8-2016

Set and element-level compatibility of spatial and location-word stimuli paired to eye-movement, vocal, and keypress response modalities

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Graduate School Form 30
Updated 1/15/2015

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Courtney Janai Griffin-Oliver

Entitled

Set and Element-Level Compatibility of Spatial and Location-Word Stimuli Paired to Eye-Movement, Vocal, and Keypress Response Modalities

For the degree of Master of Science

Is approved by the final examining committee:

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Approved by: Janice R. Kelly 7/22/2016
Head of the Departmental Graduate Program Date

SET AND ELEMENT-LEVEL COMPATIBILITY OF SPATIAL AND LOCATION-WORD STIMULI PAIRED TO EYE-MOVEMENT, VOCAL, AND KEYPRESS RESPONSE MODALITIES

A Thesis

Submitted to the Faculty

of

Purdue University

by

Courtney Janai Griffin-Oliver

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

August 2016

Purdue University

West Lafayette, Indiana

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ABSTRACT

Griffin-Oliver, Courtney Janai. M.S., Purdue University, August 2016. Set and Element-Level Compatibility of Spatial and Location-Word Stimuli Paired to Eye-Movement, Vocal, and Keypress Response Modalities. Major Professor: Robert W. Proctor.

Set-level and element-level compatibility are two ways to differentiate between different components of stimulus-response compatibility. Element-level compatibility (the difference between incongruent and congruent mappings) has been shown in prior studies to be an increasing function of set-level compatibility (differences between pairings of stimulus and response ensembles). When manual and vocal response sets are paired with spatial (physical location) stimuli and verbal (location-word stimuli), the difference between the incongruent and congruent mappings is larger for the spatial-manual and verbal-vocal conditions than for the alternative pairings of lower set-level compatibility.

The common use of eye tracking technology in psychological experiments necessitates investigating the set-level compatibility of the oculomotor system through use of various stimulus sets. Saccadic eye movements are known to yield element-level compatibility effects (longer response times for antisaccades in the opposite direction of the stimulus than for prosaccades in the direction of the stimulus). Although the tendency to make a prosaccade is often described as highly automatic, no attempt has

been made to evaluate the overall set-level compatibility of eye-movement responses in comparison to vocal location-naming responses or manual responses. Consequently, I conducted two experiments in which eye-movement responses were compared to those two response modalities: vocal responses (Experiment 1) and keypress responses (Experiment 2). Visual stimuli were varied through use of onsets of squares in left and right spatial locations (spatial codes) or centrally presented words ‘left’ and ‘right’ (verbal codes). The relative set-level compatibility of the two response sets was evaluated by comparing performance with a congruent mapping of spatial and verbal location stimuli; the element-level compatibility effects were evaluated by comparing the differences in performance for incongruent and congruent mappings.

The results provide evidence of set-level compatibility differences, with eye movements not only being more compatible than vocal responses with spatial stimuli than verbal stimuli, but also relatively more compatible than keypresses. This result pattern implies that eye movements are more extreme than keypress responses on the spatial end of a response spectrum, compared to vocal responses. Despite this difference in set-level compatibility, in Experiment 1 the element-level mapping effect for sets with high set-level compatibility (including eye-movement responses to spatial) was no larger than that for sets with low set-level compatibility (including eye-movement responses to verbal stimuli). A positive relation between relative set-level compatibility and the element-level mapping effect was found in Experiment 2 when eye movements were compared to keypresses, but this was due mainly to the keypress responses. That incompatible, antisaccade eye-movement responses are not slowed by higher set-level compatibility is counter to the view that set-level compatibility

increases activation of the spatially congruent response regardless of the stimulus-response mappings. Alternative possible explanations for the influence of set-level compatibility on eye-movement responses are discussed.

INTRODUCTION

Stimulus-response (S-R) compatibility is the phenomenon in which some tasks are easier (or more difficult) than others depending upon the specific sets of stimuli and responses or the manner in which the individual stimuli and responses are paired (Proctor & Vu, 2006). As a result, these lead to differences in reaction time (RT) and accuracy in choice-reaction tasks. That is, participants exhibit faster RTs if the stimuli and responses match (are congruent) than if they do not (are incongruent). A second important property of S-R compatibility concerns the notion that for a stimulus and response set, a faster RT with an optimal mapping occurs if there is dimensional overlap, or similarity, between the stimulus and response sets (Kornblum, Hasbroucq, & Osman, 1990). This notion of dimensional overlap is also an essential component in understanding and characterizing the distinction between element-level and set-level compatibility.

Stimulus-Response Compatibility

Set- and Element-Level Compatibility

Kornblum et al. (1990) distinguished set-level compatibility from element-level compatibility by drawing upon work from Paul Fitts, who explained that the difference between the two lie in the treatment of properties of stimulus and response sets (set-level compatibility) and the other focuses on specific properties of elements within sets (element-level compatibility; Fitts & Deininger, 1954; Fitts & Seeger, 1953). Traditionally, research has tended to focus on element-level compatibility, or the mappings of the individual stimulus-set members onto the members of a given response set (Wang & Proctor, 1996). For example, in a task using digits, *1* and *2*, as the stimulus set and vocal names (e.g. audibly saying "*one*" and "*two*") as the response set, a congruent mapping is one in which the stimulus *1* is paired with response set *one* and stimulus *2* with response *two*. This may be compared to the incongruent mapping for which the stimulus *1* is paired with the response *two* and the stimulus *2* with the response *one*. As can be easily imagined from this example, the congruent mapping typically yields faster and more accurate responding than the incongruent one.

Set-level compatibility was described initially by Fitts and Seeger (1953) in various terms including congruence, match, or correspondence between the aforementioned response and stimulus sets. A task where digits are used as stimuli and vocal digit names as the responses is deemed to have high set-level compatibility because of experience naming printed digits. Comparatively, a task with digits as stimuli and keypresses corresponding to the digits as the responses is said to have low set-level compatibility. In other words, the stimulus set and response set relationship is stronger in one case than another and can be thought of as varying in degree of overlap between the common properties or features of the different set combinations (Kornblum et al., 1990). If there are more features that are shared between the stimulus and response set, this results in a greater level of set-compatibility.

This distinction between element-level and set-level compatibility is one that enables gaining further insight into human performance on tasks. It is not enough to know that the mapping of the individual stimuli in the stimulus set (e.g., digits) to the individual responses in the response set (e.g., vocal names) is congruent (element-level compatibility). Set-level compatibility also needs to be taken into consideration to gain a better understanding of which of combinations of stimulus and responses sets is most optimal, and why. This difference between element-level and set-level compatibility is best observed in situations where dimensional overlap on the relevant stimulus dimension is absent. For example, Simon and Small (1969) had participants make a left or right keypress in response to a tone (low or high pitch) that was presented in either the left or right ear, where the location was an irrelevant stimulus dimension that overlapped with the response dimension. In this case, a benefit for the spatially congruent trials over the incongruent trials was evident (a phenomenon now called the Simon effect). In a secondary block of trials, the tone was presented binaurally (both ears) instead of unilaterally (one ear), and thus also had no overlap with the spatial response dimension. For that condition, there is no spatial correspondence factor, and RT was faster compared to the unilateral tone condition, possibly because of the absence of overlap of the irrelevant stimulus-location dimension with the response dimension.

A similar pattern of results occurs when using visual stimuli rather than the auditory stimuli used by Simon and Small (1969). Wallace (1971) asked participants to press either a left or right key in response to a circle or square presented in the left-right or above-below positions. Additionally, the participants were instructed to either cross or uncross their hands during the experiment. The results revealed that for the hand conditions (crossed or uncrossed) when RT data between the congruent and incongruent mappings were collapsed, there was a large difference for left-right stimuli (46 ms). For the stimuli with low dimensional overlap (above-below), there was a smaller difference (4 ms). In other words, element-level compatibility was larger for left-right stimuli than for above-below, resulting in a significant correspondence effect just for the left-right stimuli. Furthermore, lack of element-level compatibility for above-below stimuli suggests that no dimensional overlap occurred. Importantly, these results provide evidence that element-level compatibility is substantial only in the presence of set-level compatibility.

The distinction between set- and element-level compatibility is important for understanding the response-selection system and its ability to process information. The set-level component can be thought of as a representational aspect, whereas the element-level is thought to be the processing aspect. Kornblum et al. (1990) described the way in which information is processed in S-R tasks where a stimulus is presented and subsequent encoding of the stimulus is initiated. The set-level compatibility determines the amount of automatic activation that the response corresponding to a stimulus will receive, regardless of whether that response is defined as correct by the task instructions. The element-level mapping determines whether the automatically activated response is correct or not. In Kornblum et al.'s model (see also Kornblum & Lee, 1995), the response must be identified (serial search, rule-based, etc.) through an intentional response-selection route, which then is verified by comparison to the automatically activated corresponding response. If the activated response matches the one identified by the intentional process, as for a congruent mapping, then it is executed. If the activated response does not match, then it must be inhibited and the appropriate motor program retrieved before the response can be executed (see Figure 1). As an example, for a stimulus set of numerals (1, 2, 3, and 4) and a response set consisting of digit names (one, two, three, and four), presentation of the digit “1” automatically activates the response “one” (Kornblum & Lee, 1995). If the task is to say the name of the digit, the response can be executed quickly. If the task is to respond with an incongruent digit name (e.g., “three”), the activated name “one” must be inhibited before “three” can be spoken. The model further assumes that in the absence of dimensional overlap, the longer and more time consuming response-identification pathway will be employed. That is, response identification will occur by serial search, in contrast to the presence of dimensional overlap, where the simple and fastest rule set will be employed to get from the stimulus to the correct response.

In the model of Kornblum et al. (1990) and Kornblum and Lee (1995), automatic activation is a direct function of the degree of dimensional overlap. Drawing from Kahneman and Treisman (1984), strong automatic activation is of most concern to Kornblum et al. (1990). Strong automatic activation is defined as “neither facilitated by focusing on [its object] nor impaired by diverting attention from [it]” (Kahneman & Treisman, 1984, p. 43). In other words, a congruent response is one where there is dimensional overlap. The degree to which there is dimensional overlap will strengthen the degree of automatic activation, facilitating a congruent response and interfering with an incongruent response accordingly. In essence, a symbiotic relationship exists for all degrees of dimensional overlap and automaticity.

Relation Between Set- and Element-Level Compatibility

Wang and Proctor (1996) investigated the relation between set-level and element-level compatibility experimentally. They used a 2-choice task with left-right stimuli and responses. In a series of four experiments, they varied both stimulus codes (spatial, verbal) and response modalities (manual, vocal). In Experiment 1, participants were to respond with congruent or incongruent mappings. Participants were shown spatial stimuli (a square corresponding to the response location) or verbal stimuli (the word *left* or *right* corresponding to the response location). In different trial blocks, they were also to respond manually (with a left or right keypress) or vocally (by saying the word "left" or "right"). In line with results obtained by Brainard, Irby, Fitts, & Alluisi (1962), the results indicated a positive interaction between stimulus code and response modality for the congruent mappings. The comparison of main interest was averages for pairs of conditions differing in set-level compatibility but for which the stimulus and response sets were counterbalanced: (1) spatial-manual and verbal-vocal; (2) spatial-vocal and verbal-manual. The element-level mapping effect was larger for the first pair of conditions, for which set-level compatibility is high, than for the second pair, for which it is low. This outcome confirmed a prediction of Kornblum and Lee's (1995) model that the element-level compatibility would be larger when the set-level compatibility was higher, although the result was largely due to the congruent mapping rather than both mappings.

In Wang and Proctor's (1996) Experiment 2, the spatial stimuli were replaced by left/right pointing arrows or verbal stimuli (as in Experiment 1). The pattern of results was similar to that of Experiment 1: The spatial-manual and verbal-vocal conditions with higher set-level compatibility showed a larger element-level mapping effect. In the third experiment, aimed movements were investigated by using a touch screen monitor in which participants were to move to the response location (verbal stimuli remained the same). Similar to Experiments 1 and 2, RTs for the congruent mapping showed a larger element-level compatibility effect for the spatial-manual and verbal-vocal conditions than for the spatial-vocal and verbal-manual conditions. Furthermore, Experiment 3 differed from Experiments 1 and 2 as there was a significant effect of set-level compatibility on RTs for incongruent mappings and not just the congruent mappings.

Finally, in Experiment 4 each participant performed with each combination of stimulus code, response type, and mapping with keypress and aimed-movement response sets. Results showed a qualitatively similar pattern to those of Experiments 1 and 3: spatial-keypress and verbal-movement conditions together showed higher set-level compatibility and a larger element-level mapping effect than the other two combinations of stimulus codes and response modalities. This result pattern suggests that keypresses are of relatively higher set-level compatibility with spatial compared to verbal stimuli than are aimed movement responses.

Taken together, Wang and Proctor’s (1996) results suggested a continuum (or spectrum) along which keypress responses reside closest to spatial stimuli and vocal responses closest to verbal stimuli (see Figure 2, top panel). Additionally, the results provided evidence for Kornblum et al.’s (1990) hypothesis that element-level compatibility is an increasing function of set-level compatibility. However, they did not support the dimensional overlap model’s prediction that responses with the incongruent mapping should be slowed more when dimensional overlap is high, as a consequence of the stronger automatic activation. Rather, the results suggest instead that the automatic activation as a function of degree of dimensional overlap is mainly a factor for congruent mappings.

Compatibility in Eye Movements

Saccadic Responses

There are two distinguishable types of saccadic responses that can be executed in choice-reaction tasks using eye-movement responses: prosaccades and antisaccades (e.g., Laidlaw, Zhu, & Kingstone, 2016). Prosaccades require the participants to orient their eyes toward the target of interest. In contrast, for antisaccades, individuals are to avoid looking at targets or stimuli that may appear in their field of view and instead orient their eyes to an opposite location. In general, an antisaccade task leads to higher error rates and longer RTs than does a prosaccade task. The difference in performance between the two types of responses can be attributed to antisaccades requiring inhibition or suppression of a reflexive movement toward the stimulus and the subsequent initiation of a new response program toward the correct target (Guyader, Malsert, & Marendaz, 2010; Munoz & Everling, 2004). In contrast, a prosaccade does not require any type of suppression, and the reflexive movement can proceed without interruption. Note that this description is similar to the dual-route model of response selection proposed by Korblum and Lee (1995) where the appropriate motor program must be activated before the correct response can be initiated.

Taylor and Hutton (2009) examined pro-and-anti-saccadic behavior under four different instruction conditions: standard, accuracy, speed, and delay. In the standard instructions, participants were to look at a peripherally located target as quickly and accurately as possible (prosaccade) or to the mirror image location (antisaccade). In the accuracy instructions, emphasis was placed on being as spatially accurate as possible. The speeded instructions required participants to move their eyes as quickly as possible. Finally, in the delayed condition, participants were to refrain from making a saccade until after target onset. Participants initially fixated on a centrally-positioned (red) circle; after a random interval between 800-1,200 ms, a target (red circle; similar to fixation) was presented at one of six locations. Antisaccades resulted in longer latencies than prosaccades across all of their experimental conditions, with the advantage for the prosaccades being a little more than 100 ms with the standard and speed instructions.

Similarly, Walker, Walker, Husain, and Kennard (2000) had participants make reflexive (prosaccade) and antisaccadic eye movements. In their task, participants were presented with three boxes: two unfilled outer boxes and one centrally-located fixation box. At the beginning of a trial participants were required to fixate centrally for a random period of 1000-1400 ms. After fixation, the central fixation square changed to being unfilled and one of the peripheral boxes changed to being filled (target). For the prosaccade trials, participants were to make an eye movement toward the peripherally filled target, and in the antisaccade trials; they were to make an eye movement to the mirror opposite location. Results indicate a reliable difference of approximately 75 ms in the mean saccadic latency of prosaccades and antisaccades.

Compatibility in the Oculomotor System

Not only does a relevant mapping of stimulus location to saccadic responses show a compatibility effect, but so does an irrelevant correspondence between stimulus location and eye-movement direction, much as with the more widely studied manual responses. Khalid and Ansorge (2013) found a significant spatial compatibility effect for irrelevant spatial word meaning and saccade direction (i.e., a Simon-type correspondence effect). In their experiment, words indicating spatial direction (horizontal: *left* and *right* or vertical: *below* and *above*) were presented in two colors (blue or green). Participants were instructed to respond to the color of the presented word by making a saccade toward their response and to ignore the direction that the word implied. The experiment also varied the direction of the words presented and the responses to be executed by implementing both a horizontal and vertical condition. The researchers compared their eye-movement results with a separate condition in which responses were manual. The Simon effect due to irrelevant spatial meaning of the words was found for both manual finger responses and eye movements (it should be noted that a different pattern for vertical and horizontal effects in saccades was found). The results show that element-level compatibility effects in eye movements can reliably be obtained even with an irrelevant stimulus dimension, just as are found in other studies using other response modalities.

It should also be noted that saccadic compatibility effects can be observed when investigating non-human primates. Sato and Schall (2003) trained macaque monkeys to produce pro- and anti-saccade responses to a color singleton in a visual search array. They found a significant difference in RT for the prosaccade and antisaccade tasks, whereby antisaccades produced significantly longer RTs than prosaccade. Furthermore, error rates were higher in antisaccade trials than in prosaccade trials. Sato and Schall concluded that this difference in RT can be attributed to stimulus-response compatibility.

Rationale for the Present Experiments

The literature review has established that eye movements exhibit a response pattern that resembles results obtained in a traditional compatibility experiments (Taylor & Hutton, 2009; Walker et al., 2000). Although the tendency to make a prosaccadic eye-movement to a stimulus onset is characterized as automatic, no study has investigated the set-level compatibility relation between eye-movement responses and other response modalities. In other words, questions remain of where exactly on the response spectrum (posited by Wang & Proctor, 1996) eye movements fall and whether the element-level compatibility effects obtained with eye movements vary with dimensional overlap. This is an important consideration as vision research is an integral part of psychological experiments. Researchers are looking into using eye movements as a response modality because they produce rapid RTs relative to other response modalities (e.g. keypresses). If eye tracking is to be incorporated into research endeavors, it seems prudent to be aware of any potential nuances that may come along with incorporating eye tracking methods. Moreover, we know that along this continuum, vocal responses are closer to verbal stimuli and keypresses are closer to spatial stimuli. Eye movement may be similar to an aimed movement elicited by the visual system that can be performed similar to keypresses (considering both concern location; left-right response). Based on this information, it is reasonable to assume that eye movements fall somewhere closer to spatial stimuli than to verbal stimuli on this spectrum. Therefore, compared to vocal “left-right” responses, eye movements should yield a pattern of results indicating that they have higher set-level compatibility with location-specific stimuli rather than verbal stimuli. Because pro-saccadic eye movements are often characterized as highly automatic (e.g. Munoz & Everling, 2004), they also may fall closer on the continuum to spatial stimuli than do keypress responses and yield a similar but reduced pattern of set-level compatibility in comparison to them.

The primary goal of the current study thus was to determine whether stimuli presented in a left or right location have particularly strong set-level compatibility with left-right eye-movement responses. This goal was accomplished by comparing compatibility effects obtained with location stimuli and location-word stimuli mapped to eye-movement responses and “left”-right” vocal responses (Experiment 1) or left-right keypress responses (Experiment 2). The experiments followed the logic of the method used by Wang and Proctor (1996) in which set-level compatibility was varied and showed a positive relation between set-and-element-level compatibility. Experiment 1 was conducted to verify that eye movements, compared to vocal responses, are relatively more compatible with location stimuli rather than verbal stimuli, and to assess the relation between set-level and element-level compatibility. Experiment 2 tested whether eye movements are of higher set-level compatibility than keypress responses. If the tendency to make a prosaccadic response is strong, then a similar (though lesser) set-level compatibility effect favoring spatial-eye movement and verbal-keypress pairings should be obtained. Alternatively, if the saccadic responses are like the manual aimed movements of Wang and Proctor’s (1996) Experiment 4, then the results would favor the spatial-keypress and verbal-eye movement pairings.

EXPERIMENT 1: EYE MOVEMENTS AND VOCAL RESPONSES

Experiment 1 was similar to Wang and Proctor's (1996) experiment; however, eye movements rather than keypress responses were compared to vocal responses. Wang and Proctor (1996) showed an overall difference in the combinations of the response and stimulus conditions that suggests a positive relation between set-and-element level compatibility when using keypress and vocal responses. In the current study, eye movement data were collected to assess this particular response modality when paired with stimuli in a left or right location on the screen or the words "left" or "right" presented centrally (the words). Wang and Proctor concluded that keypress responses are toward one end of a spectrum and are closely related to spatial stimuli (i.e., have higher dimensional overlap with them than with location-word stimuli). Vocal responses exist on the opposite end of the spectrum and are closely related to verbal stimuli (i.e., have higher dimensional overlap with them than with location stimuli). It was predicted that eye movement responses and the spatially located squares would show a similar pattern of results relative to vocal responses as manual keypresses did: an advantage for congruent responses of the spatial-eye movement and verbal-vocal pairings, indicating a difference in set-level compatibility, and a larger element-level mapping effect for the conditions with higher set-level compatibility.

Method

Participants

Twenty-four English-speaking undergraduate students (17 males) enrolled at Purdue University participated in exchange for course credit in an introductory psychology course. Participants ranged in age from 18-21 years (M = 19.3, SD = 0.9), and all participants reported having normal or corrected-to-normal vision.

Apparatus and Stimuli

Visual stimuli were presented on a 24-in. widescreen BENQ color LCD monitor with a screen resolution of 1920 × 1080 pixels. Participants sat at a distance of approximately 98 cm from the screen with a 50 cm distance between the monitor and eye tracker in a quiet, moderately lit room. Eye movements were recorded using the retinal positioning and reflection of the cornea by using a camera-based EyeLink 1000 Plus (SR Research, Mississauga, Ontario, Canada) eye tracking system at a sampling rate (or temporal resolution) of 1000 Hz. After a 9-point calibration at the outset of the experiment, gaze-position error was capped at $0.5^{\circ} \pm 20^{\circ}$. Vocal responses were collected using an Audio-Technica Cardioid ATR20 microphone with the threshold set at 0.1.

All stimuli were presented in white (RGB: 0, 0, 0) against a black background (RGB: 255, 255, 255). Spatial stimuli were a set of left-and-right placed squares placed approximately 340 pixels symmetric to the central fixation point (fixation positioned at 960 × 540 pixels). The target was designated by a white, filled in square. Each outlined stimulus (the outer square) measured 50 pixels in width and height. The (filled) target measured 30 pixels in width and height. The initially presented outline squares served as an indicator of the locations in which a target might appear in spatial stimulus blocks; at the onset of the target in one of the boxes, a response was to be executed (Vera et. al, 2013). During the verbal and spatial conditions, both left and right possible responses were presented to the subject simultaneously (i.e., the unfilled square) and remained on-screen until a response was recorded, however, the imperative stimulus was outlined by a larger square only for the spatial trials (i.e., the location stimulus appeared inside of one of the squares). Verbal stimuli were the words *left* and *right* presented in lowercase letters at a central position on the screen (replacing the fixation cross once a trial was initiated). The word *right* measured 20 mm in width and 5 mm in height, whereas *left* measured 16 mm in width and 5 mm in height.

Design

This experiment used a within-subject design, with each participant engaging in all eight conditions of a 2 × 2 × 2 factorial design for the three variables: stimulus code (location or location-word stimuli), response modality (eye movement or vocal), and mapping (congruent or incongruent). Each participant completed four blocks with one response modality before engaging in another four blocks with the other response modality (e.g., with eye movements or vocal responses). For each response modality, the two blocks with one stimulus code were presented before the other stimulus code (e.g., spatially located squares or verbal words). Finally, the orders of the response modalities, stimulus codes, and S-R mappings were counterbalanced across participants. For the congruent mapping, the right stimulus (right-located square or the word *right*) was paired with the right response (looking at the right response box or audibly saying '*right*' out loud) and similarly for the left stimulus and left response.

For the incongruent mapping, the right stimulus was mapped to the left response and the left stimulus with the right response.

Procedure

Following calibration and validation of their eye positions, participants were provided brief instructions by the experimenter prior to beginning the experiment. Participants were told to respond to the stimuli as quickly and accurately as possible. Instructions were also provided on the screen prior to each individual block to ensure participants understood the verbal instructions provided. During the experiment, there were opportunities for the experimenter to exit out of the experiment to the drift correct/calibration module in case the position of the participant's eyes was lost or the calibration was off. Participants were also allowed to take breaks between each block before moving on to the next one. During the duration of the session, the experimenter was present and sat behind the subject out of their field-of-view.

To initiate a trial, participants were presented with a centrally-positioned fixation cross on which they were required to fixate for at least 250 ms before a stimulus would trigger. Following this fixation period, the left-and-right unfilled squares appeared for 500 ms, followed by a 200 ms interval (where the unfilled squares were not present) and then the onset of the target. At target onset, the left-and-right unfilled squares remained on the screen until a response was made. Recording of responses was also set to truncate at a maximum time of 1250 ms after stimulus onset, at which point the response would be coded as erroneous; however, all responses were made within that time frame.

For blocks comprised of eye-movement responses, responses were recorded by the computer, which also collected data for the time at which the stimulus onset, the time at which the subject initiated the eye movement, and the time at which the participant averted their eyes to the appropriate target location. RT was taken as the time a left or right saccade was initiated by movement of more than 0.5°. The time at which the participants landed within a given response target (for ~50 ms) was used to determine whether the target the subject looked at was the correct response or incorrect response. For the vocal responses, the same stimuli were presented; however, the response to be made was different. The participants were to speak the word “left” or “right” in response to the stimulus presented (see Figure 3). The time at which the participants initiated their response was recorded and treated as the RT for that particular trial. Accuracy of the response was coded online by the experimenter at the end of each trial. There were a total of 60 experimental trials given over eight blocks for a total of 480 experimental trials. The experiment was scheduled for a single session and took approximately one hour to complete.

Results

Data from one participant were incomplete due to apparatus failure. Analyses from 23 participants are reported accordingly. For each participant, proportion of correct responses (PC) and mean RT for the correct responses for each of the eight conditions were calculated. Each of these measures was analyzed separately in repeated-measures analyses of variance (ANOVAs). Trials on which the initial saccade was less than 80 ms were discarded (less than 1%).

Congruent Mapping

Because set-level compatibility is defined as differences in RT and accuracy for the congruent mappings of the respective stimulus and response sets, ANOVAs were first performed on just that mapping condition, with the factors of stimulus code and response modality. Eye-movement RT was measured as shorter than vocal RT, $F(1, 22) = 226.36$, $p < .001$, $\eta^2 = .91$, and responses to spatial stimuli were faster than those to verbal stimuli, $F(1, 22) = 40.02$, $p < .001$, $\eta^2 = .65$. Of most importance, the interaction of stimulus code × response modality was significant, $F(1, 22) = 130.89$, $p < .001$, $\eta^2 = .86$. Responses were faster for the spatial-eye movement and verbal-vocal conditions ($M = 399$ ms) than for the verbal-eye movement and spatial-vocal conditions ($M = 469$ ms). This pattern indicates higher set-level compatibility for the former two combinations than for the latter two.

For PC, the ANOVA showed a main effect for response modality, with lower accuracy for eye-movement responses (PC = .845) than for vocal responses (PC = .985), $F(1, 22) = 38.28$, $p < .001$, $\eta^2 = .64$. However, there was no main effect of stimulus code, $F(1, 22) = .001$, and no modality × stimulus code interaction, $F(1, 22) = .012$.

Both Mappings

Having established a set-level compatibility effect, a similar ANOVA was conducted on each measure, with the additional factor of mapping (congruent or incongruent, corresponding to prosaccades and antisaccades for the eye-movement responses).

For RT, all three main effects were significant. As for the congruent mapping alone, spatial stimuli (*M* = 439 ms) were responded to faster than verbal stimuli (*M* = 522 ms), $F(1, 22) = 105.37$ $p < .001$, $\eta^2 = .83$, and RT was faster for eye movement responses (*M* = 384 ms) than for vocal responses (*M* = 577 ms), $F(1, 22) = 216.06$, $p < .001$, $\eta^2 = .91$. Congruency showed a main effect: RT was shorter with the congruent mapping (*M* = 434 ms) than the incongruent mapping (*M* = 526 ms), $F(1, 22) = 164.74$, $p < .001$, $\eta^2 = .88$. There was also a 2-way interaction of congruency × stimulus code $F(1, 22) = 17.48$, $p < .001$, $\eta^2 = .44$, indicating a smaller congruity effect with the spatial stimuli than the verbal stimuli, but no 2-way interaction for congruency × response modality, $F(1, 22) = 0.12$, $p = .917$, $\eta^2 = .001$.

Of most importance, the 2-way interaction of response modality × stimulus code was significant, $F(1, 22) = 146.69$, $p < .001$, $\eta^2 = .87$, but there was no 3-way interaction of those two variables with congruity, $F(1, 22) = .01$, $p = .918$, $\eta^2 = .000$. In other words, across both congruent and incongruent mappings, the pattern of results was similar to that shown for the congruent mapping alone in the first analysis. Consequently, the element-level mapping effect averaged 91 ms for the two high set-level compatibility conditions (spatial-manual and verbal-vocal) compared to 93 ms for the two low set-level compatibility conditions (spatial-vocal and verbal-manual; see Table 1). What this result means is that the higher set-level pairings of the stimulus and response sets produced as much benefit for the incongruent mapping as for the congruent mapping.

For PC, there were significant main effects for congruency, $F(1, 22) = 26.12$, $p < .001$, $\eta^2 = .54$, and response modality, $F(1, 22) = 46.48$, $p < .001$, $\eta^2 = .68$. Responses were more accurate for the congruent mapping (PC = .93) than for the incongruent mapping (PC = .87) and with vocal responses (*PC* = .99) than eye-movement responses (PC = .82). The only significant 2-way interaction was that of congruency × response modality, $F(1, 22) = 21.54$, $p < .001$, $\eta^2 = .50$. The congruency effect was larger for the eye-movement responses than for the vocal responses. The 2-way interactions between congruency and stimulus code, $F(1, 22) = 2.33$, $p = .141$, $\eta^2 = .01$, and response modality and stimulus code were not significant, $F(1, 22) = 3.03$, $p = .095$, $\eta^2 = .121$, but the 3-way congruency × response modality × stimulus code interaction approached the .05 level, $F(1, 22) = 4.16$, $p = .054$, $\eta^2 = .16$. The latter trend reflects a slight tendency for a larger congruity effect in the low set-level conditions than in the high set-level conditions, which runs counter to the prediction of the dimensional overlap model.

Discussion

The results of Experiment 1 exhibit a set-level compatibility effect, for which the congruent mappings of location stimuli to eye-movement responses and location-word stimuli mapped to vocal responses yielded shorter RT than those of location-word stimuli to eye movements and location stimuli to vocal responses. The results also showed element-level mapping effects, with congruent mappings having shorter RT than incongruent mappings. However, the element-level mapping effect was no larger when the set-level compatibility was high (e.g. spatial-eye and verbal-vocal pairings) than when it was low. Kornblum et al. (1990) would predict that the pairings of eye movements with spatial stimuli and vocal responses with verbal stimuli should yield a greater element-level compatibility effect than would the conditions with lower set-level compatibility. For example, if there is a stronger tendency to make a prosaccadic response to a location stimulus than to a location word, this should not only speed responses when that response is correct but slow them when an antisaccade is required. Yet, that result was not evident.

Comparison to Wang and Proctor's (1996) Experiment 1, which was similar except for using keypress responses instead of eye-movement responses, is insightful. Results for the verbal-vocal condition and spatial-vocal condition in Experiment 1 are qualitatively similar to the same conditions of Wang and Proctor's (1996) Experiment 1. The mapping effect was 120 ms for the verbal-vocal condition and 63 ms for the spatial-vocal condition, compared to 152 ms and 41 ms, respectively, in Wang and Proctor's experiment. Although qualitatively similar, the difference in mapping effects for vocal responses paired with verbal and spatial stimuli in this experiment is roughly half that of the difference reported by Wang and Proctor.

More revealing is the comparison of the keypress response conditions of Wang and Proctor's (1996) Experiment 1 to the eye-movement conditions of the present experiment. The element-level mapping effect was comparable for the spatial stimuli, being 67 ms for their spatial-keypress condition compared to 62 ms for the spatial-eye movement condition of this experiment. The main difference in results is that the 74 ms element-level mapping effect for the verbal-keypress condition in Wang and Proctor's experiment was almost half the size of the 123 ms effect for the verbal-eye movement condition in the present experiment. In other words, the eye movements showed an element-level mapping effect for verbal stimuli that was just as large as that shown for vocal responses, whereas the keypresses did not. Because this between-study comparison seems to show that eye-movement responses yield a different pattern of element-level mapping effects than do keypresses, Experiment 2 was designed to compare the two response modalities within a single experiment.

EXPERIMENT 2: EYE MOVEMENTS AND KEYPRESSES

The results of Experiment 1 showed the expected set-level compatibility relation for eye movements compared to vocal naming responses, but they did not show the difference in element-level compatibility effects predicted by Kornblum et al.'s (1990) model and found by Wang and Proctor (1996) for keypress responses. This was evidenced by there being no significant numerical difference in the average element-level mapping effect between the high set-level and low set-level pairings, whereas for keypress and vocal responses the high set-level conditions yielded a larger mapping effect than for the low set-level conditions. Experiment 2 was designed, therefore, to determine whether eye movements differ in set-level compatibility relations from keypresses, and whether the element-level mapping effects vary in the manner suggested by the between-study comparison of Experiment 1 to Wang and Proctor's Experiment 1. Experiment 2 used the same stimuli (left-and-right located square stimuli or verbal 'left' and 'right' words), but with keypress responses in place of vocal responses.

Method

Participants

Twenty-four (16 males) new English-speaking students (from the same pool as used in Experiment 1) ranging in age 18-21 years received experimental credit (*M* =

19.6; *SD* = 1.5) for their participation. All indicated normal or corrected-to-normal vision.

Apparatus and Stimuli

Visual stimuli were presented on the same monitor as before and from the same distance. Additionally, eye movements were recorded in the same manner as in Experiment 1. Keypress responses were recorded using a Logitech QWERTY computer keyboard. Left and right responses were recorded using the left-control (L-Cntrl) button and a right response with the right-control (R-Cntrl) buttons on the bottom row of the keyboard, on which the left and right index fingers were placed. Spatial and verbal stimuli remained the same and were presented in the same manner as in Experiment 1.

Procedure

Similar to Experiment 1, participants were told the task instructions by the experimenter as well as presented with them on screen. The same central fixation point and durations were used (see Figure 3).

Again, all variables were varied within participants in a $2 \times 2 \times 2$ factorial design for the variables of stimulus code (spatial squares or verbal words ‘left’ or ‘right’), response modality (eye movements or keypresses), and mapping (congruent or incongruent). As before, each participant completed four blocks with one response modality before moving on to the other response, and for each response modality the two blocks with one stimulus code were presented before the other stimulus code. The orders of the response modalities, stimulus codes, and S-R mappings were counterbalanced across participants.

A similar drift screen/calibration screen option was present as well as the opportunity to take breaks between block sessions. RTs were recorded similar to Experiment 1.

Results

Data from one participant was incomplete due to apparatus failure. Analyses from 23 participants are reported accordingly. Analyses performed were similar to those of Experiment 1 except instead of vocal responses, keypress responses were analyzed. The independent variables were stimulus code (verbal or spatial), response modality (eye movements or keypresses), and mapping (prosaccade or antisaccade for the eye movement condition; congruent or incongruent for the keypresses). Trials on which the initial saccade was less than 80 ms were discarded (less than 1%).

Congruent Mapping

For RT, ANOVA of the congruent mapping as a function of stimulus code and response modality revealed faster responses with eye movements than with keypresses, $F(1, 22) = 86.80$, $p < .001$, $\eta^2 = .80$, and for the spatial stimuli than the verbal stimuli, $F(1, 22) = 120.70$, $p < .001$, $\eta^2 = .85$. Critically, there was a significant interaction, $F(1, 22) = 7.59$, $p = .012$, $\eta^2 = .26$, with responses faster for the combination of spatial-eye movement and verbal-keypress (*M* = 377 ms) than for verbal-eye movement and verbal-keypress (*M* = 404 ms). This interaction indicates that eye-movement responses have relatively greater set-level compatibility with spatial stimuli compared to verbal stimuli than do keypress responses.

For PC, the ANOVA of the congruent mapping as a function of stimulus code showed a main effect for response modality, indicating accuracy was lower for eye-movement responses (PC = .895) than for keypress responses (PC = .981), $F(1, 22) = 28.71$, $p < .001$, $\eta^2 = .57$. However, there was no main effect of stimulus code, $F(1, 22) = .053$, or interaction, $F(1, 22) = 1.89$, $p = .184$, $\eta^2 = .08$, indicating that the set-level effect was mainly evident in the RT data.

Both Mappings

For the 3-factor ANOVA of RT, all three main effects were significant. As for the congruent condition alone, spatial stimuli were responded to faster ($M = 361$ ms) than verbal stimuli ($M = 515$ ms), $F(1, 22) = 182.11$, $p < .001$, $\eta^2 = .89$, and eye-movement responses ($M = 383$ ms) were faster than keypress responses ($M = 494$ ms), $F(1, 22) = 132.12$, $p < .001$, $\eta^2 = .86$. There also was a congruency effect: Participants exhibited faster reactions with the congruent mapping ($M = 391$ ms) than with incongruent mapping ($M = 486$ ms), $F(1, 22) = 180.13$, $p < .001$, $\eta^2 = .89$. The 2-way interaction of congruency × stimulus code was significant as well, $F(1, 22) = 57.22$, $p < .001$, $\eta^2 = .72$. As in Experiment 1, the congruency effect was larger for the verbal stimuli than for the spatial stimuli. Neither the 2-way interaction between congruency and modality, $F(1, 22) = 1.45$, $p = .242$, $\eta^2 = .06$, nor that between modality and stimulus code $F(1, 22) = 1.66$, $p = .210$, $\eta^2 = .07$, was significant.

Unlike Experiment 1, the 3-way interaction for congruency × stimulus code × response modality was significant, $F(1, 22) = 14.43$, $p = .001$, $\eta^2 = .40$. The element-level effect averaged 110 ms for the two high set-level compatibility conditions (spatial-eye movement and verbal-keypress) compared to 79 ms for the two low set-level compatibility conditions (verbal-eye movement and spatial-keypress; see Table 2). Comparison of the RT results for Experiments 1 and 2 showed a 4-way congruency × modality × stimulus code × experiment interaction, $F(1, 44) = 6.74$, $p = .013$, $\eta^2 = .13$, confirming that the pattern in Experiment 2 differed from that in Experiment 1.

For PC, the significant main effects were for congruency, $F(1, 22) = 50.99$, $p < .001$, $\eta^2 = .70$, and response modality, $F(1, 22) = 45.02$, $p < .001$, $\eta^2 = .67$. Responses were more accurate for the congruent condition (PC = .94) than for the incongruent condition (PC = .88) and with keypress responses (PC = .97) than with eye-movement responses (PC = .85). The two-way interaction of congruency × modality was significant, $F(1, 22) = 12.39$, $p = .002$, $\eta^2 = .36$, as was the modality × stimulus code interaction, $F(1, 22) = 11.35$, $p = .003$, $\eta^2 = .34$. The interaction between congruency and stimulus code failed to reach significance, $F(1, 22) = 1.42$, $p = .245$, $\eta^2 = .05$. Critically, there was a three-way interaction between congruency × stimulus code × response modality, $F(1, 22) = 5.09$, $p = .034$, $\eta^2 = .19$, indicating a larger element-level mapping effect for the conditions with high set-level compatibility than for those with low set-level compatibility. Again, comparison to Experiment 1 showed the 4-way congruency x modality x stimulus code x experiment interaction to be significant, $F(1, 44) = 9.202$, $p = .004$, $\eta^2 = .17$, indicating that the result patterns differed.

Discussion

The results of Experiment 2 produced a set-level compatibility effect for the congruent mapping indicating that eye-movement responses are relatively more compatible with spatial stimuli compared to verbal stimuli than are keypress responses. This outcome suggests that eye movements reside closer to the spatial end of the spectrum than do keypress responses (see Figure 2, bottom panel). An implication of this proposed relation is that spatial location stimuli tend to activate the corresponding response more strongly for eye movements than for keypresses. This relation can be seen in Table 2, which shows that the advantage in congruent RT for the spatial stimuli compared to the verbal stimuli is 147 ms for eye-movement responses compared to 92 ms for keypress responses.

Unlike Experiment 1, a significant element-level mapping effect was evident between the conditions classified as of relatively high-set level compatibility and those classified as low-set level compatibility. However, this difference was due mainly to the keypress responses, which showed a much larger mapping effect with the location-word stimuli (148 ms) than with the location stimuli (51 ms). Keypress responses were faster to the latter stimuli than to the former ones for both congruent and incongruent mappings, but the difference was larger for the incongruent mapping, resulting in the smaller mapping effect.

Comparison of the eye-movement conditions to the comparable ones from Experiment 1 and of the keypress conditions to those of Wang and Proctor (1996)'s Experiment 1 again is informative. The eye-movement responses show a smaller element-level mapping effect with spatial stimuli than with verbal stimuli, although the difference (36 ms) is not as large as in Experiment 1 (61 ms). The keypress responses show a different result pattern than in Wang and Proctor's experiment: The element-level mapping effect is 97 ms larger with the verbal stimuli than with the spatial stimuli in the present experiment compared to being only 7 ms larger in Wang and Proctor's experiment. The reason for this discrepancy is not entirely clear. But it is apparent that the much larger element-level effect for the verbal-manual condition accounts for the larger element-level mapping effect for the high set-level category in the present study, into which it is grouped on the basis of the set-level analysis of the congruent mapping conditions. Perhaps the presence of the boxes throughout the experiment produced competing spatial codes that manifested in the selection of responses. That is, during the verbal trials, participants saw both the left/right-located squares and the centrally positioned word (i.e. either "left" or "right"). The boxes could have impacted the participants' performance by producing competition with the verbal stimulus information.

As noted, the combination of conditions with relatively higher set-level compatibility also showed a larger element-level mapping effect. Wang and Proctor (1996) concluded that while the element-level compatibility effect was an increasing function of set-level compatibility, this was largely due to the congruent mapping. In contrast, the dimensional overlap model (Kornblum, 1990) would predict that as facilitation and interference increase when set-level compatibility increases, stimulus code and response modality for the incongruent mapping should interact similarly. However, because this pattern was only observed in the congruent mapping they concluded this was due entirely to the congruent mapping. The present experiment shows a dissimilar pattern in which the effect is present in both the congruent and incongruent mappings.

Wang and Proctor's (1996) Experiment 3 with aimed movements similarly shows a set-level compatibility effect for the congruent mapping as the other experiments (Experiment 1: keypresses; Experiment 2: arrow stimuli) for the spatially-manual and verbal-vocal conditions than the spatial-vocal and verbal-manual conditions. The average element-level compatibility effect was larger for the two high set-level compatibility than the low set-level compatibility. However, there was also a significant set-level compatibility effect for the incongruent mapping. It should be noted that while present, this effect was very small (24 ms) for the high vs low compatibility categories. Again, this pattern of results is inconsistent with the dimensional overlap model. Comparisons between the present Experiment 2 and Wang and Proctor's (1996) Experiment 3 reveal that they produce similar numerical values. Their average mapping effect for the high set-level spatial-manual and verbal-vocal conditions (100 ms) is greater than the one for the low set-level spatial-vocal and verbal-manual conditions (74 ms). The current Experiment 2 produced a similar pattern with high set-level combinations spatial-eye and verbal-keypress (110 ms) greater than low set-level combinations spatial-keypress and verbal-eye movements (79 ms). The eye movements seem to closely resemble the pattern of Wang and Proctor (1996) spatial-manual conditions (44 ms) and verbal-manual conditions (97 ms). The spatial-eye conditions and the verbal eye conditions produced average effects of 71 ms and 107 ms, respectively. While the effect numerically conforms to the results of Wang and Proctor (1996), it appears that this difference in effect is smaller (53 ms vs 36 ms). One possible explanation is that eye movements behave similarly to aimed movements once a response is executed.

GENERAL DISCUSSION

The present experiments used saccadic eye-movement responses and compared them to keypress and vocal responses. Because of the increased use of eye movements in psychology experiments, research into the technology is warranted if eye tracking is to be used as a response type (compared to keypresses, vocal responses, joystick movements, mouse movements, etc.). For Experiment 1, eye movements were compared to vocal responses when made to spatial and verbal stimuli. A set-level compatibility effect was evident for the congruent mapping, with the spatial-eye movement and verbal-vocal conditions together showing faster responses than the spatial-vocal and verbal-eye movement conditions. However, the element-level mapping effect was no larger for the conditions of high set-level compatibility than for those of low set-level compatibility. Of importance, incongruent (antisaccadic) trials in the eye-movement condition saw even more benefit of location stimuli compared to verbal stimuli than did the congruent (prosaccadic) movements, resulting in a smaller congruency effect for saccadic eye movements to physical location stimuli than to location words.

Accounting for the Size of Effects

The difference between antisaccades and prosaccades for spatial stimuli was only 62 ms. It should be noted, though, that others have found small effects, including

Ethridge, Brahmbhatt, Gao, McDowell, and Clementz (2009). In their experiment, participants completed prosaccade and antisaccade responses in three different blocking conditions: blocked, long-lead interleaved, and simultaneous interleaved conditions. They found a modest 37 ms RT effect (for the spatial stimuli). Likewise, Pratt and Trottier (2005) found a similar prosaccade and antisaccade difference in a task when they investigated prosaccade and antisaccades to onset and offset targets. Their Experiment 1 “onset target” condition was similar to that of the present set of experiments. In the onset target condition, participants were presented with an initial centrally located-circle (black) followed by a colored fixation (green) and then the target. In the onset condition, participants were to make a prosaccade to the target or an antisaccade to the mirror-location. In the offset condition, participants initially saw the centrally-located circle (black) then two potential target locations followed by the disappearance of one of the peripheral targets. Participants were again instructed to make a prosaccade to the target or an antisaccade to the opposite location. The results indicated a reliable difference between prosaccades (236 ms) and antisaccades (294 ms) leading to a 58 ms difference between the two.

The present Experiment 2 also produced a similar set-level compatibility effect for the congruent mapping, with the spatial-eye movement and verbal-keypress conditions together yielding faster responses than the verbal-eye movement and spatial-keypress conditions. This outcome implies that the eye movement responses have relatively higher set-level compatibility with the spatial than verbal stimuli compared to the keypress responses. In Experiment 2, though, the element-level mapping effect was larger for the high-set level compatibility conditions than for the low-set level compatibility conditions. In the context of the spectrum proposed, it can be concluded that that eye movements have relatively higher set-level compatibility with spatial stimuli than with keypresses.

Eye Movements as Aimed Movements

Proctor and Wang (1997) looked at alternative manual response sets including aimed movements and keypresses, considering both bimanual and unimanual responses for each condition. In one experiment, participants made bimanual aimed movements and keypresses on a keyboard. No significant stimulus code × response type interaction was evident for either the congruent or incongruent conditions. On this basis, Proctor and Wang concluded that there was neither a difference in set-level compatibility nor in the size of element-level compatibility. In another experiment, participants made bimanual and unimanual aimed movements on a screen to verbal and spatial stimuli. The authors attributed the differences found in a distinction between bimanual and unimanual responses as the basis for the differences in set-level compatibility (for spatial-verbal stimuli).

Indeed, the present experiments can be thought of in terms of this bimanual and unimanual distinction. One might think of eye movements as equivalent to a unimanual response and keypresses as a bimanual response. Wang and Proctor (1996) highlight that while unimanual responses also have a left-right target component, the central location (fixation) must also be encoded. Furthermore, this center location is where the verbal stimuli are presented rather than where they are presented for the spatial trials (farther left-right locations). Future research might consider manipulating the presence of the left-and-right located unfilled target boxes during the fixation of each trial.

Anticipation and Prediction

In Experiment 2, eye movements showed higher set-level compatibility then keypresses for the congruent trials. One possible explanation is that there was stronger activation when the mapping was congruent. However, the pattern of results also replicated when the mapping was incongruent, suggesting that the benefit was available in this condition as well. This finding is counter to the automatic activation account as one would expect to see this benefit only for the congruent mapping. Perhaps the presence of the unfilled squares had an impact on the ability of the presented stimuli to evoke a natural, automatic response to an object appearing in participants' field of view on the congruent trials, such that the squares' presence was beneficial regardless of the mapping (whether incongruent or congruent). By alluding to the potential target areas before the participants are to make their response, perhaps the current experimental manipulations allow the participants some preparatory period which subsequently impacts the overall automaticity of the saccadic eye movements. That is, participants are "tipped off" to the location at which they *could* make a saccade and the present findings are the result of some anticipatory mechanism.

These 'predictive saccades' have been systematically investigated (Findlay, 1981; Shelhamer & Joiner, 2003, Lee et al., 2016; Stark, Vossius, & Young, 1962). Participants were presented with a target scheduled to alternate between two locations with a fixed temporal frequency. Within a few alternations (less than five), they began to make predictive saccades prior to the target's appearance in an alternative location. Furthermore, this led to saccades arriving at the target around the same time as the target onset. The phenomenon also appears to be persistent. Joiner and Shelhamer

(2006) found that when they allowed three saccades at a given frequency, participants were able to generate temporally accurate predictive eye movements. This effect persisted even when the stimulus frequency was changed; participants continued to generate up to three predictive saccades at the original frequency, despite having been changed. With regard to this potential issue, it should be noted that the present experiments attempted to avoid this by randomly presenting the stimuli to the subject. However, with a two-choice reaction time task, participants have a 50% chance of correctly predicting the location of the target. Similarly, for the present experiments, the area in which the participants needed to fixate was designated as approximately 150 pixels in width and height (this information is not available to participants). However, attempts were made to restrict this fixation AOI (area of interest) such that it was as small as possible to rule out any anticipatory effects.

Pairings With Other Types of Directional Stimuli

It is also possible that eye movements would better benefit from a pairing with directional stimuli such as left or right pointing arrows or eye gaze stimuli rather than verbal stimuli. Wang and Proctor (1996) also looked at arrow stimuli paired with keypresses or vocal responses in their Experiment 2. While they found an interaction for the congruent mapping, they did not find a similar pattern for the incongruent mapping as was found in the present Experiment 2. Furthermore, their results replicate the findings of Experiment 1 where there were set-and element-level compatibility effects and imply that manual responses pair fairly well with arrow stimuli. While the evidence for pairings with arrow stimuli is compelling, perhaps there is a pairing that might be an even more advantageous. Wolohan and Crawford (2012) examined saccadic performance in a gaze cueing paradigm with faces. In their experiment, participants were presented with two trial types: GTT (gaze toward target) or GAT (gaze away from target). They found that GTT trials were responded to significantly faster than that of GAT trials. Their results reveal a significant set-level compatibility effect for the congruent mapping that is similar to the results of the present Experiment 2. Experiment 2 also produced a benefit for the incongruent mapping ($p < .001$) that was also evident in Wolohan and Crawford's (2012; $p < .00$) experiment. It is reasonable to assume based on these results that when paired with gaze-directed stimuli, eye movements could possibly benefit more than when paired with other types of spatial stimuli (location squares, arrows, etc.).

Related to this point, Gregory and Hodgson (2012) highlight the fact that there is conflicting evidence in the literature regarding gaze cues automatically activating responses compared to non-biological cues such as the aforementioned arrows. In their experiments, they found that gaze, and not arrows, facilitated saccadic latencies (Experiment 1), directional word cues produced no reliable effect (Experiment 2), and finger pointing cues reduced latencies at short SOAs (Experiment 3). That is, for antisaccades, only socially and biologically relevant gaze cues were able to influence saccadic response. It should be noted, however, that in their experiment the gaze cue was irrelevant. The researchers acknowledge that this is in direct opposition of what is posited by research on covert attention (e.g., Hommel, 2001) and conclude that this effect may be different in contextually-related scenarios where attention needs to be directed (i.e., gaze relevant).

Top-Down and Bottom-Up Considerations

Due to the small mapping effects evidenced for eye movements in the present experiments, one possibility is that this set of experiments did not sufficiently tap into potential top-down or bottom-up influences. Many bottom-up manipulations can be employed within the eye-tracking paradigm. One of particular interest, in light of the current experiment set, is to consider varying the number of distractors present within a subject's field of view during experimental trials. The present experiments used a two-choice reaction task where participants may not have had a true salient distractor, which in turn did not significantly impact saccades (antisaccades in particular) as predicted. That is, while the target did elicit an automatic tendency to generate a saccade, a benefit was found for both the congruent and incongruent mappings.

Perhaps the congruent-based tendency would present itself more strongly when a larger set of distractors is used, thus diminishing the effect for the incongruent mapping. Doing so might impact antisaccade trials in such a way that is consistent with the automatic activation account. Theeuwes et al. (1998) varied the number of potential targets to which a subject could make a saccade. Participants were presented with six circular stimuli arranged around a centrally-located fixation. At the onset of a trial participants were instructed to make a saccade toward a color singleton when all but one of the six peripheral circles changed in color. On half of the trials, a distractor was present at one of four locations concurrently with the color singleton. The results showed that on half of the distractor trials, a saccade was initially made to or near the distractor followed by a correction to the singleton. Additionally, latencies significantly increased. The authors suggested that the presence of the cue facilitated an attentional shift to the singleton's location prior to the presentation of the distractors. In essence, there was facilitation to the singleton's location instead of the distractor.

Stimulus Eccentricity

Similarly, the eccentricity from the central fixation point may be of great importance. Previous research has found that the farther a distractor is located from the target, the lesser the degree of oculomotor interference that is present (Doyle & Walker, 2001; McSorley, Haggard, & Walker, 2009). In the present set of experiments, the target and potentially unintended distractor (the square at a mirror opposite positioning) were equi-distant from one another. As mentioned, participants had access to potential location of the target. Thus, participants' degree of uncertainty toward the target/saccadic goal may have been diminished such that a strong tendency to make an automatic eye movement emerged but, again, had no significantly different impact on the congruent mapping as compared to the congruent mapping. However, many studies have shown that it *is* possible to reduce prosaccade latencies. A solution lies in presenting a cue (as opposed to the aforementioned proposal to increase distractors) to the participants prior to the onset of the stimulus. Positive effects of gaze cueing have been shown both in the presence and absence of eye movements (Posner, 1980; Cavegn, 1996). Similarly, a relationship such that the presence of an incongruous cue target will increase latencies and also impact detection has been shown (Walker, Deubel, Schneider, & Findlay, 1997).

Task Demand Considerations

Taken together, the presence of distractors and/or cues suggests the possibility of increasing the demands of the task more generally. Trottier and Pratt (2005) investigated the influences of top-down processing and the impact on response latencies by giving participants two different task instructions: 1) make a saccade as fast as possible to a peripheral target (*look condition*), and, 2) to determine whether the center of a target was displaced to the left or right (*look-obtain condition*). They found shorter SRT's (saccadic reaction times) for the *look-obtain* condition than for the *look* condition. Their results indicate that saccadic latencies can be reduced when participants must identify properties of a target rather than simply making a reflexive saccade. Guyader et al. (2010) followed up on this work by investigating identification of a target and its effects on saccade latencies. They used a cueing paradigm where a cue was presented before the target. Participants were instructed to either identify or simply glance at targets. They found an effect of task instruction (gaze or identify) for the prosaccade latencies but not for antisaccades. The researchers concluded that this was due to two processes required in generating an antisaccade. These two processes are first characterized by inhibition of an initial eye movement and then the generation of a (new) voluntary saccade (Munoz & Everling, 2004; Abegg, Sharma, & Barton, 2012). Given these results, it is plausible that the benefit for the prosaccades in the current experiment set would be that much more significant, especially if antisaccadic latencies remain the same. That is, it seems possible to facilitate prosaccade latencies but not antisaccades latencies and also maximize the benefit of the congruent mapping.

Individual Differences in Working Memory

Differences in working memory capacity might also be considered. Working memory processes are thought to play a critical role in inhibition of responses (Mitchell, Macrae, & Gilchrist, 2002). It has been proposed that the prefrontal cortex

(PFC) and superior colliculus (SC) play a critical role in modulating antisaccadic and prosaccadic movements, respectively. To investigate the differences of attentional mechanisms, Mitchell et al. (2002) looked at dual and single tasks. In their dual-task manipulation (Experiment 1), participants performed prosaccades and antisaccades concurrently with an n-back task aimed at taxing the “fronto-executive” load. There were three types of *n*-back tasks: *0*-back, *1*-back, and *2*-back. Compared to controls, all of the (dual-task) *n*-back conditions resulted in increase of error as well as increased latencies for both congruent prosaccade and antisaccade trials. The researchers noted that these effects are not only present for low-working memory or aging individuals, but can also be induced in a laboratory setting based on instruction. Similarly, Berggren, Hutton, and Derakshan (2011) recruited individuals who experience self-reported cognitive failures in addition to healthy adults for a standard pro/antisaccade task. Their analysis revealed that for the antisaccadic trials, load significantly increased response latencies; however, load did not significantly impact error rates.

Crawford, Parker, Solis-Trapala, and Mayes (2011) likewise found that differences in working memory capacity did not have an impact on antisaccadic errors. While antisaccadic errors were strongly indicative of prosaccadic mean response times, these differences were not due to differences in working memory. In antisaccade trials, participants were instructed to “direct their gaze towards a position in space, equally distance but in the opposite direction to the target, as quickly and as accurately as possible”. In the prosaccade trials, participants were instructed to “direct their gaze towards the target lights as quickly and accurately as possible”. Working memory was assessed by recollection of words recalled in the correct order after which participants were assigned to either a high-working memory or low-working memory condition. As previously stated, no interaction among the antisaccade task and group (high versus low) was shown. Instead, the researchers attributed their findings to the speed of saccadic programming. They highlight that in a standard antisaccade task, working memory may not be relevant because “there is only a single salient stimulus” (Crawford et al., 2011). Instead, the effect might reveal itself in the context of multiple distractors where there is more competition. The present experiments more closely resemble that of a standard antisaccade (and prosaccade) paradigm. Furthermore, because no explicit attempts were made to gauge participants’ working memory capacity any potential effects cannot be evaluated at this time.

Switch Costs

One last consideration is that of the possibility of potential switch costs. In the present experiment set, participants completed blocks of all prosaccade or antisaccades before switching to the other. Hodgson et al. (2004) replicated Hallet and Adams (1980) original findings that produced no difference between pro and antisaccade trials when they were presented within the same block. Interestingly, they found a significant reduction in errors on antisaccadic trials such that errors were lower on trials immediately following a task switch. On this basis, effects of task switching for the present experiments are not attributed to the pattern of results obtained.

CONCLUSION

In two experiments, I tested various combinations of stimulus and response for eye movements, keypresses, and vocal responses. The experiments revealed a reliable set-level compatibility effect (congruent mapping) for spatial-eye movement and verbal-vocal conditions. Response times were faster than with the spatial-vocal and verbal-eye movement conditions. However, the element-level differed across the experiments with one indicating no larger effect for high set set-level compatibility relationships (Experiment 1) while the other did show a larger effect for high set-level compatibility relationships that was mainly due to keypress responses (Experiment 2). Comparisons to Wang and Proctor's (1996) experiments reveal that the pattern of results obtained is most consistent with eye movements behaving similarly to that of the aimed movements. The fact that a benefit was available in both the congruent and incongruent mappings is inconsistent with the automatic activation account proposed by Kornblum et al. (1990).

A high degree of dimensional overlap would predict a reciprocal high degree of automatic activation for the congruent mapping. Analyses revealed a benefit in the incongruent mapping that is puzzling. The use of a two-choice task may have imparted some influence on the result such that there was no strong competition for resources where a congruent (prosaccade) mapping would have a benefit over the incongruent (antisaccade) mapping. That is, future research should consider the effects of task demands. The fact that eye movements produced the expected pattern of benefit from pairing with spatial stimuli rather than verbal stimuli suggests that there is a degree of automaticity present. The present eye-movement data in Experiment 2 resemble that of the pattern obtained in Wang and Proctor’s (1996) Experiment 3 with aimed movements. While the difference between Wang and Proctor’s spatial-manual and verbal-manual pairings was numerically larger than the current Experiment 2 (53 ms vs. 36 ms), they are consistent with one another. On this basis, I posit that eye movements share similar properties of both automaticity and continuousness.

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APPENDICES

Appendix A

Table 1

Experiment 1: Reaction Time in Milliseconds and Proportion Correct (in Parentheses) for Left, Right and Both Responses on Congruent and Incongruent Trials for Each Stimulus-Response Set Pairing (Classified as High and Low Set-Level Compatibility), With Mapping Effects (Incongruent – Congruent Reaction Times) for the Respective Pairings Indicated

	High Set-Level Compatibility		Low Set-Level Compatibility	
Mapping	Spatial-Eye	Verbal-Vocal	Spatial-Vocal	Verbal-Eye
Left response				
Congruent	297 (.83)	522 (.99)	537 (.98)	405 (.86)
Incongruent	327 (.79)	646 (.99)	608 (.97)	517 (.75)
Right response				
Congruent	255 (.91)	523 (.99)	541 (.99)	395 (.88)
Incongruent	340 (.78)	641 (.99)	596 (.99)	513 (.73)
Both responses				
Congruent	276 (.87)	523 (.99)	539 (.99)	400 (.87)
Incongruent	338 (.79)	643 (.99)	602 (.98)	523 (.74)
Mapping effect	62	120	63	123
Avg. Mapping Effect	*92*		*93*	

Table 2

Experiment 2: Reaction Time in Milliseconds and Proportion Correct (in Parentheses) for Left, Right and Both Responses on Congruent and Incongruent Trials for Each Stimulus-Response Set Pairing (Classified as High and Low Set-Level Compatibility), With Mapping Effects (Incongruent – Congruent Reaction Times) for the Respective Pairings Indicated

	High Set-Level Compatibility		Low Set-Level Compatibility	
Mapping	Spatial-Eye	Verbal-Keypress	Spatial-Keypress	Verbal-Eye
Left response				
Congruent	269 (.89)	499 (.97)	402 (.99)	417 (.91)
Incongruent	338 (.79)	633 (.92)	439(.98)	522 (.83)
Right response				
Congruent	263 (.89)	477 (.98)	391 (.98)	409 (.90)
Incongruent	336 (.79)	639 (.93)	455 (.99)	518 (.80)
Both responses				
Congruent	266 (.89)	488 (.98)	396 (.99)	413 (.91)
Incongruent	337 (.79)	636 (.93)	447 (.99)	520 (.82)
Mapping effect	71	148	51	107
Avg. Mapping Effect	*110*		*79*	

Appendix B

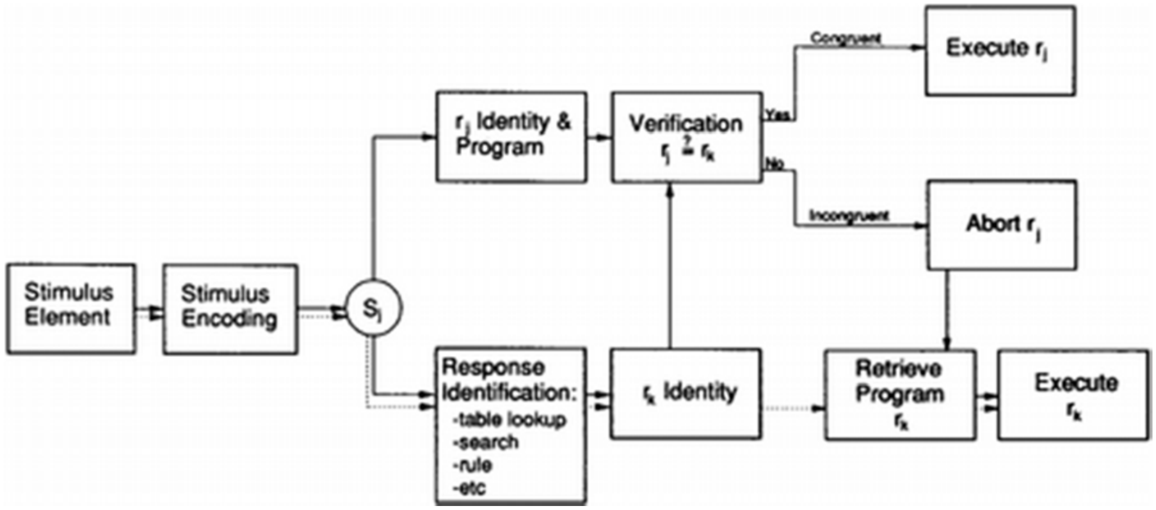

Figure 1. Kornblum et al.'s (1990) model of the information-processing operations in stimulus-response (S-R) compatibility tasks when dimensional overlap is present (solid lines) and when it is absent (dotted lines). Top branch: The automatic route through which automatic activation (for the congruent response) occurs for sets with dimensional overlap. Bottom branch: The intentional route, through which identification of the correct response as assigned for the task occurs. From S. Kornblum, T, Hasbroucq, & A. Osman, Dimensional Overlap: Cognitive Bias for Stimulus-Response Compatibility-A Model and Taxonomy. *Psychological Review, 97*, 253-270, 1990. American Psychological Association. Reprinted with permission.

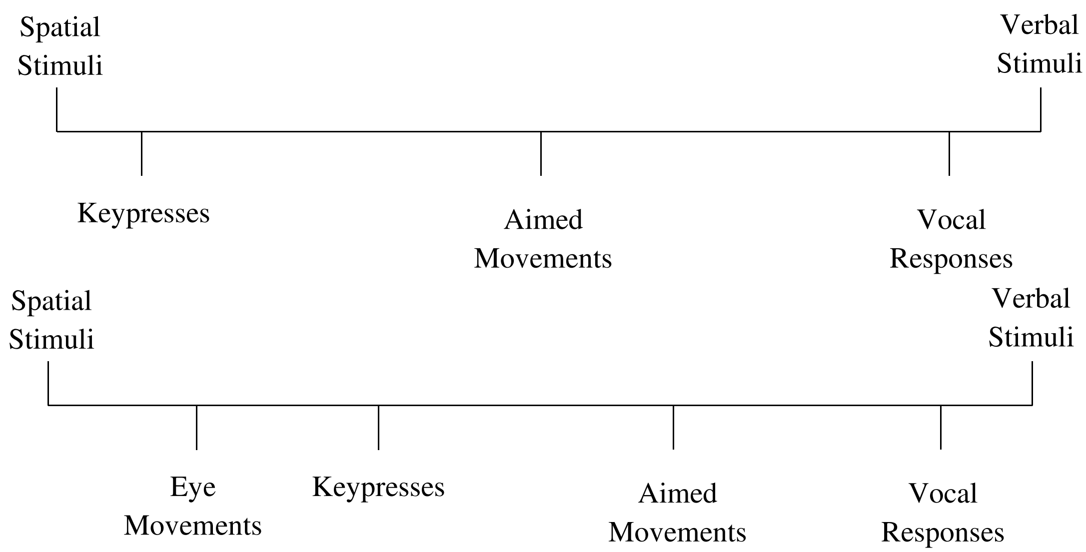

Figure 2. Top panel: The spectrum depicting the relative compatibility of different response types with spatial and verbal stimuli. Close proximity to the left indicates a relationship with spatial stimuli and close proximity to the right indicates a relationship with verbal stimuli (Wang & Proctor, 1996). Bottom panel: The relative compatibility of spatial stimuli with eye movements.

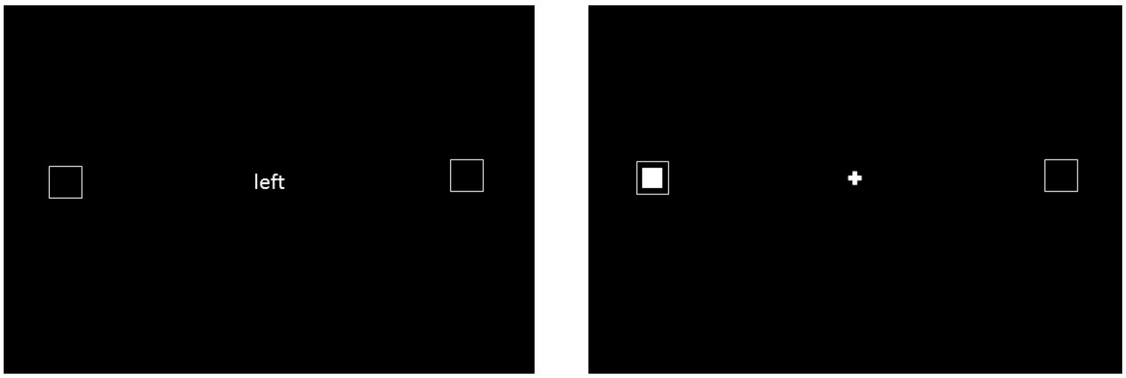

Figure 3. Experiment 1: Example trial types for the verbal (left; location-word stimuli) and spatial (right; location stimuli) trials. On a prosaccade, participants looked to the peripheral target (spatial trial) or to the target indicated by the location-word stimulus (verbal trial). For antisaccade trials, participants looked to the opposite of the peripheral target to the mirror-located target (spatial trial) or to the opposite target indicated by the location-word stimulus (verbal trial). For vocal responses, participants audibly indicated the congruent location (of the location target) or to the incongruent location (opposite location of the target). For verbal trials, on congruent trials, participants indicated the location-word or the opposite (incongruent).