*
Incorrect	90	6.3	720	0.95*	0.22	0.94	0.97
Correct	1350	93.8	720	0.92*	0.27	0.90	0.94
Total	1440	100	1440				

Note: CI = confidence interval; LL = lower limit; UL = upper limit. (*) indicates significant at the .05 level.

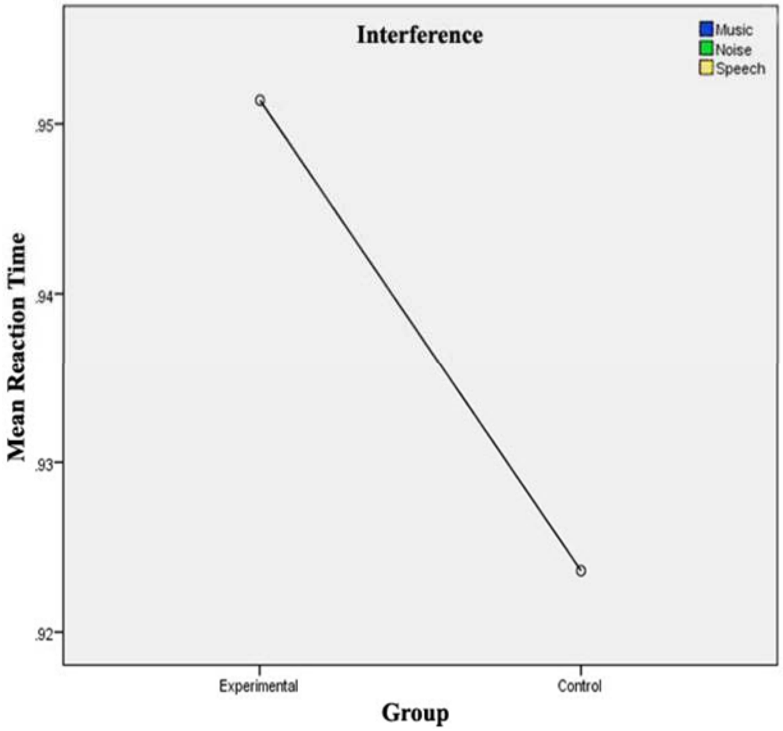


Figure 20. Difference in mean recognition accuracy (percent correct) between groups in Experiment 2a. It illustrates the effect of auditory interference between the experimental and control groups..

A two-way contingency table analysis also was conducted relating age and experimental condition to the dependent variable RA $X^2(3, N = 1440) = 114.39, p < .01$, and gender and experimental condition, $X^2(1, N = 1440) = 251.72, p < .01$. The strength of the relationship between gender and condition as assessed by Cramer's *V*, was .42, indicating a strong relationship. Cramer's *V*, was also .42 for the strength of the relationship age and condition. Further analysis using the Kruskal-Wallis test to evaluate whether the population means for RA were the same across all levels of age-range was found to be significant, $X^2(2, N = 1440) = 159.40, p < .01$.

Using a univariate analysis, I evaluated differences in mean RT by condition between groups. The main effect of group was found to be significant, *F*(1, 1440) = 86.14, *p* < .01; and the main effect of condition was found to be significant, *F*(3, 1440) = 3.42, *p* = .02. However, the group by condition interaction was not found to be significant, *F*(2, 1440) = .03, *p* = .97. Graphic representations of the differences are shown in Figures 21 and 22.

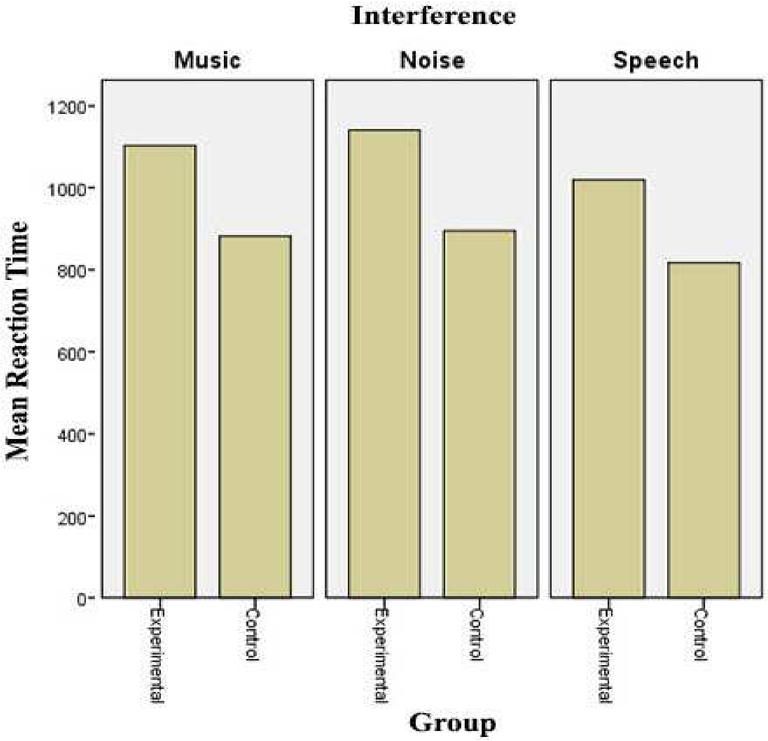


Figure 21. Difference in mean reaction time (RT) and auditory interference by group in Experiment 2a. It illustrates the interference effect by group for each type of auditory interference.

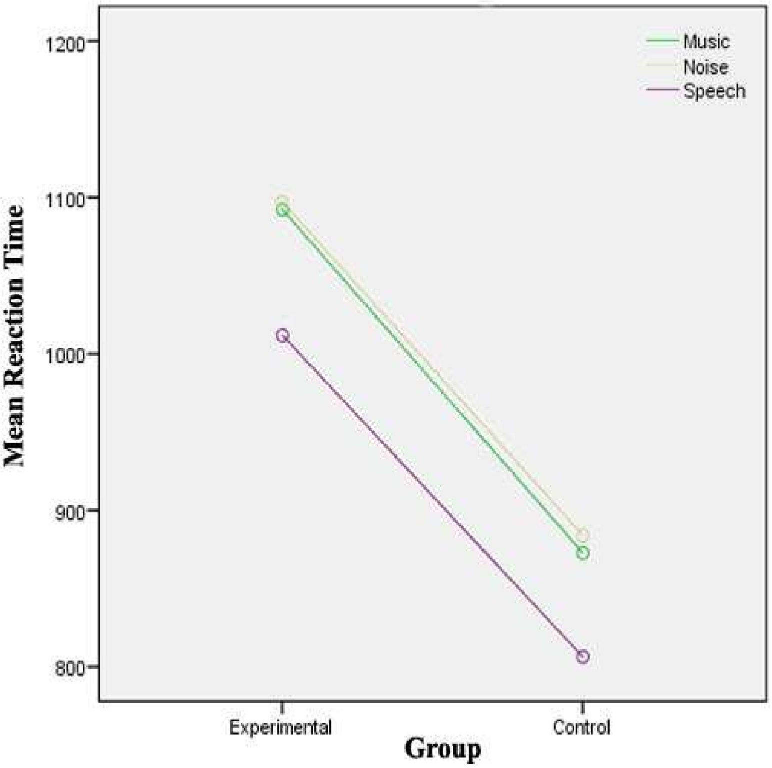


Figure 22. Comparison of reaction time (RT) and auditory interference by group in Experiment 2a. It illustrates the overall difference in mean reaction time for auditory interference by group.

The chi-square test for independence, also called Pearson's chi-square test or the chi-square test of association was conducted to evaluate whether spatial location was processed differentially between men and women under the three types (speech, music, and noise) of audio interference. The test required meeting two assumptions: 1) the two variables should be measured at the ordinal or nominal level (i.e., categorical data), and 2) the two variables used should consist of two or more categorical, independent groups. Both assumptions were satisfied for the chi-square test. The two-way contingency table for the data, I conducted revealed no differences between male and female participants for the effect of interference on performance. Gender and interference were not significantly related, Pearson $X^2(6, N = 780) = 6.60$, $p = .36$, for male participants, and Pearson $X^2(6, N = 657) = 4.01$, $p = .67$, for female participants. The proportion of men who were affected by spatial location and the three types of interference were 33.5, 33.3, and 33.2 percent, while women were 33.2, 33.3, and 33.5 percent.

Notwithstanding these data, slight differences were noted based on retinotopic mapping. Both men and women made more errors in spatial location perceptions for speech and music than for noise interference (see Figure 23 for men, and Figure 24 for women). For men, more errors were made for speech interference when geometric shapes were projected to the left visual field areas 1, 2 of the striate cortex (V1) and 5, 6 of the parastriate cortex (V2), and women when geometric shapes were projected to the left visual field or right visual field areas 3, 4 of the striate cortex (V1) and 7, 8 of parastriate cortex (V2). For music interference, men made more errors when geometric shapes were projected to the bottom visual field areas 2, 4 of the striate cortex (V1) and 6, 8 of the parastriate (V2), and women when geometric shapes were projected to the left visual field areas 1, 2 of the striate cortex (V1) and 5, 6 of the parastriate cortex (V2). For men, more errors were made for noise interference when geometric shapes were projected to the left visual field areas 1, 2 of the striate cortex (V1) and 5, 6 of the parastriate cortex (V2), and women when geometric shapes were projected to the left visual field or right visual field areas 3, 4 of the striate cortex (V1) and 7, 8 of parastriate cortex (V2). These results were consistent with research hypotheses 2 and 3.

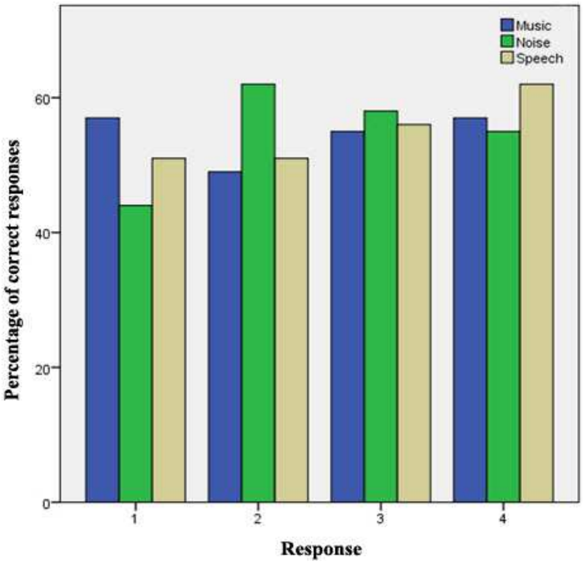


Figure 23. Proportion of correct responses by condition and spatial location for males in Experiment 2a. Left = "1", Right = "2", Top = "3", and Bottom = "4." It illustrates the effect of auditory interference on object recognition based on visual projections around a center fixation point for males.

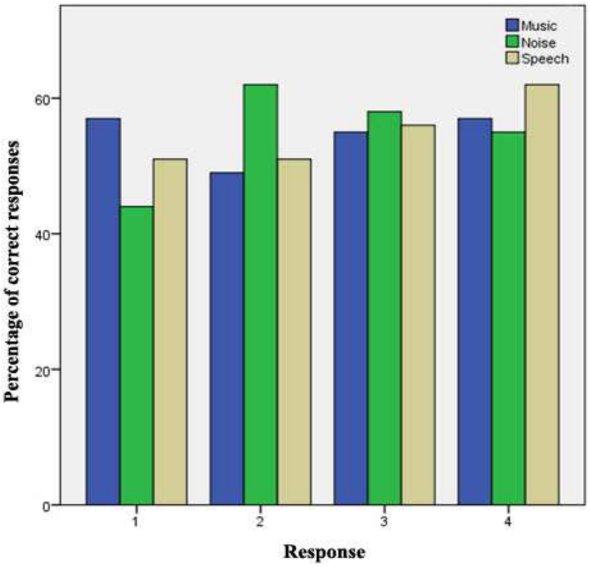


Figure 24. Proportion of correct responses by condition and spatial location for females in Experiment 2a. Left = "1", Right = "2", Top = "3", and Bottom = "4." It illustrates the effect of auditory interference on object recognition based on visual projections around a center fixation point for females.

Experiment 2b: Object Detection

Data Preparation

For Experiment 2b, all assumptions, except #5 and #6 were met. For assumption #5, The Box's M test was not computed due to fewer than two nonsingular cell covariance matrices. The Levene's test of equality of error variances also was not significant *F*(24, 1415) = 3.25, *p* < .001, indicating the equal variances cannot be assumed. Initially, 44 data points were identified as multivariate outliers (see Figure 25).

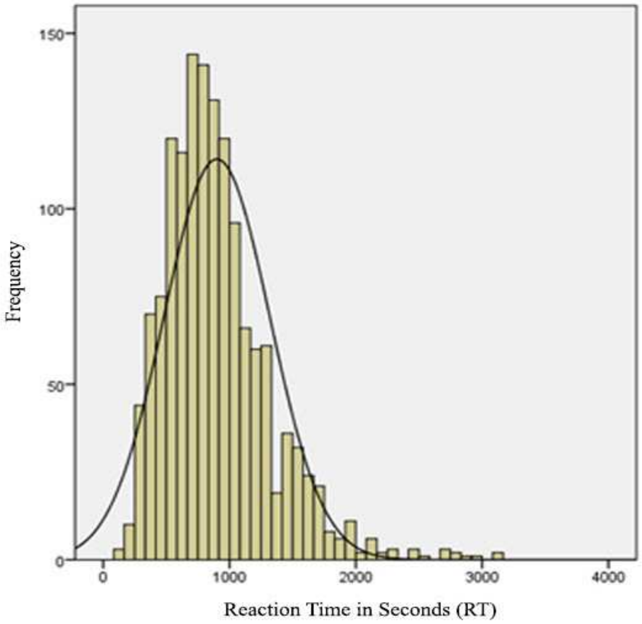


Figure 25. Reaction time (RT) in Experiment 2b for both groups. It illustrates the dispersion of RT before the transformation of outliers.

The distribution revealed a skewness value of 1.17 for the experimental group and 1.31 for the control group; and a kurtosis of 2.51 for the experimental group and 3.50 for the control group. As in Experiment 1, the MAD formula utilized was the following equation for the threshold of outliers: $M - 3(MAD) < \text{RT} < M + 3(MAD)$. The symbol *M* is the median of the RT scores. MAD = 313.89, and *M* = 828.5, yielded an interval of -

113 < RT < 1770. All RT data above 1770 ms were recoded instead of being removed, resulting in the transformation of 49 RT data points (3% of the original RT data total). After I transformed these outliers, a more normal distribution was produced (see Figure 26). The extreme values ranged between 97 and 3161 milliseconds.

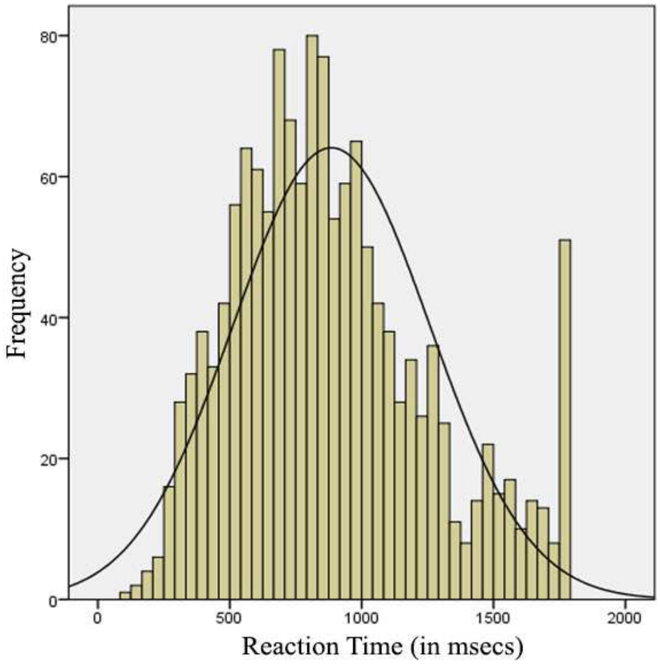


Figure 26. Reaction time (RT) in Experiment 2b for both groups after transformation of extreme RT data points. It illustrates the dispersion of RT after outlier transformation.

Following the recommendations of Whelan (2008) that several transformations of RT should be calculated, both transformed RT and Sqrt_RT for the experimental group (see Figure 27) and for the control group (see Figure 28) are reported.

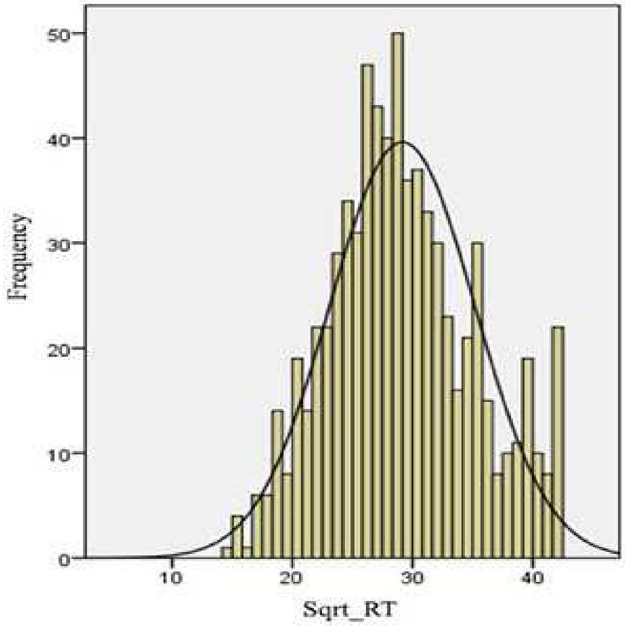


Figure 27. Transformed reaction time (RT) for the experimental group in Experiment 2b. It illustrates the dispersion of square root RT for the experimental group.

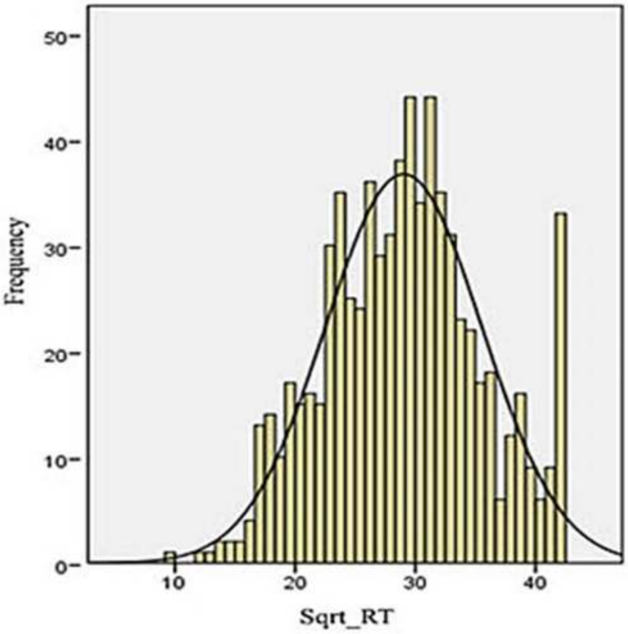


Figure 28. Transformed reaction time (RT) for the control group in Experiment 2b. It illustrates the dispersion of square root RT for the control group..

For Experiment 2b, the one-way MANOVA I conducted for the RA, and the Wilk's lambda for the main group effect was significant, $F(2, 861) = 7.91$, $p < .01$, indicating that there was multivariate normality, and the Box's M test was not significant $F(3, 133747920) =6.79$, $p = .08$, indicating the equal variances could be assumed. However, the distribution revealed a slight skewness value of -1.05 for the control group and -1.84 for the experimental group; and a kurtosis of 2.11 for the experimental group and 3.22 for the control group. Because of the small sample size, the negative skewness was expected for the RA scores with most score closer to 100%. Therefore, it was decided that transformations of the RA dependent variable were not required.

Data Analysis

Using a one-way ANOVA, I evaluated the effect of age group on RT. Using the Bonferroni method, the data revealed significant mean differences between all age groups, $F(3, 1436) = 21.12$, $p < .01$, except for between the age groups of 18-28 and 29-39, 18-28 and 51-60, and 29-39 and 51-60, $p > .05$ (see Figure 29).

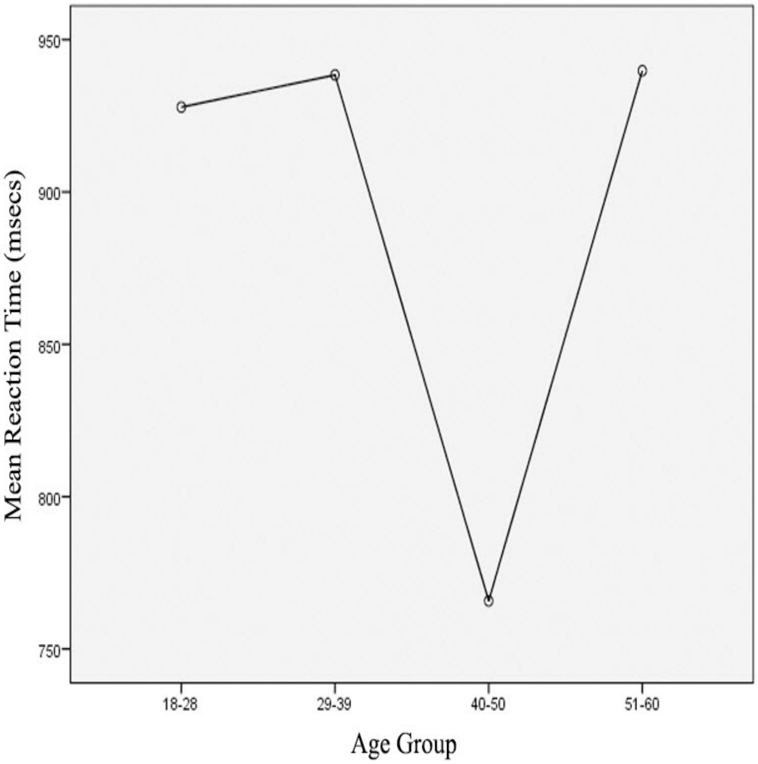


Figure 29. Object detection mean reaction time (RT) by age group. It illustrates mean RT performance between each age group.

I used the Pearson product moment correlation coefficient (*r*) to assess the degree that age group and RT were linearly related in the sample. The regression analysis indicated that the relationship between age and RT were statistically significant, [R^2 = .089, R^2_{adj} = .008, $F(1, 1438) = 11.51$, $p < .01$]. Table 9 shows the mean differences for RT between age groups. The results suggested that RT scores were affected by the age of the study participants.

A univariate analysis I conducted to evaluate the mean differences in RA scores between the experimental and control groups was found to be significant, $F(1, 1440) = 9.44$, $p < .01$ (see Figure 30). In addition, an independent samples *t*-test for mean differences in RA between the experimental and control groups was significant, *t*(1438) = 38.64, *p* = .002). Table 10 shows a comparison of RA (percent correct) for both groups. The data revealed that for the overall effect of interference on RA performance of study participants was less for the control group (no interference) (*M* = .92, *SD* = .266) than the experimental group (*M* = .88, *SD* = .331). These results were consistent with research hypothesis 3.

Table 10

Part-Whole Matching Recognition Accuracy (Percent Correct) for Both Groups

						95% CI	
Response	Frequency	Percent	*n*	*M*	*SD*	*LL*	*UL*
Incorrect	145	10.1	720	0.88*	0.33	0.85	0.90
Correct	1295	89.9	720	0.92*	0.27	0.90	0.94
Total	1440	100	1440				

Note: CI = confidence interval; LL = lower limit; UL = upper limit. (*) indicates significant at the .05 level.

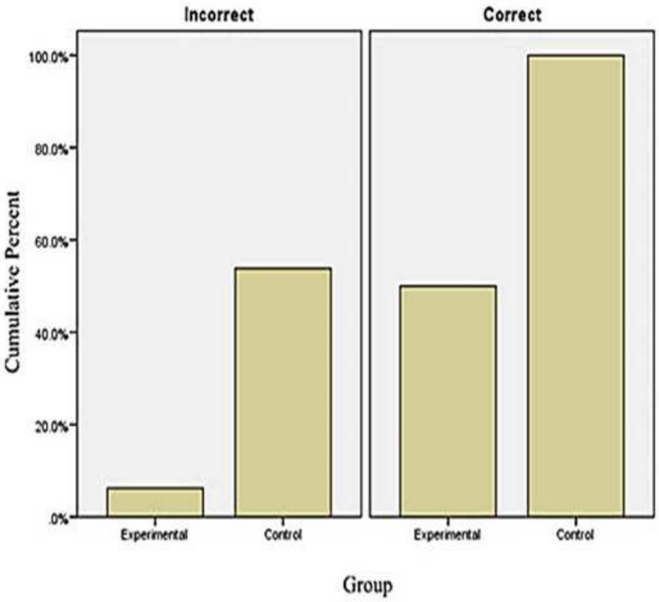


Figure 30. Difference in recognition accuracy (percent correct) between groups in Experiment 2b. It illustrates the effect of auditory interference between the experimental and control groups..

I conducted a univariate analysis to evaluate differences in mean RT by condition between groups. The main effect of group was not found to be significant, *F*(1, 1440) = ..003, *p* = .96; and the main effect of condition was found to be significant, *F*(2, 1440) = 8.97, *p* < .01. However, the group by condition interaction was not found to be significant, *F*(2, 1440) = .45, *p* = .63. Graphic representations of the differences are shown in Figure 31.

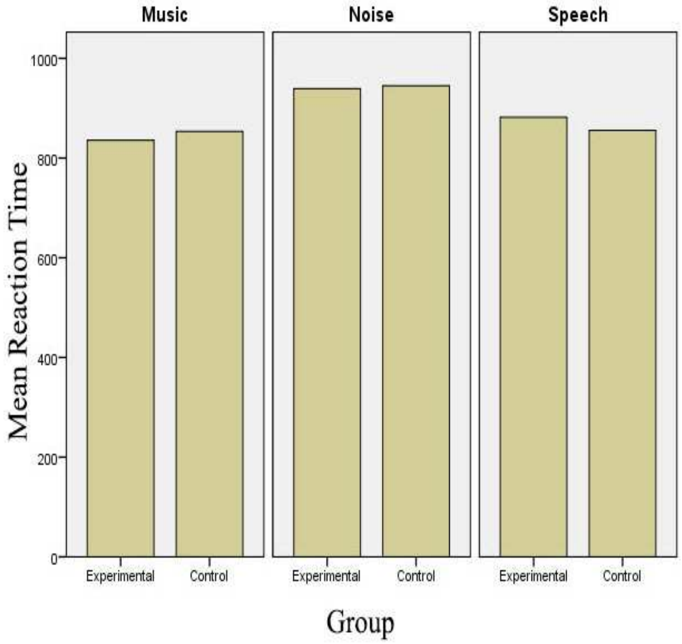


Figure 31. Comparison of mean reaction time (RT) and auditory interference by group in Experiment 2b. It illustrates the interference effect on RT performance for the experimental and control groups.

Using a one-way MANOVA I evaluated differences in mean RT by condition and spatial location. Examination of the multivariate tests indicated that the Wilk's lambda for the main effects of condition, *F*(4, 2856) = .07, p < .01, and location, *F*(6, 2856) = .98, *p* < .01 were significant. In addition, The Wilk's lambda for the condition by location interaction was also significant, *F*(12, 2856) = .96, *p* < .01 (see Figure 32).

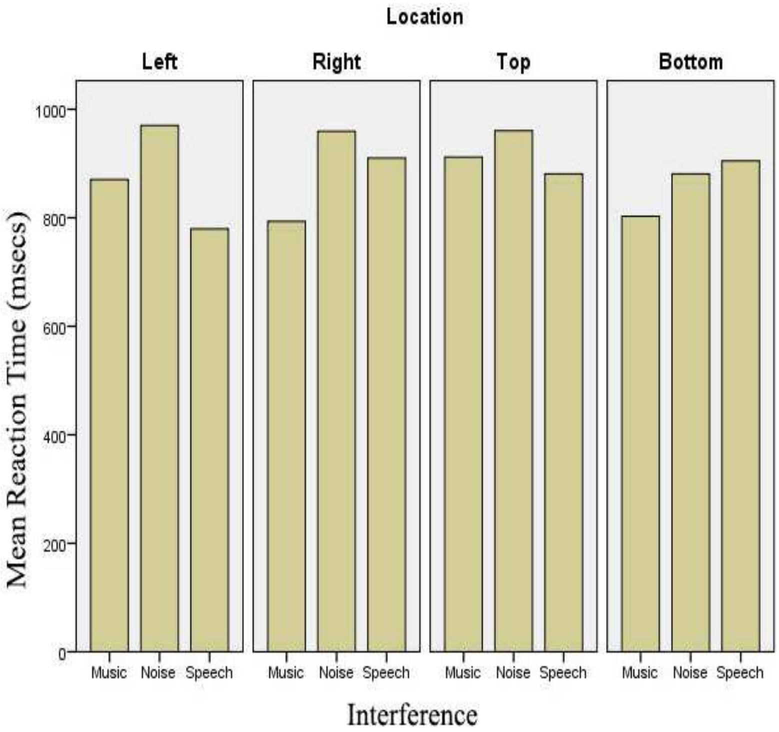


Figure 32. Difference in mean reaction time (RT) and auditory interference by spatial location in Experiment 2b. It illustrates overall reaction time performance for spatial location and interference condition..

The data revealed slight differences based on retinotopic mapping. For speech and music interference, participants' reaction times were faster when geometric shapes were projected to the left visual field areas 1, 2 of the striate cortex (V1) and 5, 6 of the parastriate cortex (V2). For music interference, reaction times were faster when geometric shapes were projected to the bottom visual field areas 2, 4 of the striate cortex (V1) and 6, 8 of the parastriate (V2). RT was slower when geometric shapes were projected to all visual fields for noise interference. These results were consistent with research hypothesis 2.

Experiment 3: Part-Whole Matching

Data Preparation

For Experiment 3, a one-way MANOVA I conducted revealed that all assumptions were met for the continuous variable RT, except for assumption #9. The Box's M test was not significant, $F(3, 953856720) = .852$, $p =.46$, indicating that equal covariance matrices cannot be assumed and there are differences in the matrices. This contention was also supported by Levene's test of equality of error variances which also was not significant for RA, $F(1, 2302) = .66$, $p = .42$, and reaction time, $F(1, 2302) = .64$, $p = .42$, indicating the equal variances cannot be assumed. In addition, Wilk's lamba for the main group effect was significant, $F(2, 2301) = .07$, $p < .01$, the Wilk's lambda for both RA and RT was significant, $F(2, 2301) = 17.04$, $p < .01$. Pairwise comparisons between groups for RA were insignificant, $F(1, 2302) = .16$, $p = .68$, but was significant, $F(1, 2302) = 34.10$, $p < .01$ for reaction time.

However, the distribution revealed a skewness value of 1.91 for the experimental group and 2.06 for the control group; and a kurtosis of 5.59 for the experimental group and 9.00 for the control group. The data revealed outliers (see Figure 33), which were transformed for both groups overall. Initially, 117 data points were identified as multivariate outliers. It is questioned as to whether these data points should be considered as true multivariate outliers caused by participant errors, or the results of delays in spatial information processing. The extreme values ranged between 40 and 2592 milliseconds. After I transformed these outliers, a more normal distribution was produced (see Figure 34). The distributions for the transformed RT are displayed for the experimental group (see Figure 35) and the control group (see Figure 36).

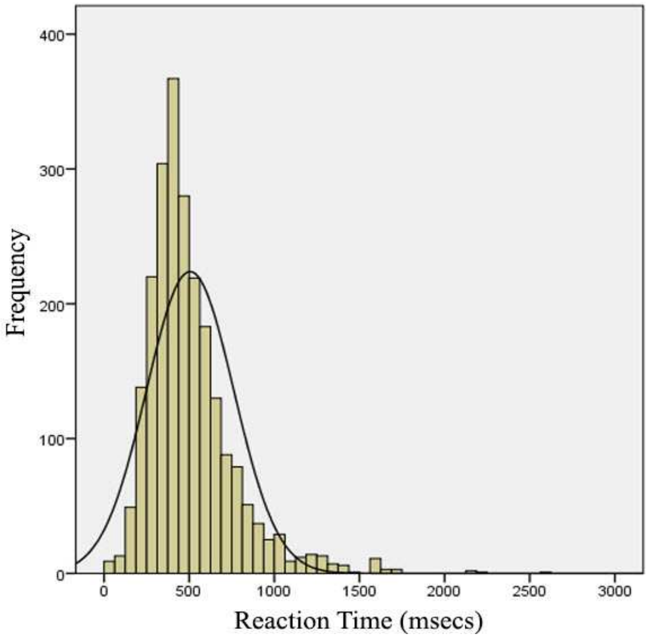


Figure 33. Reaction time (RT) in Experiment 3 for both groups. It illustrates the distribution of RT performance before the transformation of outliers.

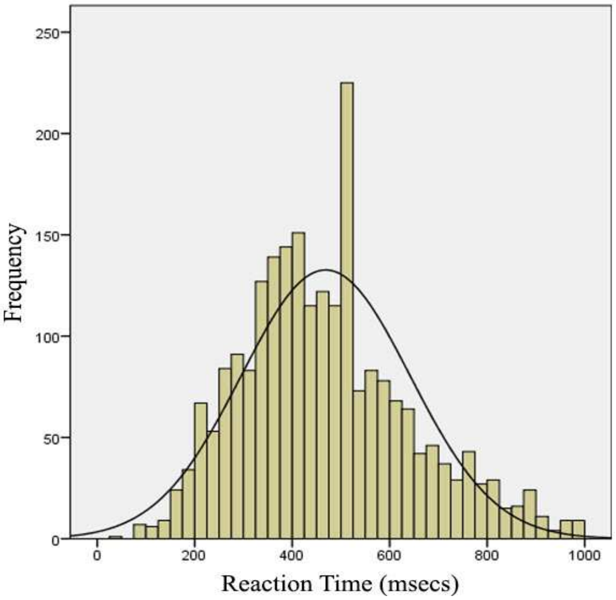


Figure 34. Reaction time (RT) in Experiment 3 for both groups after transformation of extreme RT data points. It illustrates reaction time performance after the tranformation of extreme RT data points.

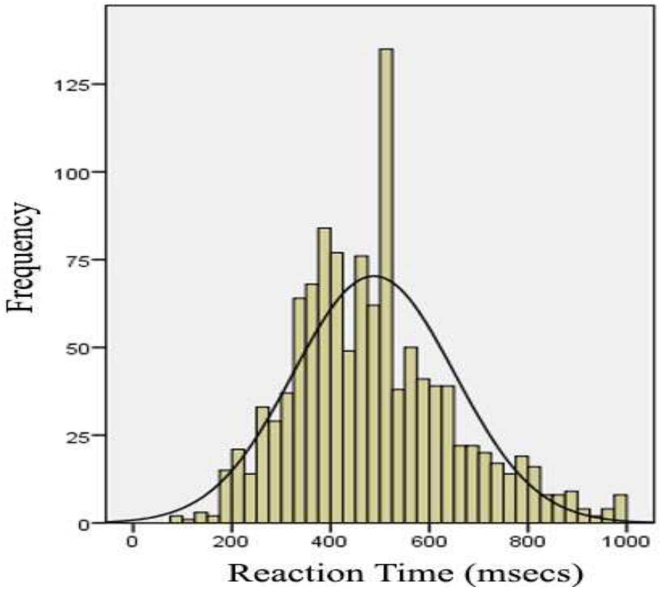


Figure 35. Transformed reaction time (RT) for the experimental group in Experiment 3. It illustrates RT performance after transformation of outliers for the experimental group.

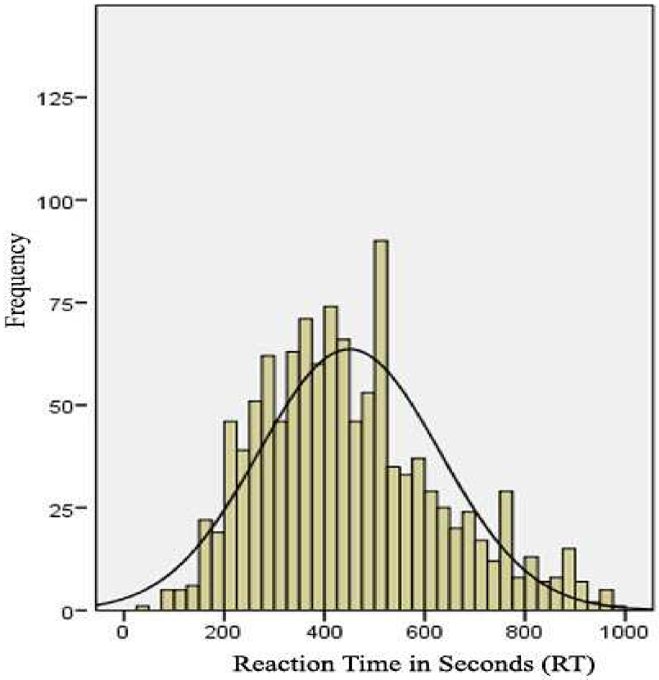


Figure 36. Transformed reaction time (RT) for the control group in Experiment 3. It illustrates RT performance after transformation of outliers for the control group.

Data Analysis

Using a one-way ANOVA, I evaluated the effect of age group on RT. Using the Bonferroni method, the data only revealed significant mean differences between the 18-28 and 51-60, 29-39 and 51-60, 40-50 and 51-60 age groups, *F*(3, 2303) = 70.28, *p* < .01. No other age group differences were noted. (see Figure 37).

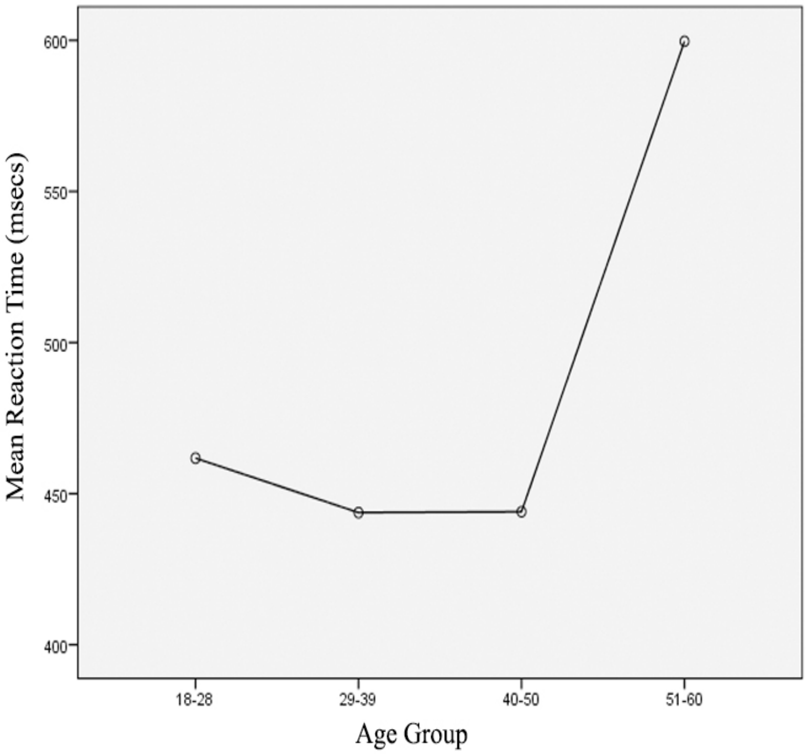
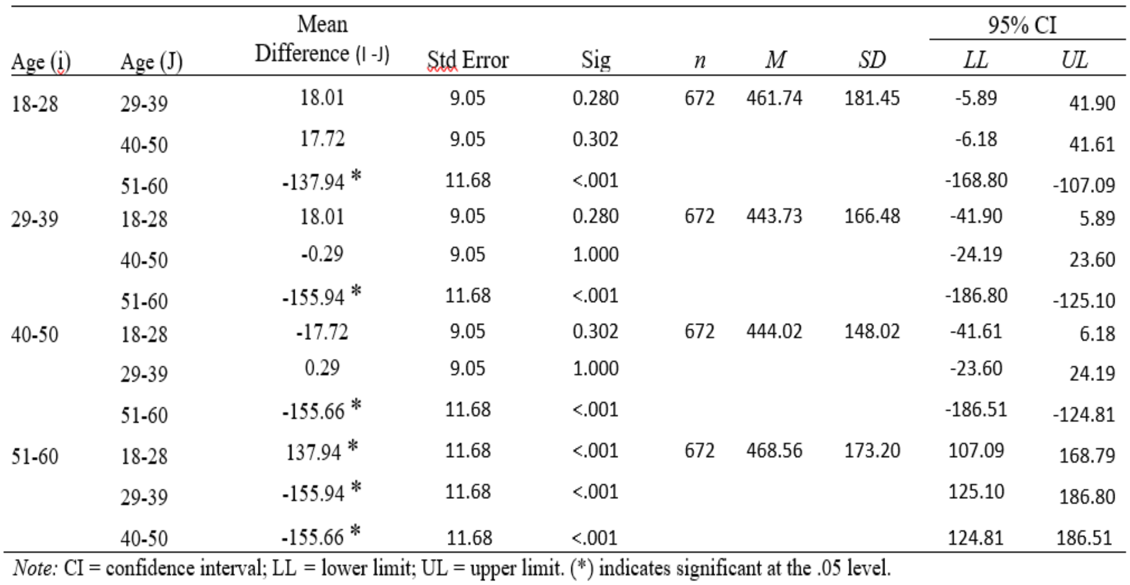


Figure 37. Part-whole matching mean reaction time (RT) by age group in Experiment 3. It illustrates differences in mean RT performance for each age group in Experiment 3.

I used a Pearson product moment correlation coefficient (r) to assess the degree that age group and reaction time were linearly related in the sample. The regression analysis indicated that the relationship between age and RT were statistically significant, [$R^2 = .025$, $R^2_{\text{adj}} = .024$, $F(1, 2303) = 58.80$, $p < .01$]. Table 11 shows the mean differences for RT between age groups. The results suggested that RT scores were affected by the age of the study participants.

Table 11

Mean Differences for Part-Whole Matching Reaction Time Between Age Groups



Age (i)	Age (J)	Mean Difference (I -J)	Std Error	Sig	*n*	*M*	*SD*	95% CI *LL*	95% CI *UL*
18-28	29-39	18.01	9.05	0.280	672	461.74	181.45	-5.89	41.90
	40-50	17.72	9.05	0.302				-6.18	41.61
	51-60	-137.94 *	11.68	<.001				-168.80	-107.09
29-39	18-28	18.01	9.05	0.280	672	443.73	166.48	-41.90	5.89
	40-50	-0.29	9.05	1.000				-24.19	23.60
	51-60	-155.94 *	11.68	<.001				-186.80	-125.10
40-50	18-28	-17.72	9.05	0.302	672	444.02	148.02	-41.61	6.18
	29-39	0.29	9.05	1.000				-23.60	24.19
	51-60	-155.66 *	11.68	<.001				-186.51	-124.81
51-60	18-28	137.94 *	11.68	<.001	672	468.56	173.20	107.09	168.79
	29-39	-155.94 *	11.68	<.001				125.10	186.80
	40-50	-155.66 *	11.68	<.001				124.81	186.51

Note: CI = confidence interval; LL = lower limit; UL = upper limit. (*) indicates significant at the .05 level.

A one-way univariate ANOVA I conducted on the data for RA, and the Levene's test of equality of error variances also was not significant, *F*(1, 2302) = .66, *p* = .42, indicating the equal variances can be assumed for recognition RA groups. The univariate tests for between-subjects effects were not significant for the main effects of group, *F*(1, 2304) = .16, *p* = .68. The results of the pairwise comparisons indicated the differences in the adjusted means were .006 (.897 - .891) between the control and experimental group. Based on the LSD, the pairwise differences for RA for gender between groups was not significant, *p* = .68 (see Figure 38). These results were inconsistent with research hypothesis 4, therefore the null hypothesis was accepted based on group differences.

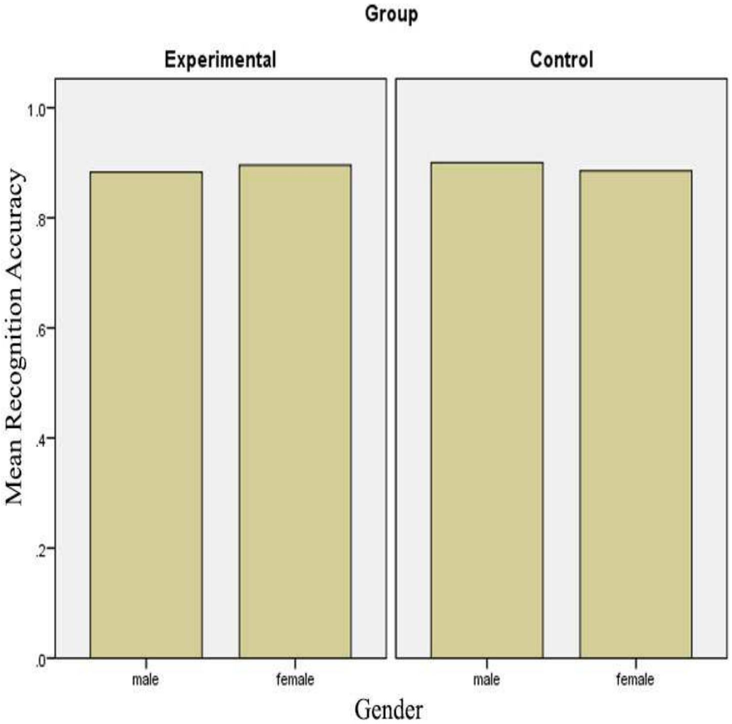


Figure 38. Recognition accuracy (percent correct) for gender between groups in Experiment 3. It illustrates mean RA for gender between the experimental and control groups.

Using a univariate analysis, I evaluated the effect of gender and spatial location (position) on RA. The data revealed no significant main effect, *F*(1,2304) = .00, *p* > .05 for gender, and a significant main effect, *F*(3, 2304) = 561.75, *p* < .01 for spatial location (see Figure 39), but no significant, *F*(3, 2304) = .00, *p* > .05 gender by spatial location (position) interaction. These results were inconsistent with research hypothesis 4 and the null hypothesis was accepted based on the gender main effect.

I conducted a univariate analysis to evaluate whether RA was affected by gender, interference, stimulus degradation, and spatial location (position). The data revealed significant between-subjects main effects for interference condition, *F*(2, 2304)= 10.50, *p* < .01, graphic type (stimulus degradation), *F*(2, 2304) = 5.84, *p* < .01, and spatial location (position), *F*(3, 2304) = 1194.68, $p < .01$. These results were consistent with the null hypothesis for research question 4, but indicated that the null hypothesis should be rejected for research hypothesis 5 (see Figures 39 through 43).

The data revealed that when ½ inch and 1 inch geometric shapes were projected in the left visual field participants made less errors than 1 ½ inch and 2 inch geometric shapes. When geometric shapes were projected to the right visual field less errors were made by participants for ½ inch, 1 ½ inch, and 1-inch shape sizes. Geometric shapes projected to the top-center visual field resulted in less errors by participants for 1 ½ inch and 2-inch shape sizes. For the bottom-center visual field, participants made less errors for 1 inch, 2 inch, 1 ½ inch, and ½ in geometric shape sizes, respectively (see Figure 39).

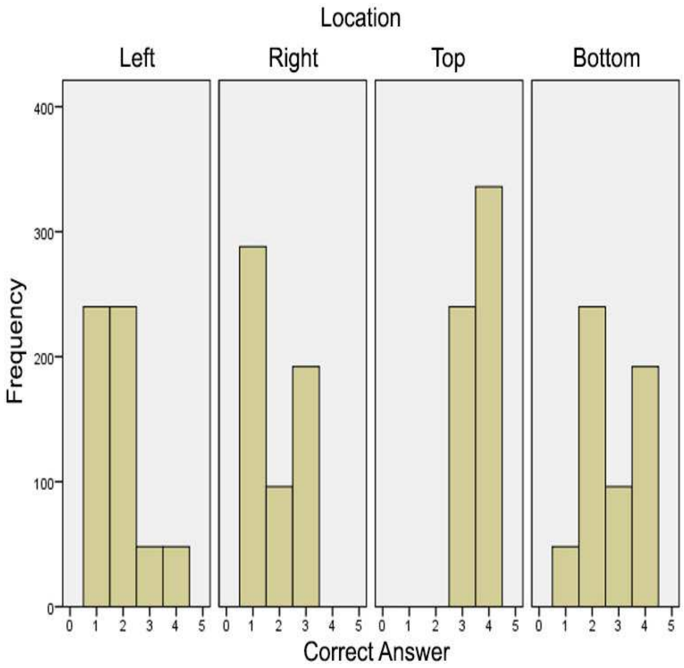


Figure 39. Recognition accuracy (correct responses) by geometric shape size and spatial location in Experiment 3. “1” = ½ inch, “2” = 1-inch, “3” = 1 ½ inch, and “4” = 2-inch arc/circles. It illustrates overall RA performance for geometric shape sizes based on visual field projections.

The data revealed differences based on geometric shape size, stimulus degradation, and spatial location. For normal or non-degraded geometric shape sizes, participants made less errors when ½ inch geometric shapes were projected to the right visual field, followed by 2-inch geometric shapes projected to the top-center visual field, followed by 1 and 1 ½ in geometric shapes projected to the bottom center visual field. For degraded or dashed geometric shape sizes, participants made less errors when 2-inch geometric shapes were projected to the top-center visual field, followed by ½ inch and 1-inch geometric shapes projected to the left visual field, followed by ½ inch geometric shapes projected to the right visual field, followed by 1 ½ inch geometric shapes projected to the top-center visual field. For degraded or dotted geometric shape sizes, participants made less errors when 1 ½ inch geometric shapes were projected to the right visual field, followed by ½ inch and 1-inch geometric shapes projected to the left visual field, followed by 1 ½ inch and 2-inch geometric shapes projected to the top-center visual field, followed by 1-inch and 2-inch geometric shapes projected to the bottom-center visual field (see Figure 40). These data are consistent with research hypothesis 4 and 5.

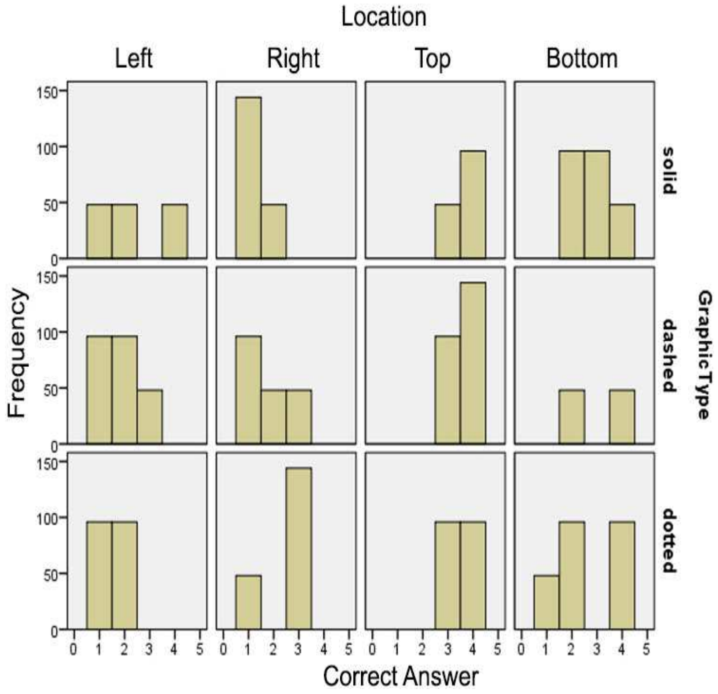


Figure 40. Recognition accuracy (correct responses) by geometric shape size by graphic type and spatial location in Experiment 3. “1” = ½ inch, “2” = 1-inch, “3” = 1 ½ inch, and “4” = 2-inch arc/circles. It illustrates overall recognition accuracy performance for geometric shape sizes based graphic type and visual field projections

In addition, the data revealed significant interactions for interference condition by graphic type (stimulus degradation), *F*(4, 2304) = 50.80, *p* < .01 (see Figure 41); interference condition by spatial location (position), F(6, 2304) = 55.89, p < .01 (see Figure 42); graphic type (stimulus degradation) by spatial location (position), *F*(6, 2304) = 90.17, *p* < .01 (see Figure 43); and interference condition by graphic type (stimulus degradation) by spatial location (position), *F*(10, 2304) = 107.89, *p* < .01 (see Figures 41 through 43).

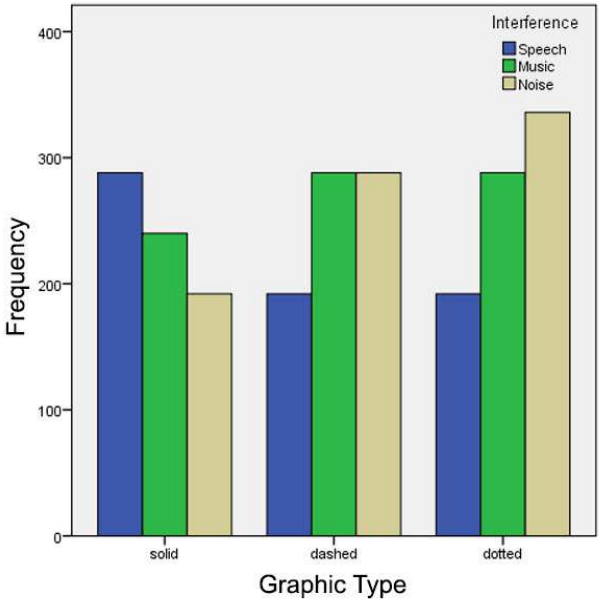


Figure 41. Recognition accuracy (correct responses) by interference condition and graphic type in Experiment 3. It illustrates overall RA performance based on interferference condition and graphic type.

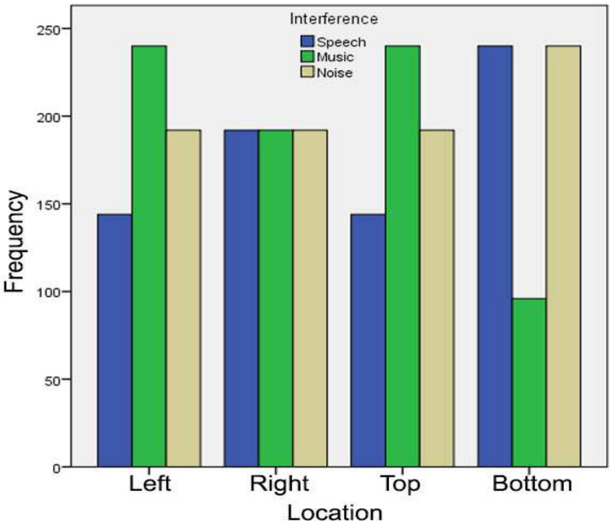


Figure 42. Recognition accuracy (correct responses) by interference condition and spatial location in Experiment 3. It illustrates overall RA performance based on interference condition and visual field projections.

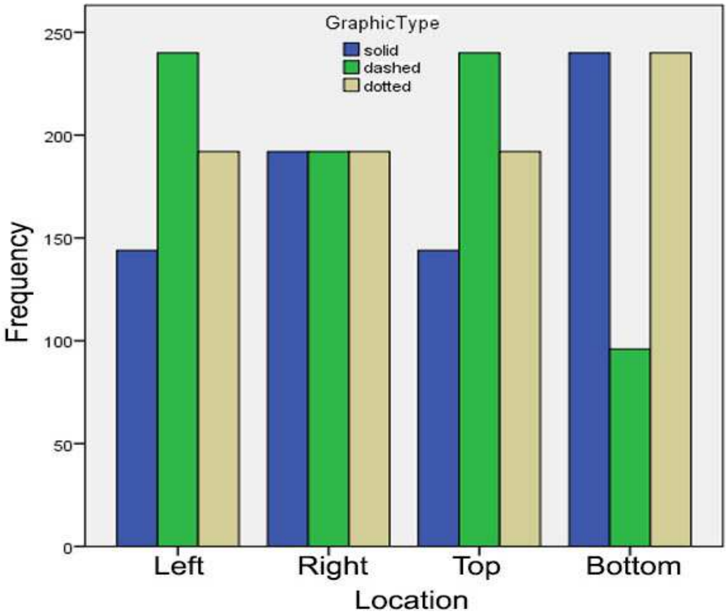


Figure 43. Recognition accuracy (correct responses) by graphic type and spatial location in Experiment 3. It illustrates overall RA performance based on graphic type and visual field projections.

Summary and Transition

The current chapter provided details of the data preparation and data analysis of three experiments investigating the effects of auditory interference on the processing of verbal and spatial information, under conditions of irrelevant speech, music, and noise. The chapter began with a restatement of the purpose of the study, followed by a description of the demographics of the participants, details regarding how data was collected, prepared, and analyzed; and presented the statistical results for the three experiments conducted. All treatments were administered as planned without any challenges that prevented their administration as described in Chapter 3. Summaries, conclusions, and recommendations are provided in Chapter 5.

Chapter 5: Summary, Recommendations, and Conclusions

Introduction

Auditory interference of various types has been identified by researchers. Speech has been recently studied by Banbury and Berry (1997, 1998), Beamon (2005), Halin, Marsh, Haga, Homgren, and Sorqvist (2014) and Kawashima and Sato (2015). Music has also been of interest to researchers (Beamon, 2005; Elliott et al., 2014; Gamble & Luck, 2011; Golumb, 2015; Roberts & Besner, 2005; Shams & Seitz, 2008). Noise has also been studied recently by numerous researchers and has been shown to be a distractor that impacted cognitive performance both negatively and positively (Beyan, Demiral, Hikmet, & Ergor, 2016; Klatte, Bergstrom, & Lachman, 2013; Levy, Fligor. Cutler, & Harushimana, 2013; Roer, Bell, & Buchner, 2013; Shelton, Elliott, Eaves, & Exner, 2009; Smith, Waters, & Jones 2010; Sorqvist, 2010; Sparks, 2015; Yeshurun and Marciano, 2013).

Of the over 400 studies researched by MacLeod (1991) on the interference in the Stroop color-word task (Stroop, 1935b), limited research investigating the congruency-incongruency effect of word and shape stimuli under conditions of cross-modal resource conflict, attentional capture, and different types of auditory interference has been conducted over the past 50 years. Since the advent of these research studies, technology has enriched our lives with devices that have become ubiquitous, entering the workplace, learning environments, and our personal spaces (Sparks, 2015). While there have been benefits, technological products are becoming obtrusive distractors (Shams & Seitz, 2008). In this study, I focused on the degree to which auditory stimuli draws upon the attentional resources in verbal and spatial information processing, and traditional perceptual tasks.

Overview of the Study

Over a 2-month period from June to July 2017. I solicited study participants. The recruitment process yielded nine participants in the first month and 15 participants in the second month. Data collection continued over the 2-month period, until 24 participants were acquired. All participants were adult men and women between the ages of 18 and 60 years of age. During the data collection process, there were no events, no withdrawals during the prescreening process, and no participant withdrawals from the study. After I completed the recruitment process, data collection, data screening and cleansing were performed, statistical assumptions were checked, followed by statistical analyses, and the interpretation of the findings.

Interpretation of the Findings

For the data analysis of this study, I utilized one-way ANOVA and MANOVA, regression analysis, Kruskal-Wallis, Cramer's V, chi-square, and independent samples *t*-tests, Wilk's lambda, Pearson product moment correlation coefficient (r), and pairwise comparisons between groups. These statistical methods were helpful in revealing significant mean differences between groups, main effects and interactions, and the strength of correlations and linearity between variables. The findings for the individual research questions are discussed in more detail in the following sections.

Research Question 1: Verbal Information Processing

What is the effect of auditory interference and stimulus degradation on the reaction times and recognition accuracy of adult men and women, for verbal information processing in working memory?

In Experiment 1, the findings of a one-way ANOVA indicated that reaction time performance for gender and age group was affected by auditory interference between experimental conditions, and recognition accuracy was affected only by experimental conditions. As expected, the control group performed better for color naming of congruent and incongruent words on the Stroop Test. Several studies have reported differences based on differential levels of practice and that color naming performance benefited from extended practice depending on age (Brown, 1915; Ligon, 1932; and Lund, 1927). This study limited that amount of practice to one task sequence or 12 trials, and still found differences in color naming and word-reading based on age. Age group 18-28 completed the Stroop Test faster than all of the other age groups, followed by age group 29-39, age group 40-50, and lastly age group 51-60.

In the original Stroop (1935) study, interference effects were found based on the congruency of the test items, with differences and superior performance of women over men. The current study revealed an opposite result based on stimulus degradation, where overall, men produced less recognition errors than women for both normal and degraded stimulus presentations. Although, this study provided a variation of previous Stroop or Stroop-like studies, possible explanations for the differences in performance between men and women were the presence of extraneous variables such as completion, fatigue, priming, and prior knowledge in visual tasks (MacLeod, 1991; (Donohue, Appelbaum, Park, Roberts, & Woldorff, 2013; Gregoire & Perruchet, & Poulin-Charronnat, 2013; Kristjánsson, & Jóhannesson, 2014; Van Zoest, Hunt, & Kingstone, 2010) that were not controlled for or not intentionally studied.

Studies investigating interference and facilitation have produced spurious results, making interpretation complicated and inconclusive (MacLeod, 1991). In over 700 studies reviewed by Dyer (1973c) and Jensen and Rohwer (1966) and mentioned in the MacLeod (1991) study, theoretical explanations for the Stroop effect were more in favor of the parallel processing of irrelevant and relevant dimensions rather than attentional bottlenecks. However, the Wicken's multiple resources theory would suggest a conflict between attentional resources and a limited capacity between the dorsal and ventral information processing streams in the brain (Connolly & Van Essen, 1984; Kahneman, 1973; Navon & Gopher, 1979; Wickens, 2002).

Conclusions for Experiment 1: As a result, research hypothesis 1a advocating that auditory interference affects reaction times and recognition accuracy scores for verbal information processing was accepted, and the null hypothesis was rejected by the researcher. Research hypothesis 1b advocating the auditory interference affects reaction times and recognition accuracy scores for degraded verbal information processing in working memory also was accepted, and the null hypothesis was rejected by the researcher.

Research Question 2: Object Recognition

To what extent is spatial location information processed differentially than structural object features for adult men and women?

In Experiment 2a, the findings of a one-way ANOVA indicated that reaction time performance for recognizing object features were affected by auditory interference between age groups, and recognition accuracy was affected by experimental conditions. As expected, auditory interference produced slower reaction times for recognizing the spatial location of geometric shapes than the control group. Age and the specific type of auditory interference were factors that produced differential cognitive performance for recognizing the spatial location of geometric shapes. The researcher found that differential reaction time performance was revealed as a function of both interference type and age of study participants. Noise auditory interference affected reaction time performance for the experimental group, followed by music, then by speech. The control group's reaction times were not the consequence of auditory interference, but as expected were faster than the experimental group. Both the Age group 18-28 and Age group 29-39 recognized the spatial location of geometric shapes faster than Age group 40-50 and 51-60. In addition, the experimental group produced better recognition (percent correct responses) than the control group, due to the influences of auditory interference.

The object recognition tasks in Experiment 2a were also affected by the extraneous variables of completion, fatigue, priming, and prior knowledge in visual tasks. Both men and women participants viewed that task as similar to a video game and remarked, "This is fun. It is like a video game," and made exclamatory statements when an error was made. The feature integration theory (FIT) (Treisman & Gelade, 1980) posited that attention is a serial process which requires the perceiver to separately focus on the conjunctive stimulus elements in a display when multiple features are needed to characterize or distinguish the objects presented. FIT researchers also purported that coding of a visual scene is based on several stimulus dimensions and mentions spatial frequency, but not spatial location as a pre-attentive stimulus property.

Experiment 2a revealed age-related differences in object recognition, but no differences specific to gender. The literature on visual information processing is expansive and both gender and age-related differences have been found in various domains. This study, I reported results consistent with past research (Sharps, 1997; Sharps & Gollin, 1987) that age-related differences in the processing of visuo-spatial information processing in favor of younger adults are linked to cognitive decline in older adults, while semantic information processing remains intact. Consistent with findings by Sharp (1997), I found gender, age-related differences in favor of younger adults.

Conclusions for Experiment 2a: As a result, research hypothesis 2a advocating that spatial location is processed differentially than structural object features for adult men and women was rejected, and the null hypothesis was accepted by the researcher. Overall reaction times for object recognition ranged from 900 to 1250 milliseconds between age groups, and indicated that variances based on age, but not gender. Based on these results, evidence for the temporal order of spatial location information was inconclusive. Therefore, I conducted a further investigation in Experiment 2b to understand whether spatial location has a temporal order in the processing of stimulus properties or processed serially, under conditions of auditory interference.

Research Question 3: Object Detection

To what extent are there speed-accuracy tradeoff differences in spatial information processing in working memory, for adult men and women, under conditions of auditory interference-based on visual field presentation?

In Experiment 2b, the findings of a one-way ANOVA indicated that reaction time performance for detecting the spatial location of objects was affected by auditory interference between age groups. In addition, reaction time was affected by the type of interference and spatial location. Recognition accuracy was found to be affected by interference condition and spatial location. As expected, auditory interference produced slower reaction times for recognizing the spatial location of geometric shapes than the control group. Age group 40-50 detected the features of geometric shapes based on spatial location faster than all other age groups, followed by age group 18-28, and both the age group 29-39 and age group 51-60. Noise auditory interference affected reaction time performance for the experimental group followed by speech then by music. The control group's reaction times were not the consequence of auditory interference, but as expected were faster than the experimental group.

The findings of a one-way MANOVA indicated that overall, reaction times were more affected for geometric shapes presented to the left (visual field) of the fixation point under noise interference, followed by the right visual field, then the top visual field. However, when geometric shapes were presented to the bottom (visual field), reaction times were slower under task irrelevant speech conditions. As expected the experimental group produced more recognition errors (percent correct) than the control group, due to the influences of auditory interference.

Conclusions for Experiment 2b: As a result, research hypothesis 2b, that there are speed-accuracy tradeoff differences in spatial information processing in working memory, under conditions of auditory interference, based on visual field presentation was accepted, and the null hypothesis was rejected. Spatial location was revealed to have a temporal order depending on age and visual field projection. Overall reaction times for object detection ranged from 760 to 940 milliseconds. Based on this evidence, spatial location of geometric shapes was shown to produce speed-accuracy tradeoff differences in spatial information processing when stimuli are processed in the dorsal stream under conditions of auditory interference based on visual field presentation. The data also indicated that spatial location information was processed differentially than structural object features in working memory, for adult men and women, under conditions of auditory interference based on visual field presentation. These findings were consistent with research by Robert and Sovoie (2006).

Research Question 4: Spatial Location of Objects

Does auditory interference affect the speed-accuracy of detecting the spatial location of degraded objects based on visual field presentation, for adult men and women?

For Experiment 3, the findings of a one-way ANOVA indicated that reaction time performance for assessing part-whole relationships was affected by auditory interference between age groups. Recognition accuracy was also found to be affected by interference condition between experimental groups. Age group 29-39 and age group 40-50 recognized part-whole relationships faster than age group 18-28 and age group 51-60 based of object size and spatial location. Both genders performed equally well under auditory interference conditions for recognizing part-whole relationships based on object size and spatial location. As expected the experimental group produced more recognition errors (percent correct) than the control group, due to the influences of auditory interference.

Studies by researchers investigating part-whole matching tasks were previously conducted using patients with cerebral commissurotomies which tended to reflect a left-hand advantage and superiority of the right hemisphere (Nebes, 1971a), and the reverse effect with intact brains, where right-handers performed significantly better than left-handers. The Nebes (1971b) study also reported superior performance for right-handers than left-handers. For this reason, this study used normal, right-handed adult male and female participants to explore the research question over several verbal and spatial information processing tasks.

The Jennings (1977) study was an extension of the Nebes (1971b) study that investigated part-whole matching with normal participants and presented stimuli tachistoscopically. The evidence was consistent with the findings of Gier et al. (2010), Nebes (1971b) and Jennings (1977) and indicated that a right visual field advantage continued to exist, but was specific to age group, geometric shape size, and visual field projection. For example, results that were inconsistent with previous studies were a left visual field advantage and right hemisphere superiority for ½-inch, and1-inch geometric shape sizes projected to left of the center fixation point; a top-center visual field advantage for 1 ½-inch and 2-inch geometric shape sizes projected above the center fixation point; and a bottom-center visual field advantage for all geometric shape sizes when projected below the center fixation point.

The explanation for recognition accuracy scores for the top-center and bottom center visual field projections are that these instances of spatial and object processing may be drawing attentional resources from the dorsal and ventral streams, instead of just one or the other streams in the cortices of the brain. Previous researchers have posited that cognitive processing entails communication from all areas of the brain in a synergism of neural communications "whole-brain processing" (Claffey, 2013; Dougherty et al., 2003; Gilbert & Li, 2013; Kossyln & Miller, 2013). The use of both streams at the same time would be consistent with the theoretical assumption of whole-brain processing.

Research Question 5: Cross-modal Interference

Does cross-modal interference affect the speed-accuracy of size and shape perception of geometric shapes for objects presented in locations peripheral to a central fixation point, for adult men and women?

Recognition accuracy (correct responses) was more affected for both the Experimental and Control groups when two-inch hemi-circles were projected to the top (visual field) of the fixation point, followed by half-inch hemi-circles project to the right visual field, followed by half-inch and one-inch hemi-circles project to the right visual field, then by one-inch hemi-circles projected to the bottom visual field. Recognition accuracy (correct responses) were also influenced by graphic type and spatial location. Solid or normal half-inch hemi-circles produced lesser errors when projected to the right visual field. Lesser errors for two-inch dashed hemi-circles were produced when projected to the top visual field. Dotted one and a half hemi-circles produced fewer errors when projected to the right visual field.

Conclusions for Experiment 3: As a result, research hypothesis 3a advocating that there are speed-accuracy tradeoff difference in the detection of spatial location of degraded objects based on visual field presentation was accepted, and the null hypothesis was rejected by the researcher. Research hypothesis 3b advocating that cross-modal interference will affect the speed-accuracy of size and shape perception of geometric shape features and spatial information processing for objects presented in locations peripheral to a central fixation point based on visual field presentation was accepted, and the null hypothesis was rejected by the researcher. This evidence is consistent with interference theory (Anderson, 2003; Muller & Pilzecker, 1990) and multiple resources theory (Kahneman, 1973; Navon and Gopher, 1979; Wickens, 1984), both of which researchers advocated interference effects and deficits in cognitive performance related to conflicts between sensory modalities (cross-modal).

Limitations

There were several aspects of the study believed to be limitations 1) sample size, 2) homogeneity of the sample, 3) the ecological validity of the sample, and 4) the relationship of findings to neurological correlates of brain function.

The first concern is sample size. The study utilized 12 participants per group for a total of 24 participants. While the number of participants based on estimates for effect size and statistical procedures were deemed to be adequate, the small sample size limits the generalizability of the results to the general population, and are to be considered relevant only to the sample of participants that were utilized in the study.

The second concern is the homogeneity of the sample population. The sample consisted of federal employees who were representative of the adult male and female population who were right-handed, with more than average education, comprised an age distribution between 18 and 60 years of age. Therefore, generalizations to younger age groups are limited.

The third concern, ecological validity. While object recognition and detection, color-word naming using the Stroop test, and part-whole matching tasks may be considered common everyday cognitive tasks, they have produced artificial behaviors in a laboratory environment, and under conditions of auditory interference and stimulus degradation.

The fourth concern, the relationship of findings to neurological correlates of brain function were discussed in regard to the visual field projections in the occipital lobe. While the findings are of value and significant, they may need to be confirmed through further testing and through the use of methods in neuroscience, such as functional magnetic resonance techniques. Acknowledging all of these limitations is warranted and allows the consideration of study implications that are positive.

Implications for Social Change

Positive social change can be realized from a better understanding of and stricter attention to the effects of auditory interference which may improve cognitive performance in both the workplace and learning environments. Most of the studies by researchers on how auditory interference affects cognitive performance has concentrated on development prior to adolescence, so research that further advances our knowledge of how the brain functions, allocates attentional resources, and processes multisensory information between the two hemispheres continues to be of interest in cognitive psychology as well as the neurosciences. In this study, I found that the data indicated that there are specific conditions in which differential performance between men and women occurred depending on sex, age and cortical projections of visual stimuli under specific types of auditory interference conditions. I submit that using the results of this research may provide information valuable to the construction offices, classrooms, and other workplace and learning environment and how they are used. I suggest in addition to the use of devices for improving physical health, benefits may be realized for cognitive control, attention, better concentration, as well as mental performance through stricter attention to environment distractors and the semantic and sonic characteristics of visual and auditory stimuli in our daily environment. I also believe that workplace and learning environments could be tailored for and specific to the sensitivities of individuals to auditory interference, better construction of these environments that eliminate frequencies, energies, and other distractors may be developed.

I contend that further implications for social change may be the use of the data on auditory interference in military applications. Irrelevant sound, extraneous speech and noise has been of interests to human factors practitioners based on studies implying that up to 15% of aeronautical accidents were the result of human error caused by distraction (Chappelow, 1999; Landstrom, Soderberg, Kjellberg, & Nordstrom, 2002). Understanding the sonic parameters under which human error occurs as a result of individual differences and auditory distraction may be valuable for the design and use of better aeronautical devices, simulators, cockpits, and biometric weaponry.

Recommendations for Action and Further Study

Every day, new products that utilize technologies that were nonexistent when traditional cognitive studies on attention, memory, verbal and spatial information processing were documented. The positive and negative effects of auditory interference are well-documented by researchers, but the types of auditory interference utilized in this research have been until now, studied individually and under different paradigms and conditions. Advocacy for a stricter attention to the effects of auditory interference on cognitive has been provided (Chappelow, 1999; Landstrom, Soderberg, Kjellberg, & Nordstrom, 2002; Beamon, 2005).

According to Dougherty, Koch, Brewer, Fischer, Modersitzki and Wandell (2003), correspondence between specific areas of the brain and the primary visual cortex (V1) are not clearly defined in the parastriate cortex (V2) and the peristriate cortices (V3) of the occipital lobe. As the interests and progress of cortical and retinotopic brain mapping continues, furthering this line of research is proposed. The neurological correlates of brain function were discussed in regard to the visual field projections in the occipital lobe. While the findings are of value and significant, they may need to be confirmed through further testing and through the use of methods in neuroscience, such as functional magnetic resonance techniques.

Further understanding of hemispheric lateralization and cortical mapping, cognitive processing and neurological correlates of perceptual processes are critical and vital to the human genome itself. The past viewpoint of hemispheric lateralization still is a prominent philosophy of the mapping (Kosslyn & Miller, 2013) of brain function and the relationship between hemispheres, but recent research and efforts have now been promoted that emphasize cross-modal interaction and information-sharing between cortical zones due to advances in research methodologies in cognitive neuroscience. Therefore, replicating the current experiments and observing the results of cognitive performance using neuroscience methods and tools are the next step to build upon this dissertation research.

In this study, I provided evidence that noise and music at specific frequencies affect cognitive performance when performing Stroop task, object recognition and detection task, and part-whole matching task using geometric shapes of different sizes, under auditory interference conditions. Researchers have identified frequencies of the human body, mostly below 1000 Hz, related to human health and sickness. Beamon (2005) studied the ‘irrelevant sound effect” in short-term memory which is believed to have direct consequences for cognitive performance in office and other workplace environments, using single serial tasks and a single population of young adults (Banbury

& Berry, 2005; Banbury, Tremblay, Macken, & Jones, 2001). While researchers of these studies reported and used a plethora of noise sources (such as telephone ringing, printer noise, typing on a keyboard, outside noise, etc.), it is believed that these distractors alone do not adequately provide an understanding of the sound parameters produced by the sources from a neurological perspective. For example, what are the specific frequencies produced by these distractors? How are these frequencies processed and how do they affect information processing? What is the impact of these frequencies in the environment on the performance of common, daily tasks? What is relationship of specific frequencies to human pathologies? I believe further investigation to determine the influence of these frequencies on different cognitive tasks is warranted, and their correlations to neurological functions in the brain could be explored and documented.

General Conclusions

The results of all three experiments were found to be consistent with the cognitive performance reported in the multiple resource theory (Wickens, 2002), interference theory (Anderson, 2003; Muller & Pilzecker, 1990), and feature integration theory (Treisman & Gelade, 1980). Attentional capture represented by the auditory interference conditions of task irrelevant speech, the engaging sound of Hip-Hop music, and 44100 Hz, 32-bit stereo processed white noise were effective distractors that produced mean differences in reaction time and recognition accuracy between adult men and women and between age groups in the Stroop test.

Attentional capture also affected cognitive performance for age and between groups for object recognition, but was only affective for recognition accuracy between groups, and not between men and women. In addition, reaction times were affected overall by spatial location of geometric shapes. For object detection, attentional capture was an effective distractor that produced mean differences in reaction time and recognition accuracy between adult men and women and between age groups.

For part-whole matching mean differences were revealed for reaction time for age group and for recognition accuracy between groups. Different geometric shape sizes than the Jennings (1997) study were used, and auditory interference produced mean differences that were dependent on visual field projection.

Age-related differences in the processing of visuo-spatial information processing in favor of younger adults were linked to cognitive decline in older adults, while semantic information processing remained intact. The findings were inconsistent with past research findings for gender, indicating superior performance of women over men based on both stimulus type and stimulus degradation. Age-related differences were found and expected, in favor of younger adults, for the Stroop test, part-whole matching, but not for object detection reaction time performance.

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Appendix A: Participant Approval Form

This form will be used to determine your eligibility for participation in the dissertation research entitled, “Effect of Attentional Capture and Cross-modal Interference in Multisensory Cognitive Processing.” Please respond to the questions listed below.

Participant Name:
Participant No.:
Age: 18-28___ 28-38___ 39-49___ 50-60___ 60 and Above___
Gender: Male____ Female____
Ethnicity: White___ Black ___ Hispanic____ Other_____
Email Address: Phone Number: ( ) -

No.	Question	Response	
1	Have you previously participated in a Stroop test before?	Yes	No
1a	If you answered yes to question 1, approximately when did you participate?		
2	Have you previously participated in a reaction time test before?		
2a	If you answered yes to question 2, approximately when did you participate?		
3	Are you right-handed?		
4	Are you left-handed?		
5	Do you have normal visual acuity (20/20 vision)?		
6	Do you have corrected or near normal vision (Between 20/32 and 20/63)?		
7	Are you nearsighted?		
8	Are you far-sighted?		
9	Do you have normal hearing?		
10	Do you ever experience ringing in your ear(s)?		
11	Do you currently experience ring in your ear(s)?		
12	Have you ever suffered from hearing loss, in your left or right ear?		
13	Do you like Hip-Hop music?		
14	Do you like classical music?		
15	Are you easily distracted when performing a reading task?		
16	Do you have a high school diploma or equivalent education?		
17	Do you have normal color vision?		

Appendix B: Data Collection Form

Participant Name:	Participant No.:
Group	Condition

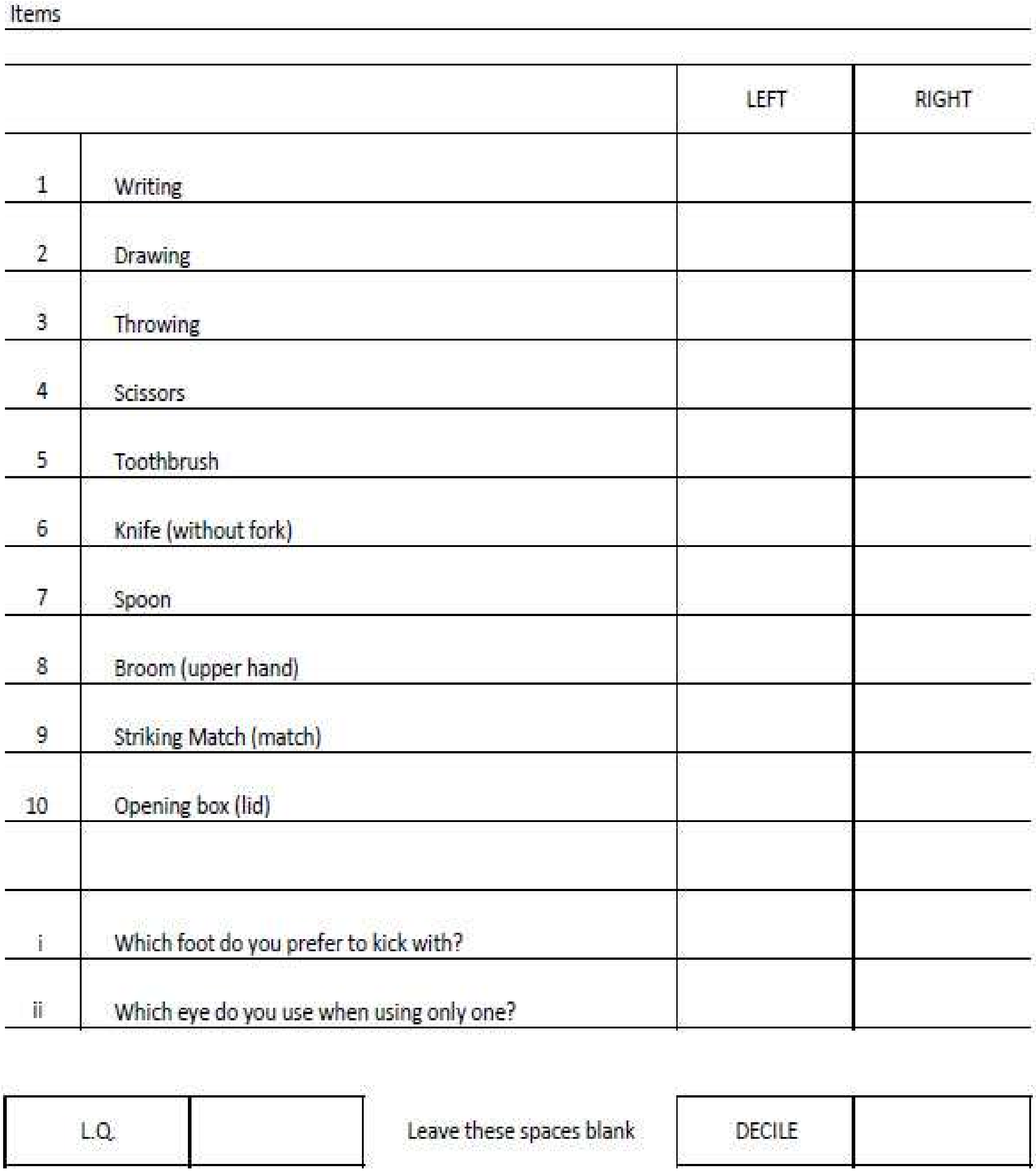
	Experiment 1: Stroop Test											
Trial #	Normal Words						Degraded Words					
	Speech		Music		White Noise		Speech		Music		White Noise	
	RT	Acc	RT	Acc	RT	Acc	RT	Acc	RT	Acc	RT	Acc
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

Participant Name:									Participant No.:									
Group:									Condition:									
Experiment 2: Object Feature Recognition																		
	Green Shapes						Yellow Shapes						Light-Blue Shapes					
Trial #	Circle		Triangle		Square		Circle		Triangle		Square		Circle		Triangle		Square	
	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		
19																		
20																		

Participant Name:									Participant No.:									
Group:									Condition:									
Experiment 2: Object Detection																		
	Green Shapes						Yellow Shapes						Light-Blue Shapes					
Trial #	Circle		Triangle		Square		Circle		Triangle		Square		Circle		Triangle		Square	
	RT	Num	RT	Num	RT	Num	RT	Num	RT	Num	RT	Num	RT	Num	RT	Num	RT	Num
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		
19																		
20																		

Participant Name:									Participant No.:									
Group:									Condition:									
Experiment 3: Part-Whole Marching																		
	Speech						Music						Noise					
Trial #	Solid		Dotted		Dashed		Solid		Dotted		Dashed		Solid		Dotted		Dashed	
	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc	RT	Loc
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		

Appendix C: Edinburgh Handedness Inventory

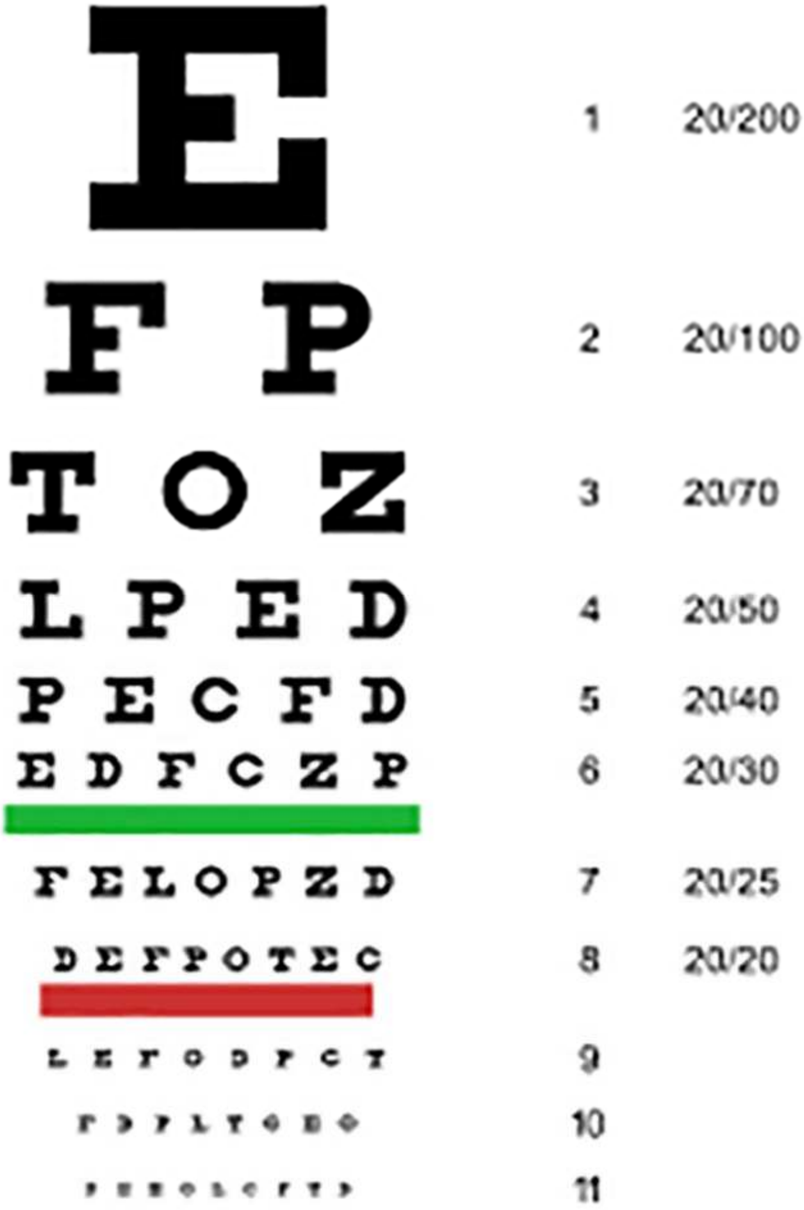


Items

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	DECILE	

Appendix D: Snellen Eye Chart



Appendix E: Stimulus Representations for Experiment 1

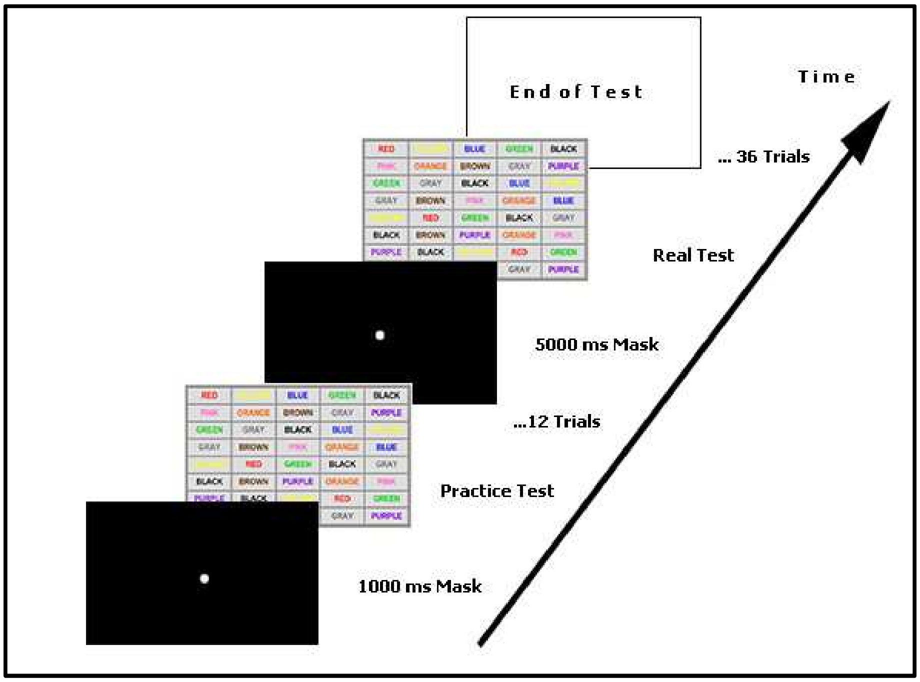
Congruent Word List

RED	YELLOW	BLUE	GREEN	BLACK
PINK	ORANGE	BROWN	GRAY	PURPLE
GREEN	GRAY	BLACK	BLUE	YELLOW
GRAY	BROWN	PINK	ORANGE	BLUE
YELLOW	RED	GREEN	BLACK	GRAY
BLACK	BROWN	PURPLE	ORANGE	PINK
PURPLE	BLACK	YELLOW	RED	GREEN
ORANGE	PINK	BROWN	GRAY	PURPLE

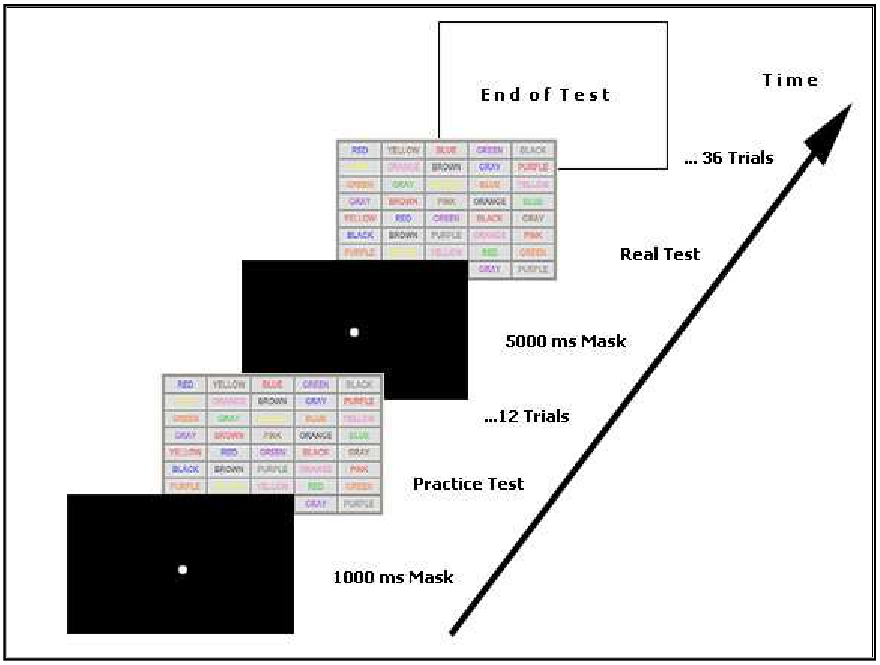
Incongruent Word List

RED	YELLOW	BLUE	GREEN	BLACK
PINK	ORANGE	BROWN	GRAY	PURPLE
GREEN	GRAY	BLACK	BLUE	YELLOW
GRAY	BROWN	PINK	ORANGE	BLUE
YELLOW	RED	GREEN	BLACK	GRAY
BLACK	BROWN	PURPLE	ORANGE	PINK
PURPLE	BLACK	YELLOW	RED	GREEN
ORANGE	PINK	BROWN	GRAY	PURPLE

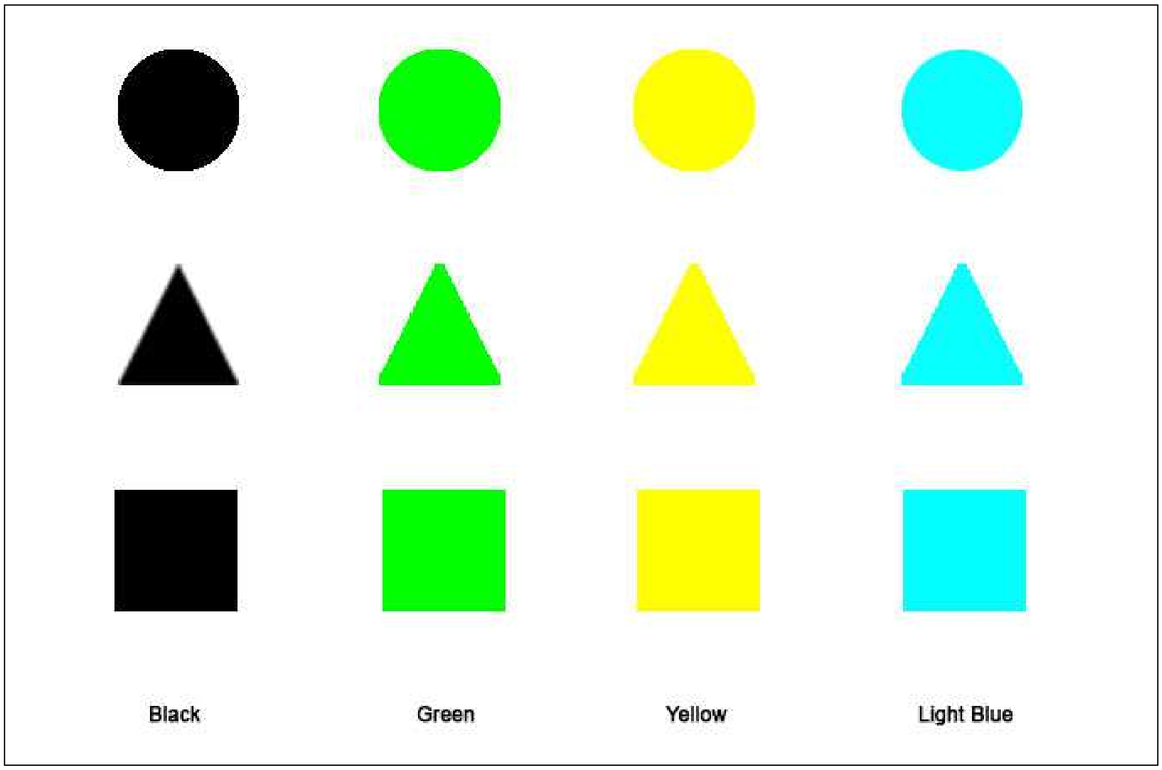
Appendix F: Experiment 1: Congruent Word List



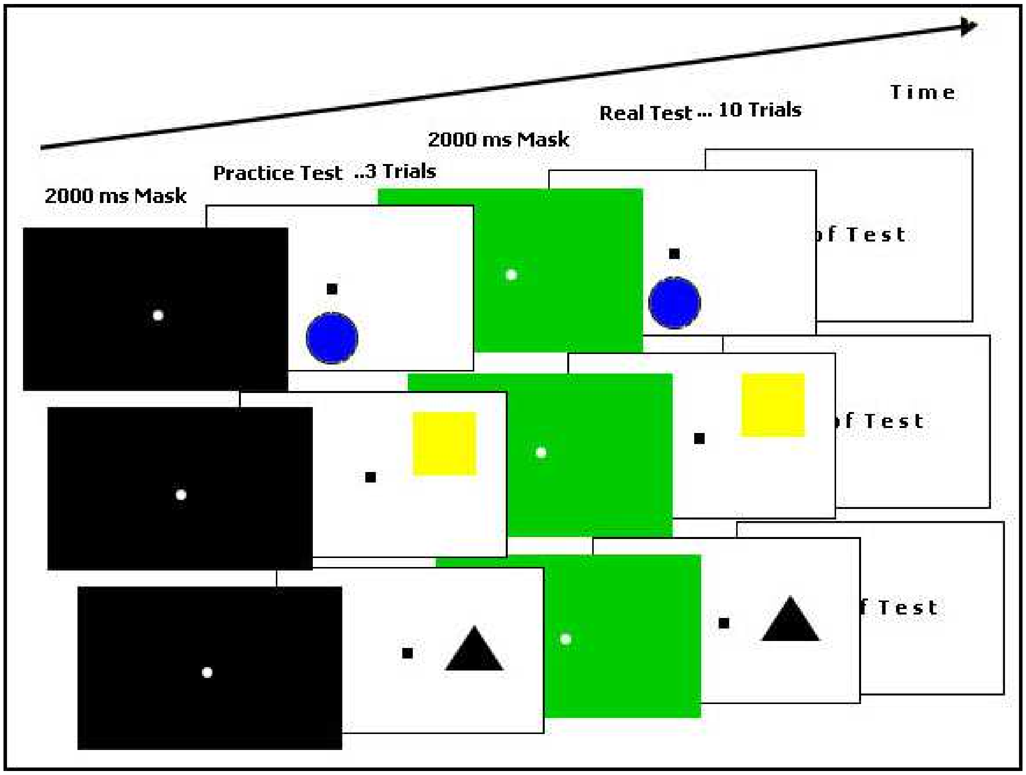
Appendix G: Experiment 1: Incongruent Word List



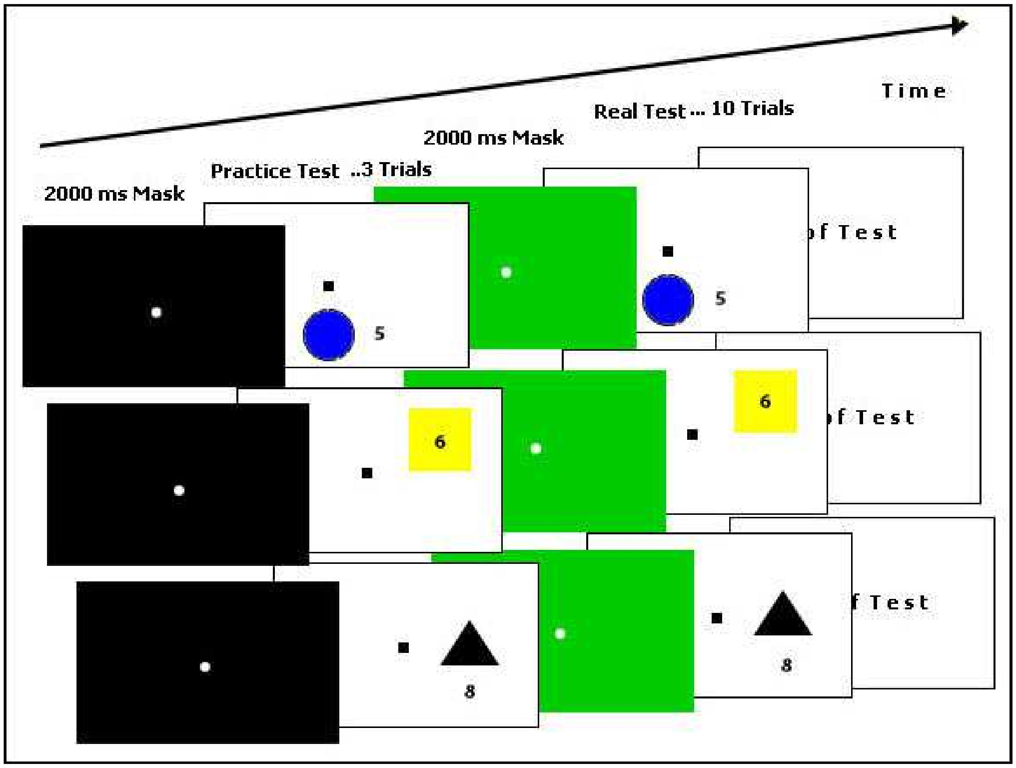
Appendix H: Stimulus Representations for Experiment 2



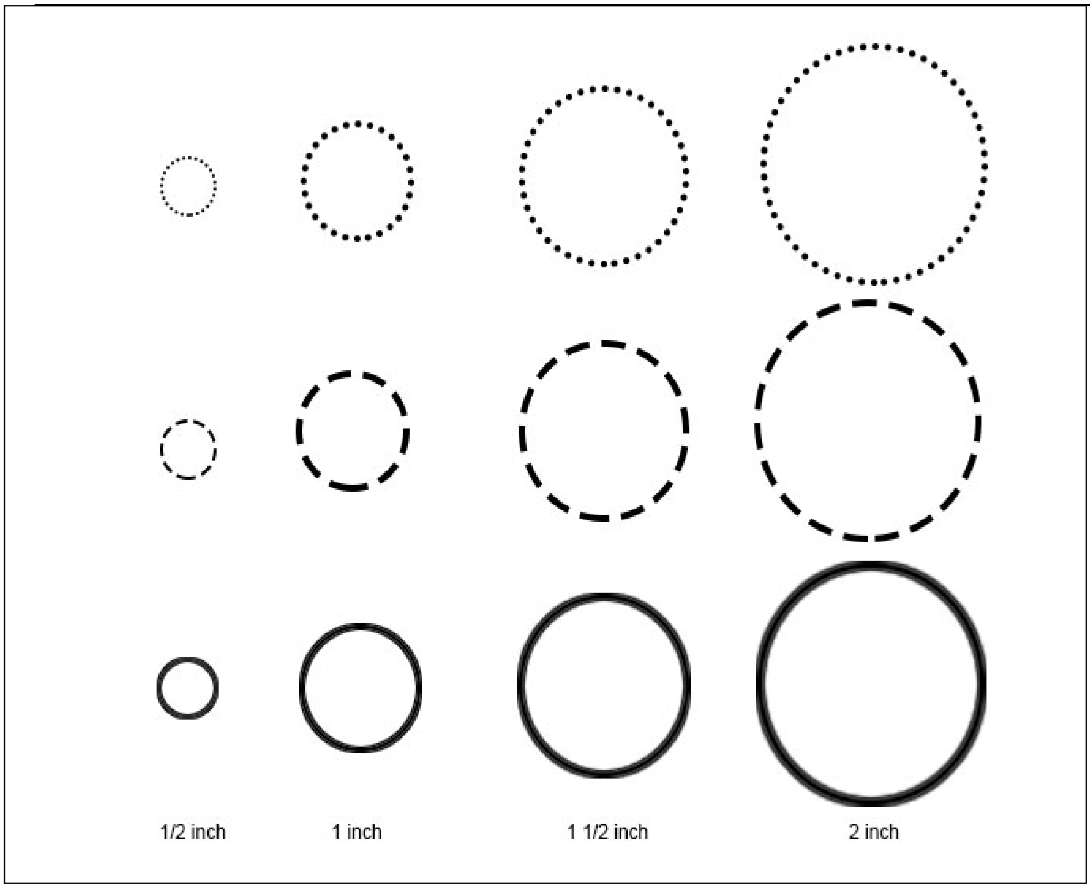
Appendix I: Experiment 2: Object Recognition Task Sequence



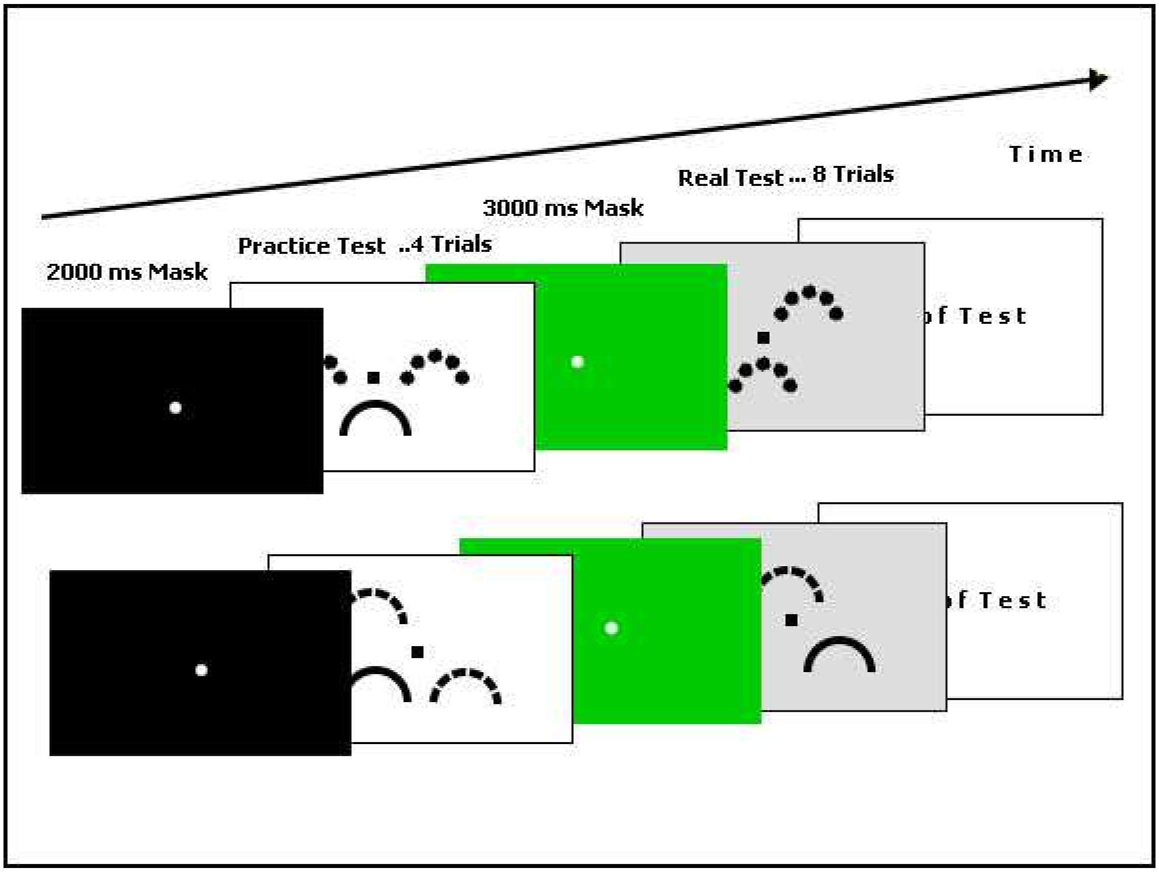
Appendix J: Experiment 2: Object Detection Task Sequence



Appendix K: Stimulus Representations for Experiment 3



Appendix L: Experiment 3: Part-Whole Matching Task Sequence



Appendix M: Color Vision Evaluation Form

This form will be used to evaluate the participant's color vision for participation in the dissertation research entitled, "Effect of Attentional Capture and Cross-modal Interference in Multisensory Cognitive Processing." For the ten colored boxes below, place one of the letters (A – J) that you think describes the color of the box in the space provided:

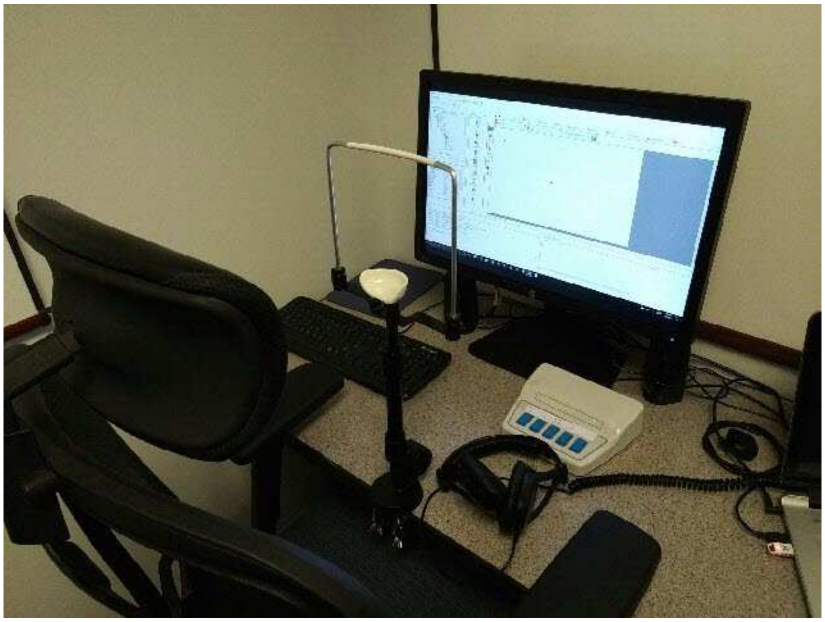
LEGEND

A= Black
B= Green
C= Pink
D= Red
E= Purple
F= Gray
G= Yellow
H= Brown
I= Light Blue
J= Orange

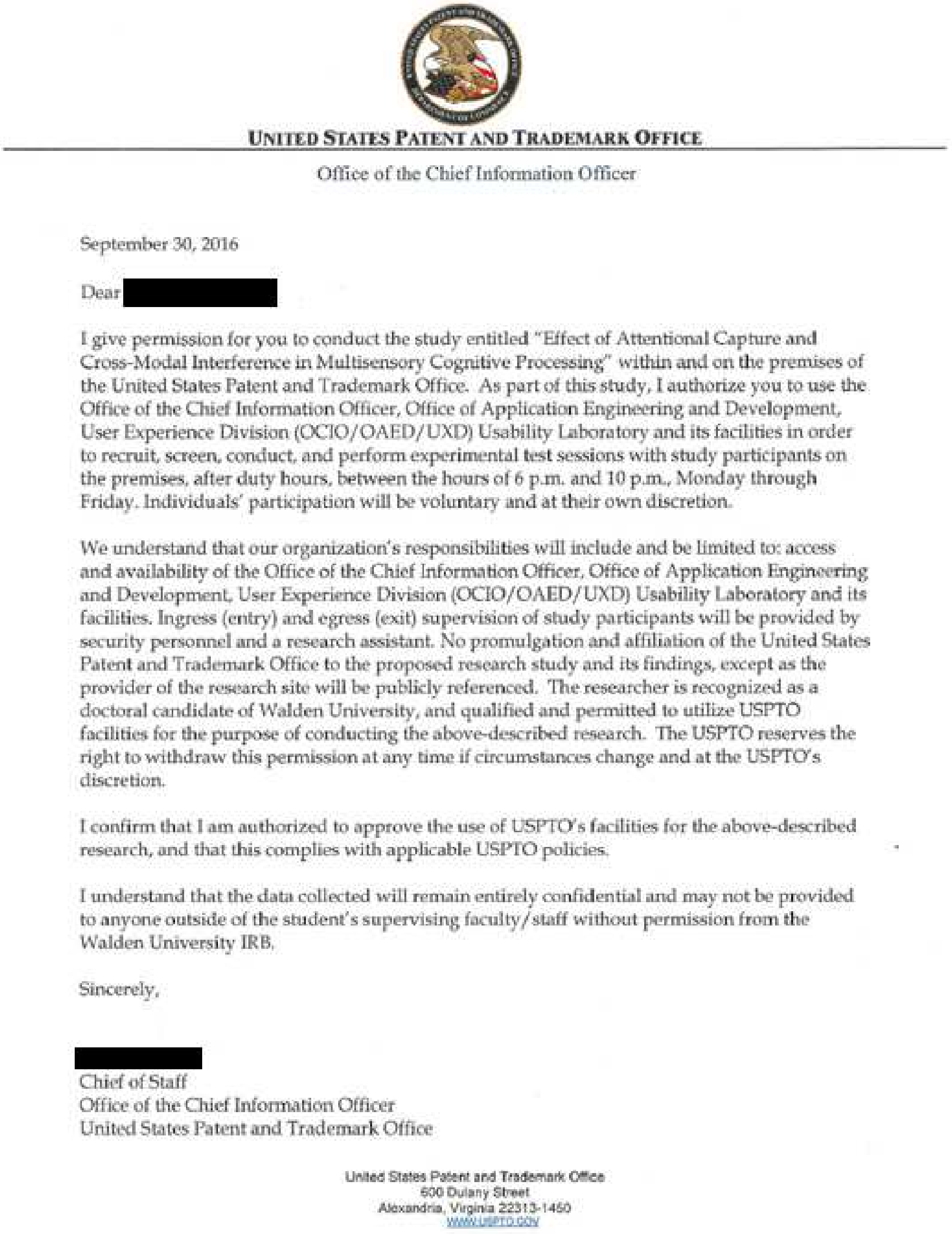
No.	**Color**	**Letter for Color Name**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Appendix N: Experiment Stations One to Three

Appendix O: Experiment Station Three



Appendix P: Letter of Cooperation Approval



UNITED STATES PATENT AND TRADEMARK OFFICE
Office of the Chief Information Officer

September 30, 2016

Dear [redacted]

I give permission for you to conduct the study entitled "Effect of Attentional Capture and Cross-Modal Interference in Multisensory Cognitive Processing" within and on the premises of the United States Patent and Trademark Office. As part of this study, I authorize you to use the Office of the Chief Information Officer, Office of Application Engineering and Development, User Experience Division (OCIO/OAED/UXD) Usability Laboratory and its facilities in order to recruit, screen, conduct, and perform experimental test sessions with study participants on the premises, after duty hours, between the hours of 6 p.m. and 10 p.m., Monday through Friday. Individuals' participation will be voluntary and at their own discretion.

We understand that our organization's responsibilities will include and be limited to: access and availability of the Office of the Chief Information Officer, Office of Application Engineering and Development, User Experience Division (OCIO/OAED/UXD) Usability Laboratory and its facilities. Ingress (entry) and egress (exit) supervision of study participants will be provided by security personnel and a research assistant. No promulgation and affiliation of the United States Patent and Trademark Office to the proposed research study and its findings, except as the provider of the research site will be publicly referenced. The researcher is recognized as a doctoral candidate of Walden University, and qualified and permitted to utilize USPTO facilities for the purpose of conducting the above-described research. The USPTO reserves the right to withdraw this permission at any time if circumstances change and at the USPTO's discretion.

I confirm that I am authorized to approve the use of USPTO's facilities for the above-described research, and that this complies with applicable USPTO policies.

I understand that the data collected will remain entirely confidential and may not be provided to anyone outside of the student's supervising faculty/staff without permission from the Walden University IRB.

Sincerely,

[redacted]
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United States Patent and Trademark Office

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