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Capuchin (Cebus [Sapajus] Apella) Change Detection

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CAPUCHIN (*CEBUS [SAPAJUS] APELLA*) CHANGE DETECTION

by

JESSE LEINWAND

Under the Direction of Sarah F. Brosnan, PhD

ABSTRACT

Change blindness is a phenomenon in which individuals fail to detect seemingly obvious changes in their visual fields. Like humans, several animal species have also recently been shown to exhibit change blindness; however, no species of New World monkey has been tested to date. Nine capuchins (*Cebus [Sapajus] apella*) were trained to select whether or not a stimulus changed on a computerized task. In four phases of testing, the search display and mask durations were varied systematically. Only one phase yielded significant results, with subjects detecting changes most accurately with longer search displays and, perplexingly, least accurately when there was no mask. No interactions between search display and mask durations were found in any test phase, suggesting that the relationship between the two parameters may be less important to how capuchins perceive changes.

INDEX WORDS: Change blindness, Change detection, Monkey, Capuchin, Attention

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1   LITERATURE REVIEW

1.1   Introduction

The ability to detect changes to one's environment is a useful skill, particular when performing acts that require vigilance. For instance, when driving, it is clearly beneficial to notice when a traffic light changes color, not only to avoid a ticket, but also to ensure the safety of oneself and those nearby. Similarly, it is in an animal's best interest to detect the presence of a predator to avoid being eaten. As observers, people tend to believe that they will immediately be able to detect any change occurring in front of them, so long as it is sufficiently large (Levin, Momen, Drivdahl, & Simons, 2000). However, despite the usefulness of this skill and the belief that we are capable of detecting changes within our visual field, people are consistently unable to detect not just subtle, but also large and dramatic changes in their visual field, a phenomenon known as *change blindness* (Rensink, O'Regan, & Clark, 1997; for reviews, see Gibbs, Davies, & Chou, 2016; Rensink, 2000a, 2008; Simons & Ambinder, 2005; Simons & Levin, 1997; Simons & Rensink, 2005). Even individuals who are able to successfully recognize a previously seen object on a memory test may fail to notice a change to that very object (Hollingworth & Henderson, 2002).

Change blindness is not restricted to changing images, but extends to changes in motion pictures and videos clips (Angelone, Levin, & Simons, 2003; Levin & Simons, 1997, 2000). In one striking study, Simons and Chabris (1999) showed subjects a video of several individuals in white and black shirts passing two basketballs (https://www.youtube.com/watch?v=vJG698U2M vo). The subjects were instructed to mentally count how many times individuals in one of the two colors passed the ball as everyone walked in circles passing the ball around. Despite the circuitous and intentionally confusing patterns walked by the basketball passers, subjects were

generally able to keep track of the total number of passes. Incredibly, many subjects did, however, fail to notice a man in a gorilla suit walking through the basketball passers, even though he stopped in the middle to pound on his chest. This form of change blindness, known as inattentional blindness, provides support for the hypothesis that attention is required for changes to be detected (Neisser, 1979). Yet, O'Regan et al. (2000) found that even when fixated on the change location, subjects still failed to detect the change over 40% of the time. Thus, even seemingly obvious details that might be crucial to our lives, such as the moments proceeding a car accident or recalling what a thief *who we saw* looked like or was wearing, can be easily missed, resulting in potentially damaging consequences (for review, see Hyman Jr., 2016). Attention is therefore an important component of change blindness, but clearly attention alone does not explain the phenomenon.

Gradual changes, such as lights diming or one color fading into another, are also difficult for observers to detect, again, even when they are attending to them and there are no disruptions masking the change (Hagmann & Cook, 2013; Simons, Franconeri, & Reimer, 2000). Yet, perhaps most surprising and unsettling of all is the degree to which we are blind to changes occurring in the real world. This was demonstrated by Simons and Levin (1998) who had an experimenter carrying a map stop and ask individuals on a college campus for directions. Following a minute or so of discussion, two confederates dressed as construction workers and carrying a door walked between the experimenter and subject. The passing construction workers and door served as a mask, enabling a second experimenter to surreptitiously change places with the first experimenter. Despite wearing different clothing and many physical differences between the two experimenters, 8 out of 15 subjects failed to report noticing the change, despite now being engaged in conversation with a completely different individual. Interestingly, all of

the subjects who did notice the change were roughly the same age (20-30 years old) as the experimenters, while those who failed to detect the change were older (approximately 35-60 years old), implying a potential bias for detecting changes to in-groups over out-groups.

Accordingly, a second experiment in which the experimenters dressed as construction workers was run with exclusively graduate and undergraduate students to explore the role of social group membership on change detection. Under these conditions, only 4 of 12 subjects reported noticing the change when asked if they had seen anything unusual, while five subjects failed to report the switch and were surprised to learn of it. The final three subjects did not report noticing anything unusual; however, they later claimed to have noticed the switch of experimenters, although, unlike the four who reported the switch, these three subjects were unable to describe any of the differences between the two experimenters. Thus, unlike the student participants in the first experiment who all noticed the change in experimenter, the students in the second experiment struggled to detect the seemingly obvious change in conversation partner when the experimenters were dressed as out-group members (i.e., construction workers).

That this striking perceptual failure readily occurs in the real world, where detecting changes can have life or death implications, strongly supports the need for further research and understanding of the phenomenon. In particular, it is important to determine whether the phenomenon is a result of something about human culture (most of these studies have been run in Westernized societies) or is the result of a more basic phenomenon shared with other species. This is key to determine how best to address this phenomenon in situations in which it can have grave side effects. Therefore, beyond studying change blindness in humans, additional research is also needed to determine how widespread and consistent the phenomenon is among non-

human animals. Although this has been explored in some species, it has not yet been done with New World monkeys, who are primates more distantly related to humans. We opted to test whether brown tufted capuchins (*Cebus [Sapajus] apella*) experience patterns of change blindness comparable to humans and the other species that have been tested by systematically varying two critical parameters of several change detection tasks: the duration of the search display and the duration of the mask.

The majority of research on change blindness has focused on one's ability to detect a change, or simply *change detection* (for reviews, see Rensink, 2002; Simons & Rensink, 2005). Two main types of tasks have been used to do this, *change localization* tasks, in which observers must determine the location of a change (e.g. Fernandez-Duque & Thornton, 2000), and *change identification* tasks, in which observers must either identify the changing item or the type of change that occurred (e.g. Mondy & Coltheart, 2000). One advantage of having multiple paradigms is the ability to compare subjects' performance across tasks, which helps to identify which features are the most important. Although change blindness occurs in both methods, subjects tend to struggle the most with change identification. This is likely due to the fact that people are often able to sense that something is different before they are able to actually pinpoint what that difference is (Rensink, 2002, 2004), suggesting perhaps that different mechanisms are involved in each process (Wilken, Mattingley, Korb, Webster, & Conway, 1999). Given that the subjects are generally unable to articulate the exact nature of the change, the majority of human change blindness research has focused on simply detecting which stimulus in an array changed.

Several types of observer responses have been used in these tasks, from explicit responses to "yes/no" or "go/no-go" in response to a possible change (Rensink et al., 1997; Simons, 1996; Wilken et al., 1999) to semi-explicit responses which are triggered by a "feeling"

that a change, such as lights dimming, is occurring. Semi-explicit responses may therefore entail

responding that a change has occurred even if the subject cannot pinpoint the exact nature of the

change (Rensink, 2000a). A third category, implicit responses, are measured by the extent to

which a change that was not consciously perceived can influence a conscious decision, for

instance on a forced-choice guess about the location of a change (e.g. Fernandez-Duque &

Thornton, 2000). Lastly, *visuomotor* responses, such as pointing or eye fixation to a change can

be measured to assess whether subjects are experiencing change blindness (e.g. Bridgeman,

Lewis, Heit, & Nagle, 1979; Goodale, Pelisson, & Prablanc, 1986).

1.2   Parameters influencing change detection

Change blindness does not occur in every circumstance, and a number of parameters have

been shown to influence it. These include the number of times the change is repeated as well as

the size, complexity, and duration of the search display. The form of the stimulus or array of

stimuli, which are initially presented in their unaltered form as the search display, can further

affect subject's accuracy, with changes easier to detect in some types of stimuli than others.

Similarly, both the duration of the mask between sample and test displays and the type of mask

used can influence responses. Considerable research has also focused on the effects of varying

the content of the stimuli used in change detection tasks, often with an emphasis on faces and

familiarity (Buttle & Raymond, 2003; Jackson & Raymond, 2008; Pashler, 1988).

1.2.1   *Repetition of change*

The number of times a change is repeated plays a critical role in change detection. The

most common paradigm to test for change blindness is a change detection task using a visual

disruption of some sort between the original and changed stimulus, often referred to as a flicker,

to mask the change (Rensink et al., 1997). In the *one-shot* paradigm, observers view the

sequence of the initial display, a mask, and then the changed display just once before determining if a change occurred, and thus performance is typically measured via response accuracy. This technique minimizes the involvement of eye movements and long-term memory (e.g. Blackmore, Brelstaff, Nelson, & Trościanko, 1995; Levin & Simons, 1997; Wright, Green, & Baker, 2000). Given that attention plays an important role in change detection, the one-shot method is often used for change detection tasks with non-human subjects who, short of fixing their heads in place, cannot simply be asked to "pay attention to the screen." This is important to keep in mind as it may introduce differences between human and non-human designs that impact our ability to directly compare results.

Alternatively, in the *flicker* paradigm, observers view a display continually cycling between the original display, a mask, and the changed display, providing repeated viewings of the change (e.g. Aginsky & Tarr, 2000; Hollingworth & Henderson, 2000; Rensink et al., 1997; Wallis & Bulthoff, 2000). Given that subjects see the change multiple times in the flicker paradigm, performance is typically measured via response time, although accuracy data may also be collected. Multiple viewings also rule out the possibility that performance is due to a failure to consolidate the necessary information in memory (Rensink, 2000b). Thus, this procedure may be beneficial because it emphasizes visual attention to the changing region rather than the more rapid attentional capture associated with the one-shot task. However, it is not as good for testing non-human species because subjects' reaction times may be more dependent on paying attention to the task than actually detecting the change.

Because the two paradigms measure different things, ideally we can compare how subjects respond across both. Both the flicker and one-shot paradigms are able to induce comparable levels of change blindness. However, because the flicker paradigm provides

subjects with multiple viewings of the change, most subjects will eventually detect a change. The repeated viewings in the flicker paradigm also enable subjects to visually search for the location or identification of the change, whereas the one-shot method requires subjects to rely on attentional capture and their short-term memory of the search display to determine if a change occurred. Most change detection tasks utilizing the one-shot method thus use arrays of fairly simple stimuli, such as line drawings or colored squares, which may or may not change following the mask. This may be ideal for teasing apart different features that may influence change differently (i.e., color vs. shape vs. location) but may be less ecologically relevant. Conversely, the flicker paradigm is more commonly used when subjects are asked to find a change between pictures, photographs or complex arrays of stimuli in which multiple viewings of the scene are typically required before subjects detect the change (Simons, 2000). Oddly, while the stimuli frequently used in flicker paradigm studies tend to be more complex and thus a better reflection of the real world than those used in the one-shot task, the flicker method actually has less ecological validity than the one-shot method. In real world situations, most changes to our environment occur without providing the opportunity to reexamine the original scene, let alone repeatedly alternate views between the original and changed scene (Pearson & Schaefer, 2005). Taken as a whole, it is clear that both methods offer advantages and in an ideal world, both are used to determine the parameters of change blindness in a given species and context.

1.2.2 *Duration and size of search display*

The duration the search display is visible prior to the mask has also been varied extensively, typically depending on the specific questions being asked. For instance, extremely short display lengths may be used to investigate questions related to attentional capture (Pearson & Schaefer, 2005), whereas longer presentation lengths may incorporate working memory and

even long term memory. Increasing the duration of the search display has been found to result in increased memory capacity for items in change detection tasks (Alvarez & Cavanagh, 2004; Eng, Chen, & Jiang, 2005). However, these findings come from studies in which multiple items from within a category, such as colored squares, letters, or faces, are presented as opposed to a single item being presented, which then may or may not change following the mask. As such, longer search displays may be associated simply with more time to encode additional items into working memory or even long term memory. Conversely, when presenting only a single stimulus, which may or may not change, subjects need not rely on a large visual working memory *capacity*, but are able to attend solely to whether or not a change occurs even with a shorter search display time.

Thus, using a single stimulus and a change/no-change design reduces the role of visual working memory capacity, which has been found to vary depending on the type of stimuli used and subjects' familiarity with those stimuli (Alvarez & Cavanagh, 2004; Cowan, 2001; Eng et al., 2005; Luck & Vogel, 1997; Luria, Sessa, Gotler, Jolicœur, & Dell'Acqua, 2009; Sørensen & Kyllingsbæk, 2012). This type of change detection task requires subjects to attend to the search stimuli and decide whether a change occurs, without any potential confounds from individual differences in visual working memory capacities. Given the significant variability in working memory capacities among individual humans and individual non-human primates, a change/no-change paradigm thus seems most appropriate for nonhuman primates (Elmore et al., 2011; Elmore & Wright, 2015; Leising et al., 2013; Luck & Vogel, 1997; Pashler, 1988). These findings have also shown the usefulness of change detection tasks in assessing cognitive abilities beyond change blindness. For instance, change detection tasks have been used extensively to measure visual working memory capacity by varying the number of stimuli in the search display.

As one might expect, the more stimuli there are, the harder it is to detect which stimulus is changing (Rensink, 2002). This is likely a result of an informational bottleneck and is in line with prior research on memory capacity. Since Miller's (1956) paper on information processing proposed the magical number seven, plus or minus two, as a limit to processing ability, numerous change detection studies have been conducted to measure working memory capacity under a variety of conditions and using a variety of stimuli. Following decades of research, the so-called magic number for short-term memory has been reduced to four, plus or minus one, items (Cowan, 2001). These items are not, however, restricted to individual features. Rather, multiple features or items can be chunked together, such as several colors together forming a rainbow, and such that people appear capable of remembering four, plus or minus one, chunks of information, regardless of how complex those chunks may actually be (Awh, Barton, & Vogel, 2007; Luck & Vogel, 1997).

Furthermore, different stimuli have resulted in different capacity estimates. Alvarez and Cavanagh (2004) tested visual short-term memory capacity in six human subjects, using a variety of stimulus categories differing in complexity. After a practice phase using line drawings from Snodgrass and Vanderwart (1980), subjects were tested on a change detection task with arrays ranging from one to 15 stimuli from the same category (shaded cubes, random polygons, letters, Chinese characters, or colored squares). Following a 500 ms search display and 900 ms blank screen serving as a mask, the test display was presented. In half of the trials, the test display was identical to the search display while in the other half of the trials, one object changed. Subjects were asked to indicate whether or not a change occurred. Averaged across subjects, capacity estimates varied significantly depending on the type stimuli. For instance, subjects were able to remember more (and thus more accurately detect changes to) colored squares than random

polygons or Chinese characters, in contrast with previous research suggesting that working memory capacity has a fixed threshold (Cowan, 2001; Luck & Vogel, 1997). These conflicting results again indicate that a change/no-change task involving the presentation of a single item may be more useful for the study of change detection, while tasks utilizing arrays of stimuli may be more suitable for memory capacity research.

1.2.3   Type and length of mask

Researchers have also explored numerous methods of masking the change as well as varying the length of the mask. With no mask, humans are reliably able to detect changes between alternating stimuli, and although performance typically still remains above chance following the introduction of a mask, the decrease in accuracy and increase in response time following even a short mask are nonetheless significant indicators of the fragility of our mental representation of the world. Indeed, subjects struggle to detect changes made during natural eye blinks or during a saccade of the eyes (Bridgeman et al., 1979; Carlson-Radvansky & Irwin, 1995; Henderson & Hollingworth, 1999). Likewise, changes made during a sudden shift of the entire display, thus simulating a saccade, can induce change blindness regardless of whether the subject's eyes move in response to the shift or not (Blackmore et al., 1995). Change blindness can also be induced by having the change occur at the same time as the appearance of brief distractors, commonly referred to as *splats* (O'Regan, Rensink, & Clark, 1999). Although less severe than with other methods, this technique does still induce change blindness despite the change itself occurring uninterrupted. Alternatively, change blindness can also be induced when the change occurs while the target item is briefly occluded (Rich & Gillam, 2000; Simons & Levin, 1998).

Perhaps the most common method for inducing change blindness is referred to as the *gap-contingent* technique, in which the change occurs during a gap—often a blank screen, though sometimes a patterned mask—between the original and altered stimuli (e.g. Pashler, 1988; Phillips, 1974; Rensink et al., 1997; Simons, 1996). This technique has been found to induce relatively robust levels of change blindness as the gap mimics a long eye blink or a cut from one scene to another in a film. Researchers have also varied the duration of the mask significantly, with Pashler (1988), for example, finding that increasing the duration of the mask resulted in significantly more errors by subjects on a change detection task. Further research has supported this finding, with longer masks associated with less accurate change detection. This general pattern appears to remain relatively consistent across multiple species, including macaques and pigeons (Elmore, Magnotti, Katz, & Wright, 2012; Eng et al., 2005; Leising et al., 2013).

1.2.4   *Content of change and role of familiarity with stimuli*

The content of the change has also been found to influence change blindness, with changes to familiar objects detected more accurately than changes to unfamiliar objects (Curby, Glazek, & Gauthier, 2009; Sørensen & Kyllingsbæk, 2012). For instance, Werner and Thies (2000) found that football "experts" were quicker than "novices" to detect changes to images of football scenes, while change blindness tasks with alcohol and cannabis users have shown that they are better able to identify changes to alcohol or cannabis paraphernalia than non-users (Jones, Bruce, Livingstone, & Reed, 2006; Jones, Jones, Smith, & Copley, 2003). Similarly, car experts outperformed car novices on a change detection task using cars as stimuli, however, this advantage was orientation specific, with the effect disappearing when inverted stimuli were used,

implying that familiarity (i.e. experience with right-side up cars as opposed to upside down cars) can enhance change detection (Curby et al., 2009).

1.2.4.1   Faces and Familiarity

Change detection accuracy is also often enhanced for changes to parts of a scene judged to be interesting (Rensink et al., 1997). Human faces are familiar and interesting stimuli that have been used in a number of change detection studies; however, it has been debated whether this is due to faces being "special" and the presence of a face-specific processing brain region, or if faces are simply more familiar to us than the majority of other stimuli (Barton, Deepak, & Malik, 2003; Buttle & Raymond, 2003; Diamond & Carey, 1986; Farah, Wilson, Drain, & Tanaka, 1998; Gauthier et al., 2000; McCarthy, Puce, Gore, & Allison, 1997). People appear to be better able to detect changes to faces of their own race compared to other races, a finding known as the "own-race effect" (Hirose & Hancock, 2007; Humphreys, Hodsoll, & Campbell, 2005; but see New, Cosmides, & Tooby, 2007), as well as famous faces compared to unknown faces (Buttle & Raymond, 2003; Jackson & Raymond, 2008), and emotional faces compared to non-emotional faces (Bradley et al., 1997; Curby & Smith, 2010; Hariri, Tessitore, Mattay, Fera, & Weinberger, 2002; Jackson, Wu, Linden, & Raymond, 2009). Unlike most objects, faces are processed holistically, which may explain why humans have been found to have a greater visual short-term memory capacity for faces than other items (Barton et al., 2003; Curby & Gauthier, 2007; Davies & Hoffman, 2002; Jiang, Shim, & Makovski, 2008; Ro, Russell, & Lavie, 2001). Although these findings also indicate that people are better at detecting changes to faces than other items, there remains a significant amount of variability in subjects' performance depending on the exact nature of the questions being asked.

Accordingly, in order to further disambiguate between the specialness of faces and their obvious familiarity, researchers have presented subjects with familiar and unfamiliar stimuli, including faces, which are either upright or inverted. The role of familiarity has subsequently been shown to be more important than a so-called specialness of faces for performance on change detection tasks, with subjects detecting changes to various upright stimuli faster and more accurately than inverted stimuli. Beyond faces (Bartlett & Searcy, 1993; Barton et al., 2003; Barton, Keenan, & Bass, 2001; Valentine, 1988; Xu & Tanaka, 2013), inversion also reduces change detection performance for cars (see above: Curby et al., 2009) and photographs (Shore & Klein, 2000). Similarly, chess experts have more difficulty identifying changes to scenes of unnatural chess games than natural chess games (Reingold, Charness, Pomplun, & Stampe, 2001), again suggesting that familiarity with the stimuli can reduce change blindness.

Further evidence for the importance of familiarity comes from (Sørensen & Kyllingsbæk, 2012) who tested adults as well as six-, eight-, and ten-year-old children on a change detection task using either letters from the alphabet or drawings from the Snodgrass and Vanderwart (1980) picture set. They reasoned that, if visual short-term memory depends on expertise, adults should outperform the children, particularly the younger children, on the task when presented with an array of letters, given a lifetime of reading and writing. Conversely, they hypothesized that little to no difference between adults and children should be seen when using pictures. Supporting their prediction, adults significantly outperformed children when presented with letters, with the older children also outperforming the younger children. However, no such effect was found in the picture conditions, providing further evidence that visual short term memory, an essential component of change detection, depends on one's expertise with the stimuli.

1.2.4.2   Threatening stimuli

Change detection tasks have also revealed that people may be better able to identify changes to threatening or survival relevant stimuli than neutral stimuli. For example, McGlynn et al. (2008) found that more repetitions of the change were needed for people to identify changes to neutral images than to snake-related images. Similarly, combining eye-tracking with the flicker paradigm, Rosa, Gamito, Oliveira, and Morais (2011) instructed participants to fixate on the location of a change between two scenes of either snakes or neutral images and found that people detected changes to snake images more rapidly than changes to neutral images. This same effect is even more pronounced when subjects are fearful of snakes to begin with (Wilamowska, 2006). A proposed explanation for these results comes from the "snake detection theory," which posits that over the past 100 million years of concurrent evolution of snakes and primates, the risk of injury or even death posed by snakes promoted the development of fear and avoidance in our evolutionary lineage, resulting in greater attention directed towards snakes (Isbell, 2006, 2009; Soares, Lindström, Esteves, & Öhman, 2014).

Similar to threatening stimuli, using survival-related stimuli has also been shown to reduce change blindness. In one such study, after controlling for perceptual distinctiveness, humans were found to detect changes to high-relevance survival stimuli (e.g., fire extinguishers) more accurately than changes to low-relevance survival stimuli (e.g., butterflies). However, there was no difference in response time for the two types of stimuli, and a follow up study revealed that this effect may have simply been a product of increased arousal for high-relevance survival stimuli given that arousal is a known attentional capture and attention is an important component of change detection (VanWormer, Blalock, & Powers, 2016).

1.3   Change blindness in non-human subjects

The change blindness phenomenon appears to be universal for humans, yet relatively little research has explored whether animals are also susceptible to change blindness. Just as with humans, noticing even the smallest change to one's environment is critical to an animal's survival. Animals must be vigilant to possible predators and prey, while many social animals, such as primates, must also keep tabs on the activities of their group mates. Monitoring group mates ensures that individuals do not lose the rest of their group, that they know the location of potentially aggressive dominant group members, and that they recognize when a group mate finds a desired resource, such as food, or encounters a potentially dangerous situation, such as a predator. Consequently, failure to detect a change in scenery, such as the appearance of a venomous snake or members of a rival group, could prove harmful or even deadly to animals in their day-to-day lives.

Ideally, change blindness would be tested in the field, where animals are in their natural habitats and failure to detect a change has real survival implications. Unfortunately, outside of a captive setting it is nearly impossible to adequately control all the variables necessary to measure change blindness in animals in any way even close to what Simons and Levin (1998) managed to do in their real-world change blindness study in which one experimenter used workers carrying a door to mask switching places with another experimenter receiving directions from a subject. A certain degree of ecological validity must therefore be sacrificed in favor of internal validity to adequately study change detection in animals (although once the parameters of the phenomenon are established in the laboratory, more naturalistic studies can be more feasibly designed).

Accordingly, the vast majority of change blindness research in animals to date has been conducted by presenting stimuli on a computer screen, which enables rapid alteration back and

forth between changed and unchanged displays, resulting in the flicker effect (Rensink et al., 1997). Computerized versions of the task enable easy and tightly controlled adjustments to numerous parameters, such as the number of times the change is repeated, the type and length of the mask, the display size and initial length of stimuli presentation, and the content of the stimuli used, among others. These controlled settings also enable comparisons to be made between subjects and between species when similar procedures are used. Researchers have thus designed computerized change detection tasks for several non-human species that have begun to help illuminate how widespread the change blindness phenomenon truly is.

Several species of primates and birds have been tested on change detection tasks, revealing that they, too, experience change blindness when a mask is used between an initial array of stimuli and an altered test display. As with humans, display size also appears to be a critical factor in primate change detection studies. Heyselaar, Johnston, & Paré (2011) presented two female macaques with memory arrays consisting of two to five identically sized but differently colored squares for 500 ms followed by a 1,000 ms delay, at which point the test array, in which one square had changed color, appeared. Monkeys' eye movements were recorded with an eye tracker and the monkeys were required to make a saccade from a central fixation spot to the changed stimulus within 500 ms to receive a reward. Performance at all set sizes was significantly above chance, though as predicted, performance declined gradually as set size increased. Similarly, Chau, Murphy, Rosenbaum, Ryan, and Hoffman (2011) used a flicker change detection task to test object-in-scene memory in humans and macaques, finding that both species had similar search time patterns, suggesting a common underlying memory process.

In an effort to measure visual short term memory capacity in six humans and two rhesus macaques (*Macaca mulatta*), Elmore et al. (2011) adjusted the display size (i.e. 2, 4, 6, 8, or 10

stimuli) on a change detection task, using colored squares in one experiment and clip art in a second experiment. Monkeys viewed the sample display for 5 seconds, followed by a delay of 50 ms masking the change. As expected, human and macaque performance decreased as the display size increased, with humans correctly identifying the change to both colored squares and clip art nearly 100% of the time with a display size of 2, over 90% with a display size of 4, slightly over 80% with a display size of 6 or 8, and about 75% with a display size of 10. The monkeys' performance followed the same trend, albeit with less overall accuracy, correctly identifying the change approximately 80% of the time with a display size of 2, 70% of the time with a display size of 4, and 65% of the time with a display size of 6. Overall, the macaques performed slightly better when detecting changes to clip art than to colored squares regardless of display size, while this same effect was only noticeable among humans with the larger display sizes of 8 and 10.

Interestingly, these results were replicated with no significant differences when the two macaques were retested using the same stimuli and display sizes, but with a 1,000 ms delay as opposed to just 50 ms (Elmore & Wright, 2015). Although the researchers opted to use a longer delay to ensure that change detection would be based on visual short-term memory rather than attentional capture, results from human change detection tasks (Pashler, 1988) suggest that the macaques should have performed worse with the longer delay. This may simply be a result of the small sample size, as the subjects used here also had extensive experience with cognitive testing and thus may have performed better than expected due to prior experience with similar tasks.

Besides macaques, there is also evidence for change blindness in chimpanzees (*Pan troglodytes*). Tomonaga and Imura (2015) administered a change detection task to three

chimpanzees and six humans, varying the duration of the search display (i.e. initial, unchanged array) between 90 ms and 320 ms and the display size among three, six and nine items. Change type was also varied throughout, with the target stimulus alternating between present or absent, shifted 10 mm, or changed to a different stimulus entirely. Using a touchscreen, chimpanzees were trained to touch the changing stimulus for a food reward while the search array and target array were repeatedly presented with no mask between them. After attaining 90% accuracy on the task, subjects advanced to test sessions which included three types of trials. No-blank trials were identical to training and did not include a mask between the search and test displays. On blank trials, a blank screen (i.e. mask) was displayed for 90 ms or 180 ms between the search and test displays to create the flicker effect. Lastly, on control-blank conditions, subjects were presented with the repeating sequence of search display, then test display, then blank screen, then test display again, then search display again, and then blank screen. This was done to rule out the possibility that poor performance on the blank condition was simply due to the insertion of a distracting stimulus (i.e. blank screen), regardless of whether it was placed directly between the search and test displays as a mask or elsewhere in the sequence such that there was no mask between the search and test displays.

The chimpanzees participated in 32 sessions consisting of 108 trials each, and were able to detect changes significantly more accurately in the no-blank and control-blank conditions than in the blank condition. Moreover, only in the blank condition was there an effect of display size, with larger displays resulting in poorer accuracy, while positional shift changes were significantly more difficult to detect than the other two types of changes used. These results were nearly identical to the patterns seen in the human data, further suggesting that primates are appropriate models for change detection research.

Species other than primates are also susceptible to change blindness. Pigeons (*Columba livia*) are able to detect changes in visual arrays when there is no inter stimulus interval (i.e. flicker), but they exhibit change blindness just as primates do with the introduction of a blank screen between stimuli (Herbranson et al., 2014; Herbranson & Jeffers, 2017). In their first experiment, Herbranson et al. (2014) had pigeons peck at a screen to indicate whether a change had occurred following either a 250 ms mask or no mask between search and test displays. As expected, the pigeons were significantly better at detecting changes when no mask was used. In a second experiment, the researchers reduced the duration of the mask by half (i.e. 250, 125, 60, 30, 15, 7, 3 ms) every test ten days. Here, the pigeons continued to exhibit change blindness compared to control conditions, but their accuracy steadily improved as the duration of the mask decreased.

In a follow up study, increasing the salience of the change resulted in improved change detection by pigeons, similar to what has been seen in humans (Herbranson, 2015). In a different paradigm, pigeons were also able to detect continuous changes in brightness; however, when these changes in brightness occurred more slowly, the pigeons again experienced human-like patterns of change blindness (Hagmann & Cook, 2011, 2013). Cleland, Taylor, Lee, Wolf, and Leising (2016) presented humans and pigeons with a location change detection task using arrays of two, three, or four colored circles, and found that performance declined as set size increased in both species, though subjects still performed above chance levels at all display sizes, suggesting that both species have capacity limits, although those of humans are larger than those of pigeons. Moreover, both pigeons and macaques have shown that they are able to transfer their performance on change detection tasks to significantly longer delays than in training; however, as expected, accuracy for both species decreased as the duration of the mask increased (Leising

et al., 2013). Recently, Herbranson and Davis (2016) also found that increasing the length of the mask impairs change detection accuracy in pigeons, while shorter search display presentations were found to impair accuracy in the no-mask conditions similar to what has been seen in human and primate studies (Leising et al., 2013; Pashler, 1988; Tomonaga & Imura, 2015).

1.4   Present study and hypotheses

Prior to the present study, the change blindness phenomenon had yet to be studied in any species of New World monkey, a lineage that split off from that of humans 32-36 million years ago (Glazko & Nei, 2003; Schrago & Russo, 2003). It is important to look at the phenomenon across the entire primate order, as well as in non-primates, to determine whether there are differences in how the phenomenon manifests in different taxa and, if so, to determine how these differences may correlate within each species' evolutionary history. Such understanding may provide insight into the evolutionary causes of change blindness, which would help in determining situations in which it is likely to occur. The relatively similar patterns of change blindness seen to date across primate species when variables such as length of search display and length of the mask are adjusted suggest similarity in the underlying mechanisms responsible for change detection across the primate order. However, the relationship between mask duration and search display presentation remains less clear, as evidenced by the variable results both between and within species, suggesting that further manipulations of these variables in change detection tasks across multiple species are needed.

New World monkeys are prime candidates as, unlike the other species tested on change blindness tasks, there is more variation within and between their visual systems, and thus they are too often discounted as potential models for humans (Gomes, Pessoa, Tomaz, & Pessoa, 2002). Yet, in order to understand the origins of human cognitive abilities, studying apes and

Old World monkeys, our closest relatives, only tells part of the story. The variability seen within and between New World monkeys can thus yield important insights into our evolutionary history, in particular convergent and divergent evolutionary traits. Accordingly, should differences in change detection exist across the primate order, New World monkeys appear the likeliest candidates to exhibit potentially novel patterns of change blindness.

In addition, to date, the overwhelming majority of change blindness studies with non-humans have relied on extremely small sample sizes, often no more than two or three subjects. This is concerning given the considerable individual differences that exist in individuals' attention and visual working memory capacity, which should also indicate large individual differences in performance on change detection tasks. Considering the breadth of these differences in human change detection research, similar variation should be expected in primates. Accordingly, change detection studies with non-human subjects are greatly in need of larger sample sizes to sufficiently both compare to the data acquired from studies with human subjects (to help determine whether the level of variability is comparable) as well as explore and analyze the differences seen among numerous animal subjects. Given the survival importance of detecting changes to one's environment, determining how and why individual differences in change detection occur in primates may shed further light on the evolutionary mechanisms behind humans' ability to first attend to and then maintain items in visual working memory.

I therefore conducted a change detection study with an as yet untested species: tufted capuchin monkeys (*Cebus [Sapajus] apella*). Capuchins are highly social monkeys who typically live in relatively small and stable social groups of approximately 7-30 individuals (Di Bitetti, 2001) whose home ranges often overlap with one or more other troops (Spironello, 2001). Accordingly, they must frequently monitor their surroundings for potentially disruptive

or even dangerous changes, such as social disruption in their own group or the appearance of a rival group member. With their small body sizes, they are also predated upon by a number of different species (snakes, cats, and avian predators), which also presumably selected for them to notice changes in the environment. Thus, as with other primates, it is in capuchins' best interests to be able to detect changes to their environment because there are harmful implications for failure to do so. It is also important to further understand how the length of time a stimulus is visible influences change detection, as well as how this search display duration interacts with masks of various durations between original and potentially altered stimuli. This interaction may provide additional insights into the mechanisms, namely attention and visual working memory, associated with change blindness, and whether one is more important than the other under certain conditions.

Moreover, capuchins are perhaps the most appropriate New World monkey species to compare with humans given several similarities between the two species, and their apparent convergent evolution. Capuchins, who are frequently used in cognitive and behavioral research, live in complex social groups in which they are known to cooperate (Brosnan, 2011; de Waal & Davis, 2003; Hattori, Kuroshima, & Fujita, 2005; Perry, Manson, Dower, & Wikberg, 2003), share food (de Waal, 1997, 2000), and exhibit prosocial behavior under some circumstances (Lakshminarayanan & Santos, 2008). While these traits are all shared with humans, they are certainly not found in all primates, thus adding to the value of capuchin research.

Capuchins are also highly intelligent, capable of using tools (Fragaszy, Visalberghi, & Fedigan, 2004; Ottoni & Mannu, 2001; Visalberghi & Trinca, 1989; Westergaard & Fragaszy, 1987), and possessing aspects of metacognition (Beran & Smith, 2011; Fujita, 2009) and numerosity (Judge, Evans, & Vyas, 2005). Capuchins also boast an impressive brain to body

size ratio, which is equivalent to that of chimpanzees (Dunbar, 1992; Gibson, 1986). Of course, these are all features of human behavior as well, but are rare in other primates and, in particular, in New World monkeys. The seemingly convergent evolution of many cognitive abilities in capuchins and Old World monkeys and apes have made capuchins an intriguing species to study, to uncover possible shared environmental and social contexts that may have led to these shared traits.

From a practical standpoint, capuchins have been successful trained to use computerized touch screens (e.g., McGonigle, Chalmers, & Dickinson, 2003) or joysticks enabling the monkeys to control a cursor on the screen (Evans, Beran, Chan, Klein, & Menzel, 2008). Using the joystick model, a number of researchers have successfully trained capuchins to complete an array of computerized cognitive tasks (e.g., Beran, 2008; Fragaszy, Johnson-Pynn, Hirsh, & Brakke, 2003; Leighty & Fragaszy, 2003). These monkeys are able to discriminate between various stimuli presented on a computer screen, such as faces (Talbot, Leverett, & Brosnan, 2016) and most colors (Goulart, Bonci, Galvão, Silveira, & Ventura, 2013). They have also been successfully trained on same/different match-to-sample tasks with variable delays (Truppa, De Simone, Piano Mortari, & De Lillo, 2014; Truppa, Mortari, Garofoli, Privitera, & Visalberghi, 2011), with their response accuracy decreasing and response time increasing on trials with longer delays. Together, these results suggested that capuchins would be able to learn the contingencies of a change detection task.

In the current study, subjects were presented with varied durations of a search display (i.e., original stimulus) and the mask (i.e., blank screen) to determine if capuchins experienced change blindness comparably to the rest of the primate order. These results may also prove useful in determining the best durations to use for these two parameters in future research into

primate change detection and visual working memory research, as well as provide reference points to compare the capuchins' performance with that of other species. In the present study, and in line with previous human research (Alvarez & Cavanagh, 2004; Eng et al., 2005; Pashler, 1988), as the time to attend to and encode the search display increased, I predicted that change detection accuracy would also increase. Furthermore, in line with previous research demonstrating that longer masks result in impaired change detection performance (Elmore et al., 2012; Pashler, 1988), I predicted that as the duration of the mask increased, the monkeys' change detection accuracy would decrease. This pattern was expected for each phase of testing; however, given the increasing difficultly of each phase, subjects were expected to detect changes most accurately in the easiest phase (the same/different phase), followed by the more subtle occlusion phase, and finally struggle the most with the feature location changes in my final checkerboard design.

2   JOURNAL MANUSCRIPT

2.1   INTRODUCTION

The ability to detect changes to one's environment is a useful skill, particular when performing acts that require vigilance. For instance, when driving, it is clearly beneficial to notice when a traffic light changes color, not only to avoid a ticket, but also to ensure the safety of oneself and those nearby. Similarly, it is in an animal's best interest to detect the presence of a predator to avoid being eaten, a conspecific to be able to predict upcoming social changes, or a member of another group approaching to avoid being attacked. As observers, people tend to believe that they will immediately be able to detect any change occurring in front of them, so long as it is sufficiently large (Levin et al., 2000). However, despite this belief, people are consistently unable to detect not just subtle, but also large and dramatic changes in their visual field, a phenomenon known as *change blindness* (Rensink et al., 1997; for reviews, see Gibbs et al., 2016; Rensink, 2000a, 2008; Simons & Ambinder, 2005; Simons & Levin, 1997; Simons & Rensink, 2005).

Change blindness is not restricted to changing images, but extends to include changes in motion pictures and videos clips (Angelone et al., 2003; Levin & Simons, 1997, 2000). In one striking study, Simons and Chabris (1999) showed subjects a video of several individuals in white and black shirts passing two basketballs. The subjects were instructed to mentally count how many times individuals in one of the two colors passed the ball as everyone walked in circles passing the ball around. Despite the circuitous and intentionally confusing patterns walked by the basketball passers, subjects were generally able to keep track of the total number of passes. Incredibly, many subjects did, however, fail to notice a man in a gorilla suit walking through the basketball passers. This form of change blindness, known as inattentional blindness,

provides support for the hypothesis that attention is required for changes to be detected (Neisser, 1979). Yet, O'Regan et al. (2000) found that even when fixated on the change location, subjects still failed to detect the change over 40% of the time. Thus, even seemingly obvious details that might be crucial to our lives, such as the moments proceeding a car accident or recalling what a thief looked like or was wearing, can be easily missed, resulting in potentially damaging consequences (for review, see Hyman Jr., 2016). Attention is therefore an important component of change blindness, but clearly attention alone does not explain the phenomenon.

Perhaps most surprising - and unsettling - is the degree to which we are blind to changes occurring in the real world. This was demonstrated by Simons and Levin (1998) who had an experimenter carrying a map stop and ask individuals on a college campus for directions. Following a minute or so of discussion, two confederates dressed as construction workers and carrying a door walked between the experimenter and subject. The passing construction workers and door served as a mask, enabling a second experimenter to surreptitiously change places with the first experimenter. Despite wearing different clothing and many physical differences between the two experimenters, eight out of 15 subjects failed to report noticing the change, despite now being engaged in conversation with a completely different individual. Subjects who noticed the change tended to be roughly the same age as the experimenters, implying a potential bias for detecting changes to in-groups. In a second experiment, the experimenters again dressed as construction workers but all subjects were either graduate or undergraduate students creating the appearance of an in-group out-group divide between the experimenters and participants. Here, only one third of the subjects noticed the change, providing further support for an in-group change detection bias. While this was a harmless study occurring on a college campus, it

nonetheless suggests that we may fail to detect changes in more serious situations, such as while driving, resulting in far more serious consequences.

That this striking perceptual failure readily occurs in the real world, where detecting changes can have life or death implications, strongly supports the need for further research and understanding of the phenomenon. In particular, it is important to determine whether the phenomenon is a result of something about human culture (most of these studies have been run in Westernized societies) or is the result of a more basic biological phenomenon, in which case we might expect it to be shared with other species. This is key to determine how best to address this phenomenon in situations in which it can have grave side effects. Therefore, beyond studying change blindness in humans, additional research is also needed to determine how widespread and consistent the phenomenon is among non-human animals, and whether it shares the same cognitive foundations.

In an effort to understand the boundaries of change blindness, the duration the search display is visible prior to the mask has been varied extensively, typically depending on the specific questions being asked. For instance, the longer the search display, the more time subjects have to attend to and encode the stimuli, enabling a trace of the item of to be stored in visual working memory and then recalled at the test display as opposed to relying solely on attentional capture as required for the shortest search displays. Accordingly, varying the duration of the search display can provide insights into how executive control and memory consolidation function with respect to how long we are able to attend to stimuli. Unsurprisingly, increasing the duration of the search display has been found to result in improved retention of items in change detection tasks (Alvarez & Cavanagh, 2004; Eng et al., 2005). However, these findings come from studies in which multiple items from within a category, such as colored

squares, letters, or faces, are presented, as opposed to a single item being presented, which then may or may not change following the mask. As such, longer search displays may be associated simply with more time to encode *additional* items into working memory or even long term memory. Conversely, when presenting only a single stimulus, which may or may not change, subjects need not rely on a large visual working memory *capacity*, but are able to attend solely to whether or not a change occurs. Thus, using a single stimulus and a change/no-change design reduces the role of visual working memory capacity, which has been found to vary depending on the type of stimuli used and subjects familiarity with those stimuli (Alvarez & Cavanagh, 2004; Cowan, 2001; Eng et al., 2005; Luck & Vogel, 1997; Luria et al., 2009; Sørensen & Kyllingsbæk, 2012). This paradigm seems most apt for nonhuman primates, whose visual working memory capacities appear to be smaller than those of humans and even more variable, depending on the type of stimuli (Elmore et al., 2011; Elmore & Wright, 2015; Leising et al., 2013), which would bias our interpretation of the change blindness phenomenon.

Perhaps the most common method for inducing change blindness is referred to as the *gap-contingent* technique, in which the change occurs during a gap—often a blank screen, though sometimes a patterned mask—between the original and altered stimuli (e.g. (Pashler, 1988; Phillips, 1974; Rensink et al., 1997; Simons, 1996). This technique has been found to induce relatively robust levels of change blindness as the gap mimics a long eye blink or a cut from one scene to another in a film. Moreover, increasing the duration of the mask resulted in significantly more errors (Pashler, 1988), a pattern that appears to remain relatively consistent across multiple species, including macaques and pigeons (Elmore, Magnotti, Katz, & Wright, 2012; Eng et al., 2005; Leising et al., 2013). The mask may inhibit memory consolidation if the search display is not sufficiently long (Rensink, Kevin O'Regan, & J Clark, 2000), while varying

the duration of the mask offers clues as to the nature of the mechanisms directly causing change blindness.

Primates also seem to be more susceptible to change blindness as display size increases. Heyselaar et al. (2011) presented two female macaques with a color change detection task using arrays of two to five colored squares and found that performance at all set sizes was significantly above chance, though as predicted, performance declined gradually as set size increased. Similarly, Chau et al. (2011) used a flicker change detection task to test object-in-scene memory in humans and macaques, finding that both species had similar search time patterns, suggesting a common underlying memory process. In an effort to measure visual short term memory capacity in six humans and two rhesus macaques (*Macaca mulatta*), Elmore et al. (2011) adjusted the display size (i.e., 2, 4, 6, 8, or 10 stimuli) on a change detection task, using colored squares in one experiment and clip art in a second experiment, finding that the macaques performed slightly better in the clip art condition than the colored square condition regardless of display size, while this same effect was only noticeable among humans with the larger display sizes of eight and ten. Interestingly, these results were replicated with no significant differences when the two macaques were retested using the same stimuli and display sizes, but with a 1,000 ms delay, as opposed to just 50 ms, in contrast to the decline in performance longer masks are associated with in human change detection studies (Elmore & Wright, 2015).

Besides macaques, there is also evidence for change blindness in chimpanzees (*Pan troglodytes*). Tomonaga and Imura (2015) found that chimpanzees were able to detect changes significantly less accurately when a mask was inserted between search and test displays. Recently, pigeons (*Columba livia*) have also been found to exhibit change blindness, with

Herbranson and Davis (2016) finding that subjects performed better when the duration of the mask was reduced and when the length of the search display was increased.

Prior to the present study, the change blindness phenomenon had yet to be studied in any species of New World monkey, a lineage that split off from that of humans 32-36 million years ago (Glazko & Nei, 2003; Schrago & Russo, 2003). It is important to look at the phenomenon across the entire primate order, as well as in non-primates, to determine whether there are differences in how the phenomenon manifests in different taxa and, if so, to determine what these differences may have correlated with in each species' evolutionary history. Such understanding may provide insight into the evolutionary causes of change blindness, which would help in determining situations in which it is likely to occur. The relatively similar patterns of change blindness seen across primate species when variables such as length of search display and length of the mask are adjusted suggest similarity in the underlying mechanisms responsible for change detection across the primate order.

Capuchins (*Cebus [Sapajus] apella*) are perhaps the most appropriate New World monkey species to compare with humans given several similarities between the two species, and their apparent convergent evolution. Capuchins, who are frequently used in cognitive and behavioral research, live in complex social groups in which they are known to cooperate (Brosnan, 2011; de Waal & Davis, 2003; Hattori et al., 2005; Perry et al., 2003), share food (de Waal, 1997, 2000), and exhibit prosocial behavior under some circumstances (Lakshminarayanan & Santos, 2008). Part of living in a social group is monitoring the location and activities of group mates, and this is particularly true in species like capuchins that have dominance hierarchies where relationships vary from one individual to another. As such, detecting changes to the location or activity of a group mate is important for social decision-

making. Additionally, capuchins are highly intelligent monkeys, capable of using tools

(Fragaszy, Visalberghi, & Fedigan, 2004; Ottoni & Mannu, 2001; Visalberghi & Trinca, 1989;

Westergaard & Fragaszy, 1987), and possessing aspects of metacognition (Beran & Smith, 2011;

Fujita, 2009) and numerosity (Judge et al., 2005). Capuchins also boast an impressive brain to

body size ratio, which is equivalent to that of chimpanzees (Dunbar, 1992; Gibson, 1986).

Accordingly, capuchins have been successful trained to use computerized touch screens (e.g.,

McGonigle, Chalmers, & Dickinson, 2003) or joysticks enabling the monkeys to control a cursor

on the screen (Evans et al., 2008) to complete an array of computerized cognitive tasks (e.g.,

Beran, 2008; Fragaszy, Johnson-Pynn, Hirsh, & Brakke, 2003; Leighty & Fragaszy, 2003). This

provides an added benefit to our study, as unlike earlier studies, which relied on two to three

subjects, we were able to test a larger number (nine), shedding light on the individual differences

we see in this change blindness.

In the present study, subjects were presented with varied durations of a search display

(i.e., original stimulus) and the mask (i.e., blank screen) to determine if capuchins experienced

change blindness comparably to the rest of the primate order. Aside from providing information

on capuchins' propensity for change blindness, these results may prove useful in determining the

duration of these two parameters in future research into primate change detection and visual

working memory research, as well as provide reference points to compare the capuchins'

performance with that of other species. Due to the increased time to attend to and encode the

stimulus (Alvarez & Cavanagh, 2004; Eng et al., 2005; Pashler, 1988), I predicted that as the

duration of the search display increased, change detection accuracy would also increase. In line

with previous research demonstrating that longer masks result in impaired change detection

performance (Elmore et al., 2012; Pashler, 1988), I also predicted that as the duration of the

mask increased, the monkeys' change detection accuracy would decrease. This pattern was expected for each phase of testing; however, given the increasing difficulty of each phase, subjects were expected detect changes most accurately in the same/different phase, followed by the more subtle occlusion phase, and finally struggle the most with the feature location changes in a checkerboard design.

2.2 METHODS

*Subjects***:** Twenty-two capuchin monkeys at Georgia State University participated in the training phase of the study; however, only nine subjects successfully passed the training phase and completed testing. All subjects were mother-reared in captivity, providing them with species typical social exposure. All were housed in large, stable, mixed-sex and mixed-age social groups in indoor/outdoor enclosures with extensive environmental enrichment (climbing structures, ropes, toys, etc.). Outdoors, the monkeys had visual and auditory access to neighboring groups. Indoors, two groups (Nkima's and Griffin's groups) had visual and auditory access to each other. The monkeys were never food deprived (except for veterinary necessity) and received chow, fresh fruits and vegetables throughout the day in addition to any food rewards during research. All monkeys had *ad libitum* access to water, including during test sessions, and subjects were trained to voluntarily separate for short periods of time from their group for cognitive and behavioral testing. Monkeys were never restricted from food, water, social contact, or outdoor access as a means to encourage participation in research studies. The LRC is fully accredited by the Association for Assessment and Accreditation of Laboratory Animal Care and all procedures are approved by the Institutional Animal Care and Use Committee of Georgia State University (IACUC) and are in accordance with the Association for the Study of Animal Behaviour/Animal Behavior Society's guidelines for the use of animals in research.

*Materials***:** The monkeys were tested using the Language Research Center's Computerized Test System comprising a personal computer, digital joystick, 17-inch color monitor, and pellet dispenser. The test program was written in Python. Contacting the appropriate stimulus with the joystick-controlled cursor resulted in a food reward of a single 45 mg banana flavored pellet (Bio-Serv, Frenchtown, NJ). Auditory feedback was also provided for all response (details of the testing system can be found in Evans, Beran, Chan, Klein, & Menzel, 2008). All subjects have extensive experience with computerized tasks requiring the use of a joystick to manipulate a cursor on screen.

Stimuli: Unlike all other species tested on change blindness tasks to date, male capuchins and many females are dichromats, unable to discriminate between red and green, limiting the types of stimuli that may be appropriately used (Gomes et al., 2002). Although they can see colors, they do not perceive them the way that people do, complicating the experimental design because we cannot be sure how large of an effect a change in color is for them. Accordingly, whereas macaques have been tested using arrays of colored squares and clip art (e.g., Elmore et al., 2011, 2012; Elmore & Wright, 2015; Heyselaar et al., 2011), subjects here were presented with only black and white stimuli (i.e., Snodgrass line drawings; Snodgrass & Vanderwart, 1980). These line drawings have been regularly used in psychological testing and have importantly been normed on visual complexity, as well as familiarity, name and image agreement for human memory research. During testing, subjects were tested with different sets of stimuli than during training to avoid an experience effect; however, given that all image sets are black and white line drawings, training performance was expected to carry over to the novel stimuli used for each testing phase.

The stimuli for same/different training were the Snodgrass and Vanderwart (1980) line drawings. Subjects were trained to select the "change" icon when the stimuli were different or the "no change" icon when the stimuli remained the same. Next, the stimuli for same/different testing involving variable search display and mask durations were Nishimoto, Ueda, Miyawaki, Une, and Takahashi's (2012) set of 360 line drawings that, like the Snodgrass drawings, are also normed for numerous variables, including visual complexity. The first phase of change detection testing, in which small sections of line drawings were occluded, utilized Bonin, Peereman, Malardier, Méot, and Chalard's (2003) set of 299 line drawings, which have also been normed for numerous variables, including visual complexity. The changes here were fairly subtle and differed from one line drawing to the next, resulting in somewhat limited experimental control. In the remaining change detection tasks, subjects were tested on feature location changes. A four by four checkerboard design with first eight black checkers (i.e., black circles) and next just two black checkers randomly placed in eight of the sixteen possible squares on the grid was initially presented. Following the search display and ensuing mask, on half of all trials one of the checkers changed location to an available adjacent square. Here, although the change was still relatively subtle, the nature of the change was extremely well controlled.

Thus, the two phases of change detection testing were designed to complement one another with regard to internal validity to present the first investigation of capuchins' ability to detect multiple types of changes under varying levels of experimental control. In the occlusion phase, the potential change was either an addition or subtraction to a line drawing while the change in the feature location change phase never added or removed parts of the checkerboard, but instead one feature of the checkerboard changed location. These tasks were chosen based on

the types of situations primates encounter and monitor in the wild, such as the appearance or disappearance of a predator, or a group member moving nearby.

*Same/Different Training Procedure (see Figure 2.2.1)***:** Prior to testing, monkeys were trained to indicate whether or not a stimulus changed. Each trial began once the subject used the joystick to move the cursor to a start box in the center of the screen, at which point the cursor disappeared and one Snodgrass line drawing appeared in the center of the screen. The stimulus remained visible for five seconds, at which point it was either replaced by a different line drawing from the image set, or no change occurred and the original drawing remained visible. As we cannot force the monkeys to attend to the computer screen, the five second search display was chosen to provide the monkeys ample time to view the stimulus during the training phase. This is the also the same search display duration as used in training for previous change detection tasks with another primate species, rhesus macaques (Elmore et al., 2012; Leising et al., 2013).

At this point, two distinct icons that indicated "change" and "no change" appeared below the drawing and the cursor reappeared between these two icons. The change icon was a dotted blue square that always appeared on the subject's left side of the screen, while the no change icon was a hashed yellow circle that always appeared on the right (the sides were not counterbalanced so that location could be another cue for the icon's meanings). Subjects had up to five seconds to make a selection. Correctly selecting the blue square when a change had occurred or the yellow circle when no change had occurred resulted in a food reward (pellet) and auditory feedback (*ding*), followed immediately by the start screen. Choosing incorrectly resulted in no food reward, negative auditory feedback (*buzz*), and a 20 second timeout (grey screen) before the start screen reappeared. If no selection was made within the five second window, the program reverted back to the start screen. Each day, subjects received an unlimited

number of session blocks, each consisting of 120 trials, until criterion was met. Subjects were required to achieve 80% accuracy on the final completed session block on two consecutive days to move on to testing.

Figure 2.2.1 Same/Different Training

Eighteen of the 22 subjects either exhibited a persistent side bias or struggled to learn the task, and so were switched to a simpler training task (see *Figure 2.2.2*). This supplemental training involved identical methods as the initial training; however, rather than using randomized Snodgrass line drawings, a total of six differently colored geometric shapes were used as stimuli.

Criterion remained at greater than 80% accuracy on the final completed session block on two consecutive days. Once criterion was met, subjects were still required to meet criterion on the initial training with line drawings before moving on to testing. Subjects who continued to struggle with these much simpler six stimuli received a further modification to the training module in which the display time was reduced from five seconds to one second (during training only) in an attempt to improve the monkeys' attentiveness to the screen. As the subjects were able to complete as many trials as they chose each day and did not all run on the task the same number of times per week, subjects were given approximately four months from when they began supplemental training rather than a set number of trials to meet training criterion before being dropped from the study. A total of nine subjects (five of whom required supplemental training) ultimately passed the training phase and moved on to testing.

Figure 2.2.2 Same/Different Supplemental Training

Same/Different Testing Procedure (see Figure 2.2.3): Testing relied on nearly identical

procedures as training; however, a blank screen of different durations was inserted as a mask

between the search display and test display. Search display duration (i.e. length of time the

initial stimulus is visible) and the duration of the mask between search and test displays were

varied systematically. Search display lengths were selected based on the range of times used in

previous change detection research and included 250 ms, 500 ms, 1,000 ms, 2,500 ms, and 5,000

ms. This combination was selected given that extremely short search displays may rely solely on

attentional capture, whereas longer search displays may primarily rely on visual short term memory. Accordingly, making use of a range of search display lengths in conjunction with varying the duration of the mask should help establish under which conditions (i.e., attentional capture or short term memory) change blindness may be attenuated. Furthermore, varying the duration of the search display helps determine if capuchins exhibit patterns of reduced change blindness as the duration of the search display increases, as has been seen in some human change blindness research (e.g., Eng et al., 2005).

Similarly, the duration of the mask was also varied within the range of times typically used in previous research, consisting of 0 ms, 50 ms, 100 ms, 250 ms, 500 ms, and 1,000 ms, with the 0 ms condition serving as the control. This was done to determine if capuchins exhibit change blindness similarly to humans, macaques, and pigeons, all of whom show change detection accuracy that decreases as the duration of the mask increases (Elmore et al., 2012; Eng et al., 2005; Leising et al., 2013; Pashler, 1988). Additionally, determining the mask durations that both maximize and minimize change blindness may provide insight into the role of executive control and attention in change detection.

Subjects completed 120 trial session blocks consisting of four trials of each possible combination of search display and mask duration. Trials occurred in a randomized order as determined by the computer program. Subjects were able to complete as many sessions as they chose to per day, and data from incomplete sessions were discarded. Accordingly, subjects needed to complete at least one entire 120 trial session block per day for their data to be analyzed. Subjects completed a total of 40 session blocks over as many test days as they required. This resulted in 4,800 total trials, or 160 trials of each possible combination of search display and mask duration per subject.

As with training, subjects first needed to move the cursor to a start box prior to each trial to initiate the trial and, hopefully, focus their attention. Once the start box was contacted, a line drawing would appear in its place and remain visible for a predetermined duration (i.e., the search display length), at which point the screen would go blank for a predetermined duration (i.e., the mask length). Following the mask, either the same line drawing or a new line drawing appeared where the previous stimulus had been, while the "change" and "no change" icons also appeared on either side of the lower half of the screen, with the cursor reappearing between them. Subjects then had five seconds to move the cursor to indicate whether a change occurred or not, with the dotted blue square still signifying that a change had occurred and the hashed yellow circle still signifying that no change occurred. Correct responses resulted in a food reward (pellet) and auditory feedback (*ding*), followed immediately by the start screen. Choosing incorrectly resulted in no food reward, negative auditory feedback (*buzz*), and a 20 second timeout (grey screen) before the start screen reappeared. Accuracy (i.e., correctly indicating a change did or did not occur) was collected on each trial to analyze with respect to search display duration and mask duration.

Figure 2.2.3 Same/Different Testing

Occlusion Change Detection Testing Procedure (see Figure 2.2.4): The first phase of change detection testing involved occlusion changes and consisted of far more subtle changes than the entire stimulus changing, as occurred in same/different testing. Subjects were initially presented with a black and white line drawing from the Bonin et al., (2003) stimulus set. The stimulus appeared as originally drawn on half of all trials, while on the other half of trials the

stimulus appeared with a small section occluded (i.e., whited out). The occluded sections were chosen by the experimenter based on the nature of each line drawing, and thus lacked a considerable degree of internal validity between stimuli, though all subjects were presented with the same original and changed stimuli. Following the predetermined search display duration and mask duration, the same stimulus would reappear. If subjects were initially presented with an unaltered stimulus, then following the mask a small section of the stimulus would appear occluded (i.e., subtraction change) on half of the trials while the stimulus would reappear unaltered on the other half of these trials (subtraction no-change). If, however, subjects were initially presented with a partially occluded stimulus, then on half of the trials the same occluded stimulus reappeared following the mask (addition no-change) while on the other half of trials the same stimulus reappeared but no longer occluded (i.e., addition change). At this point, the subjects once again selected either the "change" or "no change" icon. If the monkeys failed to make a selection within the five second window, the program returned to the start screen. Subjects again completed a total of 40 120-trial session blocks resulting in 4,800 total trials. Thus, subjects completed a total of 1,200 trials (40 of each combination of search display and mask durations) for subtraction change, subtraction no-change, addition change, and addition no-change trials.

Figure 2.2.4 Occlusion Change Detection Testing

Feature Change Detection Testing Procedure (see Figure 2.2.5): The final phase of change detection testing utilized identical procedures as in both the same/different testing and the occlusion change detection testing. However, rather than an entirely new stimulus or a portion of the stimulus being occluded, a feature of the stimulus change could change location.

Specifically, subjects were trained to identify if changes occur to a four by four checkerboard design of alternating white and light gray squares.

Eight "checkers" (i.e., black circles) also appeared, randomly placed on eight of the 16 possible checkerboard squares. Following the predetermined search display and mask durations, the same checkerboard reappeared. On half of the trials, following the mask the eight checkers remained in the same locations as during the search display. On the other half of trials, following the mask one of the eight checkers moved to one of the empty squares adjacent to it (i.e., above, below, left, or right). Subjects then indicated whether or not a change had occurred by moving the cursor to either the dotted blue square if a change had occurred or the hashed yellow circle if no change had occurred.

Subjects again received 40 session blocks of 120 trials, with a change randomly occurring on half of them and no change occurring on the other half. If the monkeys failed to make a selection within the five second window, the program returned to the start screen. Each session entailed presenting the same set of 120 unique checkerboards consisting of eight randomly placed checkers. The potential change (i.e., which checker moves and where it moves) was different across sessions such that although the checkers start in the same positions on one trial per 120 trial session block, there were five different possible changes for each original checkerboard that was presented.

Figure 2.2.5 Feature Change Detection Testing

Given the difficulty of detecting a change to one of eight possible checkers, subjects were subsequently retested using identical procedures; however, this time two checkers were used rather than eight (see *Figure 2.2.6*). 120 unique checkerboards consisting of each possible combination of checker locations on the four by four grid were used. Similar to the eight checker version, the potential change (i.e., which checker moves and where it moves) was different across sessions such that there were three different possible changes for each original

checkerboard that was presented. Three possible changes were used here rather than five as in

the eight checkers task since several potential locations of just two checkers have only three

potential changes that can be made.

Figure 2.2.6 Simple Feature Change Detection Testing

2.3   RESULTS

Group results: To explore performance at the group level, we combined all subjects' data

for each test phase, respectively. We then conducted a generalized linear mixed model for each

test phase after transforming the variables search display duration and mask duration to more

similar scales. The five search display durations ranging from 250 ms to 5000 ms were recoded

as 1 to 5 while the six mask durations from 0 ms to 1000 ms were recoded as 1 to 6. Search

display duration, mask duration, and the interaction between the two were used as fixed effects

while subject was used as a random effect in the model to predict the binary outcome of whether

the subject chose correctly (that is, whether a change, or lack thereof, was accurately detected).

Test 1 same/different: We found that our overall model predicted change detection

accuracy significantly better than the null hypothesis ($\chi 2(3) = 274.37$, $p < .001$). Both search

display duration ($\beta = .15$, $z = 8.266$, $p < .001$) and mask duration ($\beta = .05$, $z = 3.309$, $p < .001$)

were significant predictors of accuracy; however, the interaction between the two was not (see

Table 2.3.1).

Table 2.3.1 GLMM Predicting Test 1 Change Detection Accuracy

Fixed effects	β	SE	Z	Sig
Intercept	0.566	0.174	3.257	.001*
Search Display	0.149	0.019	8.266	< .001**
Mask Duration	0.049	0.016	3.307	< .001**
Interaction	-0.007	0.005	-1.424	.154

*Note. *p = .001, **p < .001*

Comparing means (see *Figure 2.3.1*), subjects performed best (80% correct) when the

search display was 5000 ms and the mask was any duration other than 0 ms. Subjects performed

worst (65% correct) when the search display was 250 ms and the mask was 0 ms; however, they

nonetheless consistently performed above chance levels (50%) across conditions.

Figure 2.3.1 Test 1 Change Detection Accuracy Across Conditions

Test 1 results also revealed intriguing differences between sets of participants. Six of our subjects (*LRC*) who have extensive computerized testing experience performed considerably better than three other subjects (*NIH*) who have significantly less computerized testing experience. Specifically, these three *NIH* monkeys correctly detected whether or not a change occurred on 62.19% of trials (see *Figure 2.3.2* for mean accuracy by condition), regardless of condition, whereas the *LRC* monkeys mean accuracy was 80.21% (see *Figure 2.3.3* for mean accuracy by condition). Additionally, unlike the *LRC* monkeys, the other three subjects' change detection accuracy did not decline significantly when there was a 0 ms mask and a short search display (250 ms, 500 ms, 1000 ms). We therefore decided to rerun our analyses, this time excluding the three subjects whose performance seemed to remain relatively consistent regardless of search display and mask duration.

Figure 2.3.2 Test 1 Change Detection Accuracy (NIH)

Figure 2.3.3 Test 1 Change Detection Accuracy (LRC)

We once again found that our overall model predicted change detection accuracy

significantly better than the null hypothesis ($\chi2(3) = 409.56$, $p < .001$). Both search display

duration ($\beta = .238$, $z = 9.966$, $p < .001$) and mask duration ($\beta = .096$, $z = 4.918$, $p < .001$) were

significant predictors of accuracy; however, the interaction between the two was not (see *Table*

2.3.2). Excluding these three subjects from the analysis resulted in an improved model (*AIC =*

28032, *BIC* = 28073) compared to when all subjects were included (*AIC* = 47117, *BIC* = 47160)

Table 2.3.2 GLMM Predicting Test 1 Change Detection Accuracy for LRC Monkeys

Fixed effects	β	SE	Z	Sig
Intercept	.513	.123	4.165	< .001*
Search Display	.238	.024	9.966	< .001*
Mask Duration	.096	.019	4.918	< .001*
Interaction	-.011	.006	-1.818	.069

*Note. *p < .001*

Test 2 subtle occlusion: We found that our overall model did not predict change

detection accuracy significantly better than the null hypothesis and neither predictor variable nor

the interaction was a significant predictor of change detection accuracy (see *Table 2.3.3*).

Table 2.3.3 GLMM Predicting Test 2 Change Detection Accuracy

Fixed effects	β	SE	Z	Sig
Intercept	0.104	0.069	1.485	.138
Search Display	0.009	0.019	0.516	.606
Mask Duration	0.009	0.016	0.527	.598
Interaction	-0.001	0.005	-0.289	.773

Collectively, subjects were most accurate (57%) when the search display was 500 ms and

the mask was 1000 ms, and least accurate (51%) when the search display was 500 ms and the

mask was 0 ms (*see Figure 2.3.4*). Although accuracy at each condition was above chance

(50%), subjects' performance at their most accurate in test two was nonetheless considerably

worse than their worst performance in test one.

Figure 2.3.4 Test 2 Change Detection Accuracy Across Conditions

Test 3 eight checkers location change: We once again found that our overall model did not predict change detection accuracy significantly better than the null hypothesis and neither predictor variable nor their interaction was a significant predictor of change detection accuracy (see *Table 2.3.4*).

Table 2.3.4 GLMM Predicting Test 3 Change Detection Accuracy

Fixed effects	β	SE	Z	Sig
Intercept	0.024	0.07	0.338	.735
Search Display	0.01	0.021	0.492	.623
Mask Duration	0.004	0.018	0.23	.818
Interaction	-0.001	0.005	-0.168	.866

Subjects performed at approximately chance (50%) levels across all combinations of search display and mask durations (*see Figure 2.3.5*).

Figure 2.3.5 Test 3 Change Detection Accuracy Across Conditions

Test 4 two checkers location change: We once again found that our overall model did not predict change detection accuracy significantly better than the null hypothesis and neither predictor variable nor their interaction was a significant predictor of change detection accuracy (see *Table 2.3.5*).

Table 2.3.5 GLMM Predicting Test 4 Change Detection Accuracy

Fixed effects	β	SE	Z	Sig
Intercept	0.099	0.08	1.244	0.214
Search Display	-0.001	0.023	-0.016	0.987
Mask Duration	0.002	0.019	0.084	0.933
Interaction	-0.002	0.006	-0.386	0.7

Subjects performed at approximately chance (50%) levels across all combinations of search display and mask durations (*see Figure 2.3.6*).

Figure 2.3.6 Test 4 Change Detection Accuracy Across Conditions

Individual results: To explore results at the individual level, we ran a binary logistic regression for each subject to determine the effects of search display duration and mask duration on change detection accuracy. Search display duration, mask duration, and their interaction were included in the model. The longest search display duration (5000 ms) was used as the reference contrast as we predicted that subjects would detect changes most accurately when they had longer to view the stimulus. We picked the shortest mask duration (0 ms) as the reference contrast because we also predicted subjects would perform their best when the change was not asked as it occurred.

Test 1 same/different: Our analyses revealed that our model was a significant predictor of change detection accuracy for Gonzo ($\chi2(29) = 80.157$, $p < .001$, *Nagelkerke R^2* = .026, see *Table 2.3.6*), Gretel ($\chi2(29) = 97.372$, $p < .001$, *Nagelkerke R^2* = .032, see *Table 2.3.7*), Logan

($\chi^2(29) = 201.814$, $p < .001$, *Nagelkerke* $R^2 = .074$, see *Table 2.3.10*), Nala ($\chi 2(29) = 123.47$, $p < .001$, *Nagelkerke* $R^2 = .037$, see *Table 2.3.11*), Nkima ($\chi 2(29) = 97.697$, $p < .001$, *Nagelkerke* $R^2 = .034$, see *Table 2.3.12*), and Widget ($\chi 2(29) = 110.831$, $p < .001$, *Nagelkerke* $R^2 = .035$, see *Table 2.3.14*), but not for Ira (*Nagelkerke* $R^2 = .009$, see *Table 2.3.8*), Albert (*Nagelkerke* $R^2 = .01$, see *Table 2.3.9*), or Paddy (*Nagelkerke* $R^2 = .008$, see *Table 2.3.13*).

Table 2.3.6 Logistic Regression Results for Test 1 (Gonzo)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			50.634	< .001***	
Search Display (250 ms)	-.586	.116	25.451	< .001***	.556
Search Display (500 ms)	-.625	.116	29.118	< .001***	.535
Search Display (1000 ms)	-.510	.117	18.978	< .001***	.601
Search Display (2500 ms)	-.091	.124	.539	.463	.913
Mask			13.534	.019*	
Mask (50 ms)	.368	.122	9.189	.002**	1.445
Mask (100 ms)	.304	.121	6.354	.012*	1.356
Mask (250 ms)	.321	.122	6.948	.008**	1.379
Mask (500 ms)	.364	.122	8.920	.003**	1.439
Mask (1000 ms)	.258	.119	4.665	.031*	1.294
Mask * Search Display			12.230	.908	
Mask (50 ms) by Search Display (250 ms)	.258	.388	.444	.505	1.295
Mask (50 ms) by Search Display (500 ms)	.324	.384	.713	.398	1.383
Mask (50 ms) by Search Display (1000 ms)	-.105	.384	.075	.784	.900
Mask (50 ms) by Search Display (2500 ms)	-.285	.417	.466	.495	.752
Mask (100 ms) by Search Display (250 ms)	-.135	.388	.122	.727	.873
Mask (100 ms) by Search Display (500 ms)	-.124	.383	.105	.746	.883
Mask (100 ms) by Search Display (1000 ms)	-.072	.395	.033	.855	.930
Mask (100 ms) by Search Display (2500 ms)	-.518	.419	1.528	.216	.595
Mask (250 ms) by Search Display (250 ms)	-.355	.399	.793	.373	.701
Mask (250 ms) by Search Display (500 ms)	-.312	.395	.624	.429	.732
Mask (250 ms) by Search Display (1000 ms)	-.503	.401	1.574	.210	.605
Mask (250 ms) by Search Display (2500 ms)	-.694	.431	2.590	.108	.499
Mask (500 ms) by Search Display (250 ms)	-.070	.383	.034	.854	.932
Mask (500 ms) by Search Display (500 ms)	.277	.386	.517	.472	1.320
Mask (500 ms) by Search Display (1000 ms)	-.083	.388	.046	.831	.921
Mask (500 ms) by Search Display (2500 ms)	-.187	.424	.193	.660	.830
Mask (1000 ms) by Search Display (250 ms)	.088	.380	.054	.817	1.092
Mask (1000 ms) by Search Display (500 ms)	.229	.379	.365	.546	1.257
Mask (1000 ms) by Search Display (1000 ms)	.118	.387	.093	.761	1.125
Mask (1000 ms) by Search Display (2500 ms)	-.569	.405	1.978	.160	.566
Constant	1.307	.036	1328.740	< .001***	3.697

*Note. *p < .05; **p < .01; ***p < .001*

Table 2.3.7 Logistic Regression Results for Test 1 (Gretel)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			53.407	< .001***	
Search Display (250 ms)	-.662	.124	28.653	< .001***	.516
Search Display (500 ms)	-.655	.124	27.980	< .001***	.519
Search Display (1000 ms)	-.680	.124	30.317	< .001***	.507
Search Display (2500 ms)	-.175	.132	1.765	.184	.839
Mask			16.703	.005**	
Mask (50 ms)	.317	.125	6.386	.012*	1.373
Mask (100 ms)	.323	.126	6.635	.010*	1.382
Mask (250 ms)	.243	.124	3.862	.049*	1.276
Mask (500 ms)	.409	.127	10.268	.001**	1.505
Mask (1000 ms)	.465	.131	12.694	< .001***	1.593
Mask * Search Display			21.327	.378	
Mask (50 ms) by Search Display (250 ms)	.741	.415	3.194	.074	2.098
Mask (50 ms) by Search Display (500 ms)	.284	.400	.503	.478	1.328
Mask (50 ms) by Search Display (1000 ms)	.583	.405	2.072	.150	1.791
Mask (50 ms) by Search Display (2500 ms)	.468	.438	1.141	.285	1.597
Mask (100 ms) by Search Display (250 ms)	-.003	.414	.000	.993	.997
Mask (100 ms) by Search Display (500 ms)	.499	.424	1.386	.239	1.647
Mask (100 ms) by Search Display (1000 ms)	.476	.421	1.280	.258	1.610
Mask (100 ms) by Search Display (2500 ms)	-.161	.436	.137	.711	.851
Mask (250 ms) by Search Display (250 ms)	.357	.404	.781	.377	1.429
Mask (250 ms) by Search Display (500 ms)	.845	.415	4.142	.042*	2.329
Mask (250 ms) by Search Display (1000 ms)	.279	.398	.491	.484	1.322
Mask (250 ms) by Search Display (2500 ms)	.226	.429	.279	.598	1.254
Mask (500 ms) by Search Display (250 ms)	.241	.419	.330	.566	1.272
Mask (500 ms) by Search Display (500 ms)	.228	.417	.300	.584	1.256
Mask (500 ms) by Search Display (1000 ms)	.558	.423	1.738	.187	1.747
Mask (500 ms) by Search Display (2500 ms)	.208	.449	.215	.643	1.232
Mask (1000 ms) by Search Display (250 ms)	-.044	.439	.010	.920	.957
Mask (1000 ms) by Search Display (500 ms)	-.165	.434	.144	.704	.848
Mask (1000 ms) by Search Display (1000 ms)	.000	.436	.000	.999	1.000
Mask (1000 ms) by Search Display (2500 ms)	.115	.477	.058	.810	1.122
Constant	1.452	.038	1482.619	< .001***	4.271

*Note. *p < .05; **p < .01; ***p < .001*

Table 2.3.8 Logistic Regression Results for Test 1 (Ira)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			14.573	.006**	
Search Display (250 ms)	-.211	.097	4.750	.029*	.810
Search Display (500 ms)	-.161	.097	2.743	.098	.851
Search Display (1000 ms)	-.303	.096	9.911	.002**	.738
Search Display (2500 ms)	-.014	.098	.019	.890	.987
Mask			2.917	.713	
Mask (50 ms)	.034	.106	.100	.752	1.034
Mask (100 ms)	-.017	.106	.025	.874	.983
Mask (250 ms)	.042	.106	.157	.692	1.043
Mask (500 ms)	-.090	.105	.726	.394	.914
Mask (1000 ms)	-.085	.105	.648	.421	.919
Mask * Search Display			14.340	.813	
Mask (50 ms) by Search Display (250 ms)	-.031	.333	.009	.926	.970
Mask (50 ms) by Search Display (500 ms)	-.168	.333	.254	.614	.845
Mask (50 ms) by Search Display (1000 ms)	-.195	.334	.343	.558	.822
Mask (50 ms) by Search Display (2500 ms)	-.692	.340	4.149	.042*	.500
Mask (100 ms) by Search Display (250 ms)	-.229	.332	.474	.491	.795
Mask (100 ms) by Search Display (500 ms)	-.227	.334	.461	.497	.797
Mask (100 ms) by Search Display (1000 ms)	-.652	.331	3.880	.049*	.521
Mask (100 ms) by Search Display (2500 ms)	-.525	.344	2.330	.127	.592
Mask (250 ms) by Search Display (250 ms)	-.292	.335	.764	.382	.746
Mask (250 ms) by Search Display (500 ms)	-.373	.335	1.239	.266	.688
Mask (250 ms) by Search Display (1000 ms)	-.482	.335	2.074	.150	.617
Mask (250 ms) by Search Display (2500 ms)	-.645	.345	3.494	.062	.525
Mask (500 ms) by Search Display (250 ms)	-.270	.328	.678	.410	.763
Mask (500 ms) by Search Display (500 ms)	-.026	.333	.006	.938	.975
Mask (500 ms) by Search Display (1000 ms)	-.482	.329	2.146	.143	.618
Mask (500 ms) by Search Display (2500 ms)	-.495	.340	2.124	.145	.609
Mask (1000 ms) by Search Display (250 ms)	-.283	.332	.727	.394	.754
Mask (1000 ms) by Search Display (500 ms)	-.496	.332	2.238	.135	.609
Mask (1000 ms) by Search Display (1000 ms)	-.497	.332	2.242	.134	.608
Mask (1000 ms) by Search Display (2500 ms)	-.696	.341	4.156	.041*	.499
Constant	.639	.030	439.786	< .001***	1.895

Note. $*p < .05$; $**p < .01$, $***p < .001$

Table 2.3.9 Logistic Regression Results for Test 1 (Albert)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			13.944	.007**	
Search Display (250 ms)	-.253	.099	6.544	.011*	.776
Search Display (500 ms)	-.226	.099	5.187	.023*	.798
Search Display (1000 ms)	-.303	.099	9.483	.002**	.738
Search Display (2500 ms)	-.333	.098	11.449	.001**	.717
Mask			7.835	.166	
Mask (50 ms)	-.090	.107	.708	.400	.914
Mask (100 ms)	.112	.109	1.056	.304	1.118
Mask (250 ms)	-.152	.106	2.037	.153	.859
Mask (500 ms)	-.097	.107	.826	.363	.907
Mask (1000 ms)	-.107	.107	1.013	.314	.898
Mask * Search Display			13.431	.858	
Mask (50 ms) by Search Display (250 ms)	-.346	.338	1.044	.307	.708
Mask (50 ms) by Search Display (500 ms)	-.556	.344	2.618	.106	.573
Mask (50 ms) by Search Display (1000 ms)	-.156	.338	.212	.645	.856
Mask (50 ms) by Search Display (2500 ms)	-.440	.343	1.645	.200	.644
Mask (100 ms) by Search Display (250 ms)	.177	.347	.259	.611	1.193
Mask (100 ms) by Search Display (500 ms)	-.241	.349	.476	.490	.786
Mask (100 ms) by Search Display (1000 ms)	.041	.341	.014	.904	1.042
Mask (100 ms) by Search Display (2500 ms)	-.468	.343	1.861	.173	.626
Mask (250 ms) by Search Display (250 ms)	-.280	.336	.694	.405	.756
Mask (250 ms) by Search Display (500 ms)	-.464	.342	1.841	.175	.629
Mask (250 ms) by Search Display (1000 ms)	-.144	.335	.186	.667	.865
Mask (250 ms) by Search Display (2500 ms)	-.457	.340	1.805	.179	.633
Mask (500 ms) by Search Display (250 ms)	-.246	.342	.517	.472	.782
Mask (500 ms) by Search Display (500 ms)	-.728	.344	4.467	.035*	.483
Mask (500 ms) by Search Display (1000 ms)	-.109	.341	.101	.750	.897
Mask (500 ms) by Search Display (2500 ms)	-.771	.342	5.079	.024*	.462
Mask (1000 ms) by Search Display (250 ms)	-.148	.339	.191	.662	.862
Mask (1000 ms) by Search Display (500 ms)	-.440	.343	1.639	.200	.644
Mask (1000 ms) by Search Display (1000 ms)	-.121	.336	.130	.719	.886
Mask (1000 ms) by Search Display (2500 ms)	-.567	.340	2.782	.095	.567
Constant	.696	.031	511.456	< .001***	2.006

*Note. *p < .05; **p < .01; ***p < .001*

Table 2.3.10 Logistic Regression Results for Test 1 (Logan)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			105.901	< .001***	
Search Display (250 ms)	-1.203	.160	56.300	< .001***	.300
Search Display (500 ms)	-1.246	.159	61.665	< .001***	.288
Search Display (1000 ms)	-.953	.164	33.859	< .001***	.386
Search Display (2500 ms)	-.224	.181	1.532	.216	.799
Mask			24.454	< .001***	
Mask (50 ms)	.478	.156	9.405	.002**	1.613
Mask (100 ms)	.686	.157	19.117	< .001***	1.986
Mask (250 ms)	.535	.158	11.462	.001**	1.707
Mask (500 ms)	.547	.159	11.885	.001**	1.728
Mask (1000 ms)	.373	.149	6.285	.012*	1.452
Mask * Search Display			30.499	.062	
Mask (50 ms) by Search Display (250 ms)	.059	.510	.013	.908	1.060
Mask (50 ms) by Search Display (500 ms)	.273	.524	.271	.603	1.313
Mask (50 ms) by Search Display (1000 ms)	-.126	.524	.058	.810	.881
Mask (50 ms) by Search Display (2500 ms)	-.193	.622	.096	.756	.825
Mask (100 ms) by Search Display (250 ms)	1.302	.494	6.931	.008**	3.676
Mask (100 ms) by Search Display (500 ms)	.898	.490	3.357	.067	2.455
Mask (100 ms) by Search Display (1000 ms)	1.143	.520	4.841	.028*	3.137
Mask (100 ms) by Search Display (2500 ms)	.087	.575	.023	.880	1.091
Mask (250 ms) by Search Display (250 ms)	-.056	.543	.011	.918	.945
Mask (250 ms) by Search Display (500 ms)	-.212	.547	.150	.699	.809
Mask (250 ms) by Search Display (1000 ms)	.063	.568	.012	.912	1.065
Mask (250 ms) by Search Display (2500 ms)	-.821	.624	1.729	.188	.440
Mask (500 ms) by Search Display (250 ms)	.687	.567	1.468	.226	1.988
Mask (500 ms) by Search Display (500 ms)	-.441	.543	.662	.416	.643
Mask (500 ms) by Search Display (1000 ms)	-.391	.553	.499	.480	.677
Mask (500 ms) by Search Display (2500 ms)	-.821	.624	1.729	.188	.440
Mask (1000 ms) by Search Display (250 ms)	.642	.480	1.792	.181	1.901
Mask (1000 ms) by Search Display (500 ms)	.447	.484	.855	.355	1.564
Mask (1000 ms) by Search Display (1000 ms)	.452	.496	.831	.362	1.572
Mask (1000 ms) by Search Display (2500 ms)	-.081	.574	.020	.888	.922
Constant	1.959	.047	1723.334	< .001***	7.091

*Note. *p < .05; **p < .01; ***p < .001*

Table 2.3.11 Logistic Regression Results for Test 1 (Nala)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			97.697	< .001***	
Search Display (250 ms)	-.924	.114	65.804	< .001***	.397
Search Display (500 ms)	-.916	.114	64.533	< .001***	.400
Search Display (1000 ms)	-.777	.115	45.427	< .001***	.460
Search Display (2500 ms)	-.365	.120	9.203	.002**	.694
Mask			6.107	.296	
Mask (50 ms)	.244	.119	4.229	.040*	1.277
Mask (100 ms)	.199	.118	2.861	.091	1.221
Mask (250 ms)	.206	.117	3.087	.079	1.229
Mask (500 ms)	.158	.117	1.839	.175	1.171
Mask (1000 ms)	.243	.118	4.240	.039*	1.275
Mask * Search Display			9.419	.978	
Mask (50 ms) by Search Display (250 ms)	.145	.402	.131	.718	1.157
Mask (50 ms) by Search Display (500 ms)	.307	.401	.584	.445	1.359
Mask (50 ms) by Search Display (1000 ms)	.238	.411	.337	.562	1.269
Mask (50 ms) by Search Display (2500 ms)	.003	.422	.000	.994	1.003
Mask (100 ms) by Search Display (250 ms)	.340	.398	.728	.394	1.404
Mask (100 ms) by Search Display (500 ms)	.472	.397	1.411	.235	1.603
Mask (100 ms) by Search Display (1000 ms)	.000	.400	.000	1.000	1.000
Mask (100 ms) by Search Display (2500 ms)	.185	.419	.195	.659	1.203
Mask (250 ms) by Search Display (250 ms)	.485	.387	1.567	.211	1.624
Mask (250 ms) by Search Display (500 ms)	.706	.388	3.315	.069	2.025
Mask (250 ms) by Search Display (1000 ms)	.511	.395	1.674	.196	1.667
Mask (250 ms) by Search Display (2500 ms)	.499	.413	1.462	.227	1.647
Mask (500 ms) by Search Display (250 ms)	.560	.391	2.053	.152	1.751
Mask (500 ms) by Search Display (500 ms)	.692	.390	3.153	.076	1.998
Mask (500 ms) by Search Display (1000 ms)	.190	.392	.235	.628	1.209
Mask (500 ms) by Search Display (2500 ms)	.299	.410	.531	.466	1.348
Mask (1000 ms) by Search Display (250 ms)	.408	.393	1.074	.300	1.504
Mask (1000 ms) by Search Display (500 ms)	.600	.393	2.328	.127	1.822
Mask (1000 ms) by Search Display (1000 ms)	.375	.400	.879	.348	1.455
Mask (1000 ms) by Search Display (2500 ms)	.323	.416	.601	.438	1.381
Constant	1.119	.034	1061.896	< .001***	3.061

Note. *p < .05; **p < .01; ***p < .001

Table 2.3.12 Logistic Regression Results for Test 1 (Nkima)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			47.566	< .001***	
Search Display (250 ms)	-.535	.131	16.622	< .001***	.586
Search Display (500 ms)	-.517	.132	15.381	< .001***	.597
Search Display (1000 ms)	-.688	.130	28.244	< .001***	.502
Search Display (2500 ms)	-.015	.143	.011	.915	.985
Mask			23.871	< .001***	
Mask (50 ms)	.361	.132	7.442	.006**	1.435
Mask (100 ms)	.436	.133	10.798	.001**	1.547
Mask (250 ms)	.501	.133	14.072	< .001***	1.650
Mask (500 ms)	.539	.136	15.742	< .001***	1.714
Mask (1000 ms)	.485	.135	12.964	< .001***	1.625
Mask * Search Display			18.940	.526	
Mask (50 ms) by Search Display (250 ms)	-.317	.444	.510	.475	.728
Mask (50 ms) by Search Display (500 ms)	-.197	.438	.202	.653	.821
Mask (50 ms) by Search Display (1000 ms)	-.280	.426	.432	.511	.756
Mask (50 ms) by Search Display (2500 ms)	-.313	.479	.425	.514	.732
Mask (100 ms) by Search Display (250 ms)	.146	.425	.118	.732	1.157
Mask (100 ms) by Search Display (500 ms)	.346	.421	.675	.411	1.414
Mask (100 ms) by Search Display (1000 ms)	.413	.411	1.011	.315	1.512
Mask (100 ms) by Search Display (2500 ms)	.259	.470	.304	.581	1.296
Mask (250 ms) by Search Display (250 ms)	.179	.431	.173	.678	1.196
Mask (250 ms) by Search Display (500 ms)	.426	.429	.987	.320	1.531
Mask (250 ms) by Search Display (1000 ms)	.649	.423	2.356	.125	1.914
Mask (250 ms) by Search Display (2500 ms)	-.048	.459	.011	.916	.953
Mask (500 ms) by Search Display (250 ms)	-.003	.416	.000	.993	.997
Mask (500 ms) by Search Display (500 ms)	.584	.425	1.884	.170	1.793
Mask (500 ms) by Search Display (1000 ms)	.904	.424	4.554	.033*	2.469
Mask (500 ms) by Search Display (2500 ms)	.460	.477	.931	.335	1.584
Mask (1000 ms) by Search Display (250 ms)	-.301	.461	.426	.514	.740
Mask (1000 ms) by Search Display (500 ms)	-.146	.456	.102	.749	.865
Mask (1000 ms) by Search Display (1000 ms)	-.084	.446	.035	.851	.920
Mask (1000 ms) by Search Display (2500 ms)	-.739	.479	2.384	.123	.478
Constant	1.658	.040	1681.155	< .001***	5.248

*Note. *p < .05; **p < .01; ***p < .001*

Table 2.3.13 Logistic Regression Results for Test 1 (Paddy)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			5.296	.258	
Search Display (250 ms)	-.093	.092	1.016	.313	.911
Search Display (500 ms)	.054	.092	.349	.555	1.056
Search Display (1000 ms)	-.075	.092	.664	.415	.928
Search Display (2500 ms)	-.131	.092	2.035	.154	.877
Mask			2.802	.730	
Mask (50 ms)	-.132	.101	1.724	.189	.876
Mask (100 ms)	-.021	.101	.042	.837	.979
Mask (250 ms)	-.087	.101	.753	.386	.916
Mask (500 ms)	-.086	.101	.724	.395	.918
Mask (1000 ms)	-.010	.101	.009	.923	.990
Mask * Search Display			20.863	.405	
Mask (50 ms) by Search Display (250 ms)	.580	.318	3.326	.068	1.786
Mask (50 ms) by Search Display (500 ms)	.199	.321	.385	.535	1.220
Mask (50 ms) by Search Display (1000 ms)	.254	.318	.638	.424	1.289
Mask (50 ms) by Search Display (2500 ms)	.078	.318	.060	.806	1.081
Mask (100 ms) by Search Display (250 ms)	.686	.320	4.595	.032*	1.985
Mask (100 ms) by Search Display (500 ms)	.074	.321	.053	.817	1.077
Mask (100 ms) by Search Display (1000 ms)	.129	.318	.163	.686	1.137
Mask (100 ms) by Search Display (2500 ms)	.028	.319	.008	.931	1.028
Mask (250 ms) by Search Display (250 ms)	.379	.318	1.421	.233	1.461
Mask (250 ms) by Search Display (500 ms)	-.028	.321	.008	.931	.973
Mask (250 ms) by Search Display (1000 ms)	.204	.319	.410	.522	1.226
Mask (250 ms) by Search Display (2500 ms)	.028	.319	.008	.931	1.028
Mask (500 ms) by Search Display (250 ms)	-.028	.320	.008	.929	.972
Mask (500 ms) by Search Display (500 ms)	-.361	.322	1.254	.263	.697
Mask (500 ms) by Search Display (1000 ms)	-.354	.320	1.222	.269	.702
Mask (500 ms) by Search Display (2500 ms)	-.078	.321	.060	.807	.925
Mask (1000 ms) by Search Display (250 ms)	.404	.318	1.612	.204	1.498
Mask (1000 ms) by Search Display (500 ms)	-.028	.321	.007	.931	.973
Mask (1000 ms) by Search Display (1000 ms)	.541	.321	2.835	.092	1.718
Mask (1000 ms) by Search Display (2500 ms)	-.072	.319	.052	.820	.930
Constant	.187	.029	41.242	< .001**	1.205

*Note. *p < .05; **p < .001*

Table 2.3.14 Logistic Regression Results for Test 1 (Widget)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			62.059	< .001***	
Search Display (250 ms)	-.734	.119	38.162	< .001***	.480
Search Display (500 ms)	-.673	.119	31.703	< .001***	.510
Search Display (1000 ms)	-.565	.121	21.794	< .001***	.569
Search Display (2500 ms)	-.129	.128	1.005	.316	.879
Mask			33.270	< .001***	
Mask (50 ms)	.444	.119	13.793	< .001***	1.558
Mask (100 ms)	.622	.126	24.513	< .001***	1.863
Mask (250 ms)	.402	.118	11.557	.001**	1.495
Mask (500 ms)	.468	.121	15.027	< .001***	1.596
Mask (1000 ms)	.527	.121	19.002	< .001***	1.693
Mask * Search Display			17.195	.640	
Mask (50 ms) by Search Display (250 ms)	-.214	.383	.312	.577	.808
Mask (50 ms) by Search Display (500 ms)	-.131	.389	.113	.737	.877
Mask (50 ms) by Search Display (1000 ms)	.123	.395	.097	.755	1.131
Mask (50 ms) by Search Display (2500 ms)	.067	.409	.026	.871	1.069
Mask (100 ms) by Search Display (250 ms)	-.729	.426	2.937	.087	.482
Mask (100 ms) by Search Display (500 ms)	-.772	.429	3.236	.072	.462
Mask (100 ms) by Search Display (1000 ms)	-.438	.437	1.002	.317	.646
Mask (100 ms) by Search Display (2500 ms)	-.528	.449	1.380	.240	.590
Mask (250 ms) by Search Display (250 ms)	-.022	.380	.003	.954	.978
Mask (250 ms) by Search Display (500 ms)	.183	.390	.220	.639	1.201
Mask (250 ms) by Search Display (1000 ms)	-.066	.384	.030	.863	.936
Mask (250 ms) by Search Display (2500 ms)	.033	.400	.007	.935	1.033
Mask (500 ms) by Search Display (250 ms)	.116	.389	.088	.767	1.123
Mask (500 ms) by Search Display (500 ms)	-.325	.385	.712	.399	.723
Mask (500 ms) by Search Display (1000 ms)	-.197	.387	.260	.610	.821
Mask (500 ms) by Search Display (2500 ms)	.373	.423	.778	.378	1.452
Mask (1000 ms) by Search Display (250 ms)	.423	.382	1.226	.268	1.526
Mask (1000 ms) by Search Display (500 ms)	.137	.380	.131	.718	1.147
Mask (1000 ms) by Search Display (1000 ms)	.319	.385	.686	.408	1.375
Mask (1000 ms) by Search Display (2500 ms)	.551	.411	1.797	.180	1.734
Constant	1.337	.037	1336.254	< .001***	3.807

Note. *p < .05; **p < .01; ***p < .001

Test 2 subtle occlusion: Our logistic regression analyses revealed that our model was not a significant predictor of change detection accuracy for Gonzo (*Nagelkerke R^2* = .007, see *Table 2.3.15*), Gretel (*Nagelkerke R^2* = .004, see *Table 2.3.16*), Ira (*Nagelkerke R^2* = .008, see *Table 2.3.17*), Logan (*Nagelkerke R^2* = .011, see *Table 2.3.18*), Nala (*Nagelkerke R^2* = .009, see *Table 2.3.19*), or Paddy (*Nagelkerke R^2* = .007, see *Table 2.3.20*).

Table 2.3.15 Logistic Regression Results for Test 2 (Gonzo)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			2.431	.657	
Search Display (250 ms)	-.025	.092	.077	.781	.975
Search Display (500 ms)	-.029	.092	.098	.754	.972
Search Display (1000 ms)	-.113	.092	1.528	.216	.893
Search Display (2500 ms)	.019	.092	.041	.839	1.019
Mask			4.476	.483	
Mask (50 ms)	.081	.100	.644	.422	1.084
Mask (100 ms)	-.065	.100	.424	.515	.937
Mask (250 ms)	.061	.100	.365	.546	1.063
Mask (500 ms)	.127	.101	1.597	.206	1.136
Mask (1000 ms)	.057	.101	.316	.574	1.058
Mask * Search Display			19.951	.461	
Mask (50 ms) by Search Display (250 ms)	.050	.317	.025	.876	1.051
Mask (50 ms) by Search Display (500 ms)	.577	.318	3.308	.069	1.782
Mask (50 ms) by Search Display (1000 ms)	.150	.317	.225	.635	1.162
Mask (50 ms) by Search Display (2500 ms)	.378	.318	1.415	.234	1.459
Mask (100 ms) by Search Display (250 ms)	-.101	.317	.101	.751	.904
Mask (100 ms) by Search Display (500 ms)	.201	.317	.401	.527	1.222
Mask (100 ms) by Search Display (1000 ms)	-.100	.317	.099	.753	.905
Mask (100 ms) by Search Display (2500 ms)	-.075	.317	.056	.813	.928
Mask (250 ms) by Search Display (250 ms)	.025	.318	.006	.937	1.025
Mask (250 ms) by Search Display (500 ms)	.351	.317	1.224	.269	1.420
Mask (250 ms) by Search Display (1000 ms)	-.150	.317	.224	.636	.861
Mask (250 ms) by Search Display (2500 ms)	.329	.318	1.070	.301	1.389
Mask (500 ms) by Search Display (250 ms)	-.126	.317	.157	.692	.882
Mask (500 ms) by Search Display (500 ms)	.275	.317	.754	.385	1.317
Mask (500 ms) by Search Display (1000 ms)	.050	.317	.025	.874	1.052
Mask (500 ms) by Search Display (2500 ms)	.436	.320	1.860	.173	1.546
Mask (1000 ms) by Search Display (250 ms)	-.304	.318	.912	.340	.738
Mask (1000 ms) by Search Display (500 ms)	.378	.320	1.395	.238	1.459
Mask (1000 ms) by Search Display (1000 ms)	-.328	.318	1.067	.302	.720
Mask (1000 ms) by Search Display (2500 ms)	-.353	.318	1.235	.266	.702
Constant	.134	.029	21.187	< .001*	1.143

Note. *p < .001

Table 2.3.16 Logistic Regression Results for Test 2 (Gretel)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			3.662	.454	
Search Display (250 ms)	-.156	.092	2.879	.090	.856
Search Display (500 ms)	-.106	.092	1.324	.250	.900
Search Display (1000 ms)	-.148	.092	2.580	.108	.863
Search Display (2500 ms)	-.114	.092	1.529	.216	.892
Mask			.774	.979	
Mask (50 ms)	-.025	.100	.063	.801	.975
Mask (100 ms)	.005	.100	.002	.962	1.005
Mask (250 ms)	.050	.101	.251	.617	1.052
Mask (500 ms)	.040	.101	.161	.688	1.041
Mask (1000 ms)	.005	.100	.002	.961	1.005
Mask * Search Display			11.009	.946	
Mask (50 ms) by Search Display (250 ms)	.379	.318	1.418	.234	1.461
Mask (50 ms) by Search Display (500 ms)	.177	.318	.310	.577	1.194
Mask (50 ms) by Search Display (1000 ms)	-.150	.318	.223	.637	.860
Mask (50 ms) by Search Display (2500 ms)	.102	.317	.103	.748	1.107
Mask (100 ms) by Search Display (250 ms)	.202	.317	.406	.524	1.224
Mask (100 ms) by Search Display (500 ms)	.354	.318	1.238	.266	1.425
Mask (100 ms) by Search Display (1000 ms)	-.075	.318	.056	.813	.928
Mask (100 ms) by Search Display (2500 ms)	.428	.318	1.816	.178	1.535
Mask (250 ms) by Search Display (250 ms)	.100	.319	.098	.754	1.105
Mask (250 ms) by Search Display (500 ms)	-.076	.318	.057	.812	.927
Mask (250 ms) by Search Display (1000 ms)	-.203	.319	.403	.525	.816
Mask (250 ms) by Search Display (2500 ms)	.302	.319	.896	.344	1.353
Mask (500 ms) by Search Display (250 ms)	-.028	.319	.008	.930	.972
Mask (500 ms) by Search Display (500 ms)	-.053	.319	.027	.868	.948
Mask (500 ms) by Search Display (1000 ms)	-.280	.320	.768	.381	.756
Mask (500 ms) by Search Display (2500 ms)	.047	.319	.022	.883	1.048
Mask (1000 ms) by Search Display (250 ms)	-.075	.318	.056	.814	.928
Mask (1000 ms) by Search Display (500 ms)	.025	.318	.006	.937	1.025
Mask (1000 ms) by Search Display (1000 ms)	-.177	.319	.308	.579	.838
Mask (1000 ms) by Search Display (2500 ms)	.251	.319	.622	.430	1.286
Constant	.168	.029	33.702	< .001*	1.183

*Note. *p < .001

Table 2.3.17 Logistic Regression Results for Test 2 (Ira)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			1.479	.830	
Search Display (250 ms)	.080	.092	.764	.382	1.083
Search Display (500 ms)	.093	.092	1.020	.313	1.097
Search Display (1000 ms)	.096	.092	1.110	.292	1.101
Search Display (2500 ms)	.063	.092	.471	.492	1.065
Mask			2.059	.841	
Mask (50 ms)	-.110	.100	1.214	.270	.895
Mask (100 ms)	-.024	.101	.058	.810	.976
Mask (250 ms)	-.070	.100	.493	.482	.932
Mask (500 ms)	.011	.101	.013	.910	1.011
Mask (1000 ms)	-.039	.100	.154	.694	.961
Mask * Search Display			24.504	.221	
Mask (50 ms) by Search Display (250 ms)	.075	.317	.056	.813	1.078
Mask (50 ms) by Search Display (500 ms)	-.152	.317	.229	.632	.859
Mask (50 ms) by Search Display (1000 ms)	.175	.317	.306	.580	1.191
Mask (50 ms) by Search Display (2500 ms)	.100	.317	.099	.753	1.105
Mask (100 ms) by Search Display (250 ms)	.105	.319	.108	.742	1.111
Mask (100 ms) by Search Display (500 ms)	-.378	.318	1.415	.234	.685
Mask (100 ms) by Search Display (1000 ms)	-.101	.317	.101	.750	.904
Mask (100 ms) by Search Display (2500 ms)	-.628	.318	3.907	.048*	.533
Mask (250 ms) by Search Display (250 ms)	.050	.317	.025	.875	1.051
Mask (250 ms) by Search Display (500 ms)	-.026	.317	.007	.934	.974
Mask (250 ms) by Search Display (1000 ms)	.125	.317	.156	.693	1.133
Mask (250 ms) by Search Display (2500 ms)	.000	.317	.000	.999	1.000
Mask (500 ms) by Search Display (250 ms)	.100	.317	.100	.752	1.105
Mask (500 ms) by Search Display (500 ms)	-.152	.317	.229	.632	.859
Mask (500 ms) by Search Display (1000 ms)	.404	.318	1.619	.203	1.498
Mask (500 ms) by Search Display (2500 ms)	.329	.318	1.071	.301	1.390
Mask (1000 ms) by Search Display (250 ms)	-.300	.317	.900	.343	.740
Mask (1000 ms) by Search Display (500 ms)	.053	.319	.027	.869	1.054
Mask (1000 ms) by Search Display (1000 ms)	-.175	.317	.306	.580	.839
Mask (1000 ms) by Search Display (2500 ms)	-.025	.317	.006	.937	.975
Constant	.117	.029	16.176	< .001**	1.124

Note. *$p < .05$, ** $p < .001$

Table 2.3.18 Logistic Regression Results for Test 2 (Logan)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			6.039	.196	
Search Display (250 ms)	-.082	.093	.784	.376	.921
Search Display (500 ms)	.018	.093	.035	.851	1.018
Search Display (1000 ms)	-.150	.093	2.630	.105	.861
Search Display (2500 ms)	.045	.093	.234	.628	1.046
Mask			9.706	.084	
Mask (50 ms)	.191	.101	3.552	.059	1.211
Mask (100 ms)	.191	.101	3.546	.060	1.210
Mask (250 ms)	.285	.102	7.839	.005**	1.330
Mask (500 ms)	.084	.101	.684	.408	1.087
Mask (1000 ms)	.193	.102	3.623	.057	1.213
Mask * Search Display			23.452	.267	
Mask (50 ms) by Search Display (250 ms)	.535	.321	2.780	.095	1.707
Mask (50 ms) by Search Display (500 ms)	.361	.321	1.262	.261	1.435
Mask (50 ms) by Search Display (1000 ms)	.660	.321	4.229	.040*	1.935
Mask (50 ms) by Search Display (2500 ms)	.314	.324	.941	.332	1.369
Mask (100 ms) by Search Display (250 ms)	.586	.322	3.315	.069	1.797
Mask (100 ms) by Search Display (500 ms)	.106	.321	.110	.741	1.112
Mask (100 ms) by Search Display (1000 ms)	.788	.323	5.971	.015*	2.199
Mask (100 ms) by Search Display (2500 ms)	.131	.323	.165	.684	1.140
Mask (250 ms) by Search Display (250 ms)	.478	.325	2.171	.141	1.614
Mask (250 ms) by Search Display (500 ms)	.228	.325	.492	.483	1.256
Mask (250 ms) by Search Display (1000 ms)	.371	.323	1.317	.251	1.449
Mask (250 ms) by Search Display (2500 ms)	-.055	.325	.028	.866	.947
Mask (500 ms) by Search Display (250 ms)	.711	.319	4.964	.026*	2.037
Mask (500 ms) by Search Display (500 ms)	.563	.320	3.089	.079	1.755
Mask (500 ms) by Search Display (1000 ms)	.964	.320	9.057	.003**	2.622
Mask (500 ms) by Search Display (2500 ms)	.359	.321	1.246	.264	1.431
Mask (1000 ms) by Search Display (250 ms)	.712	.320	4.959	.026*	2.039
Mask (1000 ms) by Search Display (500 ms)	.860	.324	7.040	.008**	2.362
Mask (1000 ms) by Search Display (1000 ms)	.889	.320	7.690	.006**	2.432
Mask (1000 ms) by Search Display (2500 ms)	.309	.322	.923	.337	1.362
Constant	.305	.029	108.328	< .001***	1.357

*Note. *p < .05; **p < .01; ***p < .001*

Table 2.3.19 Logistic Regression Results for Test 2 (Nala)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			3.979	.409	
Search Display (250 ms)	-.075	.092	.673	.412	.928
Search Display (500 ms)	-.155	.092	2.860	.091	.856
Search Display (1000 ms)	-.130	.092	2.013	.156	.878
Search Display (2500 ms)	-.033	.092	.133	.715	.967
Mask			3.621	.605	
Mask (50 ms)	.060	.101	.357	.550	1.062
Mask (100 ms)	-.060	.101	.361	.548	.941
Mask (250 ms)	.040	.101	.158	.691	1.041
Mask (500 ms)	-.100	.100	.998	.318	.905
Mask (1000 ms)	-.010	.101	.010	.921	.990
Mask * Search Display			25.247	.192	
Mask (50 ms) by Search Display (250 ms)	-.604	.319	3.593	.058	.546
Mask (50 ms) by Search Display (500 ms)	.427	.319	1.793	.181	1.532
Mask (50 ms) by Search Display (1000 ms)	.250	.318	.618	.432	1.284
Mask (50 ms) by Search Display (2500 ms)	-.152	.318	.228	.633	.859
Mask (100 ms) by Search Display (250 ms)	-.352	.318	1.228	.268	.703
Mask (100 ms) by Search Display (500 ms)	.051	.318	.025	.873	1.052
Mask (100 ms) by Search Display (1000 ms)	.251	.318	.625	.429	1.285
Mask (100 ms) by Search Display (2500 ms)	-.251	.318	.626	.429	.778
Mask (250 ms) by Search Display (250 ms)	-.002	.318	.000	.996	.998
Mask (250 ms) by Search Display (500 ms)	.628	.318	3.906	.048*	1.873
Mask (250 ms) by Search Display (1000 ms)	.577	.317	3.305	.069	1.780
Mask (250 ms) by Search Display (2500 ms)	.251	.318	.622	.430	1.285
Mask (500 ms) by Search Display (250 ms)	-.026	.318	.007	.934	.974
Mask (500 ms) by Search Display (500 ms)	.678	.318	4.552	.033*	1.969
Mask (500 ms) by Search Display (1000 ms)	.502	.317	2.501	.114	1.652
Mask (500 ms) by Search Display (2500 ms)	-.026	.318	.006	.936	.975
Mask (1000 ms) by Search Display (250 ms)	-.076	.318	.057	.811	.927
Mask (1000 ms) by Search Display (500 ms)	.152	.318	.227	.634	1.164
Mask (1000 ms) by Search Display (1000 ms)	.201	.318	.401	.527	1.223
Mask (1000 ms) by Search Display (2500 ms)	-.326	.318	1.055	.304	.722
Constant	.039	.029	1.770	.183	1.039

Note. $*p < .05$

Table 2.3.20 Logistic Regression Results for Test 2 (Paddy)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			7.924	.094	
Search Display (250 ms)	.072	.092	.609	.435	1.074
Search Display (500 ms)	.110	.092	1.436	.231	1.116
Search Display (1000 ms)	.051	.092	.312	.576	1.053
Search Display (2500 ms)	-.125	.091	1.878	.171	.882
Mask			2.185	.823	
Mask (50 ms)	.005	.101	.003	.958	1.005
Mask (100 ms)	.045	.101	.197	.657	1.046
Mask (250 ms)	.060	.101	.351	.554	1.061
Mask (500 ms)	-.071	.100	.501	.479	.931
Mask (1000 ms)	-.021	.100	.044	.834	.979
Mask * Search Display			13.292	.864	
Mask (50 ms) by Search Display (250 ms)	-.176	.317	.309	.578	.838
Mask (50 ms) by Search Display (500 ms)	.333	.318	1.092	.296	1.395
Mask (50 ms) by Search Display (1000 ms)	-.380	.318	1.432	.231	.684
Mask (50 ms) by Search Display (2500 ms)	.125	.316	.156	.692	1.133
Mask (100 ms) by Search Display (250 ms)	.002	.318	.000	.996	1.002
Mask (100 ms) by Search Display (500 ms)	-.075	.317	.056	.812	.928
Mask (100 ms) by Search Display (1000 ms)	-.204	.319	.409	.523	.816
Mask (100 ms) by Search Display (2500 ms)	.125	.317	.156	.693	1.133
Mask (250 ms) by Search Display (250 ms)	-.201	.318	.401	.527	.818
Mask (250 ms) by Search Display (500 ms)	.026	.317	.007	.934	1.027
Mask (250 ms) by Search Display (1000 ms)	-.279	.319	.766	.381	.756
Mask (250 ms) by Search Display (2500 ms)	.000	.317	.000	.999	1.000
Mask (500 ms) by Search Display (250 ms)	-.252	.318	.627	.428	.778
Mask (500 ms) by Search Display (500 ms)	-.100	.317	.100	.752	.905
Mask (500 ms) by Search Display (1000 ms)	-.731	.318	5.274	.022*	.481
Mask (500 ms) by Search Display (2500 ms)	-.151	.317	.226	.635	.860
Mask (1000 ms) by Search Display (250 ms)	-.301	.317	.904	.342	.740
Mask (1000 ms) by Search Display (500 ms)	.026	.317	.007	.935	1.026
Mask (1000 ms) by Search Display (1000 ms)	-.380	.318	1.430	.232	.684
Mask (1000 ms) by Search Display (2500 ms)	.050	.317	.025	.874	1.051
Constant	.134	.029	21.414	< .001**	1.144

*Note. *p < .05, **p < .001*

Test 3 eight checkers location change: Our logistic regression analyses revealed that our model was not a significant predictor of change detection accuracy for Gonzo (*Nagelkerke R^2 = .006, see Table 2.3.21),* Gretel (*Nagelkerke R^2 = .011, see Table 2.3.22),* Ira (*Nagelkerke R^2 = .005, see Table 2.3.23),* Logan (*Nagelkerke R^2 = .008, see Table 2.3.24),* or Nala (*Nagelkerke R^2 = .008, see Table 2.3.25*).

Table 2.3.21 Logistic Regression Results for Test 3 (Gonzo)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			3.286	.511	
Search Display (250 ms)	-.104	.091	1.303	.254	.901
Search Display (500 ms)	.029	.091	.102	.749	1.030
Search Display (1000 ms)	.042	.092	.212	.646	1.043
Search Display (2500 ms)	-.033	.092	.133	.716	.967
Mask			2.150	.828	
Mask (50 ms)	.000	.100	.000	.997	1.000
Mask (100 ms)	.025	.100	.063	.801	1.026
Mask (250 ms)	.126	.100	1.576	.209	1.134
Mask (500 ms)	.045	.100	.205	.651	1.046
Mask (1000 ms)	.035	.100	.124	.725	1.036
Mask * Search Display			17.488	.621	
Mask (50 ms) by Search Display (250 ms)	.100	.317	.100	.752	1.105
Mask (50 ms) by Search Display (500 ms)	.125	.316	.156	.692	1.133
Mask (50 ms) by Search Display (1000 ms)	-.251	.317	.626	.429	.778
Mask (50 ms) by Search Display (2500 ms)	.653	.318	4.226	.040*	1.922
Mask (100 ms) by Search Display (250 ms)	.225	.317	.506	.477	1.253
Mask (100 ms) by Search Display (500 ms)	.050	.317	.025	.874	1.051
Mask (100 ms) by Search Display (1000 ms)	-.175	.317	.306	.580	.839
Mask (100 ms) by Search Display (2500 ms)	.152	.317	.228	.633	1.164
Mask (250 ms) by Search Display (250 ms)	.075	.317	.056	.812	1.078
Mask (250 ms) by Search Display (500 ms)	-.100	.317	.100	.752	.905
Mask (250 ms) by Search Display (1000 ms)	.152	.318	.230	.632	1.165
Mask (250 ms) by Search Display (2500 ms)	.503	.318	2.502	.114	1.653
Mask (500 ms) by Search Display (250 ms)	.300	.317	.900	.343	1.351
Mask (500 ms) by Search Display (500 ms)	.351	.317	1.226	.268	1.420
Mask (500 ms) by Search Display (1000 ms)	.175	.317	.305	.581	1.191
Mask (500 ms) by Search Display (2500 ms)	.527	.317	2.759	.097	1.694
Mask (1000 ms) by Search Display (250 ms)	.325	.317	1.057	.304	1.385
Mask (1000 ms) by Search Display (500 ms)	.050	.316	.025	.874	1.051
Mask (1000 ms) by Search Display (1000 ms)	.050	.317	.025	.875	1.051
Mask (1000 ms) by Search Display (2500 ms)	.377	.317	1.412	.235	1.458
Constant	.028	.029	.966	.326	1.029

Note. $*p < .05$

Table 2.3.22 Logistic Regression Results for Test 3 (Gretel)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			8.435	.077	
Search Display (250 ms)	-.145	.092	2.494	.114	.865
Search Display (500 ms)	-.149	.092	2.612	.106	.862
Search Display (1000 ms)	-.262	.092	8.129	.004**	.769
Search Display (2500 ms)	-.103	.092	1.259	.262	.902
Mask			7.636	.177	
Mask (50 ms)	.071	.100	.504	.478	1.074
Mask (100 ms)	.204	.101	4.092	.043*	1.226
Mask (250 ms)	.041	.100	.163	.686	1.041
Mask (500 ms)	.050	.100	.251	.616	1.051
Mask (1000 ms)	-.060	.100	.359	.549	.942
Mask * Search Display			24.807	.209	
Mask (50 ms) by Search Display (250 ms)	-.582	.319	3.342	.068	.559
Mask (50 ms) by Search Display (500 ms)	-.507	.318	2.535	.111	.602
Mask (50 ms) by Search Display (1000 ms)	-.331	.319	1.074	.300	.719
Mask (50 ms) by Search Display (2500 ms)	-.381	.318	1.436	.231	.683
Mask (100 ms) by Search Display (250 ms)	-.715	.320	4.999	.025*	.489
Mask (100 ms) by Search Display (500 ms)	-.135	.321	.177	.674	.874
Mask (100 ms) by Search Display (1000 ms)	-.438	.320	1.874	.171	.645
Mask (100 ms) by Search Display (2500 ms)	-.514	.320	2.590	.108	.598
Mask (250 ms) by Search Display (250 ms)	-.201	.317	.402	.526	.818
Mask (250 ms) by Search Display (500 ms)	.025	.316	.006	.937	1.025
Mask (250 ms) by Search Display (1000 ms)	.351	.317	1.229	.268	1.421
Mask (250 ms) by Search Display (2500 ms)	.277	.317	.764	.382	1.320
Mask (500 ms) by Search Display (250 ms)	-.326	.317	1.059	.303	.722
Mask (500 ms) by Search Display (500 ms)	-.150	.317	.225	.635	.860
Mask (500 ms) by Search Display (1000 ms)	.276	.317	.759	.384	1.318
Mask (500 ms) by Search Display (2500 ms)	-.300	.317	.900	.343	.741
Mask (1000 ms) by Search Display (250 ms)	-.401	.317	1.603	.205	.669
Mask (1000 ms) by Search Display (500 ms)	.175	.316	.307	.580	1.191
Mask (1000 ms) by Search Display (1000 ms)	.076	.317	.057	.811	1.079
Mask (1000 ms) by Search Display (2500 ms)	-.150	.316	.225	.635	.861
Constant	.051	.029	3.081	.079	1.052

Note. *p < .05, **p < .01

Table 2.3.23 Logistic Regression Results for Test 3 (Ira)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			6.403	.171	
Search Display (250 ms)	-.072	.092	.605	.437	.931
Search Display (500 ms)	-.101	.092	1.214	.271	.904
Search Display (1000 ms)	-.227	.092	6.113	.013*	.797
Search Display (2500 ms)	-.101	.092	1.219	.270	.904
Mask			2.103	.835	
Mask (50 ms)	-.055	.100	.302	.583	.946
Mask (100 ms)	.045	.100	.205	.651	1.047
Mask (250 ms)	.025	.100	.062	.804	1.025
Mask (500 ms)	-.010	.100	.010	.920	.990
Mask (1000 ms)	.077	.101	.585	.444	1.080
Mask * Search Display			9.737	.973	
Mask (50 ms) by Search Display (250 ms)	-.226	.317	.510	.475	.797
Mask (50 ms) by Search Display (500 ms)	-.427	.317	1.809	.179	.653
Mask (50 ms) by Search Display (1000 ms)	-.226	.317	.510	.475	.797
Mask (50 ms) by Search Display (2500 ms)	-.277	.318	.762	.383	.758
Mask (100 ms) by Search Display (250 ms)	-.329	.318	1.070	.301	.720
Mask (100 ms) by Search Display (500 ms)	-.304	.318	.912	.340	.738
Mask (100 ms) by Search Display (1000 ms)	-.179	.318	.316	.574	.836
Mask (100 ms) by Search Display (2500 ms)	-.354	.318	1.239	.266	.702
Mask (250 ms) by Search Display (250 ms)	-.025	.317	.006	.938	.975
Mask (250 ms) by Search Display (500 ms)	-.151	.317	.226	.635	.860
Mask (250 ms) by Search Display (1000 ms)	.075	.317	.056	.813	1.078
Mask (250 ms) by Search Display (2500 ms)	-.151	.317	.227	.634	.860
Mask (500 ms) by Search Display (250 ms)	-.251	.317	.628	.428	.778
Mask (500 ms) by Search Display (500 ms)	-.151	.317	.226	.634	.860
Mask (500 ms) by Search Display (1000 ms)	-.076	.317	.057	.811	.927
Mask (500 ms) by Search Display (2500 ms)	-.327	.317	1.062	.303	.721
Mask (1000 ms) by Search Display (250 ms)	-.049	.320	.024	.877	.952
Mask (1000 ms) by Search Display (500 ms)	-.178	.319	.310	.578	.837
Mask (1000 ms) by Search Display (1000 ms)	-.354	.318	1.244	.265	.702
Mask (1000 ms) by Search Display (2500 ms)	-.556	.318	3.048	.081	.574
Constant	.139	.029	23.023	< .001**	1.149

*Note. *p < .05, **p < .001*

Table 2.3.24 Logistic Regression Results for Test 3 (Logan)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			7.044	.134	
Search Display (250 ms)	.033	.092	.134	.715	1.034
Search Display (500 ms)	.155	.092	2.870	.090	1.168
Search Display (1000 ms)	.155	.092	2.854	.091	1.167
Search Display (2500 ms)	-.025	.092	.075	.784	.975
Mask			1.595	.902	
Mask (50 ms)	.020	.101	.039	.844	1.020
Mask (100 ms)	-.086	.100	.736	.391	.918
Mask (250 ms)	-.041	.100	.166	.684	.960
Mask (500 ms)	-.051	.100	.258	.611	.950
Mask (1000 ms)	-.066	.100	.430	.512	.936
Mask * Search Display			20.644	.418	
Mask (50 ms) by Search Display (250 ms)	-.227	.317	.512	.474	.797
Mask (50 ms) by Search Display (500 ms)	-.355	.319	1.238	.266	.701
Mask (50 ms) by Search Display (1000 ms)	-.101	.318	.100	.752	.904
Mask (50 ms) by Search Display (2500 ms)	-.352	.317	1.232	.267	.703
Mask (100 ms) by Search Display (250 ms)	-.050	.317	.025	.873	.951
Mask (100 ms) by Search Display (500 ms)	-.130	.318	.167	.683	.878
Mask (100 ms) by Search Display (1000 ms)	-.025	.316	.006	.937	.975
Mask (100 ms) by Search Display (2500 ms)	.275	.316	.756	.385	1.317
Mask (250 ms) by Search Display (250 ms)	.201	.317	.403	.526	1.223
Mask (250 ms) by Search Display (500 ms)	-.531	.318	2.783	.095	.588
Mask (250 ms) by Search Display (1000 ms)	-.150	.317	.225	.635	.860
Mask (250 ms) by Search Display (2500 ms)	-.100	.316	.100	.752	.905
Mask (500 ms) by Search Display (250 ms)	.250	.316	.625	.429	1.284
Mask (500 ms) by Search Display (500 ms)	-.080	.318	.063	.802	.923
Mask (500 ms) by Search Display (1000 ms)	.276	.317	.757	.384	1.318
Mask (500 ms) by Search Display (2500 ms)	.300	.317	.900	.343	1.350
Mask (1000 ms) by Search Display (250 ms)	.477	.317	2.259	.133	1.611
Mask (1000 ms) by Search Display (500 ms)	-.104	.319	.107	.744	.901
Mask (1000 ms) by Search Display (1000 ms)	.478	.318	2.264	.132	1.614
Mask (1000 ms) by Search Display (2500 ms)	.326	.317	1.060	.303	1.386
Constant	.064	.029	4.846	.028*	1.066

Note. $*p < .05$

Table 2.3.25 Logistic Regression Results for Test 3 (Nala)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			4.460	.347	
Search Display (250 ms)	.017	.092	.034	.854	1.017
Search Display (500 ms)	.134	.092	2.145	.143	1.144
Search Display (1000 ms)	.096	.092	1.104	.293	1.101
Search Display (2500 ms)	.152	.092	2.735	.098	1.164
Mask			3.033	.695	
Mask (50 ms)	-.055	.100	.303	.582	.946
Mask (100 ms)	.026	.101	.068	.795	1.027
Mask (250 ms)	-.095	.100	.903	.342	.909
Mask (500 ms)	.035	.100	.121	.728	1.035
Mask (1000 ms)	.040	.100	.159	.690	1.041
Mask * Search Display			22.268	.326	
Mask (50 ms) by Search Display (250 ms)	-.302	.317	.903	.342	.740
Mask (50 ms) by Search Display (500 ms)	-.529	.318	2.766	.096	.589
Mask (50 ms) by Search Display (1000 ms)	-.051	.318	.026	.873	.950
Mask (50 ms) by Search Display (2500 ms)	-.026	.317	.007	.934	.974
Mask (100 ms) by Search Display (250 ms)	-.176	.317	.309	.578	.838
Mask (100 ms) by Search Display (500 ms)	-.304	.319	.912	.340	.738
Mask (100 ms) by Search Display (1000 ms)	-.452	.318	2.026	.155	.636
Mask (100 ms) by Search Display (2500 ms)	.431	.319	1.825	.177	1.539
Mask (250 ms) by Search Display (250 ms)	-.377	.317	1.411	.235	.686
Mask (250 ms) by Search Display (500 ms)	-.455	.318	2.041	.153	.635
Mask (250 ms) by Search Display (1000 ms)	-.402	.317	1.604	.205	.669
Mask (250 ms) by Search Display (2500 ms)	-.127	.317	.159	.690	.881
Mask (500 ms) by Search Display (250 ms)	-.427	.317	1.812	.178	.653
Mask (500 ms) by Search Display (500 ms)	-.705	.318	4.906	.027*	.494
Mask (500 ms) by Search Display (1000 ms)	-.552	.317	3.027	.082	.576
Mask (500 ms) by Search Display (2500 ms)	-.152	.317	.228	.633	.859
Mask (1000 ms) by Search Display (250 ms)	-.577	.317	3.308	.069	.561
Mask (1000 ms) by Search Display (500 ms)	-.830	.318	6.798	.009**	.436
Mask (1000 ms) by Search Display (1000 ms)	-.377	.318	1.405	.236	.686
Mask (1000 ms) by Search Display (2500 ms)	-.277	.317	.762	.383	.758
Constant	.017	.029	.344	.557	1.017

*Note. *p < .05, **p < .01*

Test 4 two checkers location change: Our logistic regression analyses revealed that our model was not a significant predictor of change detection accuracy for Gonzo (Nagelkerke R^2 = .005, see *Table 2.3.26*), Gretel (Nagelkerke R^2 = .01, see *Table 2.3.27*), Ira (Nagelkerke R^2 = .009, see *Table 2.3.28*), or Logan (Nagelkerke R^2 = .011, see *Table 2.3.29*).

Table 2.3.26 Logistic Regression Results for Test 4 (Gonzo)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			.192	.996	
Search Display (250 ms)	-.017	.091	.033	.856	.983
Search Display (500 ms)	.004	.091	.002	.963	1.004
Search Display (1000 ms)	-.008	.092	.008	.930	.992
Search Display (2500 ms)	.021	.091	.053	.818	1.021
Mask			5.913	.315	
Mask (50 ms)	-.035	.100	.123	.726	.966
Mask (100 ms)	.130	.100	1.691	.193	1.139
Mask (250 ms)	.045	.100	.203	.652	1.046
Mask (500 ms)	-.070	.100	.491	.483	.932
Mask (1000 ms)	.095	.100	.906	.341	1.100
Mask * Search Display			11.379	.936	
Mask (50 ms) by Search Display (250 ms)	.125	.316	.156	.693	1.133
Mask (50 ms) by Search Display (500 ms)	.225	.316	.506	.477	1.253
Mask (50 ms) by Search Display (1000 ms)	-.100	.317	.100	.751	.905
Mask (50 ms) by Search Display (2500 ms)	-.175	.317	.306	.580	.839
Mask (100 ms) by Search Display (250 ms)	.200	.317	.400	.527	1.222
Mask (100 ms) by Search Display (500 ms)	.150	.317	.225	.635	1.162
Mask (100 ms) by Search Display (1000 ms)	.176	.317	.307	.579	1.192
Mask (100 ms) by Search Display (2500 ms)	.000	.317	.000	1.000	1.000
Mask (250 ms) by Search Display (250 ms)	-.125	.317	.157	.692	.882
Mask (250 ms) by Search Display (500 ms)	.200	.317	.400	.527	1.222
Mask (250 ms) by Search Display (1000 ms)	.050	.316	.025	.874	1.051
Mask (250 ms) by Search Display (2500 ms)	.101	.317	.101	.751	1.106
Mask (500 ms) by Search Display (250 ms)	.325	.317	1.056	.304	1.384
Mask (500 ms) by Search Display (500 ms)	.451	.317	2.023	.155	1.569
Mask (500 ms) by Search Display (1000 ms)	.025	.317	.006	.938	1.025
Mask (500 ms) by Search Display (2500 ms)	-.025	.317	.006	.937	.975
Mask (1000 ms) by Search Display (250 ms)	.125	.317	.156	.693	1.133
Mask (1000 ms) by Search Display (500 ms)	.050	.316	.025	.874	1.051
Mask (1000 ms) by Search Display (1000 ms)	.252	.317	.630	.427	1.286
Mask (1000 ms) by Search Display (2500 ms)	-.075	.317	.056	.812	.928
Constant	.038	.029	1.690	.194	1.038

Table 2.3.27 Logistic Regression Results for Test 4 (Gretel)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			1.149	.886	
Search Display (250 ms)	.081	.092	.768	.381	1.084
Search Display (500 ms)	.071	.092	.600	.438	1.074
Search Display (1000 ms)	.017	.092	.034	.854	1.017
Search Display (2500 ms)	.030	.092	.105	.746	1.030
Mask			3.136	.679	
Mask (50 ms)	.049	.101	.240	.624	1.050
Mask (100 ms)	.094	.101	.869	.351	1.098
Mask (250 ms)	-.012	.101	.013	.909	.989
Mask (500 ms)	.069	.101	.470	.493	1.071
Mask (1000 ms)	-.056	.101	.315	.575	.945
Mask * Search Display			31.581	.048*	
Mask (50 ms) by Search Display (250 ms)	-.509	.319	2.550	.110	.601
Mask (50 ms) by Search Display (500 ms)	-.350	.317	1.224	.269	.705
Mask (50 ms) by Search Display (1000 ms)	.076	.317	.057	.811	1.079
Mask (50 ms) by Search Display (2500 ms)	.279	.318	.773	.379	1.322
Mask (100 ms) by Search Display (250 ms)	-.559	.319	3.065	.080	.572
Mask (100 ms) by Search Display (500 ms)	-.200	.317	.399	.528	.819
Mask (100 ms) by Search Display (1000 ms)	-.024	.317	.006	.939	.976
Mask (100 ms) by Search Display (2500 ms)	-.125	.317	.157	.692	.882
Mask (250 ms) by Search Display (250 ms)	-.761	.319	5.672	.017*	.467
Mask (250 ms) by Search Display (500 ms)	-.251	.317	.624	.429	.778
Mask (250 ms) by Search Display (1000 ms)	-.527	.317	2.758	.097	.590
Mask (250 ms) by Search Display (2500 ms)	-.276	.317	.760	.383	.759
Mask (500 ms) by Search Display (250 ms)	-.132	.320	.171	.679	.876
Mask (500 ms) by Search Display (500 ms)	.201	.317	.402	.526	1.223
Mask (500 ms) by Search Display (1000 ms)	.377	.317	1.413	.235	1.458
Mask (500 ms) by Search Display (2500 ms)	.402	.317	1.604	.205	1.495
Mask (1000 ms) by Search Display (250 ms)	-1.062	.320	11.019	.001**	.346
Mask (1000 ms) by Search Display (500 ms)	-.175	.318	.302	.582	.840
Mask (1000 ms) by Search Display (1000 ms)	-.401	.317	1.604	.205	.669
Mask (1000 ms) by Search Display (2500 ms)	-.401	.317	1.603	.205	.669
Constant	.111	.029	14.590	< .001***	1.117

*Note. *p < .05, **p < .01, ***p < .001*

Table 2.3.28 Logistic Regression Results for Test 4 (Ira)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			4.587	.332	
Search Display (250 ms)	.140	.092	2.307	.129	1.150
Search Display (500 ms)	.126	.092	1.890	.169	1.134
Search Display (1000 ms)	-.008	.092	.007	.932	.992
Search Display (2500 ms)	.038	.092	.170	.680	1.039
Mask			6.238	.284	
Mask (50 ms)	.041	.101	.163	.687	1.041
Mask (100 ms)	.058	.101	.327	.568	1.059
Mask (250 ms)	.010	.101	.011	.918	1.010
Mask (500 ms)	.025	.101	.064	.801	1.026
Mask (1000 ms)	-.161	.100	2.567	.109	.851
Mask * Search Display			21.593	.363	
Mask (50 ms) by Search Display (250 ms)	-.150	.317	.225	.635	.860
Mask (50 ms) by Search Display (500 ms)	-.025	.317	.006	.937	.975
Mask (50 ms) by Search Display (1000 ms)	.028	.319	.008	.930	1.028
Mask (50 ms) by Search Display (2500 ms)	-.151	.318	.226	.634	.860
Mask (100 ms) by Search Display (250 ms)	.509	.319	2.553	.110	1.664
Mask (100 ms) by Search Display (500 ms)	.432	.318	1.839	.175	1.540
Mask (100 ms) by Search Display (1000 ms)	.075	.317	.055	.814	1.078
Mask (100 ms) by Search Display (2500 ms)	-.227	.317	.513	.474	.797
Mask (250 ms) by Search Display (250 ms)	-.025	.318	.006	.937	.975
Mask (250 ms) by Search Display (500 ms)	-.152	.318	.228	.633	.859
Mask (250 ms) by Search Display (1000 ms)	-.629	.318	3.911	.048*	.533
Mask (250 ms) by Search Display (2500 ms)	-.404	.318	1.613	.204	.667
Mask (500 ms) by Search Display (250 ms)	.178	.318	.313	.576	1.194
Mask (500 ms) by Search Display (500 ms)	.102	.317	.102	.749	1.107
Mask (500 ms) by Search Display (1000 ms)	-.351	.317	1.229	.268	.704
Mask (500 ms) by Search Display (2500 ms)	-.177	.318	.310	.578	.838
Mask (1000 ms) by Search Display (250 ms)	.175	.317	.307	.580	1.192
Mask (1000 ms) by Search Display (500 ms)	.100	.317	.100	.752	1.105
Mask (1000 ms) by Search Display (1000 ms)	-.377	.317	1.412	.235	.686
Mask (1000 ms) by Search Display (2500 ms)	-.327	.317	1.065	.302	.721
Constant	.151	.029	27.111	< .001**	1.163

*Note. *p < .05, **p < .001*

Table 2.3.29 Logistic Regression Results for Test 4 (Logan)

Predictor	β	S.E.	Wald	Sig.	Exp(B)
Search Display			1.786	.775	
Search Display (250 ms)	-.038	.092	.175	.676	.962
Search Display (500 ms)	-.110	.092	1.450	.229	.895
Search Display (1000 ms)	-.042	.092	.213	.645	.959
Search Display (2500 ms)	-.009	.092	.010	.919	.991
Mask			10.301	.067	
Mask (50 ms)	.034	.101	.115	.734	1.035
Mask (100 ms)	-.238	.101	5.569	.018*	.788
Mask (250 ms)	-.016	.101	.025	.874	.984
Mask (500 ms)	.025	.101	.060	.806	1.025
Mask (1000 ms)	-.001	.100	.000	.993	.999
Mask * Search Display			29.181	.084	
Mask (50 ms) by Search Display (250 ms)	.708	.319	4.925	.026*	2.029
Mask (50 ms) by Search Display (500 ms)	.357	.318	1.254	.263	1.428
Mask (50 ms) by Search Display (1000 ms)	.031	.319	.009	.923	1.031
Mask (50 ms) by Search Display (2500 ms)	.733	.319	5.280	.022*	2.082
Mask (100 ms) by Search Display (250 ms)	.632	.319	3.935	.047*	1.881
Mask (100 ms) by Search Display (500 ms)	.075	.320	.055	.814	1.078
Mask (100 ms) by Search Display (1000 ms)	.155	.319	.236	.627	1.168
Mask (100 ms) by Search Display (2500 ms)	.858	.319	7.240	.007**	2.359
Mask (250 ms) by Search Display (250 ms)	.783	.319	6.029	.014*	2.188
Mask (250 ms) by Search Display (500 ms)	.482	.318	2.290	.130	1.619
Mask (250 ms) by Search Display (1000 ms)	.056	.319	.031	.861	1.057
Mask (250 ms) by Search Display (2500 ms)	.633	.319	3.943	.047*	1.883
Mask (500 ms) by Search Display (250 ms)	.557	.318	3.060	.080	1.745
Mask (500 ms) by Search Display (500 ms)	.231	.318	.528	.467	1.260
Mask (500 ms) by Search Display (1000 ms)	.610	.320	3.639	.056	1.840
Mask (500 ms) by Search Display (2500 ms)	.884	.319	7.666	.006**	2.420
Mask (1000 ms) by Search Display (250 ms)	.582	.318	3.341	.068	1.789
Mask (1000 ms) by Search Display (500 ms)	.332	.318	1.086	.297	1.393
Mask (1000 ms) by Search Display (1000 ms)	.431	.319	1.833	.176	1.539
Mask (1000 ms) by Search Display (2500 ms)	.934	.319	8.558	.003**	2.544
Constant	.023	.029	.656	.418	1.024

Note. $*p < .05$, $**p < .01$

2.4 DISCUSSION

I administered four change detection tasks to nine capuchin monkeys to explore the role of search display duration, mask duration, and their interaction on change blindness. The tasks ranged from a same/different task to a feature omission task to a feature location change task. Whereas there were significant effects of both search display and mask durations on accuracy in the relatively simple same/different test, there was no interaction between the two. Moreover, we found no significant results on the three more complex tasks that involved within-stimulus changes (deletions, omissions, or moves) to individual features within the display. I first consider the results on the same/different task and then consider why the monkeys struggled with the subsequent tasks.

In the simplest task, the same/different task, subjects had to correctly indicate whether or not a stimulus changed to an entirely new stimulus (the alternative was that it remained the same) following the presentation of a mask. Overall, subjects detected changes significantly more accurately with the longest search display (5000 ms), followed closely by the second longest search display (2500 ms), than the shorter search displays (250 ms, 500 ms, 1000 ms). These results are in line with change detection findings from humans (Pashler, 1988), chimpanzees (Tomonaga & Imura, 2015), and pigeons (Herbranson & Davis, 2016), and suggest that the monkeys performed better when they had longer to encode the stimulus into their visual working memory, likely resulting in a stronger memory trace of the stimulus than following shorter search displays.

We also found a significant effect of mask duration; however, these results are much harder to interpret and counter to what others have found. Across individuals, change detection accuracy was significantly worse when the mask was 0 ms, which is to say that subjects

performed better when there *was* a mask compared to when there was no mask. Excluding the 0

ms mask, there were no significant differences among the other mask durations. These findings

directly contradict previous research on the change blindness, in which subjects struggled when a

mask was inserted to hide the change, not when the change was unmasked (humans: Eng et al.,

2005; Phillips, 1974; Rensink et al., 1997; chimpanzees: Tomonaga & Imura, 2015; macaques:

Elmore et al., 2012; Leising et al., 2013; pigeons: Herbranson et al., 2014; Leising et al., 2013).

Indeed, the purpose of the mask is to mimic an eye blink or saccade during which a change may

transpire without being detected. As such, the mask obscures the change as it occurs so that

subjects cannot rely solely on where they detect movement to detect the change. Instead,

subjects must attend to and encode the stimulus, then maintain a trace of the stimulus throughout

the duration of the mask, and finally decide whether or not the stimulus changed based on their

memory trace and the test display. Longer masks are therefore more difficult as they require

subjects to retain the trace in their visual working memory for longer, during which time the

trace may decay. Moreover, the training should have biased subjects towards performing better

with no mask, as there was no mask in any of the training phases subjects completed.

Accordingly, there was no need to generalize or learn new contingencies in the trials without a

mask.

I do not know why this is the case, but have several thoughts. First, and most obviously,

this finding suggests that I did not actually induce change blindness in the monkeys. In addition,

even if I did not induce change blindness, it still seems intuitive that trials should be more

difficult with a mask than without one. An alternative explanation could therefore be that,

compared to the 5,000 ms search display used in training, the usage of shorter search display

times and no mask meant that these trials occurred too quickly for the monkeys to adequately

attend to, encode, and retain a trace of the search stimulus in order to make an informed selection in the test display. Subjects may thus have learned from training that they did not need to instantly attend to the search stimulus when it appeared as they had 5,000 ms to do so. Then, in test trials that happened more quickly, they may have failed to sufficiently attend to and encode the search stimulus when it was visible for shorter durations. Another possibility is that either the mask itself or the flicker effect created by alternating from search display to mask to test display was more attention catching to the monkeys then the stimuli themselves. In this case, subjects' performance could theoretically have been due to a failure to attend to the appropriate stimulus rather than a failure to encode, retain a memory trace, and make a decision. Moreover, it is possible that our subjects may not have realized that there even was a change occurring in the 0 ms mask condition. Without a blank screen acting as a mask, the search and test displays may have blended together for the subjects such that they could not correctly indicate whether or not a change had occurred because they failed to notice the appearance of a new stimulus or a change to the search display stimulus

Subjects also did very poorly on the tests beyond the same/different task regardless of search display time or mask presence/duration. Given the absence of significant results beyond the same/different test, and individual and group change detection accuracies that were functionally at chance on the next three tasks, I think it is likely that the monkeys found these three tasks too difficult and were guessing on these trials. Considering there were only two possible options, guessing was nearly as effective a strategy as attending to the task and recalling the details of the search display when the change that may have occurred was not obvious, and was certainly less cognitively taxing. This seems plausible as capuchins have been shown to rarely, if ever, make use of uncertainty responses when presented with difficult trials (Beran,

Smith, Coutinho, Couchman, & Boomer, 2009), and appear to be more tolerant of the risk of guessing and getting a trial incorrect than apes and macaques in at least some situations (Beran, Perdue, & Smith, 2014).

Moreover, if subjects are metacognitively aware that they do not know the answer, guessing could be viewed as a superior strategy as it requires less energy than attending to the task and retaining a memory trace of the stimulus. Evidence for metacognition in capuchins is extremely variable. Studies rarely find evidence for all subjects, and there is typically substantial variation within individuals as well (Beran, Perdue, Church, & Smith, 2016; Beran & Smith, 2011). While these results remain inconclusive, it has nonetheless been argued that capuchins do indeed possess at least a rudimentary form of metacognition (Vining & Marsh, 2015). It is at least possible that they were aware that the task was hard, so then chose not to learn it given their high probability of reward without having to try. However, the extent to which this ability was used in the present study is unknown, as we have no way of knowing whether any guesses were actually a result of uncertainty monitoring and metacognition.

Another possibility is that the stimuli that were used in tasks two, three, and four were too complex for the monkeys to encode sufficiently in order to then detect a change, especially one as subtle as occluding a small portion of the image or moving a single checker among eight on the board. Though capuchins are typically able to perform relatively well on delayed match-to-sample tasks (Truppa et al., 2014), one recent study found no evidence that capuchins monitor detailed contents of their memory traces (Takagi & Fujita, 2018). Accordingly, it may have been worthwhile to conduct a delayed match-to-sample task using our stimuli to ascertain whether or not the capuchins were able to recall enough details of the sample stimulus to then match it with

one of the match stimuli. If the capuchins were unable to do so, that would be evidence that less complex stimuli were needed.

Importantly, it has been argued that focused attention is required to see change (Rensink et al., 1997), and we have no way of knowing whether the subjects were reliably attending to the task, let alone focusing their attention on the potentially changing stimulus. This is particularly troublesome when the test stimuli are overly complex as these stimuli have more details to encode. Thus, if the subjects failed to focus their attention on both the search display stimulus and the possibly changed test display stimulus, they would not be expected to detect whether or not a change occurred greater than chance levels. Moreover, subjects may have overcome any failure to adequately attend to the task in the first phase in which the entire stimulus either changed or remained the same as they only needed to encode and recall minor details of the test stimulus to then determine if a change occurred. However, when the change became more complex in phases two, three, and four, a similar failure to focus one's attention may result in subjects guessing whether or not a change occurred as they were unable to encode enough details of the search display stimulus to then ascertain whether or not the test display stimulus included a change.

I also anticipated that the capuchins would generalize from training to test phases one and two, but it is possible they were unable to generalize to the occlusion phases or checkerboard tasks despite the continued presence of the "change" and "no change" icons. In both cases, the change went from being an entire image shift to a relative subtle change in the same image. If the monkeys were expecting a change of images, they may have failed to carefully attend to the details – because they had not previously need to do so – and ultimately become frustrated when they could not figure out why "no change" was not the correct response half of the time. In

particular, if this were combined with low working memory or difficulty in remembering details with precision, the subjects may never have even realized that changes were occurring.

An additional, albeit we believe unlikely, potential explanation for our results is that capuchins do not experience change blindness. The visual systems of New World monkeys are known to vary from species to species and between New and Old World monkeys (Gomes et al., 2002). Accordingly, while it seems improbable based on previous nonhuman change detection studies, the visual systems of capuchins may function in such a way that they do not experience change blindness as other species do, if they even experience it at all. Clearly, while this cannot be excluded, it is also not a conclusion that should be drawn from these data.

As always, additional research is needed to understand if and how capuchins experience change blindness. Given these results, future studies should use a sufficiently long search display so that subjects have enough time to encode and recall memory traces of the stimuli, ideally pre-testing this with a delayed match-to-sample task. Future studies may also utilize a different paradigm, such as one item in an array changing or using an eye tracker to record search paths and training subjects to fixate on the location of the change as has been done with macaques (Chau et al., 2011). The flicker paradigm should also be tried in addition to the one-shot paradigm used here to determine if providing subjects with multiple viewings of the change improves change detection accuracy in capuchins as it does in other species. Further modifications to the type of change occurring (i.e. addition, subtraction, movement, etc.), the type of mask (i.e. blank screen, distractor images, etc.), and the type of stimuli (i.e. clip art, faces, etc.) may provide further insight into how capuchins experience change blindness. In particular, less complicated stimuli should be used first and it may also be useful to require subjects to pass multiple training sessions, for instance slowly building up the complexity of the

stimulus or number of stimuli in an array. In sum, despite very few significant results, nine out of 22 of our capuchins were nonetheless able to learn how to indicate whether or a not a change occurred, suggesting that additional change blindness research with capuchins is feasible, and it certainly is also much needed.

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