MORE THAN MEETS THE EYE: STIMULUS-RESPONSE COMPATIBILITY EFFECTS IN EYE MOVEMENTS

by

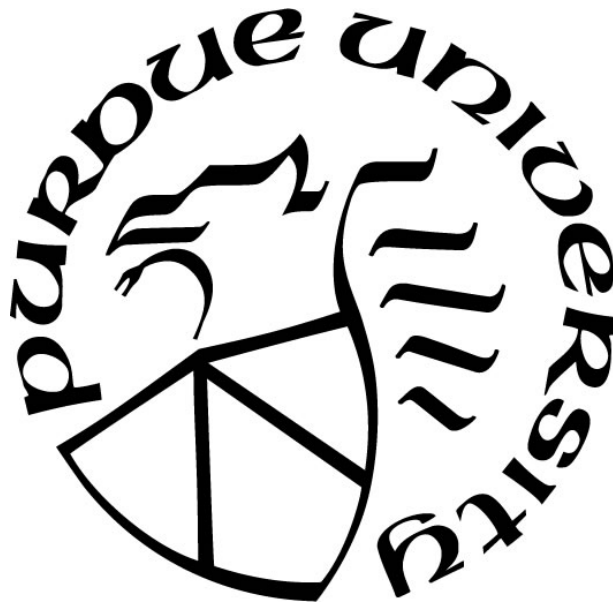**Courtney Janai Griffin-Oliver**

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ABSTRACT

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Distinctions between set- and element-level compatibility have been made regarding stimulus-response compatibility (SRC) effects. Prior research has revealed a relationship between these two types of compatibility such that an increase in set-level effects results in an analogous increase in element-level effects. There are different ways that location information can be conveyed visually: location-words ("left" and "right"), directional-arrows (pointing *left* and *right*), and physical-locations (stimuli appearing in the *left* or *right* areas of the visual field). Set-level compatibility is higher for location-words paired with vocal "left"-"right" responses than for the other two stimulus modalities, and vice versa for pairings with left-right keypress responses, and the element-level compatibility effects differ in size accordingly.

My dissertation research focused on examining set- and element-level compatibility effects within the saccadic eye-movement system. These effects were considered within the dimensional overlap framework proposed by Kornblum, Hasbroucq, and Osman (1990), according to which the element-level mapping effects are an increasing function of set-level compatibility. All experiments were conducted using introductory psychology students.

In Experiment 1, participants responded using a left-right unimanual joystick movement or eye movement to a location-word or physical-location stimulus. In addition

to an analysis of variance (ANOVA) of mean reaction time (RT) and response accuracy for the respective conditions, compatibility effects across the RT distribution were investigated by dividing trials into quantiles. Experiment 1 produced a set-level compatibility effect for the congruent mapping: Eye-movement responses (rather than joystick movements) were found to be relatively more compatible with physical-location stimuli than with location-word stimuli. In addition, the high set-level compatibility conditions exhibited a larger element-level mapping effect than the low set-level compatibility conditions. RT distribution analysis showed that both eye- and joystick-movements yielded a steadily increasing element-level mapping effect across bins, except for physical-location stimuli mapped to joystick responses, for which the function was flat.

In Experiment 2, the location-word stimuli used in Experiment 1 were replaced by directional-arrow stimuli. Eye movements (and not joystick movements) showed larger set- and element-level SRC effects when paired with physical-location stimuli than with directional-arrows. As in Experiment 1, the physical-location stimuli paired with eye-movement responses demonstrated an increase in the element-level mapping effect across the RT distribution. However, for the three other three set-level pairings, the element-level mapping effects were relatively constant across the RT distribution. This pattern further indicates a preferential benefit for eye movements paired with physical-location stimuli.

Experiment 3 directly compared the location-word stimuli used in Experiment 1 and the directional-arrow stimuli used in Experiment 2. The element-level mapping effect was larger for location-words than for directional-arrows, but both types of stimuli

produced similar interaction patterns regarding the set-level manipulation. That is, the differences between each response modality and stimulus type produced similar patterns of element-level mapping effect differences. The location-word stimuli produced consistently large effects and served as a driving factor across the set-level comparisons. The location-words showed a large increase in element-level mapping effect across the RT distribution compared to only a small increase for the directional-arrows, which in both cases did not differ between eye- and joystick-movement responses.

Together the three experiments provide support for the hypothesis that eye-movement responses to physical-location stimuli are a unique, highly optimal set-level pairing relative to location-words or directional-arrows denoting spatially relevant location. In the context of a continuum outlining the relative position of different response and stimulus pairings, the results imply that eye-movement responses are similar in compatibility to joystick movements, except for the specific pairing with physical-location stimuli.

The results offer some support for Kornblum et al.'s (1990) account that suggests a tightly coupled relationship between set- and element-level compatibility effects. Not only do the results provide understanding about the existence of compatibility effects within the saccadic system, they allow for some considerations about how attention is allocated preferentially to certain stimuli rather than others. They also enable predictions about similar underlying mechanisms that might be involved in saccadic and manual response modalities. Taken together, it seems that the eye-movement system adheres to conventional notions about motoric behavior; however, it also has its own unique properties that make it highly tuned to exogenously guided stimuli.

INTRODUCTION

Characterizations of the human mind have been shaped no doubt by great strides in computer technology. In fact, one prominent viewpoint, information-processing theory, likens the mind to a computer (Sternberg & Sternberg, 2012). Conceptualization in this manner presents a complex, intertwined network of circuitry whereby information is introduced into a system through sensory processing. Perception is enacted in a way such that it draws upon reserves of attentional resources, long-term memory, and working memory. Once the objects are perceived, an appropriate response is selected and then executed accordingly. A simple way to conceptualize this is through the summation of these processes into three main components: perception, response selection, and response execution, along with attention and memory (Wickens & Hollands, 2000; see Figure 1). While these processes can be isolated and studied in terms of their individual contributions, the way they work in tandem is more critical to understanding how the human mind operates. Yet, systematic inquiry into the human information-processing benefits of individual components enables one to get at the underlying mechanisms that culminate in the human perceptual experience.

To this end, I have elected to study this intertwining relationship using compatibility tasks. Furthermore, I am specifically interested in visual attention and how/where individuals allocate and direct attention. Moreover, conscious and unconscious distribution of attention is considered. This dissertation makes use of the stimulus-response compatibility (SRC) task in which only a single, relevant stimulus is presented on each trial, to which an assigned response is to be made. This task avoids competition from irrelevant stimuli or features, as in the flanker task (in which flanking

stimuli are irrelevant; Eriksen & Eriksen, 1974) and the Simon task (in which stimulus

location is irrelevant; Simon, 1990). Moreover, I have opted to deviate from traditional

use of keypress responses. Popular use of keypresses is likely due in part to use of

computer-based systems in most research settings. However, there remain other response

modalities that have not received much consideration until recently, including eye

movements, the focus of the present study.

Again, the advantageous nature of computer technologies has been a feat of

human ingenuity. We are now able to consider other methods of response to infer

behavioral characteristics, some more unconscious and non-deliberate, than before. For

example, functional magnetic resonance imaging (fMRI) research has aided in the

development of biomedical imaging (e.g., Weis, Estner, Krick, Reith, & Lachmann,

2015). While keypresses are the archetype used to investigate SRC effects, other types of

response modalities, including vocal, foot pedal, and aimed (arm/hand) movement

responses (e.g., Proctor & Vu, 2005), have been used. For vocal responses, reaction time

(RT) is the time from stimulus onset until the first utterance of a response is made.

Response accuracy is typically coded in real-time by the researcher. Foot-pedal responses

have also been used in attempts to disassociate effects of laterality of effectors in general

from those due to left-right keypress responses. Nevertheless, compatibility effects still

emerge in all these cases.

In the interest of solidifying the nature of the relation between stimulus input and

response output in manual response sets, with the goal of understanding motoric

behavior, another response-mode candidate is eye movements. The reasoning for this lies

in the relative similarity between eye movements and other left-right manual responses

compared to vocal responses. Eye tracking is the process of measuring gaze by the eyes relative to the position of the head (Duchowski, 2017). Eye tracking has been used in a variety of capacities including psycholinguistics, human-computer interaction, user-experience design, and education. At present, relatively inexpensive and minimally invasive methods of studying eye movements are widely available. Rayner (1998) asserted, "Eye movements provide an unobtrusive, sensitive, real-time behavioural index of ongoing visual and cognitive processing" (p. 373). Given this property, eye-tracking presents an especially compelling opportunity to study SRC as there are many overlapping features that eye movements share with other typically used response modalities, including keypresses. Notably, the way that compatibility research defines congruent or incongruent responses can be applied analogously to eye movements through prosaccadic and antisaccadic behavior. Eye movements also afford investigation of many issues in visual attention, more generally.

Stimulus-Response Compatibility

SRC effects occur when certain ensembles of stimuli and responses are paired together leading to benefits for some pairings, rather than others, in part due to the way in which these stimuli and responses are arranged. For example, a set of digits can be used as the stimulus component while a vocal response can be used as the response mode. Here, an optimal mapping of digit stimulus (i.e., the numbers "1" or "2) and accompanying vocal response (i.e., saying "one" or "two" audibly) emerges. On the other hand, a [digit] stimulus and a vocal response for which the mapping is counter (i.e., stimulus: "1" or "2" and response: "two" and "one", respectively) will lead to decrements in performance (Kornblum, 1992). Performance is typically measured through RT and

accuracy. These RT measures are further qualified and quantified by differences between congruent and incongruent experimental conditions, with the former yielding shorter RT than the latter. For accuracy, a similar disparity between congruent and incongruent trials can be observed. That is, congruent trials lead to greater accuracy, while incongruent trials lead to more error-prone performance. The treatment of stimulus and response set combinations (rather than their individual aspects), necessitates a distinction between different types of compatibility effects – namely, set- and element-level compatibility.

Set-Level Effects

Set-level compatibility explores the relationship between comparisons of optimal stimulus and responses ensemble pairings themselves (e.g. comparisons between "digit stimuli-vocal responses" or "directional arrow stimuli-keypress responses"). In this example, the first relationship (digit-stimuli and vocal responses), for which persons say the name of the stimulus digit, will yield faster response selection (i.e., greater set-level compatibility) than one that compares digit-stimuli and keypress responses, for which each digit stimulus is assigned a unique response (Kornblum et al., 1990). Accordingly, stimulus and response sets interact with their corresponding [stimulus and response] codes (Wang & Proctor, 1996).

Although outside the scope of many SRC studies, set-level effects are important when attempting to consider all factors that have an impact on stimulus-response (S-R) relationships. In two studies, Fitts and Seeger (1953) evaluated set-level compatibility by instructing participants to move a stylus as rapidly as possible in the direction of a single stimulus light or dual stimulus lights. They used a variety of stimulus arrays including one with eight possible choices (S_A, each appearing at 45˚) forming a circle, one with four

choices (S_B, 90˚) forming a diamond and one with horizontal left-right or up-down (S_C, 180˚). Analogous response sets were denoted (R_A, R_B, R_C). With some response sets, participants were to respond using two hands, whereas for others they were to respond using a single hand. Fitts and Seeger found that every pairing of stimulus set with its corresponding response set (e.g., stimulus set A paired with response set A) produced better performance than the pairings with non-corresponding response sets (e.g., stimulus set A paired with response set B or C). Thus, they concluded that to achieve fast responses, the specific S-R ensembles must be arranged such that the transfer of information from stimulus to response is direct. This means that the arrangements minimize the number of recoding steps necessary to translate the stimulus into a response (Fitts & Seeger, 1953).

Greenwald (1970) also discussed the role of set-level compatibility in developing his ideomotor theory, which asserts, "Voluntary responses are centrally represented in the form of images of the sensory feedback they produce and… these images play a controlling role in performance of their corresponding actions" (p. 20). He provided an example whereby if a sensory image (e.g., spoken letter name) is presented and to which a response in a specific modality is to be made (e.g., vocal letter name), correspondence in the same modality will rapidly activate the response. Across five experiments, stimulus modality and response task were varied such that participants were presented with visual and auditory letter or digit stimuli while being required to speak (naming) or write (printing) the presented letter or digit. The results indicated an interaction between stimulus and response modalities. If a written response was required, performance was

best if the stimulus was visual, and if a spoken response was required, performance was best if the stimulus was auditory.

Dimensional Overlap Model

The dimensional overlap model proposed by Kornblum et al. (1990) describes a relationship whereby the overlap between shared properties and/or features is the critical driving factor. Kornblum (1992) and Kornblum et al. (1990) assert that this is due to conceptual similarity as well as physical similarity. When stimulus and response sets have a high degree of overlap, the degree of compatibility is likewise high. This account (see Figure 2) is best understood as a sequence of information-processing operations that produce sufficient activation, which in turn elicits a response.

The process begins with the initial presentation of a stimulus. The stimulus and its constituent parts must be encoded in a meaningful manner. That is, relevant features of the visual stimulus must be extracted from its representation to be subsequently processed. Identification and initiation of an appropriate motor program occurs whereby activation occurs via automatic and intentional response-selection routes. Two possible options exist: First, if the responses activated by the two routes match, as is the case with a congruent S-R mapping, the motor program is executed without interruption. Alternatively, if there is a mismatch in the responses activated by the two routes, as with an incongruent mapping, then the program that is activated automatically must be aborted, a new program retrieved, and then executed. These differences account for the behavior produced. This can be further qualified in terms of overlap possibilities. If concepts overlap conceptually (e.g., via spatial information), set-level compatibility will be higher if they also are perceptually similar (or, what Lu & Proctor, 2001) called mode

similarity, than if they are not (e.g., left and right locations mapped to keypress responses compared to left and right words).

Element-Level Effects

Within the present cognitive psychology literature, the S-R relationship at the element-level mapping is typically the central focus (Dassonville et al., 2001). This is the relationship characterized by investigations of individual stimulus-set members and their mapping onto particular response sets (i.e., digits and/or vocal naming; Wang & Proctor, 1996). It can also be defined in terms of match, that is, congruence in the mappings among individual members of the response and stimulus sets (Fitts & Deininger, 1954, p. 490). At the element-level, responses are faster and more accurate with the congruent mapping rather than the incongruent mapping.

One should take caution to avoid attempts at definitively designating a 'best type of display or response'; it is more appropriate to designate or better or worse ensemble code (Fitts, 1959, p. 7). In other words, it is the relative combination of both sets together rather than the individual contributions of the stimulus or response set (Kornblum et al., 1990), as in the dimensional overlap model. Furthermore, Kornblum et al. (1990) asserted that in terms of set- and element-level compatibility, set-level compatibility involves a representational aspect. Conversely, element-level effects are more involved in processing matters. "Representation" determines the amount of automatic activation of the corresponding response. "Processing" determines whether that automatically activated response is the correct response (i.e., the congruent mapping) or not (i.e., the incongruent mapping). Conjunctively, the two imply that the input and subsequent output

are intertwined – with the most benefit accruing to a congruent element-level mapping for stimulus and response sets with high set-level compatibility.

Regarding the relationship between stimulus and response sets, more optimal pairings of stimulus and response sets are said to yield greater set-level compatibility (Proctor & Wang, 1997). These set-level compatibility comparisons, although not typically focused on, are important when attempting to consider all factors that have an impact on S-R relationships wholly. That is, although element-level compatibility experiments have provided considerable information about coding of stimuli and responses, there is much to be learned by also considering the set-level impacts. One of the benefits investigations of this nature stand to offer is to provide an understanding of the underlying mechanisms and forces at play within visual attention and the execution of responses. Extensive investigations into set-level compatibility effects and manipulations provide insights into the predictions that can be made by having prior knowledge about a given pairing of stimulus and response sets. These predictions can lead to other, novel situations in the laboratory studies, such as the nature of saccadic eye movements, which have been studied previously in other contexts. In addition, in applied or practical applications, the design of many technologies that are dependent on knowing how a human operator will behave has implications for taking advantage of and utilizing the knowledge gained for design purposes.

Studies Investigating the Relation Between Set- and Element-Level Compatibility

The topic of compatibility has a rich history steeped in methodically controlled and constrained investigations. As a result, many studies using a variety of stimuli and response sets have been considered. The research born of these studies has helped to

solidify many theories as well as enabling specific predictions given what is currently known. A variety of spatial stimuli and response modalities of various response effectors have been explored. For example, it is known that if a given spatial stimulus set (e.g. directional-arrows) is paired with an appropriate response set (e.g. keypress responses); more overlapping features are available to facilitate a fast and automatic response corresponding to the stimulus (Lu & Proctor, 1995). Compare this situation to one in which the [spatial] stimulus and response sets do not have many overlapping features (e.g. vocal responses and unrelated stimuli), and a disparity in performance emerges (Lu & Proctor, 2001). This pattern of results has been replicated numerous times across stimulus and response modalities. Some of the stimuli include directional-words, directional-arrows, and tones (presented to the left and right ears). Response effectors have included foot pedal responses, aimed unimanual/bimanual movements, vocal responses, and unimanual joystick movements (Kornblum, 1992; Teichner & Krebs, 1974; Wang & Proctor, 1996).

Across four experiments, Wang and Proctor (1996) examined set- and element-level compatibility by varying stimulus codes and response modalities. In Experiment 1, participants were presented with a spatial stimulus, a square presented in a left or a right location (physical-location), or a verbal stimulus, the word *left* or *right* (location-word). Manual responses involved a left or right keypress while a vocal response required an audible utterance of "left" or "right". In all cases, the mapping could be congruent or incongruent. The individual stimulus and response pairings were grouped into pairs of conditions designated as high (spatial-manual and verbal-vocal) or low (spatial-vocal and verbal-manual) set-level compatibility based on differences in RT for the congruent

mappings. The results revealed a larger element-level mapping effect for the pair designated as high set-level compatibility than for that designated as low.

In three other experiments, Wang and Proctor (1996) varied response and stimulus pairings. In Experiment 2, they replaced the spatial stimuli with arrows indicating a left or right direction, while the verbal stimuli remained constant. Experiments 3 and 4 utilized aimed movement responses (on a touchscreen), whereby participants made a movement to a target location using their index fingers. These two experiments also considered performance of aimed movements paired with vocal responses (Experiment 3) and keypress responses (Experiment 4).

In all four experiments, Wang and Proctor (1996) found that high set-level pairings were accompanied by a larger element-level mapping effect. It should be noted that this relationship was most strongly evidenced in their third and fourth experiments. Clearly, the results of those latter experiments demonstrated the greater amount of dimensional overlap present between given stimulus and response sets.

Moreover, Wang and Proctor's results corroborated Kornblum and Lee's (1995) prediction that element-level effects are largest when the degree of set-level compatibility is highest. Consequently, a continuum for stimulus and response pairings was posited such that keypress responses are best paired (i.e., having higher set-level and producing a larger element level effect) with spatial stimuli, vocal responses with verbal stimuli, and aimed movements falling mid-place. As such, element-level compatibility is said to be an increasing function of set-level compatibility.

Compatibility Effects With Spatial Stimuli

Regardless of whether spatial information is relevant or irrelevant, compatibility effects can be studied. Both types of effects have been studied using stimuli that convey location information including directional-arrows, physical-locations, and location-words. For tasks in which stimulus location is irrelevant, the resulting correspondence effects are called Simon effects, rather than SRC effects. One main difference between the SRC and Simon effects is that when location information is irrelevant, the effect is typically smaller than when it is relevant (Vu & Proctor, 2004). Two response routes are often implicated: (1) a direct route that considers that the corresponding response is automatically activated because of long-held associations, and (2) an indirect route, where there is deliberate translation (of the short-term nature) based on the current demands of the task (Kornblum & Lee, 1995). The congruent S-R mapping seems to benefit from both routes compared to an incongruent mapping.

Physical-Locations

As noted, spatial information can be conveyed in several ways, with the most popular being with physical-locations, directional-arrows, and location-words. In the case of physical-locations, Craft and Simon (1970) tasked participants with pressing a left or right button to colored lights that conveyed information about direction. Using a modified viewer equipped with a visual field partition, stimuli were presented monocularly (Block 1), such that they were seen in the left or right visual field, or binocularly (Block 2), such that they were perceived as located in the center. Red or green command lights indicated a right (button) response to a red light or left response to a green light. The other half of the participants responded with an opposite color-response mapping. When the stimuli

were presented monocularly, responses were faster when the eye stimulated (and perceived location) was congruent with the response than when it was incongruent. A second experiment modified the participants' field of view such that with monocular presentation the lights were perceived as centrally located. Here, with the directional cue removed (as in the blocked condition of Experiment 1), there was no congruity effect, indicating that stimulus location and not eye that was stimulated was the crucial factor. When location conflicts with the response signaled by the color, participants must inhibit an initial response tendency, which, in turn, delays responding.

Location-Words

In word-naming tasks, some of the seminal work is born from studying spatial variants of the Stroop task in which both the relevant information and irrelevant information are spatial (e.g., Luo & Proctor, 2013). For example, vocally naming a location requires more processing time when a location-word stimulus does not agree with the location. In addition, if participants are instructed to make a manual response to the word stimulus, then differential patterns emerge such that keypresses benefit less than vocal responses paired with the same word stimulus (Luo & Proctor, 2013).

Directional-Arrows

Directional-arrows depicting left and right locations have also been investigated. Eimer (1995) found that when directional-arrows are used and paired with keypresses, their compatibility is comparable to the pairing of keypresses with physical-locations. Furthermore, directional-arrow stimuli tend also to be stronger than location-words when paired with keypresses (Liao & Wang, 2015). An explanation for these disparities relies on differences in the stimulus dimension as well as the response dimension. Again, the

more similar the stimulus and response sets are across these features, the stronger the association.

Pure vs. Mixed Blocks

The dimensional overlap model predicts that the element-level mapping effect should persist irrespective of how the location information is presented, although the size of the effect may differ. This means that whether location information is conveyed using physical-locations, directional-arrows, or location-words, and whether the response modality is vocal location names or keypresses), conceptual similarity is sufficient to produce effects. Furthermore, presentation of the mappings in pure blocks of only congruent or incongruent trials or in blocks in which congruent and incongruent trials are mixed should not matter, either, because automatic activation of the corresponding response is assumed to occur in all cases (Vu & Proctor, 2004). However, Shaffer (1965) provided evidence of an elimination of the effect when trials were presented in a mixed setting. He instructed participants to respond to left-right physical-locations with a left or right keypress. A horizontal or vertical line was presented simultaneously with the location stimulus to signify congruent and incongruent mapping, respectively. Mean RT for pure blocks in which mapping was constant was significantly faster than for mixed blocks, and the mixed blocks showed no indication of a benefit for the congruent mapping. De Jong (1995) also found that SRC effects for arrow stimuli were reduced if presented in mixed blocks of congruent and incongruent mappings compared to pure blocks of only a single mapping.

Accordingly, researchers have posited an explanation for this elimination of the SRC effect in mixed settings: the suppression account. The suppression account assumes,

like Kornblum et al.'s (1990) dimensional overlap model, that response selection proceeds through a direct or indirect route. The key difference is that the response can be initiated without requiring intentional response identification through recruitment of the direct route rather than the indirect route (de Jong, 1995; Stoffels, 1996a, 1996b). Because of overlearned associations, the direct route is a more efficient use of resources when trials with congruent mapping are presented in a pure block. For mixed blocks, the direct route is suppressed because it would result in conflict on trials where there in an incongruent mapping (Vu & Proctor, 2004).

In this case, physical-locations and directional-arrows stand to benefit more from presentation in a pure blocking procedure compared to location-words. While location-words paired with manual keypress responses have conceptual similarity but no perceptual similarity (Proctor & Wang, 1997; Wang & Proctor, 1996), physical-locations and directional-arrows are both visuospatial stimuli and benefit from pairing with manual [keypress] responses, accordingly.

Compatibility Effects Across RT Distributions

Different types of spatial representations produce different compatibility effects across RT distributions. Ratcliff (1979) introduced the Vincentizing analysis of group RTs by separating congruent and incongruent trials into various bins (e.g. the fastest 20%, next fastest, etc.; Miles & Proctor, 2012). For each bin, compatibility effects are calculated and plotted accordingly. When the results are laid out in this manner, one of the most common tendencies is for SRC effects to increase linearly with RT (Miles & Proctor, 2009; Vu & Proctor, 2004), although Simon effects typically decrease (Proctor, Miles, & Baroni, 2011).

Simon Effects

When spatial information is irrelevant, as it is with the Simon effect, the effect size changes across the distribution. De Jong, Liang, and Lauber (1994) found that Simon effects for stimuli presented to the right and left with accompanying left and right responses, decreased as RT increased. One explanation for this is that visuomotor processes are activated rapidly but then dissipate over the course of time, if they are irrelevant to the task. A conflicting response can be programmed that might interfere with task-relevant features. When stimuli are presented in a left-right fashion, visuospatial codes are posited to be activated whereas with other types of spatial information (e.g. location-words), semantic-spatial codes are activated. For these other types of spatial information, however, the reverse occurs: Simon effects increase (Pellicano, Lugli, Baroni, & Nicoletti, 2009). This may be because location-words (with semantic-spatial signals) are not processed as efficiently as those with more general spatial signals.

SRC Effects

When spatial information is relevant, element-level SRC effects for all (spatial) stimuli increase as RT increases (Miles & Proctor, 2009; Vu & Proctor, 2004). Vu and Proctor (2004) investigated this relation by displaying colored location stimuli in a pure or mixed blocking procedure that varied between participants. In the pure conditions, participants were instructed to respond compatibility or incompatibly solely based on the location information. In the mixed condition, participants were to use the color of the stimulus to determine whether the mapping was congruent and incongruent, and to respond appropriately. They found that pure blocks, rather than mixed blocks, produced a larger SRC effect for physical-locations and directional-arrows than for location-words.

This provides evidence that there is more perceptual and conceptual similarity for physical-locations and directional-arrows compared to location-words. In contrast, for mixed blocks, the relative sizes of the SRC effects reversed. With physical-locations and directional-arrows, the SRC effect was eliminated, as in the studies of Shaffer (1965) and de Jong (1995), whereas for location-words, the SRC effect increased.

Vu and Proctor (2004) explained that, for location-words mapped to keypresses, if automatic activation via the direct route were not suppressed, then the SRC effect during the mixed block should be of similar magnitude to that in the pure condition. Yet, the SRC effect increased in the mixed condition, which means that a secondary mechanism was at work in determining the magnitude of the effect. An RT distribution analysis for the pure block showed an increase at the shortest bins that did not peak until the latter four bins. For the mixed block, the SRC effect for location-words was evident at the first bin and only increased thereafter. Evidence for this enhanced effect for location-words (to manual keypresses) is posited to be due to the activation of corresponding names of the location-word stimuli. Furthermore, the activation of location-words would be greater at the time of response selection (Vu & Proctor, 2004).

Prosaccades and Antisaccades

The saccadic system is characterized by rapid movements of both eyes between two or more phases of fixation in the same direction (Leigh & Zee, 2015). Saccades allow an organism to take in visual input by using reflexive saccades or scanning saccades. Reflexive (pro-) saccades are exogenously generated by the presence of a stimulus in peripheral vision. Antisaccades are the avoidance of looking toward the stimulus at onset. In general, they occur in a delayed fashion and lead to more errors

because individuals must inhibit the initial reflexive prosaccade before voluntarily moving in the correct direction (Guyader, Malsert, & Marendaz, 2010; Munoz & Everling, 2004). Prosaccades do not involve inhibition and instead are reflexive – like other response modalities (i.e., keypresses).

Many studies have considered the left-right dimension of prosaccadic and antisaccadic eye movements. Similarly, many compatibility studies have dealt with stimuli on the horizontal dimension (Proctor & Reeve, 1990). In the context of SRC, dominance on the left-right dimension rather than the above-below dimension has also been studied (Nicoletti & Umiltà, 1984, 1985; Rubichi, Vu, Nicoletti, & Proctor, 2006). Several interpretations for this dominance have been proposed. First, perhaps the use of the left and right hands is more naturally spelled out than for the above-below dimension (Proctor & Reeve, 1990). However, this does not provide a definitive answer as a similar pattern of results with hands only persists in mixed-modality settings where the hand and foot are recruited as responses (Nicoletti & Umiltà, 1985). Another possibility is that attention is selectively allocated to the left-right dimension, however, use of tones in place of visual stimuli has ruled out this possibility as well. Finally, using a paradigm like that of Nicoletti and Umiltà (1984, 1985), Hommel instructed half of the participants to respond in terms of vertical locations and another half in terms of horizontal locations. He found that for both the horizontal and vertical planes, SRC effects were still evident. Thus, it is possible to see effects in the vertical plane, particularly when participants' instructions match the dimension to which they should respond.

Compatibility Effects in Eye Movements

Eye movements, like other manual responses, can produce compatibility effects. Bertera, Callan, Parsons, and Pishkin (1975) demonstrated SRC effects in the oculomotor system. They measured RT using simple- and choice-reaction tasks. In the simple task, tones were presented randomly to the left or right ear that were to be responded to with a left saccade in one trial block or a right saccade in another. In the choice-reaction task, participants were make a left or right saccade based on the pitch (high or low) of a tone in the left or right ear (the latter of which was irrelevant). In the simple RT task, no correspondence effects emerged. For the choice RT task, however, a Simon effect occurred for which RT was facilitated when the tone was located in the ear congruent with the saccade that was to be made. Comparing eye-movement and manual responses, Bertera et al. concluded, "Since the compatibility effects… are so similar between hand and eye-movement responses we might speculate that the response codes for left and right are quite similar between the two systems" (p. 180).

In their investigations, Khalid and Ansorge (2013) found Simon effects could be studied with eye movements. They presented participants with colored location-words for which color was the relevant dimension. Based on the color, participants were to make a saccade in the correct direction but to ignore the word meaning. Khalid and Ansorge (2013) also compared their eye-movement responses to keypresses. The Simon effect for word meaning was evident for keypresses and eye movements, but the RT distribution patterns differed. Whereas the word-based Simon effect with keypress responses increased in size across the RT distribution, as in Vu and Proctor's (2004) study, the effect with eye-movement responses decreased.

Hodgson, Parris, Gregory, and Jarvis (2009) also found that linguistic cues could prime behavior. Participants were to respond to one of four stimulus colors (red, green, blue, or yellow) presented in the center of a display screen by making a saccade to the corresponding color patch, located in an up, down, left, or right location. The centered color stimulus could spell out an irrelevant color word (red, green, blue, or yellow) or irrelevant response location (up, down, left, or right). A congruity effect was found for both the color words and location-words, with saccadic RT being longer for incongruent than congruent trials. The authors conclude that location-words can directly activate saccadic responses, much as they do keypresses and other response types.

Attention

Attention is known to play a significant role in the processing of visual stimuli and accompanying motor behavior within the human organism (Henderson, 1992; Klein, 1980; Kustov & Robinson, 1996). Many strides have been made in attempting to understand and characterize the underlying mechanisms behind attention and its effects on guiding human motoric behavior. One way in which to the study this relationship between attention and motor execution is SRC relations and investigations into their impacts in a variety of visual processing and motor response paradigms.

Within the world, there is a gap between the totality of visual information that is available to people and their finite ability to process all facets of this information. As such, the unique manner by which the human visual system has evolved to be arranged dictates perceptual experience. This relationship has been considered through investigations of visual attention (Egeth & Yantis, 1997). Sighted individuals are constantly bombarded with visual information that must be processed through a

sophisticated neural network. How this process occurs has historically been (and continues to be) a major focus of studying human information processing. Distinct and common mechanisms have been proposed, investigated, and yielded subsequent generations of models. Furthermore, distinctions between different types of attention have been made. These distinctions include top-down versus bottom-up selective attention, spatially directed selective attention versus attention based on features or objects, and the processing of stimuli without an accompanying orientation versus orienting movements (Moore & Zirnsak, 2017).

Top-Down Attention

Top-down attention concerns the execution of control using knowledge structures to guide perception. According to Dror and Fraser-MacKenzie (2008): "Top-down influences include, among other things, contextual information, expectation, what we already know, hope, motivation, and state of mind" (p 54). When an organism is confronted with a visual scene, a complex network of brain states changes to accommodate the variety of influences from incoming stimuli. That information has the potential to be transduced so that, if warranted, some action could be taken in the natural environment.

Bottom-Up Attention

Bottom-up attention refers to the automatic and stimulus-driven nature of perception. Salient features of a stimulus critically drive this relationship whereby the more of these salient features that are available, the more likely they are to capture (or attract) attention. These features may include physical properties of a visual stimulus such as luminance, color, size, orientation, and movement (Morland, Jones, Finlay,

Deyzac, & Kemp, 1999). One way to conceptualize this is in terms of recognizing how different the incoming stimulus is to divert and devote attention to it. This salience is the result of low-level processing that occurs early in visual processing.

Although top-down and bottom-up considerations have individual merits when attempting to conceptualize the visual experience, the two are not mutually exclusive. A stimulus that is initially driven by salient features at the outset (bottom-up) can be overridden by factors such as task demands, goals, or expectations (top-down). Understanding of these influences of top-down and bottom-up attentional processes has been well investigated in cognitive psychology.

Why Eye Movements Matter for Visual Attention

One might think of eye movements as "an observable behavioral expression of the allocation of attention in a scene…eye movements serve as a window into the operation of attention." (Henderson, 2011, p. 596). The human visual system facilitates the processing of visual input such that conscious and unconscious control can be exerted accordingly. Furthermore, eye, head, and body movements jointly work in tandem to create a visual experience that guides cognitive and behavioral activity (Land, Mennie, & Rusted, 1999). In an increasingly chaotic world, eye movements often dictate a person's understanding of the external environment. One important consideration is that in lieu of processing all objects in a given scene simultaneously, some force must be exerted such that the most important or goal-relevant features are paid attention to preferentially. As such, the relationship between attention and saccadic eye movements has been hypothesized to be a closely linked one.

Numerous psychophysical works have offered insights into the relationship between the saccadic system and attention (Awh, Armstrong, & Moore, 2006). Of interest is the possibility of common neural substrates that guide saccades as well as play a role in the deployment of spatial attention. Some of the areas that have been implicated as being involved in both oculomotor and attentional systems are the frontal eye field (FEF) and the superior colliculus (SC). To understand whether there is a causal link between selective spatial attention and programming of saccades, researchers have turned to psychophysical and neurophysiological work (Awh et al., 2006). For example, Hoffman and Subramaniam (1995) had participants initiate a saccade to a location while detecting a target prior to any eye movement. The researchers varied the location of the to-be-detected target such that attention and saccadic planning could be investigated. They found that when there was overlap between target location and detection site, attention to that location was deployed most optimally.

Deubel and Schneider (1996) also found evidence for shared mechanisms between the perceptual and motor systems. At the neurophysiological level, investigations of specific brain areas believed to be recruited by both areas have proved to be fruitful. This has involved the micro-stimulation (in non-human primates) of areas like the FEF, which has produced heightened awareness of changes in luminance and increases in sensitivity despite not evoking saccades to an attended to target (Moore & Fallah, 2004). Along with other studies, this result suggests a cluster of cells that are involved in the visuomotor system that is responsible for oculomotor control and visual selection (Awh et al., 2006).

A few prominent theories that have come about because of conceptualizations of attention and saccadic behavior include the premotor theory of attention (Casarotti, Lisi, Umiltà, & Zorzi, 2012) and orienting vs. alerting networks (Posner, 1980). The former asserts that programming of a saccade causes a shift in attention, whereas the latter suggests that saccadic programing is a by-product of attentional shifts (Hutton, 2008). Although the theories posit two different processes by which attention is deployed through eye movements, the fact that the two are enmeshed remains undisputed. This further provides evidence for overlapping neural substrates, although the exact organization of these areas remains debated. One issue that arises from this debate is that attention can vary counter to eye movements. That is, attention can be focused on a specific location while the eyes are diverted elsewhere (Casarotti et al., 2012).

More computational-based models have been suggested to counter the premotor theory of attention account and its relation to eye movements. These models propose a possible network of areas that exist to serve differing functions. For example, Posner (1980) posited two such networks: the orienting and alerting networks. He classified orienting as the alignment of attention by sensory input or some internally guided system that can be extrapolated from memory stores. This alignment is accomplished through selections of a modality or location (Petersen & Posner, 2012). Neuroimaging has offered support for the recruitment of brain areas such as the frontal, parietal, and posterior areas – and the FEF. As such, it is often associated with coding for directed motor or eye movements (Petersen & Posner, 2012). On the other hand, alerting (i.e., arousal) is the process by which attention is attracted and sustained. Neurally, this alerting is accomplished by the release of specific neurochemicals such as norepinephrine.

Most of this dissertation places special focus on the orienting network, and, distinctions between exogenously and endogenously driven stimuli. First, the way attention can be exerted must be established: externally (exogenous) or internally (endogenous). Exogenous orienting reflects the influence of a given stimulus such that it elicits a reflexively automatic movement in response to its presence in the periphery (area outside of the fovea). In contrast, endogenous orienting relies on internal shifts of attention to a predetermined location. This endogenous orienting can be accomplished in several ways by being willfully enacted or through imposed task demands. One key distinction between the two is that exogenous orienting (in the periphery) is less susceptible to outside interference relative to endogenous (central) orienting (Müller & Rabbitt, 1989). That is, endogenous cues are more readily ignored than exogenous ones.

Yantis and Jonides (1984) also provided evidence for preferential responses to the abrupt onset of stimuli rather than gradual introduction. Adopting a method from Todd and Van Gelder (1979, Experiment 5), participants were exposed to a standard visual search task with targets and non-targets. Of interest was the type of stimulus onset. For each trial, one item was presented with an abrupt onset while the distractors were presented such that camouflaging pre-masks were removed gradually (to avoid abrupt offsets). They found a processing advantage for stimulus onset relative to those where an abrupt presentation was absent. Like Posner (1980), Todd and Van Gelder attributed this to the evocation of comparisons made with the target item's representation in memory. On trials where there is a match, a positive response is emitted, whereby the opposite occurs when there is a mismatch.

Integration of SRC and Eye-Tracking

There are many overlapping similarities between SRC research and investigations into saccadic behavior. First, congruent and incongruent responses can be analogously studied by looking at prosaccades and antisaccades. Second, both tend to use stimuli arranged on the left-right, horizontal dimension (rather than the vertical one). Finally, differences in RT and accuracy between prosaccades/antisaccades and congruent/incongruent responses are present. That is, a similar decrement in response latency and accuracy are noticed for antisaccades relative to prosaccades. With these considerations in mind, I investigated whether there is anything special about the saccadic system over and beyond other response modalities. Of interest is spatial SRC effects. Given the wealth of information available that suggests that eye movements respond most favorably to stimuli with spatial connotations, I elected to examine the specific conditions that provide optimal benefits.

Previously, I found differences in set-level compatibility with response sets using eye movements compared to vocal responses (Experiment 1) and keypress responses (Experiment 2; Griffin-Oliver, 2016). Visual stimuli consisted of squares presented in left and right locations ("physical-locations") or centrally as verbal words 'left' and 'right' ("location-words"). Set –level effects were assessed by looking at the congruent mapping of visual and verbal stimuli. Element-level effects compared differences between congruent and incongruent mappings.

In Experiment 1, I also found a set-level effect for the congruent mappings: the high set-level pairing (physical-locations/eye-movements and location-word/vocal responses) yielded shorter RT than the low set-level pairing

(location-words/eye-movements and physical-locations/vocal responses). In this case, the element-level mapping effect for the high set-level pairing was not larger than the low pairing, as predicted. However, an additional experiment revealed this expected link between set-level element-level effects when eye movements and keypresses were compared (Griffin-Oliver, 2016). While these set- and element-level compatibility effects were present, they were not as large as expected. Specifically, I predicted that eye movements paired with spatially relevant stimuli would produce very large effects given the amount of overlap (conceptual and perceptual) between the stimulus and response modalities.

Consequently, I conducted a follow-up experiment which revealed that the way the physically-located stimuli are presented matters. In Experiment 1 of Griffin-Oliver (2016), target box information was available to participants prior to the onset of the imperative stimulus. In subsequent work, I found that removal of the target boxes prior to stimulus presentation produced the expected large set-level benefit for saccadic eye movements over other response modalities (e.g. keypresses and vocal responses). This result provided further evidence that exogenously-driven physical-location stimuli produce large effects relative to verbal location-words or to advance knowledge about physical-locations. Questions remained, however, about exactly where eye movements fell along the continuum of response modalities proposed by Wang and Proctor (1996).

Implications

The present experiments were aimed at directly comparing eye-movement responses and joystick- movement responses. To date, no considerations at the set and element levels have been made for these response modality pairings. This poses a missed

opportunity for a variety of reasons. First, investigations of eye movements offer a unique opportunity as they share some overlapping features with manual responses. If the logic of Kornblum et al.'s (1990) dimensional overlap model is applied, then eye-movement responses paired with spatially-relevant stimuli should produce the expected fast and automatic activation that characterizes stimulus and response sets with high dimensional overlap. In contrast, a pattern of results counter to this would imply that, in certain cases, seemingly optimal pairings of stimulus and response sets do not always produce large compatibility effects. This latter outcome would likely mean that the saccadic system is uniquely designed and not beholden to the same conceptions as manual response types.

At the same time, eye movements possess their own, exclusive properties with exogenously triggered stimuli said to be highly automatic. Because of this high degree of automaticity, studying the saccadic system rather than manual keypress responses has the potential to increase understanding of human perception and action. Given that eye movements occur automatically, study of the saccadic system offers a chance to put predictions of Kornblum et al.'s (1990) dimensional overlap framework to the test, namely that eye movements paired with physical-location stimuli should possess the highest degree of dimensional overlap, which translates into very large compatibility effects.

The experiments examined three types of spatial stimuli, with the aim of testing the specific conditions that must be met for set-level compatibility effects to emerge and their resulting relations to the element-level mapping effects. Additionally, joystick movements were recruited as the manual response modality for purpose of comparison. One reason is that keypress responses are, generally, bimanual responses, that is

responses made by different fingers, one on each hand. Consequently, joystick movements share more similarities as a response with eye movements than perhaps bimanual keypress responses do. Second, joystick movements should also benefit from being paired with spatial stimuli (rather than verbal location-words) approximately similar to the way that eye movements should. Presently, we know that, on a continuum, eye movements exist more closely related to keypress responses and aimed movements than to vocal responses. What remains unclear is the exact degree of this relationship. Together, use of different types of spatial stimuli, with response modalities that both stand to benefit, should help to sort out the exact nature of this relationship between eye-movement and other physical-spatial responses in the same experimental setting.

These experiments also considered differences in compatibility effects across the RT distribution, as laid out by Ratcliff (1979). It is known that increases across the distribution from the fastest and slowest bins typically show increasing element-level mapping effects for relevant stimulus information. As discussed previously, this is a consequence of using spatial stimuli, but the exact basis of the increase remains unknown. Given that eye movements behave relatively similarly to manual keypress responses, a comparable increase across the RT distribution is likely. What remains to be seen is by what magnitude. Furthermore, analyses of this nature allow for direct comparisons to existing knowledge about RT distributions. Given the high amount of overlap between stimuli and responses for eye movements and spatial stimuli, it is likely that distributional analyses will reveal a pattern that is at least comparable if not stronger than for other types of response modalities.

Purposeful use of highly salient spatial stimuli presents an opportunity to carefully and methodically study the conditions that must be met without outside influences factoring in. Furthermore, use of three different types of spatial stimuli that all convey information about location in some manner places necessary constraints on the conditions. A pattern of results whereby eye movements perform preferentially with verbal stimuli would suggest that eye movements are more closely related to aimed joystick movements rather than keypresses. On the other hand, if eye movements exhibit a result pattern more closely resembling that of keypress responses, this could indicate high similarity between those two response modalities. The possibility for some underlying shared mechanisms exists as well.

However, because eye movements are characterized as highly automatic, this implies that dimensional overlap paired with spatial stimuli is very high. Evidence to that effect would provide support for Kornblum et al.'s (1990) predictions about set- and element-level effects. Alternatively, the results may support the suppression hypothesis. This claim is because the present study makes use of stimuli presented in pure blocks of a single mapping rather than in a mixed-mapping setting. In this case, one would expect a similar pattern of results for directional-arrows and physical-locations compared to location-words. Finally, it is also possible that selection of eye movements is unrelated to keypresses or aimed joystick movements. This result would impact the organization of the continuum proposed by Wang and Proctor (1996), suggesting that eye movements are unique and may not adhere to traditional conceptualizations of manual response sets.

EXPERIMENT 1: PHYSICAL-LOCATION VS. LOCATION-WORD STIMULI

Wang and Proctor (1996) conducted an experiment in which they compared left-right keypress and vocal responses mapped to location-word and physical-location stimuli. They found the typical element-level mapping effect for all S-R combinations, as well as a significant set-level effects (i.e. differences in RT for the congruent mapping). Congruent location stimuli paired with keypresses and verbal stimuli with vocal responses resulted in faster responses than those of locations with vocal responses and verbal stimuli with keypress responses. The pairings with higher set-level compatibility yielded larger element-level mapping effects. That a relationship between set and element-level effects exists suggests that changes to the SRC effect is a result of variations of perceptual and conceptual similarity between the stimulus and responses.

I sought to examine this relationship in Experiment 1 using eye-movement responses in lieu of vocal responses as well as joystick movements as the manual responses instead of keypresses. One of the first relations that needed to be established was whether eye movements are more like joystick-movement responses) or keypresses. Previously, I found that whereas eye movements produced element-level compatibility effects as keypresses did (Griffin-Oliver, 2017), the pattern of results obtained was more similar numerically to that produced by aimed movements (as evidenced in Wang & Proctor, 1996). This experiment compared eye movements and joystick movements to see if that pattern persisted. That is, would eye movements and joystick movements produce different or similar effects?

If eye movements are like manual movements, we might conclude that there is little difference between the two response modalities and that eye movements are closer to aimed movements than to keypresses on Wang and Proctor's (1996) proposed continuum. In their Experiment 4, the element-level mapping effect for spatial stimuli paired with keypresses was 61 ms and with aimed movements was 38 ms. Additionally, the element-level effect for verbal stimuli was 68 ms with keypress responses and 95 ms with aimed movements. On this basis, Wang and Proctor proposed their continuum whereby the increase in (element-level) magnitude for one stimulus was qualified by a decrease in the magnitude for the other type. If a different pattern of element-level mapping effects were revealed in favor of eye movements, that finding would provide evidence that eye movements and joystick movements are indeed different and eye movements preferentially benefit from being paired with spatial stimuli.

Method

Participants

Twenty-four English-speaking undergraduate students (17 males) enrolled at Purdue University were recruited. Participants were compensated with course credit for an introductory psychology course. All recruitment practices and data collection procedures were reviewed and approved by the Institutional Review Board (IRB) at Purdue University (IRB Protocol #1209012617).

A power analysis was conducted using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) with power $(1 - \beta)$ set at 0.6 and $\alpha = .05$ for a medium-sized effect $(f = 0.25;$ cf. Cohen, 1977). The analysis suggested a sample size of 22 would be

sufficient. Participants ranged from age 18-21 years ($M = 19.3$, $SD = 0.9$), and all reported having normal or corrected-to-normal vision.

Apparatus and Stimuli

All stimuli were presented on a 24-inch widescreen BENQ color LCD monitor with a screen resolution aspect ratio of 16:9 (1920×1080 pixels). Participants sat approximately 98 cm from the screen and there was 50 cm between the screen and table-mounted tracking unit. Eye-movement responses were recorded using the retinal positioning and reflection of the cornea by means of a camera-based EyeLink 1000 Plus (SR Research, Mississauga, Ontario, Canada) system (1000 Hz sampling rate; see Figure 3). A chin rest was used to reduce head movements throughout the experiment. At the outset of the experiment, a standard 9-point calibration/validation procedure was initiated and lasted approximately five minutes. Gaze-position error was limited to less than $0.5°\pm 20°$. Joystick responses were collected using an HID-compliant CH Flightstick Pro controller. Using Control Manager, the joystick input was read as keyboard input with a *left* movement delineated as the 'a' key and a *right* response as the 'l' on a standard North American QWERTY keyboard. The left and right movement of the joystick triggered a response at approximately $12°$.

Physical-location stimuli consisted of left or right located, 50 pixels (height and width) white squares approximately 340 pixels symmetric to a central fixation cross (fixation positioned at 960×540 pixels; see Figure 4). Location-word stimuli were lowercase *left* and *right* words presented centrally (see Figure 4, right panel). Once a trial was initiated, the fixation cross was replaced by the location-word stimulus. 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. All stimuli were presented in white (RGB: 0, 0, 0) against a black background (RGB: 255, 255, 255).

Design

A $2 \times 2 \times 2$ within-subjects factorial design for the three variables: stimulus code (physical-location or location-word stimuli), response modality (eye-movement or joystick), and mapping (congruent or incongruent) was used. Each participant engaged in all iterations of the experiment, specifically, by completing four blocks with one response modality and another four blocks with the other response modality. For each response modality, two blocks with one stimulus code were completed before another block with the other stimulus code. Furthermore, the order of these blocks was counterbalanced across participants. On congruent trials, the *right* stimulus (right physical-location or the location-word *right*) required an analogous *right* response (looking at the right response box or moving the joystick *left*) and a similar response for *left* stimulus and *left* response. An incongruent trial required the opposite response to an appropriate stimulus.

Procedure

After completing the calibration process, the experimenter provided instructions to the participants. Additionally, visual instructions with an exemplar trial were provided on the screen prior to each block to provide instruction redundancy. Participants were tasked with responding with an appropriate left or right movement as quickly and accurately as possible. In the event of a serious technical issue during the experiment, the program allowed for exiting out of the experiment to address any issue with initial calibration. Rest periods between each block were also allowed to prevent eye fatigue.

Finally, the experimenter was present during all phases of the experiment, out of view of the participant.

The participant had to fixate the cross for 200 ms to initiate a trial at which time the fixation cross disappeared. Then there was a 700-ms interval followed by onset of the imperative stimulus that remained on until a response was made. Participants were required to make a response within 1250 ms; otherwise, their response was to be counted as erroneous. No participant made a response beyond that established time frame.

On eye-movement trials, responses were recorded at the time with which the participants' eye movement commenced. Furthermore, RT was designated as the time a *left* or *right* saccade was initiated that exceeded a velocity of 30°/s. The left or right target area within which the participants landed (for ~50 ms), based on the task instructions, was used to determine whether the response was correct or incorrect. For antisaccades, the mirror-opposite location (as with prosaccades) was used for this determination.

Joystick responses consisted of movement of an X-Y axis joystick in the appropriate *left* or *right* direction, using the dominant hand. The RT was recorded when the joystick deviated 12° (from the center) in the left or right direction, which designated identity of their response.

A total of 480 experimental trials were spread across eight (8) blocks (i.e., 60 trials for each block). The experiment lasted approximately one hour.

Results

Seven participants were replaced, three because of incomplete data due to apparatus failure and four others for making more than 50% errors in at least one of the trial blocks. Below are the data from 24 participants with measures of proportion of

correct responses (PC) and mean RT. Repeated-measures analyses of variance

(ANOVAs; see Appendix C, Tables 4-6) for each of the eight blocks are reported. Trials

on which the RT was less than 80 ms were discarded (less than 1%).

Congruent Mapping

ANOVAs concerning set-level compatibility (congruent mapping) for RT and

accuracy were performed. The critical factors of concern were stimulus code and

response modality. Eye-movement RT was measured as shorter than joystick RT, $F(1,$

$23) = 510.94$, $p < .001$, $\eta_p^2 = .96$, and responses to physical-location stimuli were faster

than those to location-word stimuli, $F(1, 23) = 495.27$, $p < .001$, $\eta_p^2 = .96$. Of most

importance, the interaction of stimulus code $\times$ response modality was significant, $F(1,$

$23) = 8.69$, $p = .007$, $\eta_p^2 = .27$. Responses were faster for the physical-location/eye-

movement and location-word/joystick-movement pairing ($M = 380$ ms) than for the

location-word/eye-movement and physical-location/joystick-movement pairing ($M = 399$

ms), indicating higher set-level compatibility for the former two conditions combined

than for the latter two.

For PC, the ANOVA revealed no main effect for response modality, $F(1, 23) =$

2.85, $p < .105$, $\eta_p^2 = .11$ or stimulus code, $F(1, 23) = 2.20$, $p < .151$, $\eta_p^2 = .08$.

However, participants showed a slight tendency to be more accurate for joystick-

movement responses (PC = .97) than eye-movement responses (PC = .94) and with

physical-location stimuli (PC = .97) than location-word stimuli (PC = .94). lastly, there

was no response modality $\times$ stimulus code interaction, $F(1, 23) < 1.0$.

Both Mappings

The above analyses revealed a set-level compatibility effect for RT with the congruent mapping. Element-level mapping was evaluated with a similar ANOVA that included mapping (congruent or incongruent), stimulus code and response modality.

For RT, all three main effects were significant. Physical-location stimuli ($M = 338$ ms) were responded to faster than location-word stimuli ($M = 538$ ms), $F(1, 23) = 379.81$, $p < .001$, $\eta_p^2 = .94$, and recorded RT was faster for eye-movement responses ($M = 344$ ms) than for joystick-movement responses ($M = 533$ ms), $F(1, 23) = 513.01$, $p < .001$, $\eta_p^2 = .96$. Congruency showed a main effect: RT was shorter with the congruent mapping ($M = 389$ ms) than the incongruent mapping ($M = 487$ ms), $F(1, 23) = 176.33$, $p < .001$, $\eta_p^2 = .89$, showing an element-level mapping effect. There were also 2-way interactions of congruency × stimulus code $F(1, 23) = 27.89$, $p < .001$, $\eta_p^2 = .55$, indicating a smaller congruency effect with the physical-location stimuli than the location-word stimuli, and congruency × response modality, $F(1, 23) = 7.32$, $p = .013$, $\eta_p^2 = .24$, indicating a smaller congruency effect with the joystick-movement responses rather than eye movements. However, there was no 2-way interaction of response modality × stimulus code, $F(1, 23) < 1$.

Most important, the 3-way congruency × response modality × stimulus code interaction was significant, $F(1, 23) = 22.90$, $p < .001$, $\eta_p^2 = .50$. The element-level mapping effect averaged 121 ms for the two high set-level compatibility conditions (physical-location/eye-movement and location-word/joystick-movement) compared to 71 ms for the two low set-level compatibility conditions (physical-location/joystick-movement and location-word/eye-movement; see Table 1). Note also that this interaction

reflects that the element-level mapping effect was smallest when joystick-movement responses were paired with physical-location stimuli and largest when that response set was paired with verbal stimuli (this relation is evident as well in the ordering of RT distribution functions). Wang and Proctor (1996) found a similar pattern, too, when they used verbal/movement and physical-location/movement pairings. They reported a 95-ms effect for the verbal-movement condition and 38-ms effect for the physical-location/movement condition (Experiment 4). I previously found a similar, albeit larger, effect pattern when using keypress responses paired with physical-locations and location-words. For that study, a verbal-keypress pairing produced a 148-ms effect, whereas a physical-location/keypress was 51 ms (Griffin-Oliver, 2016). Accordingly, the present results are not out of the ordinary.

For PC, there were significant main effects for congruency, $F(1, 23) = 17.09$, $p < .001$, $\eta_p^2 = .43$, and response modality, $F(1, 23) = 17.62$, $p < .001$, $\eta_p^2 = .43$, and stimulus code, $F(1, 23) = 6.94$, $p = .015$, $\eta_p^2 = .23$. Responses were more accurate for the congruent mapping (PC = .96) than the incongruent mapping (PC = .88) and with joystick-movement responses (PC = .96) than eye-movement responses (PC = .89). The only significant 2-way interaction was that of congruency × response modality, $F(1, 23) = 8.08$, $p = .009$, $\eta_p^2 = .26$. The congruency effect in PC was larger for the eye-movement responses than for the joystick-movement responses. The 2-way interactions between congruency and stimulus code, $F(1, 23) < 1$, and response modality and stimulus code were not significant, $F(1, 23) = 1.33$. Also, there was no 3-way congruency × response modality × stimulus code interaction, $F(1, 23) < 1$. This null result indicates that the influence of set-level compatibility on the element-level mapping effect was only

evident in the RT data, which is not too surprising given that the set-level compatibility for congruent trials was only in the RT data.

RT Distribution Analysis

RTs for each mapping in each condition were divided into five bins in accordance with the Vincentizing analysis (Ratcliff, 1979). With this procedure, the RTs were ordered from shortest to longest for each mapping of each participant, separately for each of the types of trial blocks. These were divided into the shortest 20% of RTs, next shortest 20%, and so on for each participant, with mean RT obtained for each bin.

An initial analysis for set-level compatibility was performed on just the RTs for the congruent mapping, and the resulting distribution functions are shown in Figure 5A. As in the analysis of mean RT, the main effects of stimulus code and response modality were significant, as was there interaction. The new information provided by this analysis concerns bin, for which the main effect was necessarily significant, $F(4, 92) = 419.86$, $p < .001$, $\eta_p^2 = .95$. The two-way interactions of stimulus code × bin, $F(4, 92) = 13.19$, $p < .001$, $\eta_p^2 = .36$, and response modality × bin, $F(4, 92) = 9.45$, $p < .001$, $\eta_p^2 = .29$, were significant. These reflect that the increase in RT across the distribution was larger for location-word stimuli than for physical-location stimuli and for joystick-movement responses than for eye-movement responses, respectively. However, the three-way interaction was not significant, $F(4, 92) = 1.36$, $p = .254$, $\eta_p^2 = .06$, indicating no difference in set-level compatibility across the RT bins. For all four stimulus code × response modality pairings, the increase in RT across the distributions was similar, though not quite identical.

For the second analysis, difference scores between incongruent and congruent RTs were obtained for each bin for all participants as a function of stimulus code and

response modality. The delta plots of these element-level mapping effects are shown in Figure 5B. An ANOVA of the mapping effects including those three factors showed the following significant effects for the terms including bin as a factor: bin main effect, $F(4, 92) = 25.86$, $p < .001$, $\eta_p^2 = .53$; bin × response modality interaction, $F(4, 92) = 4.64$, $p = .002$, $\eta_p^2 = .17$; bin × stimulus code interaction, $F(4, 92) = 4.91$, $p < .001$, $\eta_p^2 = .18$. The bin main effect means that the element-level mapping effect increased across the RT distribution. The two-way interactions were subsumed under a significant three-way interaction of bin × stimulus code × response modality, $F(4, 92) = 14.02$, $p < .001$, $\eta_p^2 = .38$, for which follow-up comparisons were performed.

For three of the four delta plots, the element-level mapping effect increased by approximately 100 ms from the shortest to longest bin, Fs$(4, 92) > 9.24$, ps $< .001$, $\eta_p^2 = .29$, with only the physical-location/joystick-movement combination showing a relatively flat, slightly decreasing function, $F(4, 92) = 1.10$, $p = .360$, $\eta_p^2 = .05$. Two-factor ANOVAs showed that the two functions for eye-movement responses did not differ significantly, $F(4, 92) = 3.73$, $p = .054$, $\eta_p^2 = .14$, though the increase across the distribution tended to be larger when the eye movements were made to the location-words rather than to the physical-locations. The functions for the joysticks did differ significantly, $F(4, 92) = 32.36$, $p < .001$, $\eta_p^2 = .59$, increasing when made to location-words but not when made to physical-locations. Another finding of note is that, when paired with the physical-location stimuli, eye movements showed a reliably larger element-level mapping effect than joystick movements at the first RT bin, $t(46) = -3.67$, $p < .001$, and this difference increased consistently across the RT distribution. Thus, even

the quickest responses showed a larger cost of anti-saccadic responses to left- or right-located stimuli than of incongruent mapping of joystick-movement responses.

Discussion

Experiment 1 revealed a set-level compatibility effect (congruent mapping) such that physical-locations paired with eye-movement responses and location-word stimuli paired with joystick responses are relatively more compatible on average than the opposite pairings of the S-R sets. This outcome can be interpreted as placement of eye movements at the spatial end of the spectrum proposed by Wang and Proctor (1996), compared to joystick responses. That is, physical-locations tend to activate the corresponding response most strongly for eye movements.

The findings agree with those obtained with keypress responses in other studies. Miles and Proctor (2009) and Vu and Proctor (2004) found that when spatial information is task-relevant, nearly all stimulus codes produce increasing element-level mapping effects as RT increases. In two experiments, Vu and Proctor (2004) investigated the mapping effects for physical-locations, directional-arrows, and location-words. In their first experiment, participants manually responded using keypresses in settings with mixed and pure mapping blocks. Results showed a large mapping effect for physical-locations and directional-arrows compared to location-words. However, in a second experiment using vocal responses, the mapping effect was larger for location-words. Vu and Proctor (2004) attributed this larger effect for vocal responses paired with location-words to a higher set-level compatibility than for keypress responses to location-words. The present experiment is in line with this finding as the relative pairing of eye movements and joystick movements is driven, primarily, by the joystick responses. Overall, RT to

location-words was longer than physical-locations, which suggests that processing of the spatial information takes longer when it is conveyed by words rather than locations.

A significant difference in element-level mapping effect was also evident for the conditions classified as high and low set-level compatibility. However, this difference was primarily driven by the joystick-movement responses, which showed a much larger mapping effect with the location-word stimuli (135 ms) than with the physical-location stimuli (31 ms), compared to the eye-movement responses, which showed mapping effects of 110 and 106 ms for location-words and physical-locations, respectively. Joystick responses were faster to physical-locations than to location-words regardless of the mapping. Nevertheless, this difference was larger for the incongruent mapping.

The distribution analysis of element-level SRC effects revealed a benefit for the physical-location stimuli paired with eye movements. Across bins, responses to physical-locations in the eye movement condition increased relative to the same stimuli paired with joystick responses. In fact, for joystick-movement responses with physical-locations, the mapping effect did not differ significantly across bins. That eye movements have a privileged relation to physical-locations in comparison to other spatial stimuli is especially compelling given that the aforementioned pattern of results did not occur with location-word stimuli. For them, there were no significant differences for eye-movement responses compared to joystick-movement responses: Location-word stimuli produced similar increasing effects across the distribution for both. This result is unsurprising, as location-words are known to produce large effects relative to other stimuli.

As noted, the combination of conditions with relatively high set-level compatibility also showed a larger overall element-level mapping effect. This difference

was pronounced for the physical-location stimuli, for which the mapping effect was 106 ms with eye-movement responses compared to 31 ms with joystick responses. Wang and Proctor (1996) concluded that element-level compatibility was an increasing function of set-level compatibility. Furthermore, the congruent played a significant role in driving this effect. Conversely, the dimensional overlap model (Kornblum, 1990) predicted an increase in facilitation and interference that accompanies set-level compatibility increases. Accordingly, these increases should also affect the incongruent mapping inversely. The present experiment finds the congruent and incongruent mappings affected similarly. Nevertheless, in the context of the proposed spectrum, it seems that eye movements are relatively higher compatibility with physical-locations than are joysticks.

Wang and Proctor (1996) also investigated aimed arm movements (Experiment 3) and found set-level compatibility effects. Furthermore, their average element-level compatibility effect was larger for the two high set-level pairings than the two low set-level pairings. Similarly, a significant set-level compatibility effect for the incongruent mapping was evident; however, this effect was very small.

Wang and Proctor (1996) found that location-word stimuli yielded large element-level mapping effects when paired with aimed-movement responses or keypress responses, although the mapping effect was 25 ms larger with aimed movements than with keypresses. It is possible that another type of stimulus code would better differentiate the pairings with the two response modes by showing higher compatibility with the aimed joystick movements. Consequently, I conducted a second experiment aimed at using a secondary type of spatial-location stimulus in lieu of location-words, that is, directional-arrows.

EXPERIMENT 2: RELATIVE-LOCATION VS. ARROW-DIRECTION STIMULI

Not only did Wang and Proctor (1996) look at aimed movement responses, but they also examined left- and right-pointing arrow stimuli in their Experiment 2. Here, they again found larger element-level mapping effects for the two higher set-level compatibility combinations than the lower set-level compatibility combinations. Experiment 1 of the present study was aimed at better distinguishing between the sets of joystick-movement and eye-movement responses used in Experiment 1. However, Experiment 2 sought to understand whether explicit directional-arrow stimuli or physical-location stimuli differ. The rationale is that Wang and Proctor's (1996) continuum treats all spatial stimuli as equivalent in that boxes appearing in a left-right location basis are like that of arrows eliciting directional left-right cues. They hypothesized this relation based on the culmination of results across their four sets of experiments. Yet, different types of location-specifying stimuli may have distinct facilitatory impacts on performance when paired with the optimal response modality. That is, the extent to which the spatial stimuli (e.g., directional-arrows and physical-locations) paired with aimed movements or eye movements differ has yet to be investigated.

It should be noted that Miles and Proctor (2012) conducted three experiments in which they investigated compatibility effects for varying types of spatial stimulus codes including directional-arrows, physical-locations, and location-words with keypress responses. They looked at instances in which the spatial information was irrelevant to task performance (i.e., a Simon task) and in which the spatial information was

task-relevant (i.e., the SRC effect). When the spatial information was relevant, the element-level mapping effects exhibited by directional-arrows and physical-locations were correlated with each other but not that produced by location-word stimuli.

More specifically, Miles and Proctor (2012) suggested that these spatial coding mechanisms are visuospatial (for physical-locations) and semantic-spatial (for location-words). For the analogous conditions involving directional-arrows, the compatibility effect was less stable suggesting that directional-arrows may rely on more than one coding mechanism. In contrast with the results obtained for relevant S-R mappings, when spatial information was task-irrelevant, the Simon effect for directional-arrows correlated with that for location-words but not the Simon effect for physical-locations. Miles and Proctor (2012) concluded that these differing relations were due largely to the demands and/or goals of the task. That is, arrow stimuli tended to be coded spatially when arrow-direction was relevant but verbally when it was irrelevant. Given that the mapping effects for physical-locations and directional-arrows behaved similarly when spatial information was task-relevant (and responses were keypresses) in Miles and Proctor's study, I conducted a comparison for eye-movement and joystick-movement responses.

Method

Participants

Twenty-four new English-speaking participants from Purdue University were recruited. Participants ranged in age from 18-20 years ($M = 19.2$, $SD = 0.9$), and all participants reported having normal or corrected-to-normal vision.

Apparatus and Stimuli

The physical-location stimuli and the calibration process were the same as in Experiment 1. The location-words from Experiment 1 were replaced with directional-arrow stimuli. These consisted of left and right-facing arrows presented at a central position on the screen. The arrow stimuli measured 18 mm in width and 8 mm in height. Each arrow contained both a protruding arrowhead and shaft (see Figure 6).

Design

Like Experiment 1, a within-subject design was used for which each participant engaging in all combinations of a $2 \times 2 \times 2$ factorial design. There were three variables: stimulus code (physical-location or directional-arrow stimuli), response modality (eye movement or joystick), and mapping (congruent or incongruent). The same blocking and counterbalancing procedures as in Experiment 1 were employed.

Procedure

Trial initiation and sequencing was similar to Experiment 1. For eye-movement and joystick-movement responses, responses and RT were collected as they were in Experiment 1. The same number (480) of experimental trials were used.

<div align="center">

Results

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Three participants were replaced because of failure to complete the task properly. Repeated-measures ANOVAs on PC and mean RT for the correct responses for 24 participants from the eight (8) blocks are reported (see Appendix C, Tables 7-9). Trials on which the initial saccade was less than 80 ms were discarded (less than 1%).

Congruent Mapping

For the congruent mapping, eye-movement RT ($M = 271$ ms) was shorter than joystick-movement RT ($M = 453$ ms), $F(1, 23) = 347.40$, $p < .001$, $\eta_p^2 = .94$, and responses to physical-location stimuli were faster ($M = 314$) than those to directional-arrow stimuli ($M = 410$ ms), $F(1, 23) = 93.45$, $p < .001$, $\eta_p^2 = .80$. Of most importance, the interaction of stimulus code $\times$ response modality was significant, $F(1, 23) = 49.62$, $p < .001$, $\eta_p^2 = .68$. Responses were faster for the physical-location/eye-movement and directional-arrow/joystick-movement conditions ($M = 346$ ms) than for the directional-arrow/eye-movement and physical-location/joystick-movement conditions ($M = 388$ ms), indicating higher set-level compatibility for the combination of the former two combinations than for that of the latter two conditions.

For PC, the ANOVA revealed main effects of response modality, with lower accuracy for eye-movement responses (PC $= .96$) than for joystick-movement responses (PC $= .99$), $F(1, 23) = 11.47$, $p = .003$, $\eta_p^2 = .33$, and stimulus code, $F(1, 23) = 7.55$, $p = .011$, $\eta_p^2 = .25$, with the directional- arrow stimuli producing fewer errors than the physical-location stimuli. There was also a response modality $\times$ stimulus code interaction, $F(1, 23) = 4.50$, $p = .045$, $\eta_p^2 = .16$. This interaction shows a set-level compatibility effect in the PC data, for which the advantage for physical-location stimuli over directional-arrow stimuli was larger for joystick responses than eye movements.

Both Mappings

A similar ANOVA was conducted for each measure that included mapping (congruent or incongruent) as an additional factor.

For RT, all three main effects were significant. Physical-location stimuli ($M = 351$ ms) were responded to faster than directional-arrow stimuli ($M = 429$ ms), $F(1, 23) = 143.58$, $p < .001$, $\eta_p^2 = .86$, and RT was shorter for eye-movement responses ($M = 304$ ms) than for joystick-movement responses ($M = 476$ ms), $F(1, 23) = 323.92$, $p < .001$, $\eta_p^2 = .93$. Congruency showed a main effect: RT was shorter with the congruent mapping ($M = 362$ ms) than the incongruent mapping ($M = 419$ ms), $F(1, 23) = 56.26$, $p < .001$, $\eta_p^2 = .71$. The 2-way congruency × response modality interaction approached significance, $F(1, 23) = 3.43$, $p < .077$, $\eta_p^2 = .13$, and the 2-way interaction of response modality × stimulus code was significant, $F(1, 23) = 31.59$, $p < .001$, $\eta_p^2 = .58$. This latter interaction indicates that there was a benefit for physical-location stimuli relative to directional-arrow stimuli for eye movements compared to joystick movements. The final two-way interaction, congruency × stimulus code interaction, was also significant, $F(1, 23) = 9.94$, $p = .007$, $\eta_p^2 = .28$, indicating a smaller congruency effect with the physical-location stimuli than the directional-arrow stimuli.

The crucial 3-way congruency × response modality × stimulus code interaction was significant, $F(1, 23) = 15.21$, $p < .001$, $\eta_p^2 = .40$. The element-level mapping effect averaged 81 ms for the physical-location/eye-movement and directional-arrow/joystick-movement combinations and 35 ms for the physical-location/joystick-movement and directional-arrow/eye-movement conditions; see Table 2). This interaction indicates that there was a relative difference in element-level mapping effect between the pairings. The difference lies primarily in the eye-movement responses, for which the effect was larger when paired with the physical-location stimuli than when paired with the directional-arrow stimuli.

For PC, there were significant main effects for congruency, $F(1, 23) = 41.45$, $p < .001$, $\eta_p{}^2 = .64$, and response modality, $F(1, 23) = 42.46$, $p < .001$, $\eta_p{}^2 = .65$. However, there was no main effect of stimulus code, $F(1, 23) = 2.46$, $p = .131$, $\eta_p{}^2 = .10$. Responses were more accurate for the congruent mapping (PC = .97) than for the incongruent mapping (PC = .92) and with joystick-movement responses (PC = .98) than eye-movement responses (PC = .91). There was a 2-way interaction of congruency $\times$ response modality, $F(1, 23) = 41.50$, $p < .001$, $\eta_p{}^2 = .64$. The congruency effect was larger for the eye-movement responses than for the joystick responses. The 2-way interactions between congruency and stimulus code, $F(1, 23) = 23.40$, $p < .001$, $\eta_p{}^2 = .50$, and response modality and stimulus code were also significant, $F(1, 23) = 9.27$, $p = .006$, $\eta_p{}^2 = .29$. This pattern reflects an advantage for the use of physical-location stimuli rather than directional-arrow stimuli whereby the effect is larger for eye movements.

Most important, for PC, there was also a 3-way congruency $\times$ response modality $\times$ stimulus code interaction, $F(1, 23) = 28.37$, $p < .001$, $\eta_p{}^2 = .55$. This pattern replicates that found in the RT data, showing that the two high set-level pairings produced larger element-level mapping effects (PC = .98) than the two low set-level pairings (PC = .90).

RT Distribution Analysis

Like Experiment 1, RTs were divided into five RT bins, and bin was added as a factor to the ANOVAs. Figure 7A shows the RT effects for the congruent mapping, whereas Figure 7B shows the element-level SRC effect for each bin.

For the congruent mapping, as in the analysis of mean RT, the main effects of response modality and stimulus code were significant, as was their interaction. The bin main effect was necessarily significant, $F(4, 92) = 208.08$, $p < .001$, $\eta_p{}^2 = .90$. The

two-way interactions of response modality × bin, $F(4, 92) = 6.75$, $p = .004$, $\eta_p^2 = .23$, and stimulus code × bin, $F(4, 92) = 4.20$, $p = .004$, $\eta_p^2 = .15$, were significant, but they were superseded by the three-way interaction of response modality × stimulus code × bin, $F(4, 92) = 13.91$, $p < .001$, $\eta_p^2 = .38$. This latter interaction indicates a set-level compatibility difference across bins.

For joystick-movement responses, there was an interaction of stimulus code and bin, $F(4, 92) = 5.26$, $p = .016$, $\eta_p^2 = .19$, due mainly to the RT advantage for physical-locations being reduced at the last of the five bins compared to the earlier ones (see Figure 7B). For eye-movement responses, the interaction was also significant, $F(4, 92) = 8.59$, $p = .004$, $\eta_p^2 = .27$, but with the increase in RT being steeper for the directional-arrow stimuli than for the physical-location stimuli across the entire RT distribution. This difference in the distributions is consistent with the hypothesis that left and right physical-location stimuli have higher set-level compatibility with eye movements than do left and right directional-arrow stimuli.

An ANOVA of the element-level mapping effect as a function of stimulus code, response modality, and bin, yielded no main effect of bin, $F(4, 92) = .784$, $p < .539$, $\eta_p^2 = .03$. Neither the response modality × bin interaction, $F(4, 92) = .501$, $p = .735$, $\eta_p^2 = .02$, nor the stimulus code × bin interaction was significant, $F(4, 92) = 1.50$, $p = .209$, $\eta_p^2 = .06$, but with sphericity assumed, there was a three way response modality × stimulus code × bin interaction, $F(4, 92) = 3.167$, $p = .017$, $\eta_p^2 = .12$ (otherwise, with the Huynh-Feld correction: $F(4, 92) = 3.167$, $p = .079$, $\eta_p^2 = .12$). This discrepancy suggests that this interaction is relatively small and should be interpreted with caution.

Three of the four conditions produced relatively flat delta plot functions (see Figure 7B), with the possible difference of the last RT bin, Fs(4, 92) > .252, ps < .908, $\eta_p{}^2 = .01$. The exception was the pairing of eye-movement responses to physical-locations which, as in Experiment 1, exhibited an increase in the element-level mapping effect as RT increased. Follow-up ANOVAs showed that the functions for joystick responses did not differ significantly for the physical-location and directional-arrow stimuli, Fs(4, 92) > 1.04, ps = .390, $\eta_p{}^2 = .04$, whereas the functions for eye-movement responses differed reliably, Fs(4, 92) > 2.75, ps = .033, $\eta_p{}^2 = .11$. That is, only when paired with physical-location stimuli did the element-level mapping effect for eye movements increase across the RT distribution. Also, as in Experiment 1, eye movements showed a large, increasing SRC effect relative to joystick movements to physical-locations for the fastest responses, $t(46) = -3.45$, $p < .001$, as well as the later RT bins.

Discussion

The results of Experiment 2 again show a set-level compatibility effect. The congruent mapping yielded an interaction of stimulus code and response mode indicative of higher compatibility for physical-locations with eye movements and directional-arrows with joystick movements than for the opposite pairings. In addition to being evident in the RT data, the interaction was significant in the PC data, suggesting that the difference between high and low set-level conditions was slightly stronger than in Experiment 1.

Again, like Experiment 1, a significantly larger element-level mapping effect was obtained for the stimulus and response sets classified as high-set level and low-set level compatibility (physical-location/eye-movement and directional-arrow/joystick-movement versus, physical-location/joystick-movement and directional-arrow/eye-movement,

respectively). In the case, of the high set-level pairing, the physical-location stimuli showed a larger element-level mapping effect with the eye-movement responses (108 ms) than with the joystick responses (43 ms), as in Experiment 1. The directional-arrow stimuli showed a larger element-level mapping effect overall than did the location-word stimuli in Experiment 1, but the effect was 26 ms larger for joystick responses paired with the arrow stimuli (53 ms) than for eye-movement responses (27 ms). Taken together, these results indicate that, compared to joystick movements, eye movements have relatively greater compatibility with physical-location stimuli relative to directional-arrow stimuli.

Inspection of the distribution analyses reveals that joystick responses to physical-locations showed a stable pattern of element-level mapping effect that slightly drops off at later RTs. The only exception to this pattern of stable effects was the pairing of eye movements with physical-locations, which showed increasingly large SRC effects across the RT distribution, as in Experiment 1. The logical conclusion is that only physical-location stimuli paired with eye movements produce greater activation of the corresponding response compared to the other pairings of stimulus and response sets.

Comparisons between the present Experiment 2 and Wang and Proctor's (1996) Experiment 3 reveal that they produced similar numerical values. Their average mapping effect for the high set-level physical-location/manual and location-word/vocal conditions (78 ms) was greater than the one for the low set-level spatial-vocal and word-manual conditions (53 ms). Previously, when investigating high and low set-level pairings for eye movements and keypress responses, I found an average mapping effect of 110 ms (physical-location/eye-movement and location-word/keypress) compared to 79 ms

(physical-location/keypress and location-word/eye-movement; Griffin-Oliver, 2016). This pattern was replicated in another experiment with 125 ms for the high set-level grouping and 80 ms for the low set-level grouping. The present experiment confirms this pattern of high set-level combinations being greater (121 ms) than low set-level combinations physical-location/joystick movement and location-word/eye-movement (71 ms). Across these four experiments, the high set-level compatibility pairings produce increasingly better gains than their low set-level compatibility counterpart does.

An important result to note is that, unlike the location-word stimuli in Experiment 1, the directional-arrow stimuli in Experiment 2 did not produce increasing SRC effects across the RT distribution for joystick or eye-movement responses. Although this difference in results may seem puzzling, in other studies location-word stimuli (when paired with manual keypress responses) generally produce larger, increasing effects than do directional-arrow stimuli (Vu & Proctor, 2011). Therefore, the present results are not out of line. Across the two experiments, eye movements to physical-locations and joystick movements to physical-location stimuli produced a consistent pattern of results.

EXPERIMENT 3: DIRECTIONAL-ARROW VS. LOCATION-WORD STIMULI

The results of Experiment 2 suggest that whereas different sizes of element-level SRC effects are elicited by the location-word and directional-arrow stimuli, at the set-level their compatibility is similar. The relative pairings of stimulus and response sets (i.e., location-words and directional-arrows) behaved similarly to one another, despite treatment of them as distinctly different types of stimuli. To explore this difference at the set- and element-level further, I conducted a third experiment. This experiment directly compared directional-arrow and location-word stimuli to one another to test whether the two stimulus types produce similar or dissimilar patterns when directly compared within a single experiment. That is, physical-locations from Experiments 1 and 2 consistently demonstrated a benefit from pairings with eye movements rather than joystick movements. Experiment 3 compared the relatively "low performing" directional-arrow and location-word stimuli against one another. Therefore, this allowed direct comparisons between stimuli that tap into visuospatial (directional-arrows) and semantic (location-words) mechanisms.

Method

Participants

Twenty-four new English-speaking undergraduate students (15 males) enrolled at Purdue University participated for course credit in an introductory psychology course. Participants ranged in age from 18-25 years ($M = 19.6$, $SD = 1.05$), and all participants reported having normal or corrected-to-normal vision.

Apparatus and Stimuli

Visual stimuli were presented in the same manner as the location-words and directional-arrows in Experiments 1 and 2. The calibration and validation setup were the same. Location-word stimuli were the location words "left" and "right", as in Experiment 1, whereas directional-arrow stimuli were left and right-facing arrows, from Experiment 2, presented at a central position on the screen (see Figure 8).

Design

Like Experiments 1 and 2, a within-subject design with each participant engaging in all combinations of a $2 \times 2 \times 2$ factorial design was used. There were three variables: stimulus code (location-word or directional-arrow stimuli), response modality (eye-movement or joystick), and mapping (congruent or incongruent). The same blocking and counterbalancing procedure as Experiment 1 was employed.

Procedure

Trial initiation and sequencing was similar to Experiments 1 and 2. Reaction time for eye movement and joystick responses was assessed using the same criteria as in Experiments 1 and 2. As in those experiments, 60 trials were given over eight blocks for a total of 480 experimental trials.

Results

Two participants were replaced because of failure to complete the task properly. Analyses from 24 participants are reported accordingly using the same procedure as Experiments 1 and 2 (see Appendix C, Tables 10-12).

Congruent Mapping

Eye-movement RT (M = 355 ms) was measured as shorter than joystick RT (M = 548 ms), $F(1, 23) = 378.46$, $p < .001$, $\eta_p^2 = .94$, and responses to directional-arrow stimuli (M = 410 ms) were faster than those to location-word stimuli (M = 493 ms), $F(1, 23) = 131.50$, $p < .001$, $\eta_p^2 = .85$. The interaction of stimulus code × response modality was not significant, $F(1, 23) = 3.25$, $p = .085$, $\eta_p^2 = .12$. There was a tendency for responses to be slower for the directional-arrow/eye-movement and location-word/joystick-movement conditions (M = 509 ms) than for the opposite pairings of stimulus and response sets (M = 502 ms).

For PC, the effect of response modality approached significance, $F(1, 23) = 3.45$, $p = .076$, $\eta_p^2 = .13$. Accuracy was slightly lower for eye-movement responses (PC = .94) than for joystick-movement responses (PC = .97). There was also no main effect of stimulus code, $F(1, 23) = 2.25$, $p = .147$, $\eta_p^2 = .09$. Participants were 97% accurate on trials with directional-arrow stimuli and 95% accurate on trials with location-word stimuli. There was a response modality × stimulus code interaction, $F(1, 23) = 6.68$, $p = .017$, $\eta_p^2 = .23$. This interaction indicates a slight benefit for directional-arrow/eye-movement and location-word/joystick-movement pairing (PC = .97) than for the opposite pairing (PC = .94).

Both Mappings

An ANOVA with the additional factor of mapping (congruent or incongruent) For RT yielded significant main effects for all three factors. Directional-arrow stimuli (M = 436 ms) were responded to faster than location-word stimuli (M = 573 ms), $F(1, 23) = 226.23$, $p < .001$, $\eta_p^2 = .91$, and RT was shorter for eye-movement responses (M = 407

ms) than for joystick-movement responses ($M = 602$ ms), $F(1, 23) = 301.98$, $p < .001$, $\eta_p^2 = .93$. Also, RT was shorter with the congruent mapping ($M = 452$ ms) than the incongruent mapping ($M = 558$ ms), $F(1, 23) = 256.69$, $p < .001$, $\eta_p^2 = .92$, and there was a 2-way interaction of congruency × stimulus code $F(1, 23) = 100.35$, $p < .001$, $\eta_p^2 = .81$, indicating a smaller congruity effect with the directional-arrow stimuli than the location-word stimuli. There was neither a two-way interaction of response modality × stimulus code, $F(1, 23) = 1.19$, nor an interaction for congruency × response modality, $F(1, 23) = 0.73$.

Unlike Experiments 1 and 2, there was also no three-way interaction of congruency × response modality × stimulus code, $F(1, 23) = 0.76$. The directional-arrow/joystick and location-word/eye-movement pairing resulted in a mapping effect of 110 ms compared to 103 ms for the directional-arrow/eye-movement and location-word/joystick pairings; see Table 3). This lack of an interaction, for RT, is consistent with the finding of no significant set-level compatibility effect on the congruent trials.

For PC, there were significant main effects for congruency, $F(1, 23) = 20.61$, $p < .001$, $\eta_p^2 = .47$, response modality, $F(1, 23) = 8.18$, $p = .009$, $\eta_p^2 = .26$, and stimulus code, $F(1, 23) = 35.99$, $p < .000$, $\eta_p^2 = .61$. Responses were more accurate for the congruent mapping (PC = .96) than for the incongruent mapping (PC = .92) and with joystick responses (PC = .95 than eye-movement responses (PC = .91), and with directional-arrows (PC = .96) than location-words (PC = .91). There was a significant two-way interaction of congruency × stimulus code, $F(1, 23) = 20.49$, $p < .001$, $\eta_p^2 = .47$. The congruency effect was larger for the location-words than for the directional-arrows. There was also a two-way interaction between response modality and stimulus

code, $F(1, 23) = 8.85$, $p = .007$, $\eta_p{}^2 = .28$. As for RT, there was no three-way

congruency $\times$ response modality $\times$ stimulus code interaction, $F(1, 23) < 1.93$, $p = .178$,

$\eta_p{}^2 = .08$. This indicated no significant difference between the directional-arrow/eye-

movement and location-word/joystick pairing (PC = .95) and the directional-

arrow/joystick and location-word/eye-movement pairing (PC = .93).

RT Distribution Analysis

Distribution analyses were performed as in the prior experiments. Figure 9A

shows the RT distribution for the congruent mapping, and, similar to Experiments 1 and

2, the main effect of bin on RT was necessarily significant, $F(4, 92) = 525.66$, $p < .001$,

$\eta_p{}^2 = .96$. Also, the two-way interactions of response modality $\times$ bin, $F(4, 92) = 2.75$, p

$= .033$, $\eta_p{}^2 = .11$, and stimulus code $\times$ bin, $F(4, 92) = 7.21$, $p < .001$, $\eta_p{}^2 = .24$, were

significant, but the 3-way response modality $\times$ stimulus code $\times$ bin interaction was not,

$F(4, 92) = 1.75$, $p = .146$, $\eta_p{}^2 = .07$. The absence of three-way interaction is like

Experiment 1 but not Experiment 2. The functions were relatively similar, with the

location-word stimuli showing a slightly greater increase across RT bins than the

directional-arrow stimuli, particularly for joystick-movement responses.

Analysis of the element-level mapping effect across bins showed a main effect of

RT bin, $F(4, 92) = 538.76$, $p < .001$, $\eta_p{}^2 = .96$, which was qualified by an interaction

with stimulus code, $F(4, 92) = 73.98$, $p < .001$, $\eta_p{}^2 = .76$. The slope of the delta plots

was greater for the location-word stimuli than for the directional-arrow stimuli, regardless

of whether the response modality was eye movements or joystick movements (see Figure

9B). No other term involving bin was significant, Fs < 1.0.

Overall, in Experiment 3, location-word stimuli showed a rather large and increasing effect across the RT distribution similar to directional-arrow stimuli. In fact, there were no significant differences between the location-word/joystick-movement and directional-arrow/eye-movement pairings compared to the alternative pairings, confirming that the mapping effect size was determined mainly by whether the stimuli were direction-arrows or location-words (see Table 3). Location-words produced larger effects than either spatially relevant directional-arrows or physical-locations.

Discussion

By comparing directional-arrows and location-words in a single experiment and utilizing a combination of conditional pairings from Experiments 1 and 2, it is possible to see that location-words consistently produced larger element-level mapping effects than did the directional-arrows. Further, across the distributions of Experiments 1 and 2, the word stimuli affected joystick- and eye-movement responses similarly. In comparison to the directional-arrow stimuli, no set-level compatibility effect emerged, nor did an influence of set-level compatibility on the element-level mapping effect that would indicate an influence of response mode. In fact, the set-level compatibility effect for one pairing (directional-arrow/eye movement and location-word/joystick at 103 ms) was like that for the other pairing (directional-arrow/joystick and location-word/eye-movement at 110 ms). For the eye movements paired with location-words, again, location-words consistently produced largely increasing effects across the distribution in both Experiments 1 and 3.

Regarding eye movements, it seems that the saccadic system has a privileged relationship to physical-location stimuli. In the case of Experiment 3, in which

physical-locations were not used and eye movements were paired with directional-arrows or location-words, no differences in set- or element-level compatibility emerged. When the joystick responses are grouped into "high" and "low" set-level groupings with eye movements, the directional-arrow vs. location-word stimulus codes critically drive the results, as indicated by the compatibility effects being similar when collapsed across the groupings, without a pattern of interaction indicative of differences in set-level compatibility. The overlap between eye movements (i.e., the response) and physical-locations (i.e., the stimulus) is both conceptual and perceptual, but so is that for directional-arrows. Yet the directional-arrow stimuli show no higher set-level compatibility for eye-movements compared to joystick-movements, in relation to location-word stimuli. This outcome implies that, even for eye-movement responses, there is an element of translation present for location-words and direction-arrows that is not required for physical-locations. Furthermore, this translation does not seem to differ significantly from that when the responses are joystick movements. Taken together, these results suggest that the two response modalities (eye movements and joystick movements) are equivalent when dealing with spatial stimuli other than those that onset in left and right locations.

GENERAL DISCUSSION

The three experiments employed two-choice SRC tasks to study set- and element-level compatibility in the oculomotor and manual systems. Moreover, the experiments investigated whether the oculomotor system adheres to an existing framework by which perception and action are governed or if it behaves distinctively. Across all experiments, three types of stimuli conveying spatial information were used: physical-locations, directional-arrows, and location-words. Rather than using bimanual keypresses as a manual response modality to compare to eye-movement responses, joystick movements were used because they are unimanual responses that are more like eye movements (i.e., the eyes move together as a single unit). Furthermore, joystick movements were hypothesized to also benefit from pairings with spatial stimuli.

Part I: Principle Findings

Summary of Experiments 1, 2, and 3

Experiment 1 established eye movement's placement near the spatial end of the stimulus and response set continuum proposed by Wang and Proctor (1996) for physical-location stimuli compared to location-words. This was evidenced by physical-locations' tendency to activate the corresponding response more strongly for eye movements than for joystick responses. First, a set-level compatibility effect emerged such that, for congruent mapping, there was greater benefit for the physical-location/eye-movement and location-word/joystick pairing rather than the opposite pairing. Furthermore, the element-level mapping effect emerged for which the high set-level pairing showed a larger cost of incongruent mapping than did the low-set level pairing.

Experiment 2 manipulated explicit indicators of location, namely by incorporating directional-arrow stimuli to compare against physical-location stimuli. Again, a set-level compatibility effect emerged for the congruent mapping. That mapping showed a benefit for the physical-location/eye-movement and directional-arrow/joystick-movement pairing compared to the opposite pairing. A larger element-level mapping effect for the high set-level pairing emerged, too, as in Experiment 1. In both Experiments 1 and 2, the set for which physical-location stimuli were paired with eye movements yielded better performance with a congruent mapping than the other sets, paired with a larger element-level mapping effect.

Because the patterns of results in Experiments 1 and 2 were similar but with larger SRC effects for location-words than directional-arrows, Experiment 3 was conducted to directly compare location-words and directional-arrows. Here, there was a noticeable absence of the interaction for congruent mappings indicative of a set-level compatibility effect and, consequently, no interaction indicating different element-level compatibility effects for the respective combinations. In other words, directional-arrow and location-word stimuli seem to go similarly well with eye-movement and joystick responses, although location-words give larger element-level mapping effects for both response modalities.

RT Distribution Analyses

To further investigate the set- and element-level effects, RT distribution analyses were conducted for all experiments. For Experiment 1, this analysis revealed no significant difference in set-level compatibility across the RT bins. That is, RT increased similarly across the distribution for the compatible mappings of all combinations of

physical-location and location-word stimuli and eye-movement and joystick-movement responses. For element-level mapping effects, the distribution analysis indicated an increase from the shortest to longest bin for three of the four functions (including the two functions for which the responses were eye movements). The increase across the distribution did not differ between the two eye-movement functions. However, overall, location-words produced large effects compared to physical-locations. Whereas the mapping effect for eye-movements paired with physical-locations increased across the distribution, the analogous stimulus pairing with joystick responses did not. The distribution analysis indicated that high set-level compatibility sets showed a larger element-level mapping effect, particularly for the physical-location stimuli.

The same analysis of the distributions performed in Experiment 2 revealed set-level compatibility differences across the RT distribution. For the element-level mapping effect, three of the functions were relatively flat. The most notable exception was for the physical-locations paired with eye movements, which increased across the RT distribution as in Experiment 1. The finding that eye movements showed this increasing mapping effect when paired with physical-location stimuli but not location-words provides evidence that eye movements and physical-locations have a privileged relation to one another. Although this effect for physical-locations and eye movements increased throughout the whole distribution, it occurred even at the earliest bins.

Finally, the analysis of directional-arrow and location-word stimuli in Experiment 3 revealed a lack of a significant interaction in RT at the set-level, indicating little difference in how naturally directional-arrows and location-words go with joystick and eye-movement responses. Joystick responses showed a slightly greater increase when

paired with location-words rather than directional-arrows. For the element-level mapping effect, no significant differences arose for the location-word/joystick and directional-arrow/eye-movement pairings compared to the directional-arrow/joystick and location-word/eye-movement pairings. Rather, larger effects were found for location-words, no matter the response modality.

Dimensional Overlap

The dimensional overlap model (Kornblum et al., 1990) predicts that element-level mapping effects are an increasing function of set-level compatibility. Pairings designated as high rather than low set-level compatibility will exhibit greater benefits of congruent over incongruent mappings at the element-level. This difference in mapping effect size is due to the amount of overlap between the stimulus and response pairings. When the stimulus set overlaps with the paired response set, automatic response activation produced by the stimulus will benefit performance for a congruent S-R mapping but impede performance for an incongruent mapping. The greater the degree of overlap, the more the disparity of performance between the congruent and incongruent mapping conditions. In addition to the predicted set- and element-level compatibility effects emerging in Experiments 1 and 2, a noticeable cost for the incongruent mapping occurred, as predicted by the dimensional overlap model.

Eye-movement responses and physical-location stimuli match in terms of high perceptual similarity (group and/or match) between response and stimulus. In addition, the present results, coupled with results I previously obtained (Griffin-Oliver, 2016), suggest that this relationship is stronger (for eye movements) than for keypress responses - as typically stated in the literature. In that study, like the present experiments, I

investigated the relation between eye-movement responses and keypresses. Physical-location and location-word stimuli were likewise used, and they produced a pattern like the results of the present Experiment 1, with the high set-level combination of physical-locations/eye-movements and location-word/keypress (110 ms) showing a larger element-level mapping effect than the low set-level combination (79 ms). Evidently, use of visuospatial stimuli, in general, is not sufficient to produce such large effects, that is, eye movements respond most favorably to physical-location stimuli. This is suggestive of a unique aspect underlying the onset of physically-located stimuli for eye movements that is non-existent for other stimuli.

In theory, the high degree of overlap between responses paired with the optimal stimuli should produce greater gains for some spatial stimuli compared to others. Here, that pattern manifests for eye-movement responses to physical-locations relative to other spatial stimuli. Of interest, the congruent mapping of physical-location stimuli to eye-movement responses benefited the most from the pairings of optimal stimulus and response sets. It is worth noting, however, that comparisons involving a single combination of stimulus and response sets are confounded and must be interpreted with caution. Nevertheless, in Experiments 1 and 2, with congruent mappings, high set-level pairings that involved eye movements behaved most efficiently when paired with physical-location stimuli. Again, this is suggestive of the notion that congruent responses (saccades) to exogenously driven stimuli (like physical-locations) are highly automatic.

Wang and Proctor's (1996) Continuum

Wang and Proctor (1996) proposed a continuum on which spatial stimulus and response sets reside. They placed physical-location stimulus sets at the left-most side and

verbal stimulus sets were at the right-most end. Additionally, their results suggested that keypress responses belonged on the left side of their continuum and vocal responses at the right end. The present set of experiments aimed to complete systematic investigations into the more "spatial" end of this spectrum by investigating highly automatic eye-movement responses and joystick-movement responses with several types of stimuli conveying spatial information. The results suggest a hierarchy of stimulus and response set pairings whereby physical-locations and eye movements are the strongest pairing. Conversely, location-words and directional-arrows are equally different from physical-locations in relation to eye movements and joystick movements. Accordingly, eye movements are proposed to behave differently in certain cases depending on the spatial stimuli with which they are paired. In the case of physical-location stimuli, eye-movements are at the spatial side on the continuum (relative to keypresses). However, when eye-movements are paired with directional-arrows or location-words, they are located similarly to the joystick movements.

<div align="center">**Part II: Closely Related Considerations**</div>

Evidence From Prior Work Concerning Set and Element-Level Effects

Previously, when investigating set- and element-level compatibility effects in eye movement and vocal responses, I found that the way in which physical-location stimuli are presented could impact saccadic responses. In that set of experiments, the target-boxes to which participants were instructed to make a saccade were available during fixation and prior to stimulus onset. A set-level compatibility effect was evident for the congruent mappings of physical-location stimuli with eye movements and location-word stimuli with vocal responses relative to the opposite pattern. However, the element-level

mapping effect was no larger than when set-level compatibility was low (Griffin-Oliver, 2016). Follow-up work, aimed at clearing this discrepancy up, removed these boxes prior to stimulus onset and subsequently had two impacts: 1) saccadic latencies were reduced and conformed to those typically found in the literature, and, critically, 2) eye movements produced the predicted element-level mapping effects, which varied as a function of high and low set-level groupings. More explicitly, the removal of target boxes, allowed the predicted automaticity elicited by physical-location stimuli to emerge. That performance was impacted in one case relative to the other suggests that sudden onsets of physically-located stimuli are strongly coupled with eye-movement responses and not other modalities.

Ideomotor Compatibility

Ideomotor (compatibility) theory seeks to provide a rationale for the link between perception and motor action. Here, the representation of a response and the resulting action is said to be moderated by images of the sensory feedback produced which subsequently are responsible for performance of corresponding actions (Greenwald, 1970). Furthermore, ideomotor compatibility can be distinguished by two interpretations (Klapp, Porter-Graham, & Hoifjeld, 1991). In the *weak* version, prior to the initiation of a response, a representation is generated, and processing is facilitated if the stimulus presented corresponds to the response goal. The *strong* conception not only considers facilitation but also the elimination of processing. This is because the stimulus and response code overlap, thus, the generation of this code is unnecessary.

Similar to the distinction between low and high set-level compatibility, ideomotor theory distinguishes its own high and low (ideomotor) compatibility groupings.

Greenwald (1972) set up an experiment whereby two possible responses could be executed: (a) moving a switch to the left or right, or (b) saying the word *left* or *right*. Similarly, there were two stimulus sets: (a) an arrow pointing to the left or right or (b) the auditory word *left* or *right*. Response Choice *a* was said to be guided by Stimulus Set a and Response Choice *b* with Stimulus Set *b* ($R_A \leftrightarrow S_A$ or $R_B \leftrightarrow S_B$) for the high ideomotor pairings, with the opposite relations for the low ideomotor pairings ($R_A \leftrightarrow S_B$ or $R_B \leftrightarrow S_A$). The key point to note is that only the first relationship is said to be ideomotor compatible (i.e., contain the highest level of compatibility).

Ideomotor theory would suggest that location-words are low on ideomotor compatibility with aimed movements and eye movements compared to vocal responses. Accordingly, small element-level mapping effects should emerge in the former two cases. However, the present experiments found large mapping effects location-words in Experiments 1 and 2. This implies that ideomotor theory alone cannot fully account for the relationship between stimulus set and response choice. Another account might provide some support for this relationship. Lu (1997) proposed that different degrees of S-R associations were defined by two factors. The first is whether there is conceptual similarity between stimulus and response sets. The second is whether a stimulus dimension is processed within the same system as the response (i.e., spatial-manual or verbal-vocal). Conceptual similarity between stimulus and response sets concerns the representational level, which is consistent with dimensional overlap (Kornblum et al., 1990). Processing within the same system considers encoding of information perceptually and in working memory. In working memory, one can represent the stimulus in either a spatial or a linguistic form. In the case of location-words, vocal responses are also

processed in this linguistic system, facilitating those responses. Analogously, non-verbal stimuli, like directional-arrows or physical-locations, are represented in spatial forms. When there is conceptual similarity, as well as processing in the same system, then the resulting S-R association will be strong – otherwise, it is said to be weak.

Having a mental representation of the intended movement and its associated effect should facilitate action, according to ideomotor theory. Therefore, the ideomotor conception operates on endogenous cues, not exogenous ones (Shin, Proctor, & Capaldi, 2010). However, in the present experiments' results, stimuli that were most exogenous in nature (i.e., physical-locations) produced larger effects than did endogenous ones (location-words or directional-arrows). This suggests that eye movements require exogenous cues rather than endogenous ones. For the saccadic system, spatial location information is important.

Large Effects With Location-Words

In Experiment 1, no matter the response modality (whether eye movements or aimed joystick movements), when location-words were paired with them, they tended to produce large effects. This effect is most evident when looking at the effects produced by the physical-location/eye-movement conditions in Experiments 1 and 2. Across both experiments, eye movements paired with physical-location stimuli produced consistent effects that were roughly equivalent. In Experiment 1, the average mapping effect was 106 ms for the physical-location/eye-movement condition and 31 ms for the physical-location/joystick condition. In Experiment 2, the mapping effect was 108 ms for the physical-location/eye-movement condition and 43 ms for the physical-location/joystick condition. That location-word stimuli consistently produce large effects across RT

distributions likely reflects the additional time needed to process the semantic properties of a location-word stimulus. Stimuli that are more exogenous in nature, on the other hand, do not required this additional time and manifests in faster RTs. Evidence of this can be found from Lu and Proctor's (2001) experiments where they found activation of the corresponding response (for location-words), did not peak until later in the time course (i.e., several hundred milliseconds after stimulus onset). Consistent with Hommel (1993), physical-locations and directional-arrows activation of the corresponding response appeared relatively early. Vu and Proctor's (2004) distribution analyses also provide some support in that at the shortest bins, no SRC effect was present for location-words. In fact, the peak SRC effect for location-words occurred approximately at the last bin.

Another consideration is that the set-level compatibility difference for the congruent mapping tended to be stronger in Experiment 2 than in Experiment 1. While the relation between set- and element-level compatibility held within the experiments, it did not hold across experiments. Because Experiment 1 used location-words and Experiment 2 directional-arrows, location-words seem to produce large effects irrespective of the response set to which they are mapped. That physical-locations and eye-movement responses yield larger element-level mapping effects in both cases, despite the inclusion of location-words (and the strong effects that accompany them) presents a compelling argument that eye movements benefit from a congruent pairing with physical-location stimuli more than with other types of spatial stimuli.

That location-word stimuli yielded mapping effects that increase across the RT distribution is unsurprising (Roswarski & Proctor, 1996). It is consistent with prior use of

location-words, directional-arrows, and physical-locations. Miles and Proctor (2012) reported increasing element-level compatibility effects for location-words in the standard blocked SRC task relative to physical-locations or directional-arrows. Similarly, Vu and Proctor (2004) investigated keypress responses to each type of aforementioned stimulus in an experimental setting. They also varied the blocking procedure by which stimuli were organized. In some cases, participants were exposed to mixed presentation of congruent and incongruent mappings and in others, they experienced pure presentations. Across all three stimulus types (directional-arrows, physical-locations, and location-words), they found an increase in the mean element-level mapping effect across distribution bins. Critically, location-words reliably produced a longer time course of activation than for directional-arrows or physical-locations.

This pattern is also supported by work from Lu and Proctor (2001) who investigated keypress responses to one dimension of two-dimensional stimuli. With varying SOAs (stimulus onset asynchronies), they presented participants with color words or locations inside an outlined arrow or a colored rectangle. When the word was irrelevant and the other dimension (direction or color) relevant, the effect did not maximize until the onset of the word preceded the arrow or physical-location stimulus. This suggests that activation of the corresponding response does not peak (for location-words) until much later in the time course (several hundred milliseconds). Alternatively, directional-arrows and physical-locations experience peak activation early. Luo and Proctor (2018) demonstrated that a computational model can fit the results obtained in keypress Simon tasks with a single activation-decay model for which the onset and

decline of activation of the corresponding response are delayed increasingly from physical-location, to directional-arrow, to location-word stimuli.

To corroborate this finding, Lu and Proctor (2001) also had participants complete the same task but with vocal naming responses rather than keypresses. An opposite pattern was found whereby the element-level mapping effect for location-words was much larger than for physical-locations or directional-arrows. Lu and Proctor asserted that this difference demonstrates changes in the mapping effect as a function of perceptual similarity between stimulus and response. Furthermore, Vu and Proctor (2011) found similar effects on the RT distribution for location-words relative to physical-locations or directional-arrows. Again, location-words rather than physical-locations or directional-arrows produced an increasing function across RT bins such that the peak of activation occurred at the later bins. In the present study, a similar pattern emerges, despite eye movements being used rather than manual keypress responses.

The present results replicate previous findings regarding physical-locations as well. For physical-locations, Vu and Proctor (2011) also found a pattern whereby RTs at the earliest bins exhibit a stable SRC pattern but steadily decrease at the later end. The present Experiment 1 demonstrates a similar pattern as evidenced by the joystick responses paired with physical-locations. The same stable pattern across the initial bins eventually leads to a decrease at the longest RTs in the distribution.

The results also provide some evidence regarding the relationship between the three spatial stimulus codes reported by Miles and Proctor (2012) earlier. They tested whether directional-arrows were more related to physical-locations or location-words in three experiments. The first two of their experiments used a standard Simon task while

the third and final experiment used a standard SRC task (see Introduction for review). They found that when spatial information was irrelevant (Simon effects), directional-arrows produced compatibility effects such that they were more related with location-words. However, when the spatial information was relevant, then they found directional-arrow and physical-locations were more related to each other than location-words. Miles and Proctor (2012) suggest that this is due to the coding of arrows involving visuo-spatial coding which is a more efficient means than semantic coding when spatial information is task relevant. The present results imply, then that eye movements do not have high set-level compatibility with visuo-spatial stimuli in general but with stimulus that appear in distinct locations. Whereas arrows yield smaller element-level effects than location words, it is an overall effect that does not depend on whether the responses are eye movements or joystick movements. It can be concluded that the link between eye movements and the processing of physical-location stimuli is above and beyond that of directional-arrows or location-words.

<div align="center">**Part III: Ancillary Considerations**</div>

Attentional Components

Discussions of left-right physically located stimuli require consideration of the different way stimuli draw attention. In the case of stimuli presented in the left or right visual field, there is a stark difference relative to centrally presented directional-arrows or location-words. Hyönä (2010) distinguished endogenously (related to task-relevant goals) and exogenously (perceptually salient stimulus features) directed stimuli. For physical-locations, the onset of the imperative (exogenous) stimulus occurs at the periphery, and eye movements to them are often referred to as visually guided saccades. In contrast,

centrally (endogenous) presented stimuli (such as directional-arrows and location-words) indicate the location to which the response should be made. In general, endogenously cued stimuli result in longer RT relative to exogenously driven saccades (Walker, Walker, Hussain, & Kennard, 2000). According to Hutton (2008), this difference reflects the necessary processing time to recruit appropriate S-R mappings. Other modulators of saccadic performance are considered below.

The natural environment contains a wealth of information that one must be able to take in, process, and decide to which aspect cognitive resources should be allocated. How this selection is accomplished depends upon how much attention is devoted to willful action. There is some debate as to whether eye movements are necessary or sufficient for attention. Some researchers have argued that what is within the field of view is a general indicator of what is the focus of attention (Theeuwes, 1991). However, other work has identified scenarios whereby objects that were in the field of view were not actually being attended to (Posner, 1980). Such instances are reflective of internal processes or (covert) shifts of attention in contrast to deliberate movements of the eyes (overt). One may selectively choose to attend to or not attend to an object in the visual field. In this case, saccades and attentional shifts are said to utilize separate neural systems but are related by their response to the same top-down and bottom-up signals. By this account, the relationship between eye movements and attention is classified as a correlational relationship rather than a functional one (Hutton, 2008). In the late 1800s, Helmholz (1894, cited in van der Heijden, 1992) reported the ability to identify letters arranged in a small field of a visual array that was flashed briefly This was accomplished without an overt shift of eye movements and instead requires an internal, covert shift of attention.

Eye-Movement Models and Frameworks

There are many models and frameworks aimed at identifying the mechanisms governing attention and eye movements, and whether they are related. First, the premotor theory of attention (Rizzolatti, Riggio, & Sheliga, 1994) suggests that spatial attention to a specific location is akin to the act of planning without acting. Programming an eye-movement produces neural activity that is said to "instantiate topographic oculomotor pragmatic maps which transform spatial information into eye movements" (Hutton, 2008, p. 3). Conversely, others suggest that attention is not a consequence of motor planning. Evidence for neurons that are involved in attention but not associated with saccadic planning have been found in non-human primates (Juan, Shorter-Jacobi, & Schall, 2004). An opposing theory, the Visual Attention Modal (VAM), proposes that targets are selected by a mechanism that is involved in "selection for action" and one for "selection for perception" (Deubel & Schneider, 1996). Despite these different accounts, clearly some relationship between eye movements and attention exists. Advances in neuroimaging have helped to implicate consistent overlap of areas involved in both.

The extent to which performance will be facilitated may lie in the presence of distractors in the visual field. That is, the more distractors that are available prior to the stimulus onset, the longer the latency of eye-movement responses. I previously found evidence for this relation when investigating eye-movement responses to physical-locations. Participants were instructed to make a saccadic eye-movement in response to either a physical-location or a location-word. In one experiment, the target to which participants were instructed to make a saccade was made available during the fixation period and remained on-screen throughout the trial. Although compatibility effects were

evoked, the set-level effects were not as large as predicted (Griffin-Oliver, 2016). In a follow-up experiment, the target-box was removed, and participants instead only saw the initial fixation cross prior to the trial initiation. The expected large benefit at the set level emerged. It was concluded that the more information one has about the scene, the greater the potential for those distractors to encroach upon the attentional capacities of an individual.

One model that considers the presence of distractors having an impact on the latency of saccades is Carpenter's (2004) LATER (Linear Approach to Threshold with Ergodic Rate) model. This model uses an existing accumulator model of decision-making and applies it to the modeling of saccadic behavior (Hutton, 2008). It assumes that signaled activity starts at some baseline level (S_0) and accumulates at a constant rate (*r*) until it exceeds some threshold (S_r) which programs a saccade toward a given target. Carpenter suggests intentional "procrastination" as a strategic attempt to process multiple targets and the need to direct attention to the most task-relevant or goal-related demands.

Note, the present study controlled for the potential for distractors to impinge on perception and response selection. During the fixation period, no visual stimulus other than the fixation cross was made available to participants. This property was consistent across all stimulus and response sets. Related to this, however, is the possibility of an unintended warning cue which might impact saccade latencies. Reuter-Lorenz, Oonk, Barnes, and Hughes (1995) found that inclusion of an acoustic warning signal presented simultaneously with a fixation offset did not completely reduce gap effects in saccades (shortening of saccadic latencies due to target offsets of the fixation), though they were greatly reduced. As mentioned, I previously investigated set and element-level effects

with other types of manual responses. One finding was that the presence of distractors (saccade target-boxes) had an impact on performance such that it slowed reaction times remarkably. Follow-up work eliminated the presence of these potential distractors and found that saccadic reaction times reduced such that they conformed to those typically found in the literature (~200 – 400 ms). Thus, the present study was conducted mindful of this potential for fixation offsets to impact performance. As such, care was taken to minimize any influence the fixation might have if it persisted until stimulus onset.

Long-Term, Short-Term, and Working Memory

It is worth considering that a large majority of behavioral data are gathered using human participants. These participants enter the highly constrained and controlled laboratory setting and bring with them a set of preconceived perceptions and experiences (Kornblum et al., 1990). Moreover, participants enter the laboratory with a rich compilation of learned associations built up over time. As such, it would be remiss not to consider memory associations and the impacts they may have on psychomotor behavior. Fitts (1959) was a firm believer in the universality of some compatibility phenomena due to how their environments are constructed.

Loveless (1962) termed these associations "population stereotypes". No doubt, these population stereotypes are the result of constant arrangement of responses that, in turn, affect behavior accordingly. In addition, if these population stereotypes are considered as universal principles, then they have likely been ingrained in long-term memory stores. Some studies suggest that saccades can be guided based on representations of spatial locations that have been stored in long-term memory (Ploner, Gaymard, Rivaud, Agid, & Pierrot-Deseilligny, 1998). Related, participants are likely to

have been exposed daily to the visual stimuli utilized in these studies. This exposure means that although the task is done in a controlled lab setting, there may be some similarity across the tasks that might be encountered in real life. That is, the participants are highly trained at discriminating signs that depict verbal language and directional commands conveyed by signage in everyday life. For, physical-locations, they have extensive experience in dealing with visual stimuli occurring at the periphery. Given this overly practiced facet of the tasks, it seems plausible that long-held associations in addition to the short-term goals of the task impacted performance. There may be two forces at play: short-term associations laid out by the demands of the task but also long-term associations that existed prior to testing.

Participants in the present study were all English-speaking individuals. Provided that all verbal stimuli in the task were English words that had location connotations, it is almost certain they have had experience with reading traffic signs with lettering. Additionally, many of these traffic signs may be accompanied with symbolic cues about direction, such as directional-arrows. Finally, physical-location information is available daily for things like avoiding collisions with unexpected objects in one's field of view.

Demands of the task during the actual testing phase are also important. While working memory was not explicitly measured or manipulated here, considerations regarding working memory are discussed. As noted, visual attention allows people to prioritize information that is relevant for their current goal state. Attention is also known to interact with visual working memory (Theeuwes, Belopolsky, & Olivers, 2009). Zahn, Roberts, Schooler, and Cohen (1998) studied manual and saccadic RTs in schizophrenic patients and a control group. They varied the preparatory interval (PI, varied by 1, 2 or 3

seconds) and preparatory interval on a preceding trial (PPI). For their manual task, they found slower RTs and PI effects in schizophrenic patients. Interestingly, saccadic PI and PPI, however, the group differences in RT were largely unaffected. They attributed their results to high SRC in the saccadic task, which placed low demands on working memory, thus facilitating performance. Furthermore, they asserted that for the manual task, the response was guided by representation in memory; however, the saccadic task was guided by the stimulus. As working memory is often a source for impairment in these populations, Zahn et al. (1998) surmised that in low SRC situations, RT is affected because the representation must be refreshed (in working memory). Comparatively, in high SRC situations, those demands are not as high, leading to a lesser cost and, in turn, better performance.

Neural and Physiological Considerations

Along with SRC and ideomotor explanations are physiological considerations. The neural organization of eye-movement responses is worth exploring. Physiological work has revealed several neural pathways that are involved in the execution and control of saccades. The superior colliculus (SC) and frontal eye fields (FEF) appear most critical to the execution of voluntary and involuntary eye-movement responses. Schiller, Sandell, and Maunsell (1987) found that lesions to the SC nor the FEF alone were not sufficient to inhibit saccadic responses. Interestingly, it was the conjunctive lesion to both structures that impaired visually guided saccades. Research in non-human primates (e.g. macaque monkeys) has revealed that the SC is paramount to "reflexive" eye-movement responses.

Another consideration for this privileged relation between eye movements and physical-location stimuli is the pathways by which stimuli are processed. A distinction

must be first made between dorsal and ventral visual pathways. The ventral pathway (i.e., the "what" pathway) is characterized as being responsible for object discrimination and recognition of stimuli. In contrast, the dorsal pathway (i.e., the "where" pathway) is said to carry out spatial localization of stimuli and the guidance of motor action (Lehky & Sereno, 2007). In the case of eye-movement responses, given that the greater benefit was evident for physical-location stimuli over any other spatially-relevant stimuli (e.g. directional-arrows or location-words), it may be that this is a function of location-properties being exacerbated or facilitated by a pathway that is already highly tuned. Physical-location stimuli would tap into the dorsal pathways naturally as it is responsible for location. This pathway is directly connected to the FEF (frontal eye field) which governs motor eye movements. The fact that the stimuli are spatial in nature and directly project into the motor areas responsible for action execution would lead to greater facilitation for these two stimulus and response sets. Here, there a direct route where no additional processing is required. This is consistent with both the dimensional overlap as well as the Lu (1992)'s conceptions of facilitation of a given stimulus dimension when processed in the same system as the response.

Compared to joystick responses and other spatial stimuli (e.g. directional-arrows and location-words), this direct route is not as obvious. It is likely that other factors are contributing to this discrepancy and producing 'less' optimal relationships with these stimulus and response sets. Furthermore, location-words and directional-arrows do not as directly (as physical-locations) map onto the dorsal or ventral pathways. Location-words and directional-arrows have other properties and or connotations to them that are not as explicit. For example, with location-words, the identification of a left or right word can

be discriminated in terms of its directional connotations while at the same time tapping into discrimination of the word meaning. Similarly, directional-arrows also denote activation of location-specificity but also require the retrieval of the symbolic meaning needed to process the stimulus appropriately.

While the same explicit terminology is not utilized when discussing goal-oriented actions in eye-movement responses, pre-saccadic shifts of attention have revealed differences in participants' performance (Armstrong & Moore, 2007; Cavanagh, Hunt, Afraz, & Rolfs, 2010). Specifically, research into goals and attentional shifts has revealed that the identification of stimuli is facilitated if they appear at the goal of the saccadic eye movement than if they appear at some other location (Rolfs, Jonikaitis, Deubel, & Cavanagh, 2011; Rolfs, 2015). This occurs when activity is built up during the preparation of a saccade in a priority map. Neural activity triggers feedback signals that facilitate processing in the retinotopic map of the visual field, which produces benefits when there is a match between the target region and/or relevant location.

To discern differences between saccadic eye-movement responses and responses from other effectors (e.g. reaching with the hands), one important consideration is that with saccade preparation and subsequent execution, attention can be withdrawn from targets requiring a reach response. However, this is not necessarily the case for eye-movement responses, where once the movement has been prepared, a saccade will be generated toward a target - regardless of whether it is the correct response or not (Jonikaitis & Deubel, 2011). This is an important consideration for the present set of experiments to make a case for the relative more beneficial set-level compatibility between eye-movement responses and stimuli that are more "spatial" in nature than

others are. Eye-movement responses perhaps benefit from their pairing with relatively explicit spatial stimuli (i.e., directional-arrows and physical-locations) than with other spatial stimuli that are not as concrete (i.e., location-words). Location-words, unlike arrows and physical-locations, require additional semantic processing and are likely processed as such, comparatively.

In the interest of making connections between eye movements and other motor response modalities, current evidence suggests there is some overlap between these motor processes. At the same time, however, there appear to be some key differences in the organization of the neural organization level from that of manual (keypress) responses.

Although action effects in the saccadic system have been investigated as well, they remain much less understood than for other response modalities. Huestegge and Kreutzfeldt (2012) found evidence for associations between saccadic eye-movement actions coupled with visual effects as a critical feature in saccadic control. Participants were instructed to respond to an auditory stimulus presented to the left or right ear while simultaneously making a saccade toward a peripheral target. A rhombus shape denoted congruent targets, incongruent trials with a square, and unrelated target were designated by a circle. The authors found shorter latencies on the congruent vs. incongruent trials. Ultimately, they concluded that learned associations between oculomotor actions and their effects affect saccade control, much like for other response modalities as proposed by the ideomotor viewpoint. This means that previous findings from manual keypress and grasping responses generalize to the visual system lending support to a strong integration of perception and action.

Implications for Eye Movements and Other Modalities

Stephan, Koch, Hendler, and Huestegge (2013) investigated specific pairings and found that stimulus and response modalities yield better dual-task performance in certain scenarios rather than in others. Precisely, visual-manual and auditory-vocal tasks lead to better performance than visual-vocal and auditory-manual tasks. They followed up on this work by investigating eye-movement responses where they were paired with vocal and manual responses. They found that conjunctive vocal and manual responses produced stronger modality compatibility effects than vocal and eye-movement responses. Interestingly, in the case of the latter, the modality compatibility effect was eliminated. For the vocal-manual set, participants were instructed to respond to a tone presented in the left or right ear by making a (left or right) vocal or keypress response (Experiment 1a). In the vocal-oculomotor response group, the same auditory and vocal responses were used (as in the vocal-manual response set), however, instead of keypress responses, participants made a saccade to a left or right target.

Previously, I also investigated eye-movement responses and their relation to vocal responses. In those experiments, I found that having eye-movement responses paired with an analogous spatial stimulus produced larger effects than if eye movements were paired with verbal stimuli. It should be noted, however, that Stephan et al.'s (2013) stimuli and my stimuli differed in a few respects. First, their auditory task used tones presented to either the left or the right ear. My experiments only involved the presentation of verbal 'left' and 'right' words or spatial stimuli (e.g. left and right physical-locations). Nevertheless, large effects emerged when eye movements were paired with an

accompanying stimulus that was spatial in nature. Similarly, opposite pairings led to decrements in performance.

Khalid and Ansorge (2013) also found for manual (e.g. keypresses) and saccadic responses, the effect of location-word stimuli increased along the distribution. However, they also noted some differences between manual and saccadic systems. They suggest that perhaps these differences arise from greater sensitivity in the saccadic system relative to the manual one. In this case, spatially relevant stimuli (i.e., physical-locations) might behave similarly to other visuospatial stimuli (i.e., directional-arrows). Relatedly, Pellicano et al. (2009) studied the Simon effect by using prototypical (explicit arrows) and non-prototypical (less/greater than symbols). Half of their participants made keypress responses to one or the other that was additionally colored blue or red (counterbalanced). Their results reveal an inverted J-shaped function, much like the results of the eye movements in Experiment 2. However, unlike Pellicano et al. (2009)'s results with keypress responses where the linear slope of the arrow stimuli is steeper, eye-movement responses produce a shallower trajectory. One explanation is provided by Ansorge (2003b), whereby directional-arrows are highly-overlearned directional stimuli and are delayed in processing comparatively to lateralized stimuli (physical-locations). Furthermore, the present results suggest that if the continuum proposed by Wang and Proctor (1996) were to be continued to be used, then in certain cases (i.e., when physical-locations are involved) eye-movement response are more left lateralized than even keypress responses. However, when physical-locations are not involved (as is the case with directional-arrows and location-words), then these other spatial stimuli

(directional-arrows or location-words) may involve other processes far removed from physical-locations.

In a third experiment, Pellicano et al. (2009) presented the words left or right (in Italian) and paired them with left or right response buttons. They predicted that the meaning of the spatial word would lead to a more delayed time course of effects compared to directional-arrows where that relation is said to be more direct. That is, the semantic properties of the presented spatial word must be accessed first in long-term memory resulting in a more time-consuming process. They found a clear Simon effect like that of the arrow stimuli, however, the time course revealed this effect was relegated to the slower, delayed bin. This supports that spatial coding of semantic stimuli is slower than symbolic ones (Pellicano et al., 2009). The present Experiments 1 and 3 are in line with this finding as semantic, location-word stimuli also demonstrate a peak at the latter bins.

In Experiment 3, there was a relative 'greater' benefit for directional-arrows paired with joystick responses than with eye movement response. This is suggestive of something else going on regarding joystick and manual keypress responses. That is, joystick responses appear to be most optimally paired with location-arrow stimuli than keypress responses. Indeed, previous work I have done looking at keypress responses to verbal (left/right word) stimuli show a slightly larger mapping effect for location-words with joystick responses (161 ms) than for keypress responses (148 ms; Griffin-Oliver, 2016). Thus, joystick responses produce large effects, overall.

Conclusion

Across a set of three experiments, I investigated two combinations of stimulus and response for joystick and eye-movement responses paired with physical-location, location-word, and location-arrow stimuli. Joystick and eye-movement responses were used to find two response modalities that shared some overlap yet retained distinct differences. Across this set of experiments, a reliable set-level compatibility effect emerged. However, this set-level compatibility effect varied as a function of which sets were "most compatible". That is, some pairings produced a larger mapping effect than others did. Experiment 3 revealed that location-words and directional-arrows produced roughly equivalent mapping effects having only a non-significant 7-ms difference for directional-arrows/eye-movements and location-words/joystick responses compared to directional-arrows/joystick response and location-words/eye-movement responses.

Location-words typically produced larger effects no matter what the pairing. This corroborates prior work in which word stimuli tend to produce larger effects than other types of spatially-relevant stimuli. Further investigations regarding joystick and eye-movement responses revealed that no significant differences between whether they were paired with directional-arrows or location-words. Instead, eye movements most benefit from pairing with physical-location stimuli.

Future Directions

Future work on this topic might consider the effect of eye-movement responses in situations that are more social in nature rather than being limited to spatial situations. For example, a growing body of work suggest that non-visually impaired humans possess a great deal of experience and practice in recognizing and processing faces, essentially

making humans "face experts" (Baron-Cohen, Wheelwright, & Jolliffe, 1997). Various physical attributes on the face enable humans to process spatial-relevant features when communicating with other beings. The eye region conveys important, spatially-relevant information between two individuals conversing. Research on this topic has investigated populations of individuals who are impaired in their processing of human emotion, particularly in individuals with autism spectrum disorder (ASD) for whom social, verbal speech skills can be challenging (Norbury et al., 2009). In the context of the present body of work, studying eye movements in conjunction with emotionally-relevant stimuli along with spatial stimuli may help further understanding of set-level considerations. Future research could investigate schematic faces whereby participants are required to make saccadic eye movements to spatially-relevant features such as the eyes. If a greater benefit for these stimuli were found over the other types of spatial stimuli investigated (e.g. location-words, directional-arrows, and/or physical-locations), this would indicate other potential factors rather than spatial information as critical to processing of location information. Thus, other considerations regarding other specific content (such as social cues) that might affect the processing of spatial information. That is, with schematic faces there is this additional "emotional" component outside of more "spatially strict" ones found in location-words or directional-arrows. This would help to rule out whether these additional factors are necessary to override the strong coupling between eye movements and physical-locations.

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APPENDIX A

Table 1

Experiment 1: Reaction Time in Milliseconds 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	
	Physical Location –	Location Word –	Physical Location –	Location Word –
Mapping	Eye	Joystick	Joystick	Eye
Left Response				
Congruent	192	518	368	378
Incongruent	288	728	482	497
Right Response				
Congruent	198	610	455	379
Incongruent	315	670	404	480
Both Responses				
Congruent[1]	195	564	412	378
Incongruent	301	699	443	488
Mapping Effect	106	135	31	110
Avg. Set-Level Mapping Effect	121		71	

[1]*Note*. Values in the congruent row are important for the set-level comparisons.

Table 2

Experiment 2: Reaction Time in Milliseconds 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	
	Physical Location – Eye	Direction Arrow – Joystick	Physical Location – Joystick	Direction Arrow – Eye
Mapping				
Left Response				
Congruent	199	488	456	347
Incongruent	298	513	456	383
Right Response				
Congruent	196	462	405	343
Incongruent	312	544	492	362
Both Responses				
Congruent[2]	197	475	430	345
Incongruent	305	528	474	372
Mapping Effect	108	53	43	27
Avg. Set-Level Mapping Effect	81		35	

[2]*Note*. Values in the congruent row are important for the set-level comparisons.

Table 3

Experiment 3: Reaction Time in Milliseconds for Left, Right and Both Responses on

Congruent and Incongruent Trials for Each Stimulus-Response Set Pairing (Classified as

Pairings 1 and 2), With Mapping Effects (Incongruent – Congruent Reaction Times) for

the Respective Pairings Indicated

	1		2	
	Direction Arrow –	Location Word –	Direction Arrow –	Location Word –
Mapping	Eye	Joystick	Joystick	Eye
Left Response				
Congruent	324	618	531	391
Incongruent	363	742	532	559
Right Response				
Congruent	316	572	472	392
Incongruent	366	769	589	546
Both Responses				
Congruent[3]	320	595	502	391
Incongruent	364	755	561	553
Mapping Effect	45	161	59	161
Avg. Set-Level Mapping Effect	103		110	

3Note. Values in the congruent row are important for the set-level comparisons.
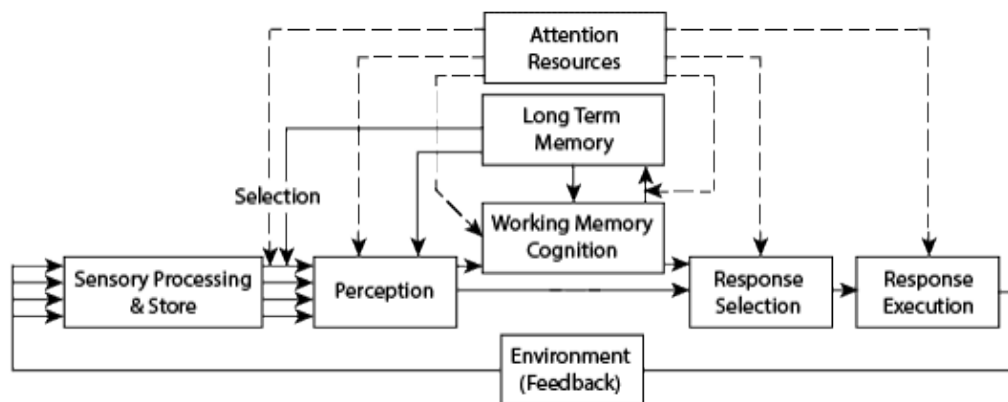
APPENDIX B

Figure 1. A model of human information processing (adapted from Wickens & Hollands,
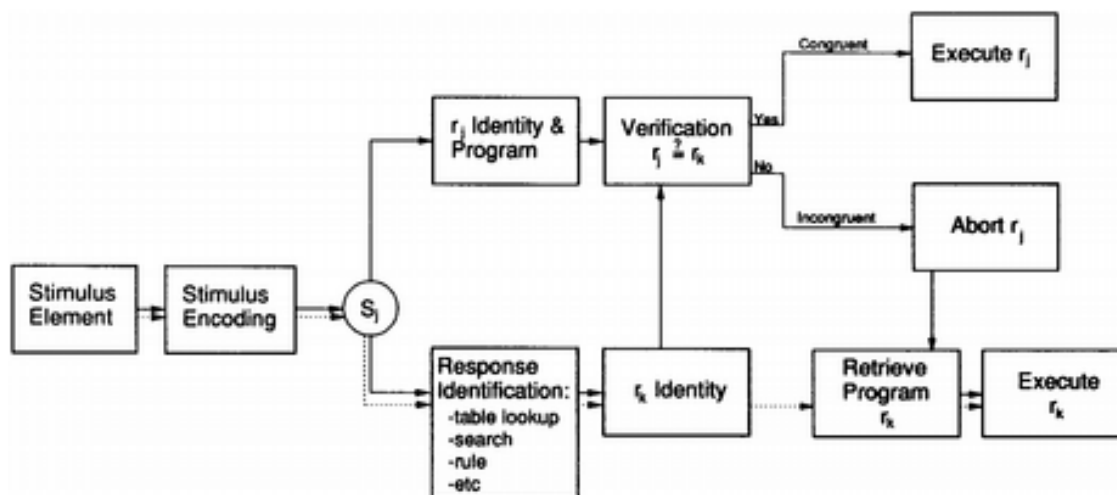
2000).

Figure 2. 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 Basis for Stimulus-Response Compatibility-A Model and Taxonomy. *Psychological Review, 97*, 253-270, 1990. American Psychological Association. Reprinted with permission.
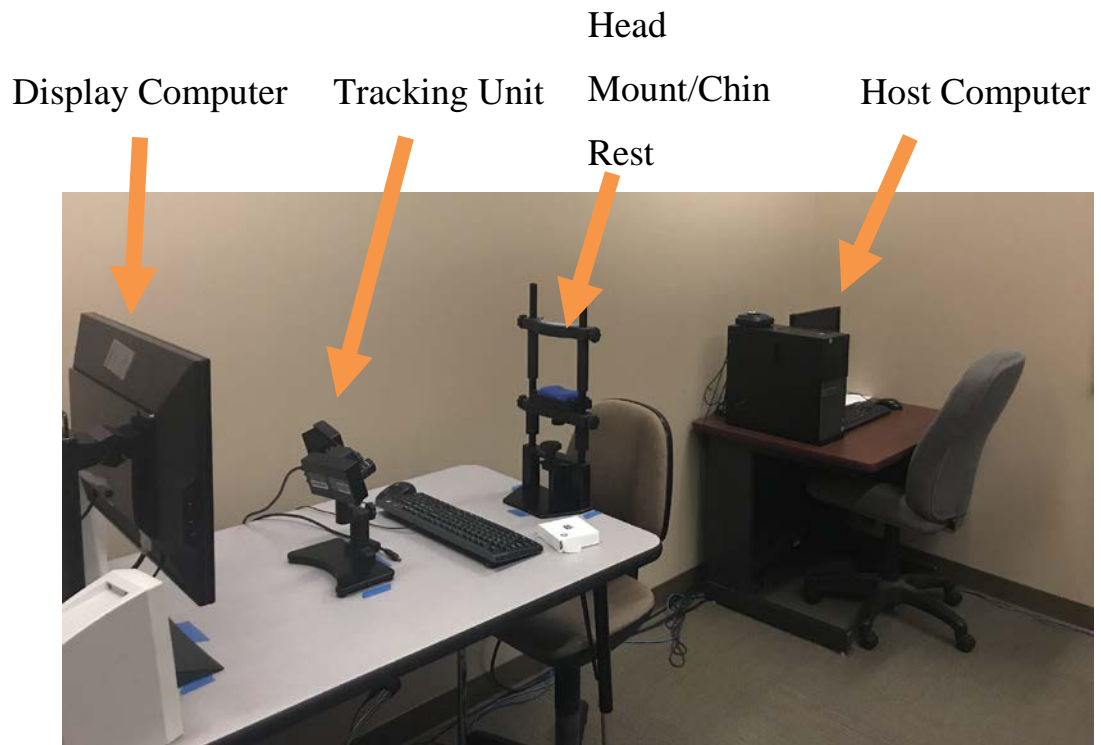
Figure 3. Configuration of the Display and Host Computer(s). All participants used a

head mount and chin rest to stabilize head movements.

Figure 4. Experiment 1: Example trial types for the physical-location (left) and location-word (right) trials (with the fixation cross for reference). On a prosaccade, participants looked to the right side of the screen indicated by the peripheral physical-location or central location-word stimulus. For antisaccade trials, participants looked in the opposite direction of the area indicated by the peripheral physical-location stimulus or central location-word stimulus. For joystick responses, participants moved the joystick in the direction indicated by the imperative stimulus (congruent) or in the opposite location of the target (incongruent).

A
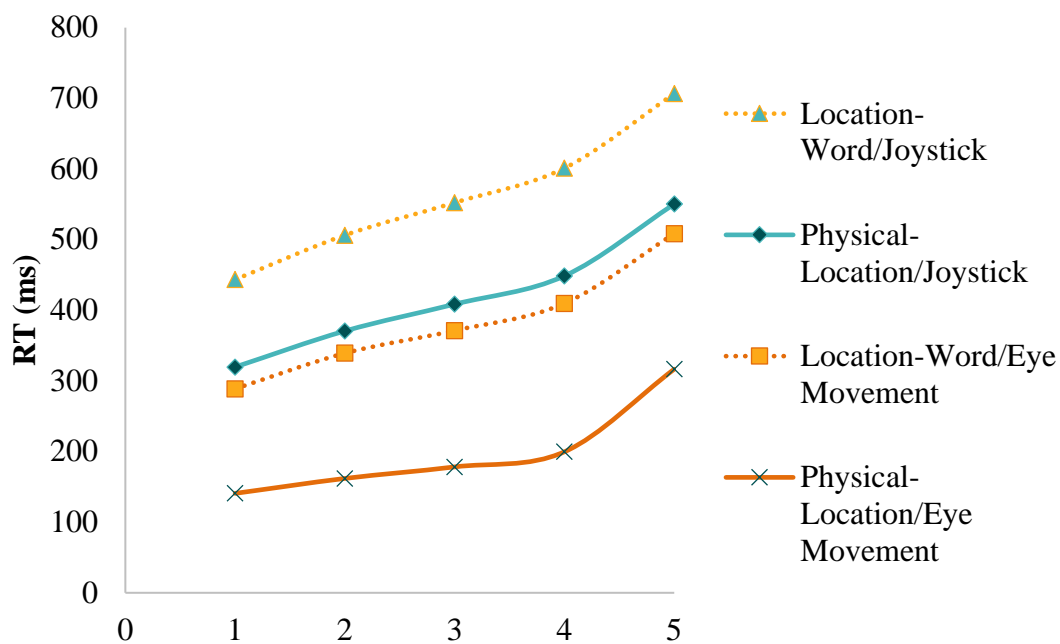
B

Figure 5. Experiment 1: Panel A. Set-level compatibility distribution for the congruent

mapping conditions. Panel B. Mean element-level stimulus-response compatibility (SRC)

effect (in ms) as a function of reaction time bin.

Figure 6. Experiment 2: Example trial types for the physical-location (left) and location-arrow (right) trials (with the fixation cross for reference). On a prosaccade, participants looked to the right side of the screen indicated by the peripheral physical-location or central location-arrow stimulus. For antisaccade trials, participants looked to the opposite of the central target to the mirror location indicated by the location-arrow stimulus or peripheral physical-location stimulus. For joystick responses, participants moved the joystick in the direction indicated by the imperative stimulus (congruent) or in the opposite location of the target (incongruent).
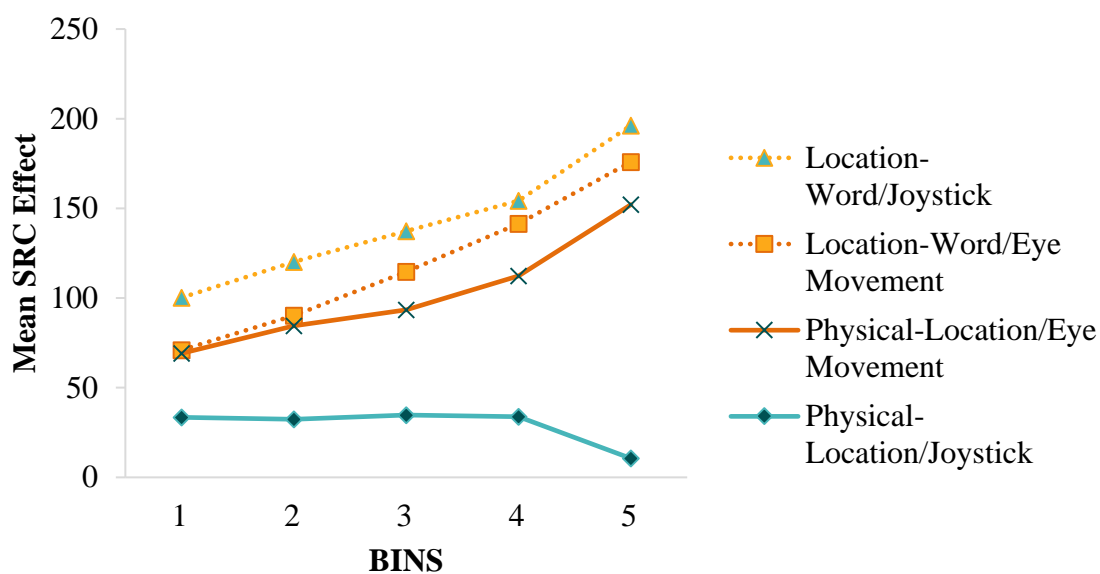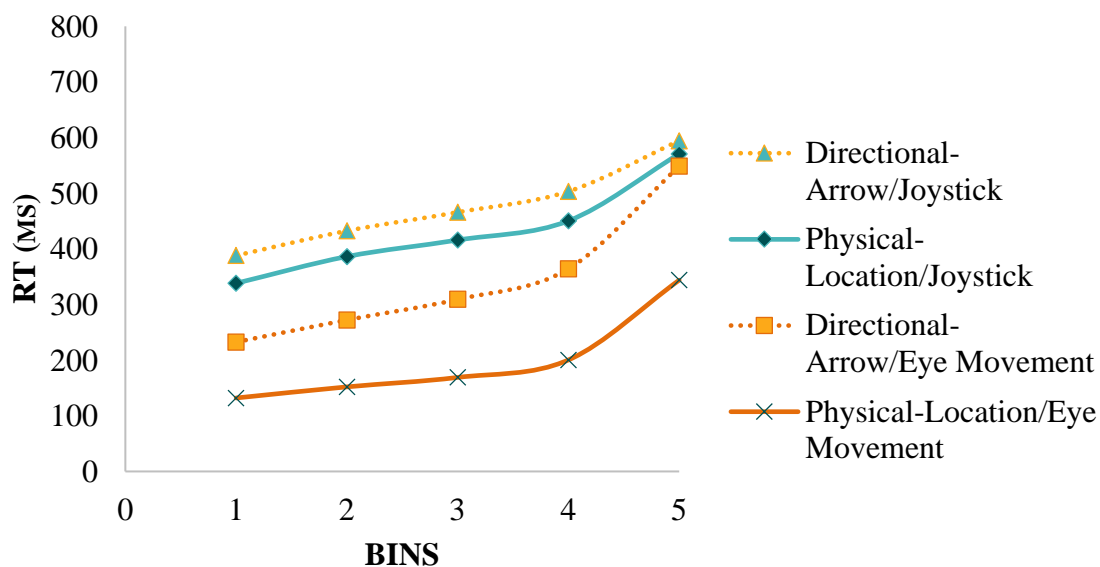
A

B

Figure 7. Experiment 2: Panel A. Set-level compatibility distribution for the congruent

mapping conditions. Panel B. Mean element-level stimulus-response compatibility (SRC)

effect (in ms) as a function of reaction time bin.

Figure 8. Experiment 3: Example trial types for the location-arrow (left) and physical-location (right) trials. On a prosaccade, participants looked to the right side of the screen indicated by the central location-arrow or location-word stimulus. For antisaccade trials, participants looked to the opposite of the central target to the mirror location indicated by the central location-arrow or location-word stimulus. For joystick responses, participants moved the joystick in the direction indicated by the imperative stimulus (congruent) or in the opposite location of the target (incongruent).
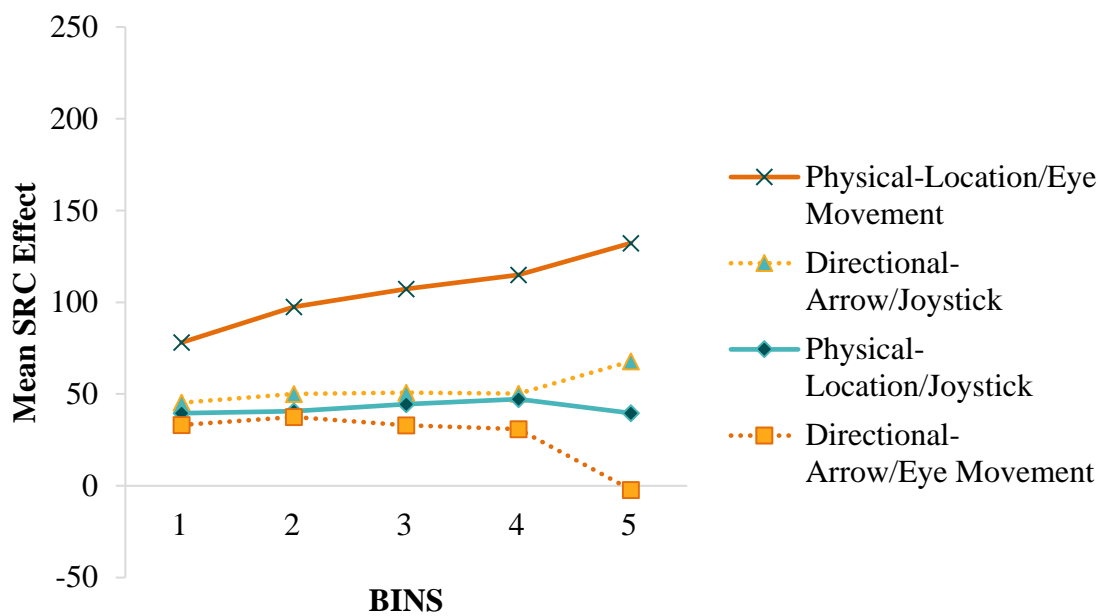
A

B
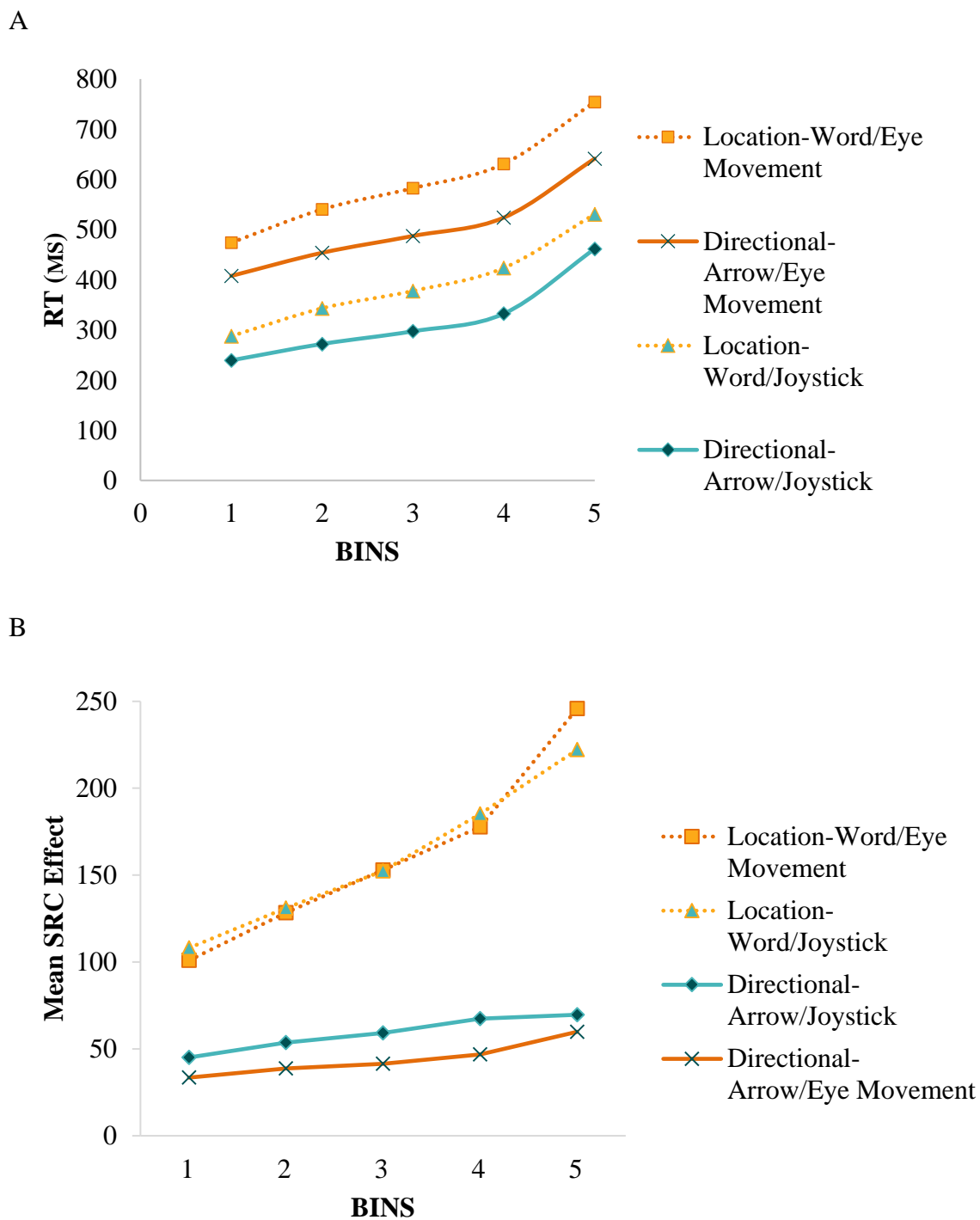
Figure 9. Experiment 3: Panel A. Set-level compatibility distribution for the congruent

mapping conditions. Panel B. Mean element-level stimulus-response compatibility (SRC)

effect (in ms) as a function of reaction time bin.

APPENDIX C

Table 4

Experiment 1: Test of Within-Participants Effects for the Congruent Mapping Only and Both Mappings

Mapping	Source	F	P	$\eta_p{}^2$
Congruent	Response Modality	510.938	.000	.957
	Stimulus Code	495.274	.000	.956
	Response Modality × Stimulus Code	8.690	.007	.274
Congruent & Incongruent	Congruency	176.327	.000	.885
	Response Modality	513.008	.000	.957
	Stimulus Code	379.811	.000	.943
	Congruency × Response Modality	7.318	.013	.241
	Congruency × Stimulus Code	27.892	.000	.548
	Response Modality × Stimulus Code	.675	.420	.029
	Congruency × Response Modality × Stimulus Code	22.896	.000	.499

Table 5

Experiment 1: Set-Level Compatibility Distribution Analysis for the Congruent Mapping for Physical-Locations and

Location-Words

Mapping	Source	F	p	η_p^2
	Response Modality	450.216	.000	.951
	Stimulus Code	461.367	.000	.953
	Bin	419.856	.000	.948
Congruent	Response Modality $\times$ Stimulus Code	10.642	.003	.316
	Response Modality $\times$ Bin	9.452	.000	.291
	Stimulus $\times$ Code Bin	13.191	.000	.364
	Response Modality $\times$ Stimulus Code $\times$ Bin	1.360	.254	.056

Table 6

Experiment 1: Element-Level SRC Effect Distribution Analysis for Physical-Locations and Location-Words

	Source	F	P	η_p^2
	Response Modality	12.697	.002	.356
	Stimulus Code	32.229	.000	.584
	Bin	25.856	.000	.529
SRC Effect	Response Modality × Stimulus Code	19.470	.000	.458
	Response Modality × Bin	4.639	.002	.168
	Stimulus Code × Bin	4.912	.001	.176
	Response Modality × Stimulus Code × Bin	14.02	.000	.379

Table 7

Experiment 2: Test of Within-Participants Effects for the Congruent Mapping Only and Both Mappings

Mapping	Source	F	P	$\eta_p{}^2$
Congruent	Response Modality	347.397	.000	.938
	Stimulus Code	93.448	.000	.802
	Response Modality × Stimulus Code	49.616	.000	.683
	Congruency	56.255	.000	.710
	Response Modality	323.922	.000	.934
	Stimulus Code	143.578	.000	.862
Congruent & Incongruent	Congruency × Response Modality	3.431	.077	.130
	Congruency × Stimulus Code	8.936	.007	.280
	Response Modality × Stimulus Code	31.588	.000	.579
	Congruency × Response Modality × Stimulus Code	15.211	.001	.398

Table 8

Experiment 2: Set-Level Compatibility Distribution Analysis for the Congruent Mapping for Directional-Arrows and Physical-Locations

Mapping	Source	F	p	η_p^2
	Response Modality	357.089	.000	.939
	Stimulus Code	93.201	.000	.802
	Bin	208.079	.000	.900
Congruent	Response Modality × Stimulus Code	48.364	.000	.678
	Response Modality × Bin	6.7510	.000	.227
	Stimulus × Code Bin	4.202	.004	.154
	Response Modality × Stimulus Code × Bin	13.905	.000	.377

Table 9

Experiment 2: Element-Level SRC Effect Distribution Analysis for Physical-Locations and Directional-Arrows

	Source	F	P	η_p^2
	Response Modality	3.501	.074	.132
	Stimulus Code	8.610	.007	.272
	Bin	.784	.539	.033
SRC Effect	Response Modality × Stimulus Code	14.521	.001	.387
	Response Modality × Bin	.501	.735	.021
	Stimulus Code × Bin	1.499	.209	.061
	Response Modality × Stimulus Code × Bin	3.167	.017	.121

Table 10

Experiment 3: Test of Within-Participants Effects for the Congruent Mapping Only and Both Mappings

Mapping	Source	F	P	η_p^2
Congruent	Response Modality	378.458	.000	.943
	Stimulus Code	131.502	.000	.851
	Response Modality × Stimulus Code	3.247	.085	.124
	Congruency	256.691	.000	.918
	Response Modality	301.976	.000	.929
Congruent & Incongruent	Stimulus Code	226.232	.000	.908
	Congruency × Response Modality	.727	.403	.031
	Congruency × Stimulus Code	100.347	.000	.814
	Response Modality × Stimulus Code	1.188	.287	.049
	Congruency × Response Modality × Stimulus Code	.764	.391	.032

Table 11

Experiment 3: Set-Level Compatibility Distribution Analysis for the Congruent Mapping of Directional-Arrows and

Location-Words

Mapping	Source	F	p	η_p^2
	Response Modality	381.275	.000	.943
	Stimulus Code	132.352	.000	.852
	Bin	525.655	.000	.958
Congruent	Response Modality × Stimulus Code	3.262	.084	.124
	Response Modality × Bin	2.745	.033	.107
	Stimulus × Code Bin	7.205	.000	.239
	Response Modality × Stimulus Code × Bin	1.747	.146	.071

Table 12

Experiment 3: Element-Level SRC Effect Distribution Analysis for Directional-Arrows and Location-Words

Source		F	P	η_p^2
	Response Modality	.592	.449	.025
	Stimulus Code	102.794	.000	.817
	Bin	38.429	.000	.626
SRC Effect	Response Modality $\times$ Stimulus Code	.835	.370	.035
	Response Modality $\times$ Bin	.590	.671	.025
	Stimulus Code $\times$ Bin	19.468	.000	.458
	Response Modality $\times$ Stimulus Code $\times$ Bin	.526	.717	.022