Action and Instrument Specificity in Musicians

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The purpose of this research was to test the hypothesis that the visual perception of musical stimuli activates the motor system of expert musicians in ways specific to their primary instrument. In two experiments, trombonists, non-trombonist musicians, and non-musicians were asked to decide if the second note of a two-note visually presented sequence was higher or lower than the first. Participants responded by moving a joystick forward or backward to indicate a higher or lower response (Experiment 1) or by pressing buttons on a computer keyboard to indicate their response (Experiment 2). In Experiment 1, response times for trombonists were slower when the potential action for performing the two-note sequence on the trombone was incompatible with the movement for a correct response on the task than when the potential action was compatible. This movement congruency effect only occurred when action required by the experimental task overlapped dimensionally with the actions required by trombone playing. There was no effect for non-trombonists in either experiment and, in Experiment 2, the movement congruity effect for trombonists was not significant. The effect of movement congruency is a kind of Stroop effect. The findings extend those of instrument specificity for musicians, demonstrated in previous studies, to a new stimulus-response interference paradigm. The results are consistent with the claims of the grounded cognition approach that the motor and perceptual systems are linked through the body’s interactions with the environment.
Action and Instrument Specificity in Musicians

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APPROVAL PAGE

Doctor of Philosophy Dissertation

Action and Instrument Specificity in Musicians

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University of Connecticut
2014
DEDICATION

For S.A.M. Papa can play with you now.
ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Roger Chaffin, who took a chance on a simple trombonist ten years ago, not knowing exactly what he was getting himself into. He has inspired me to push myself beyond my comfort zone, taught me how to ask questions and to express ideas, and most importantly how to continue believing in myself. Words cannot express my gratitude for his careful and detailed suggestions and patient guidance throughout the research and writing of this paper. His willingness to include me in his research so long ago, and push me to develop my own, has made him a truly wonderful mentor.

I am also indebted to the other members of my committee, Dr. Jay Rueckl and Dr. Heather Read, for their suggestions, insightful comments and constructive criticism on this project from proposal to defense.

I would also like to thank my fellow graduate researchers, Dr. Kristen Begosh and Dr. Alex Demos, who came on after I did and finished well before me. Their practical (and technical) advice, encouragement and general camaraderie made a huge difference.

Finally, I would like to thank my wife, Sara, who took a chance on a simple trombonist ten years ago, not knowing exactly what she was getting herself into. She has endured more than her share of sacrifices and burdens of household and parental obligations along this journey. She is my true inspiration, and my constant reminder of what is really important in life.
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Introduction

Music performance inherently involves action. Sounds are only created by acting upon something. On the piano, striking a key causes the hammer to strike the string. On the violin, the strings vibrate when plucked or bowed. Each instrument differs in the movements required to play it. For example, consider a trumpet and a trombone: on any given partial of their respective overtone series, if the performer wishes to play a lower note he or she must manipulate the valves or the slide to make the instrument body longer, thus creating a longer resonating column of air. How the instrument changes to become longer or shorter depends on the instrument. The trumpet (and other valved instruments) opens a combination of valves to direct the air moving through the horn through additional lengths of tubing. On the trombone the same lengthening of the instrument is accomplished by moving the slide outward. On one instrument, the musician uses fingers to open and close valves, on the other instrument, the musician uses wrist and arm to extend the slide.

Through thousands of hours of practice over many years, professional musicians have repeated the motor sequences to perform on their instrument countless times (Ericsson, Krampe, & Tesch-Romer, 1993), so as to make performing on them as natural an action as picking up a pencil or sitting on a chair. Does this experience with the instrument affect the way musicians perceive musical notation? Does the way in which musicians interact with their instruments affect their experience of musical notation when they are not actually playing their instrument?

In the present study, I asked trombonists and non-trombonists to decide if the second note of a two-note sequence was higher or lower than the first. They responded by moving a joystick forward or backward to indicate a higher or lower response (Experiment 1) or by pressing buttons on a computer keyboard to indicate their response (Experiment 2). For Experiment 1, I
expected that trombonists would be slower to respond when the potential action for actually
playing the two-note sequence was in an incompatible direction for the correct response to the
task, and that non-trombonists would not exhibit a similar incompatibility effect. In Experiment
2, I expected to eliminate this compatibility effect.

My goal is a better understanding of the role played by sensorimotor processes in the
comprehension of musical symbols. I will outline current research into the role these processes
play in a variety of cognitive tasks and explain how research into interference and facilitation
effects with musicians (including the results of the current study) relates to long established lines
of research into stimulus-response compatibility, including the seminal studies of Stroop (1935),
Fitts and Seeger (1953), and Simon and Rudell (1967). I will ask whether the experience of
playing different musical instruments differentially affects perception of music notation.
Answering this question will help to better understand the role the motor system plays during
music perception and, more broadly, how experience shapes the way in which individuals
interact with the world.
Chapter One: Action Compatibility, Motor Resonance and Event Coding

Action Compatibility

The traditional information-processing approach to perception and action assumes that perception occurs first, followed by action, with each divisible, in turn, into separate sub-stages. For perception, encoding is followed by memory retrieval. For action, response selection is followed by action planning (Pashler, 1994). There is, however, increasing support for the alternative notion that sensorimotor processes are a single, integrated system in which the processing of perceptual input proceeds in parallel with the preparation for the action that results from it, with action influencing perception and vice versa (Barsalou, 1999; Liberman & Mattingly, 1985; Galantucci, Fowler, & Turvey, 2006). In this chapter I will describe the main theoretical approaches and experimental findings that have argued for the close connection of action and perception.

One such approach, known as embodied cognition, holds that the function of cognition is to guide action, and thus cognition is intimately shaped by the physical context, especially the body of the actor/perceiver (see Wilson, 2002 for an overview). Support for the embodied condition approach comes from a wide variety of studies showing that sensorimotor systems and processes are recruited during sentence comprehension (Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006), speech perception (Liberman & Mattingly, 1985; Galantucci, Fowler, & Turvey, 2006; Fowler & Dekle, 1991), visual perception of objects (Tucker & Ellis, 1998) and actions (Buccino et al., 2001; Rizzolatti, Fadiga, & Gallese, 1996), formation of concepts (Jostmann, Lakens, & Schubert, 2009) and social perception and judgment (see Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005 for a review). I will discuss each in turn.
First, sentence comprehension is grounded in bodily action. In a typical study, participants read sentences implying movement in one direction (e.g. toward or away from the body), and respond with a movement in either the same (congruent) or the opposite (incongruent) direction. For example, in a reaction time task participants might be instructed to place their hand between two response keys, labeled yes and no, situated so that they must move their hand either towards or away from their body in order to respond. In one such study, Glenberg and Kaschak (2002) asked participants to judge the comprehensibility of sentences which contained an implied action. For example, the sentence “Close the drawer.” implies a movement of the hand away from the body. In contrast, the sentence “Open the drawer.” implies a movement of the hand toward the body. Incomprehensible sentences included statements such as “Joe sang the cards to you.” Participants were to respond by pressing a yes response button if the sentence made sense or a no response button if it did not. For half the participants, the yes response was located closer to them and the no response was farther away. The researchers found that participants responded faster when implied actions and task response movements were congruent than when they were incongruent. Congruent responses were those in which a yes response required the same movement as the action implied in the sentence (e.g. toward or away from the body). When the action implied by the sentence was compatible (congruent) with the action required to respond, responses were quicker than if there was a mismatch between the sentence and the response (incongruent). Glenberg and Kaschak dubbed this the action-sentence compatibility effect. To explain this effect, they invoke the indexical hypothesis (Glenberg & Robertson, 1999). The indexical hypothesis posits that when comprehending sentences, a cognitive simulation of the sentence situation takes place, including any actions.
The action-sentence compatibility effect has been extended to manual rotation by demonstrating that manual rotation responses that were congruent with actions implied by sentences (e.g. *turn down the volume*) were faster than responses that were incongruent with implied actions. Zwaan and Taylor (2006; Experiment 2) asked participants to judge sentences read aloud as either coherent or nonsensical. In order to answer *yes* or *no*, participants had to rotate a knob manually clockwise to the left or counterclockwise to the right. When they heard sentences describing an action that required manual rotation, participant response times were faster when that action was compatible (congruent) with the direction required to manually rotate the control for a *yes* response. For example, when presented with the sentence “*Turn down the volume*”, participants for whom the *yes* response was a left rotation responded faster than those for whom a *yes* response required a right rotation. The researchers also showed (Experiment 4) that merely observing a visual rotating stimulus can affect judgments about sentences describing manual rotation, even when the response required does not involve actual rotation. When the visual stimulus (a disc rotating clockwise or counterclockwise) was rotating in the same direction as the direction implied by sentences describing manual rotation (congruent), responses were faster than if the two directions were incompatible. This finding supports the idea of motor resonance during perception, even when a similar motor response is not required in response. Although the authors do not mention it, the study is representative of a larger class of studies involving Stroop-like and stimulus-stimulus compatibility effects which I will discuss in Chapter 3 (see Proctor & Vu, 2006, for discussion).

Second, the motor system is involved in speech perception (Liberman & Mattingly, 1985; Galantucci et al., 2006; Fowler & Dekle, 1991). Compatibility effects for speech production have been found for visually presented irrelevant stimuli when participants were to say the syllables
“Ba” or “Da” in response to visual cues. Kerzel and Bekkering (2000) had participants pronounce “Ba” or “Da” as indicated by an on-screen cue (“Ba” or “Da” appearing on screen, or the learned symbols “##” or “&&” representing “Ba” or “Da”). Participants were told to ignore the concurrent irrelevant video of a mouth (without sound) uttering either “Ba” or “Da”. When there was a mismatch between the irrelevant video (e.g. “Ba”) and the cued syllable (e.g. “Da”), response times were slower than when they were compatible. The authors proposed that the irrelevant speech gesture activated motor codes for producing that gesture, even as the task relevant action activated a separate motor code for a correct response. When the two codes were in conflict, responses were slower (Kerzel & Bekkering, 2000; Galantucci et al., 2006).

Neuroimaging studies also support the view that the motor system is recruited during speech perception. In an fMRI study in which participants listened to and produced monosyllabic speech sounds, listening to speech activated premotor cortex areas that are also recruited during speech production (Wilson, Saygin, Sereno, & Iacoboni, 2004).

Third, the visual perception of objects and actions is modulated by sensorimotor processes. In a task involving the identification of an object’s orientation (e.g. a coffee mug upright or upside-down), participants responded faster if the correct response was on the same side of the display as the object’s handle than if it was on the opposite side (Tucker & Ellis, 1998). The researchers concluded that although the experimental task (judgment of object orientation) was irrelevant to grasping the object, the representation of the potential action of grasping either facilitated or interfered with the orientation judgment.

Functional magnetic resonance imaging (fMRI) studies have shown that observing the actions of others leads to activation in motor-related brain areas (Buccino et al., 2001; Rizzolatti et al., 1996). When subjects viewed actions made by different effectors (e.g. mouth, hand and
foot) in a videotaped presentation, the different areas associated with those effectors in the pre-motor cortex show activation, respectively (Buccino et al., 2001).

Fourth, bodily states and experiences can affect the interpretation of concepts (see Barsalou, 2008 for a review). In one study, judgments of monetary value and justice were affected by a bodily experience of weight (Jostmann et al., 2009). In Experiment 1, participants estimated the value of foreign currencies while holding a heavy or light clipboard. Those holding heavy clipboards gave higher estimates of the value of the currency than participants holding light clipboards. In Experiment 2, the researchers investigated the abstract concept of justice by having participants rate the importance of university students having a say in a university committee decision-making process. Results again showed that participants holding a heavy clipboard felt more strongly that the committee should listen to student input than did participants holding lighter clipboards (Jostmann et al., 2009).

Fifth, judgments of attitudes and social perceptions are affected by bodily experiences and states (see Niedenthal et al., 2005 for review). For example, participants displayed approach tendencies for positive valence words, like love, and avoidance tendencies for negative valence words, like hate (Chen & Bargh, 1999). In this experiment, participants classified words as either good or bad by pushing or pulling a lever. In the congruent condition, participants responded by pulling the lever toward them for positive valence (good) words and away from them for negative valence (bad) words. In the incongruent condition, the directions were switched. Participants in the congruent condition were faster to respond than participants in the incongruent condition. That is, participants were faster to pull the lever toward themselves than to push it away for positive valence words, and faster to push the lever away than to pull it toward them for negative words. The researchers also found (Experiment 2) that even without an
overt evaluation response, the congruency effect was significant. In this experiment the task was simply to respond (push the lever for half the stimuli, pull for the other half) when each word was presented. Participants were still faster to pull the lever for positive words and to push the lever for negative words.

Another example of the embodiment of social perceptions comes from the finding that merely forming sentences from words associated with the elderly will make participants walk more slowly when leaving an experiment (Bargh, Chen & Burrows, 1996). In Experiment 2 of this study, participants were to construct sentences from scrambled word sets which contained words related to either an elderly stereotype (e.g. Florida, wrinkled, retired, dependent) or a non-age-related stereotype. The dependent measure was how long it took to walk down the hallway after the completion of the experiment. Participants in the elderly stereotype condition took significantly longer to walk to the exit than did participants in the non-age-related condition. The researchers concluded that exposure to particular stereotypes influences behavior in unconscious ways (Bargh, Chen & Burrows, 1996).

To summarize, a great deal of evidence points toward the view that sensorimotor processes integrate perceptual input in preparation for action, that is, that there are mutual influences between action and perception. Moreover, these influences are evident in the body-based nature of off-line cognition (Wilson, 2002). Of particular interest in the context of this paper is the fact that the automaticity of skilled behavior can influence seemingly unrelated behavior when there is a common mapping of action codes.

Motor Resonance

The idea of perception being grounded in bodily action, and vice versa, draws on theories of motor resonance, as well as on the discovery of so-called mirror neurons in premotor cortex
of monkeys (see Fabbri-Destro & Rizzolatti, 2008 for a review). Motor resonance theory proposes that seeing others performing an action elicits patterns of neural activity that normally occur when the observer actually performs the action him/herself. In addition to firing when observing an action being performed, recordings of neural activity in monkeys have also shown activity when hearing sounds associated with familiar actions (Kohler, Keysers, Umilta, Fogassi, Gallese, & Rizzolatti, 2002). Crucially, it appears that an assumption of intent is required for this activation to occur (Umilta et al., 2001). When monkeys were aware that food was the object of a grasping motion made by an experimenter, they showed typical mirror neuron activation. However, in the absence of food, the same grasping motion did not elicit a similar response, implying the need for a goal or intent for mirror neuron activation to occur.

**Theory of Event Coding**

Perception and action are also closely linked in the theory of event coding which proposes that the cognitive representations of perceivable events serve both perception and action (Hommel, Musseler, Aschersleben, & Prinz, 2001). The theory makes claims about the relation of events in the world and the cognitive representation of those events. Hommel argues that actions are “cognitively represented by codes of their perceptual consequences” (Hommel, 2009, p. 514) and that there is no difference between the representations of a perceived event and of the actions to produce them. Action events are represented by distributed feature networks which code features such as distance, force and direction, in much the same way as the visual cortex exists of feature networks for perceiving color, shape or motion. Binding operations exist to relate codes that are associated with the same event. On this view, a common code exists to represent perceptual information about the environment and to initiate action-planning. Thus, when receiving stimulus information from the environment, goal-directed action representations
are activated to help guide an action response. The theory of event coding is used to explain effects of stimulus-response overlap in terms of the relation of neural codes representing both perception and action.

The theory of common codes suggests that for an expert musician (for whom automated action programs have been built up and reinforced over thousands of repetitions) the perception of music notation shares a common code with the action required to play the note on the musician’s instrument. Consistent with this claim, when a musician watches another musician who plays the same instrument, the actions they see prime similar motor responses (Haueisen & Knösche, 2001). This implies that when a musician sees notated music suitable to their instrument, the motor responses involved in playing the music will be primed. Since the actions required to play the same notes on different instruments are themselves different, different musicians should behave differently according to the instrument they play. Like action verbs in sentence comprehension tasks (Glenberg & Kaschak, 2002; Borghi, Glenberg, & Kaschak, 2004), music notation provides information for musicians about what actions to take in order to perform the music.

**Grounded Cognition and the Ecological Perspective**

Theories of grounded cognition suggest that rather than viewing cognition as a process of computation in which amodal symbols are manipulated in a modular system, cognition relies on modal simulations, bodily states and situated action (Barsalou, 2008). Knowledge about musical concepts and performance, therefore, involves integration of multi-modal simulations of bodily states involved in creating musical sounds, hearing and evaluating sounds, and translating musical notation into preparations for action to produce sounds.

While still relying on representation in some form, the grounded cognition approach shares with the ecological perspective of Gibson (1977) the view that the relation between the
organism and its environment is important to understanding perception and action. This context gives rise to the complementary ideas of affordances of the environment and effectivities of the organism to take advantage of those affordances (Turvey, Shaw, Reed, & Mace, 1981). Affordances are properties of the environment that specify the possibilities for action by an organism. Effectivities are the particular abilities of an organism to act in a given environmental context. Affordances and effectivities are complementary in that, an organism’s effectivities are those properties that allow it to make use of affordances in its environment (Chemero, 2003).

On this view, properties of the environment are available to actors and perceivers in relation to their own effectivities for interacting with the environment. In the current study, for non-musicians, properties of the visual display of two musical notes in sequence include relative distance and direction which allow them to make a judgment. The joystick affords pushing or pulling toward a correct response. For musicians, the same information is available, but additional information exists related to their own effectivities, that is, the ability to play the musical notes presented on an instrument. For trombonists some of this information is related to direction of movement of a trombone slide which affords moving between two notes presented. For a cellist it might mean moving the fingers of the left hand from one position to another.
Chapter Two: S-R Compatibility

Stimulus-Response Compatibility

As early as the 1860’s, Franz Donders reported effects of stimulus response compatibility on response times (see Broadbent & Gregory, 1962; and Proctor & Vu, 2006 for review). Donders discovered that responses are faster when stimuli are paired with “natural” responses than when they are not. For example, when responding with the hand to an electrical stimulus to the foot, Donders noted that responses paired with stimuli on the same side of the body were faster than contralateral pairings (Proctor & Vu, 2006, p. 3). Nearly 70 years later, the psychologist John Ridley Stroop (1935) published his seminal article on interference in color naming tasks. Interested in the effects of practice on interference, Stroop developed a paradigm which varied the stimulus-stimulus congruity along with stimulus-response congruity. Color words (blue, red, green, etc.) were printed in the same color ink as the word name (congruent) or in a different color ink (incongruent). In his first experiment he found no interference effect for reading words printed in different colors, compared to a control condition (all black ink). However, when the task was to name the color of the ink in which a word was printed, participants took significantly longer to do this than to name the color of a square patch or symbol. In this case, the incongruent words interfered with the color naming, an effect of stimulus-response compatibility coupled with stimulus-stimulus overlap. So influential was this work that it came to be known as the Stroop effect, and the task, along with other similar tasks, are known as the Stroop task (MacLeod, 1991). The Stroop color word test and its variations are still widely used in research today as well as for neuropsychological testing of cognitive processing abilities (Lezak et al, 2004, p. 365).
It was not until the advent of the cognitive approach in the 1950’s that the terms “compatibility” and “stimulus-response compatibility” were introduced along with a new way of explaining compatibility effects. Fitts and Seeger (1953) explained the Stroop and similar effects in terms of the efficiency of programs for mapping between stimulus arrays and for mapping stimulus arrays onto response arrays. Fitts and Seeger measured response time and accuracy for responding to a stimulus light in one of eight positions, or one of eight pairs of lights in a four-light display. They found that when the response panel was arranged similarly to the stimulus panel (compatible arrangement) responses were faster than when the arrangements were dissimilar (Proctor & Vu, 2006, p. 4).

One line of research stemming from these initial investigations into stimulus-response compatibility that is still of interest to researchers today is the effect of task-irrelevant stimulus location information on response times, a compatibility effect that came to be known as the Simon effect (Hedge & Marsh, 1975). Participants in these studies were presented with the word *left* or *right* to either the left or right ear. Their task was to respond to the stimulus word by pressing the appropriate response button, either left or right (Simon & Rudell, 1967) or by moving a lever to the left or right (Simon, 1968). Although the task was to respond to the meaning of the stimulus (relevant task dimension), response times were affected by the ear to which the stimulus was delivered (the irrelevant task dimension of location). Responses were faster when the *left* stimulus was presented to the left ear and the *right* stimulus presented to the right ear than when this S-R mapping was reversed. This S-R compatibility effect was also evident when the stimuli were not location words (*left/right*) but high or low tones matched to left or right responses, but presented to either the left or right ear (Simon & Small, 1969).
Variations of S-R compatibility, the Simon effect, interference, and the Stroop effect abound in the literature over the last 50 years. MacLeod (1991) reported over 700 empirical studies of Stroop and Stroop-like tasks alone in the 20 years leading up to his review. During these decades, S-R compatibility studies explored the effects of different dimensions of stimulus-response –relations—including location, number, modality and complexity, and of different response types—including buttons, levers, rotating wheels, hands crossed or uncrossed, and many more (for a review see Proctor & Vu, 2006). In addition to exploring the effects of spatial compatibility, researchers also explored the effects of other types of S-R compatibility. S-R compatibility effects have been found for mental images (Bächtold, Baumüller, & Brugger, 1998; Tlauka & McKenna, 1998), for the perceived intensity of a visual or auditory stimulus (Romaiguère, Hasbroucq, & Seal 1993; Mattes, Leuthold, & Ulrich, 2002) and for numerosity (Miller, Atkins, & Van Nes, 2005).

In addition, compatibility effects have been found when stimuli refer to actions or potential actions with referents, for example to actions like turning down the volume (Zwaan & Taylor, 2006), grasping the mug (Tucker & Ellis, 1998), and playing a musical instrument (Drost, Rieger, Brass, Gunter& Prinz, 2005; Repp & Knoblich, 2009). This has led some researchers to point to the importance for cognitive processing of the context provided by immediate environment, leading them to advocate the embodied approach to stimulus-response compatibility effects discussed in the next chapter (Neidenthal, et al., 2005; Barsalou, 2008, ).

Dimensional Overlap

Stimulus and response dimensions can be independent, i.e., do not overlap. For example, when the task is to respond to a green light by pressing the left button and to a red light by pressing the right button, the stimulus dimensions are unrelated to the response dimensions. In
such cases, there is no overlap between the dimension on which the stimuli vary (color) and the
dimension on which the response choices vary (location).

In order to have a compatible (or incompatible) relationship between stimulus and
response, an overlap must exist on one or more dimensions between the stimulus and the
response. A dimension of the stimulus (e.g. location in the stimulus display) can be mapped onto
the same or similar dimension of the response (e.g. location in the response array), and can be set
up to be either compatible or incompatible. As described earlier, in a typical S-R compatibility
experiment, the configuration of the stimulus (e.g. lights in a horizontal or vertical arrangement)
either matches or is mismatched with the configuration of the response panel (e.g. response
buttons arranged horizontally or vertically). The general finding is that responses tend to be
faster when stimulus and response elements match, e.g., stimulus lights and response buttons are
both arranged horizontally, than when they do not match, e.g., stimulus lights are arranged
horizontally, response buttons vertically (Fitts & Seeger, 1953)

Dimensional overlap can occur on any dimension on which a concept can be described:
location, color, shape, orthography (e.g., numbers vs letters), semantic relation, etc. (Kornblum,
Hasbroucq, & Osmun, 1990). In the original Stroop task, stimulus and response overlapped in
color (Stroop, 1935). More recent variants of the Stroop task have explored the effects of overlap
on a wide variety of other dimensions including those involved in attentional bias and emotion.
For example, in a Stroop task involving emotion, Gotlib and McCann (1984) showed that
participants with depression were slower to name the color of depression-related words than of
positive or neutral words. In addition, patients with anxiety (but not normal controls) have been
shown to respond slower to name the color of threatening words than non-threatening words
(Mathews & MacLeod, 1985).
Table 1 summarizes a taxonomy proposed by Kornblum and Lee (1995) to describe the range of experimental tasks that have been used in studies of S-R compatibility. The taxonomy provides a broader context in which to place the research on instrument specificity effects. Type 1 ensembles are those for which there is no dimensional overlap between stimulus and response, like the one described above in which the stimulus varies in color and the responses vary in location. These do not exhibit compatibility effects. Type 2 ensembles, like those studied by Fitts and Seeger (1953), are ones in which stimulus and response arrays exhibit dimensional overlap, both varying in the same way on a dimension such as location or color. These produce the kind of stimulus and response compatibility effects described above (e.g., Fitts & Seeger, 1953).

<table>
<thead>
<tr>
<th>S-R Ensemble Type</th>
<th>S-R Overlap Relevant Stimulus with Response</th>
<th>S-R Overlap Irrelevant Stimulus with Response</th>
<th>S-R, S Overlap Relevant with Irrelevant Stimulus</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Digit name responses to variously colored (S_r) shapes (S_i). No overlap.</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>L-R keypress responses to letters (S_i) in various locations (S_r)</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>L-R keypress responses to words (left-right) (S_i) presented to left or right ear (S_r) (Simon, 1969)</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>L-R keypress to letters or arrows (S_i) flanked with congruent or incongruent letters (S_r) (Eriksen &amp; Eriksen, 1974)</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>L-R colored button responses to colored stimuli (S_i) in various locations (S_r)</td>
</tr>
<tr>
<td>6</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>L-R keypresses to colors and color words (S_i) in various locations (S_r)</td>
</tr>
<tr>
<td>7</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>L-R keypresses to colors (S_i) of color words in different locations (S_r)</td>
</tr>
<tr>
<td>8</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Color name responses to color names (S_i) printed in different colored ink (S_r)</td>
</tr>
</tbody>
</table>

Table 1. Taxonomy of dimensional overlap in stimulus-response compatibility (adapted from Kornblum and Lee, 1995).

Kornblum and Lee (1995) identify eight categories of dimensional overlap. In addition to the two basic types described so far, in which stimulus and response arrays either overlap or are independent, additional variants can be created by introducing additional, irrelevant dimensions into the stimulus array, the response array, or both. In these cases, the arrays are necessarily multidimensional. For example, a one-dimensional Type 2 ensemble in which the stimulus is red...
or green and the response is left or right, can be turned into a Type 3 ensemble by positioning the stimuli to left or right in the stimulus array, introducing the irrelevant dimension of location into the stimulus array. In this case, stimulus and response arrays overlap in that both include the dimension of position. Position is irrelevant for the stimulus array because correct responses are determined by the color and not the location of the stimulus, but position is relevant for the response array. This is the situation in the much-studied Simon effect (Simon & Ruddel, 1967; Simon & Small, 1969).

**Stimulus-Stimulus Dimensional Overlap**

Additional types of ensembles can be created by manipulating the overlap between relevant and irrelevant dimensions of the stimulus in tasks in which there is no overlap of stimulus dimensions with response dimensions. For example, the flanker task developed by Eriksen and Eriksen (1974) is an example of this type (Type 4). In the flanker task, participants are asked to respond (for example) by pressing either the left or right arrow to indicate the direction of a centrally located arrow stimulus. During each presentation, the central arrow has other arrows flanking it on either side which point in either the same or a different direction as the central stimulus arrow. Responses are faster when the flanking arrows point in the same direction as the central arrow (congruent) than when they point in different directions (incongruent). In this case, the relevant dimension (direction of the central arrow) overlaps with the irrelevant dimension (direction of flanking arrows). Other uses of Type 4 tasks have involved the manipulation of the affective valence of sentences and iconic symbols (Hoosain, 1977).

Manipulation of this kind of stimulus-stimulus compatibility with response compatibility results in four additional ensemble types (Types 4, 6, 7 and 8). Ensemble types 5-8 combine more than one overlapping dimension. Type 5 includes multi-dimensional responses where one
dimension overlaps with the relevant stimulus dimension and another with the irrelevant stimulus dimension but there is no overlap between the stimulus dimensions themselves. Kornblum identifies the best example of Type 5 S-R ensembles as those studied by Hedge and Marsh (1975). The investigators had subjects respond to red or green stimulus colors by moving a hand from a neutral position to a red or green button on the left or right. In this way there was dimensional S-R overlap between the irrelevant stimulus dimension (location) and the relevant stimulus dimension (color) but no S-S overlap.

Type 6 ensembles consist of those with dimensional overlap between the relevant stimulus and response as well as between the relevant and irrelevant stimulus dimensions, but not between the irrelevant stimulus dimension and the response. Type 7 would include ensembles with overlap between the irrelevant stimulus and response as well as between the relevant and irrelevant stimulus dimensions but not between the relevant stimulus dimension and the response. These two types of ensembles are addressed less frequently in the literature, and are of less interest to the present study.

The final ensemble type in Kornblum’s taxonomy is the best known because it includes the Stroop task and its many variants. In Type 8 ensembles, the response dimension overlaps with both the relevant and the irrelevant stimulus dimension. For example, in the original Stroop study (Experiment 2), the response dimension is color—the task was to name the color of the ink in which color words were printed (e.g. the word red printed in green ink) or the colors of colored square patches (control condition). The relevant stimulus dimension was the color of the ink. The irrelevant stimulus dimension was the words. There was overlap between the relevant stimulus and the response because they were both the color of the ink. There was overlap between the irrelevant stimulus dimension (of experimental trials) and the response because they were both
words (specifically, names of colors). When participants were slower to correctly name the ink color of color words (e.g. the word red printed in green ink) than to name the color of square patches (e.g. a green patch or symbol), it was assumed that the irrelevant words (color names) interfered with responses (color names) (Stroop, 1935). The Stroop task has been adapted for use with a wide variety of different dimension. In an application involving spatial orientation, Wühr (2007) had participants name the orientation of a rectangle with irrelevant words presented inside the rectangle in either a congruent or incongruent orientation. Shor (1970) had participants identify the direction of arrow shapes which were filled with direction names (left/right) that were either congruent or incongruent with the direction of the arrow. In both cases, responses were affected by the irrelevant stimuli, speeded when they were congruent and slowed when incongruent.

Of the eight ensemble types in Kornblum’s taxonomy, two are relevant to the present inquiry: Type 3 (Simon effect) and Type 8 (Stroop effect). The instrument-specificity effects reported by Drost et al. (2005, 2007) are Type 3 effects. Drost et al. (2005) reported evidence of an action-effect coupling for pianists (for details, see Chapter 3). In three experiments, they distinguish between an explanation that relies on abstract processing of chord quality to explain the interference effect, and one that relies on an action-effect coupling for sounds by expert pianists. The first experiment, which paired expert pianists with novices, demonstrated no S-R dimensional overlap between a relevant stimulus dimension and response. For the expert group there was overlap between the irrelevant stimulus dimension of actions to play the auditory stimulus and the actions to respond to the task. This did not exist for novices. There was also no stimulus-stimulus overlap for either group, making this task fall into the Type 3 ensemble in Kornblum’s taxonomy, along with Simon and Simon-like effects. Drost (2007) had irrelevant
stimuli (auditory distractor chords) exhibit multi-dimensional overlap with responses. There was overlap for the actions, or potential actions, to perform the distractor chords, which were either congruent or incongruent with correct response actions. There was also dimensional overlap with timbre. The auditory stimuli varied on how similar it was to the instrument that the participants were experts on (piano). The authors attributed this instrument-specificity effect to the participants’ experience on the piano. The high dimensional overlap between the irrelevant stimulus dimensions and the responses make this study also a Type 3 ensemble, like the Simon effect.

In both of the above studies there was S-R overlap between the irrelevant stimulus dimension (timbre of the irrelevant stimulus sound) and the response. When the auditory stimulus was the same timbre as the instrument which the participant had experience with (or was being used in the experiment) the congruity of the irrelevant stimulus (major or minor mismatch with response) affected response times. Response times were longer when the response was incongruent with the irrelevant sound (major/minor; or minor/major), but only when the timbre of the sound matched the instrument of the participants’ expertise. This is a variation of the Simon effect.

In the Simon effect, the relevant and irrelevant dimensions of the stimulus are more dissimilar than found in typical Stroop tasks. In a typical Simon task a relevant stimulus (e.g. red or green colored light) will appear in a location that is either the same as (congruent) or contralateral (incongruent) to a response button location. In this case the irrelevant information is the location of the stimulus, as the task is to respond (for example) to the green light with a left response and the red light with a right response. When the relevant and the irrelevant information are mismatched, responses are slower than when they appear in the same location.
The current study can be identified as a Type 8 ensemble. In Experiment 1, I asked trombonists and non-trombonists to decide if the second note of a two-note sequence was higher or lower than the first. They responded by moving a joystick forward or backward to indicate a “higher” or “lower” response. In Experiment 2, participants responded by pressing buttons on a computer keyboard. For trombonists in Experiment 1, the irrelevant stimulus dimension is the location of slide positions required to play the two notes in order. The relevant dimension is the relative location of the second note on the display compared to the first note (higher or lower). The response dimension is the location of the higher/lower response, which overlaps with both relevant and irrelevant stimulus dimensions.
Chapter Three: Instrument Specificity

If cognition is embodied, as suggested by theories of grounded cognition and by the ecological perspective, then musicians should possess multi-modal, bi-directional links between perception and action. Learning to play a musical instrument is an embodied process involving the coupling of motor actions, auditory signals, and visual information (Keebler, Wiltshire, Smith, Fiore, & Bedwell, 2014). In this chapter I will describe studies that support this prediction by showing that the perception of musical features can affect musical actions (Drost, Rieger, Brass, Gunter, & Prinz, 2005; Drost, Rieger, & Prinz, 2007), and that musical actions can affect the perception of musical features (Repp & Knoblich, 2007, 2009).

Action effects and spatial relations in music

In a series of studies, Drost et al. (2005) and Drost et al. (2007) showed the existence of action-effect associations in pianists and guitarists. In Experiment 1 (Drost et al., 2005), expert pianists and novices were presented with four text stimuli denoting either a major or minor chord: “C-major”, “C-minor”, “F-major” or “F-minor”. Concurrently they were presented with an auditory stimulus of a piano playing one of the four chords listed, or a non-tonal sound. Participants were asked to ignore the auditory stimulus and to play the chord presented visually (novices were trained on how to produce each of the four chords on the piano). Auditory stimuli were either congruent with the visual stimulus (same chord) or incongruent (different key and/or mode). For novices, there was no interference of auditory stimuli; but for experts there was an interference effect for incongruent stimuli — responses were slower to incongruent than to congruent conditions.

The results from Experiment 1 could be explained by a perceptual account in which an abstract process takes place which compares the auditory stimulus to the chord quality given in the visual text (major or minor) with interference stemming from the mismatch between the two,
rather than from the presumed mismatch between an action representation for the auditory stimuli and the response action. Experiments 2 and 3 were done to refute the abstract processing account. In these two experiments pianists responded to five different symbolic representations for either C major or C minor chords: 1) an image of piano keyboard with the correct response keys marked, 2) a notated C major or C minor chord in treble clef, 3) the characters c-e-g or c-eb-g to denote C major or C minor, respectively, 4) the text “C-major” or “C-minor”, or a colored red or blue square to denote C major or minor. Again, the distractor stimuli were C major or C minor chords that were either congruent or incongruent with the chord presented visually. In Experiment 2 pianists responded using a piano keyboard, as in Experiment 1, and there was a congruency effect for each type of stimulus.

Experiment 3 was identical to Experiment 2 except that, instead of responding on a piano keyboard, the response was made on a two-button response panel with one button for C major and one for C minor. This manipulation removed the usual motor response association between the stimuli and responses, and the congruency effect disappeared for all but the text condition. From this, the authors reasoned that the effect of auditory interference in Experiment 1 was a product of overlap between the action to perform the irrelevant auditory distractor and the response rather than an abstract processing of relationship of the chord quality and the meaning of the textual stimulus. The authors concluded that the results supported their hypothesis of action-effect coupling for audibly presented musical stimuli for musicians.

A similar study with musicians investigated the specificity of learned action-effects, asking whether action-effects for perceived sounds are specific to the instrument the perceiver plays (Drost et al., 2007). The participants were pianists (Experiment 1) and guitarists (Experiment 2). The studies explored whether interference effects similar to those found in the previous
experiments would occur if the timbre of the concurrent auditory stimuli were consistent (congruent) with the participant’s own instrument or not (incongruent). The participants in Experiment 1 were pianists. And the instrument timbres used were piano (congruent), organ (congruent), guitar (incongruent), flute (incongruent) and voice (incongruent). The task was to play either a C major or C minor chord, as notated on a computer screen. Concurrently, the pianists heard either congruent or incongruent C major or minor chords, as in the earlier experiment, that were also congruent or incongruent with the participant’s own instrument (piano/keyboard) on the secondary dimension of timbre.

When presented with the visual stimulus to play c-e-g (a C major triad) on a keyboard, pianists were slower to respond when presented with the auditory stimulus c-eb-g (a C minor triad) than with an auditory C major triad—but only when it was presented as a piano or organ sound, not when presented as a flute or guitar sound. The implication is that the congruent condition interfered because it was perceived as a potential action to be played, much the same way that the target visual stimulus was a potential action to perform (Drost et al., 2005). The fact that the effect occurred for organ as well as piano sounds strengthened the conclusion that it was the perception of potential action at the keyboard that was responsible for the effect. A pipe organ sounds very different from the piano because sound is produced by wind passing through the pipes, as opposed to a hammer striking a string. The similarity with the piano is that both organ and piano are keyboard instruments and so playing them involves similar kinds of movement. From the musician’s point of reference, the actions to create both sounds involve pressing of keys with the fingers, and the layout of the keyboards for both instruments are similar with respect to the 12-tone, equal-tempered scale, that is, playing a C on the piano and playing a C on the organ are both done by pressing the same key. In addition, many pianists have
experience playing organ or electronic keyboards that produce synthesized organ sounds. So the
effect for organ sounds for pianists in this study, while smaller than that for piano sounds, is not
surprising due to the nature of the actions required of the musician to perform both.

Experiment 2 replicated the results of the first experiment but with guitarists, using a
modified guitar neck to collect responses. The results were similar to those found in Experiment
1, but with guitar sounds for the guitarists, who showed no interference with piano, organ or
voice sounds. Taken together the authors conclude that action-effect couplings are instrument-
specific: sounds produced by keyboard instruments having action effect couplings for pianists
and sounds produced by guitars having action-effect couplings for guitarists.

One other study, by Repp and Knoblich (2007), has also showed that action can affect
musical perception in musicians. In their experiments, musicians (pianists and non-pianists) and
non-musicians reported the perceived direction (rising/higher or falling/lower in pitch) of
perceptually bistable pitch changes while also moving their hands in a right or left direction.
Musicians reported more rising pitch changes when moving rightward and falling pitch changes
when moving leftward than non-musicians. In addition, pianists showed a larger effect than their
non-pianist musician counterparts, suggesting that more experience with the keyboard resulted in
stronger action-effect couplings of rightward with higher and leftward with lower. For non-
musicians, there was no relationship between direction of pitch change and direction of hand
movement. This finding supports the idea that learned associations between perception and
action can influence the perception of musical sounds.

The Repp and Knoblich study demonstrates an association between a musical feature
(increasing and decreasing pitch) and direction of action in the horizontal plane (rightward and
leftward movements) that is learned as a result of musical training on a keyboard instrument. A
similar mapping of musical pitch onto the vertical plane is learned without any special musical training by infants as young as 12 months. Using a preferential looking paradigm it has been found that infants associate rising pitches with visual stimuli that are rated by adults as being associated with *up* (up arrows or lines which increase upward in thickness) and falling pitches with *down* visual images (Wagner, Winner, Cicchetti & Gardner, 1981). The mapping of pitch onto the horizontal spatial dimension, in contrast, develops only as a result of musical (keyboard) training.

*Neurological Evidence*

Neurological evidence of links between sound and action comes from the neurological studies cited in Chapter 1 showing that the sight (or sound) of a person breaking a peanut elicited from monkeys the same kind of neural activity as when the monkey did the action itself (Kohler et al., 2002; Keysers, Kohler, Umilta, Fogassi, Rizzolatti, & Gallese, 2003) and the sound of a piano playing elicited from (human) pianists the same kind of neural activity as when the pianist played him/herself (Haslinger, Erhard, Altenmuller, Schroder, Boecker, Ceballos-Baumann, 2005).

In addition, neurological imaging studies have demonstrated that the human mirror system is activated in response to abstract visual musical stimuli associated with learned actions (Behmer & Jantzen, 2011). Using electroencephalography (EEG), sensorimotor mu-desynchronization (mu-ERD) has been shown to be a reliable index of observation-induced activity in human mirror networks for finger movements (Cochin, Barthelemy, Roux, Martineau, 1999), hand clapping (Pizzamiglio et al., 2005) and observation of abstract picture drawing (Marshall, Bouquet, Shipley, Young, 2009).
With prolonged experience, it has been shown that sensorimotor associations are formed to abstract visual musical stimuli (Behmer & Jantzen, 2011). This study explored the sensitivity of the motor system to musicians’ learned associations between music notation and the physical action required to create the sounds implied by the notes. The researchers asked whether viewing music notation would produce sensorimotor mu-desynchronization (mu-ERD) in musicians (violin and trumpet players) compared to non-musicians. They found that viewing music notation alone (without audio or video of performance) elicited significant sensorimotor mu-ERD measurements in musicians but not in non-musicians. In their experiment, participants viewed performances of short melodies performed on either violin or trumpet (AV condition), listened to the performances along with viewing the sheet music notation (AS condition), viewed the sheet music notation without sound or video performance (S condition) or viewed unplayable music notation alone (U). Musicians showed significant activity in motor areas during all four conditions, whereas non-musicians only showed significant activity during the audio/video and the audio/sheet conditions but non-significant mu-desynchronization in either of the two sheet music alone conditions. Interesting with respect to the current study is that there were no differences between types of musicians (violinists and trumpet players), although musicians did differ from non-musicians as a group in the sheet music alone (S) condition. Musicians showed greater mu-desynchronization than the non-musicians.

These findings support the idea that, with prolonged experience, the human motor system can be engaged to form sensorimotor associations to abstract visual stimuli. The findings imply that perceptual mapping within the motor system is not limited to imitation of actual movement but can represent potential actions implied by symbolic notation. Music notation serves as a symbolic representation of the actions required to play the notes represented.
Summary

What I hope to add to these findings is behavioral evidence of an instrument specificity effect working on a different level of cognitive processing by addressing the ways in which the visual symbols of music notation invoke varying action-effect couplings among musicians who play different instruments. That is, to what extent is the motor system engaged for performing a specific action when musicians observe music notation alone without sound? And how much does the relevancy of the task matter in maintaining those action-effect couplings? In the Drost et al. (2007) study, if guitarists were given the same task as the pianists would they still exhibit an action-effect coupling for guitar sounds and not piano sounds? What would happen if the task was not music-performance related? Is there an instrument specific action effect for other, non-stringed instruments? In comparing trombonists to other musicians in a notation alone experiment, I hope to establish instrument-specific motor relations between groups of musicians. The experiments by Behmer and Jantzen (2011) did not find between-instrument differences on the neuroimaging measurements chosen.

Action effects in musicians have been established by the studies reviewed here. A level of instrument-specificity has been established by Drost et al. in paradigms which focus primarily on effects of an auditory stimulus. Their goal has been to establish that auditory stimuli can provide information for an action-effect coupling for listeners with experience on the instrument matching that sound. In their studies they use pianists and non-pianists, or guitarists and non-guitarists. They show that when pianists are performing a piano-related task, they exhibit interference when presented with auditory (irrelevant) stimulus that does not match the visual (relevant) stimulus—but only when the auditory input is from a keyboard instrument. They
establish a similar action-effect coupling for guitarists and guitar sounds. The sounds that musicians hear invoke the actions associated with performing those sounds.

I have implemented a procedure in which the task is non-performance oriented, but still related to the mechanics of a specific instrument. In these experiments I show an instrument specific action-effect coupling for music notation that extends beyond the task of performing at the instrument—as long as the task involves movements that are similar to performing.
Chapter Four: Experimental Goals and General Method

Two experiments assessed whether experience with a musical instrument influences reaction times differentially for performers of different instruments on a task that utilizes common music notation but that is independent of musical expertise or experience. Participants from three groups (non-musicians, trombonists and non-trombonist musicians) were shown a sequence of two notes visually displayed on a computer (without accompanying audio), and asked to decide whether the second note was higher or lower than the first. Participants responded using a joystick in Experiment 1 and a computer keyboard in Experiment 2. Reaction time was the dependent variable.

The procedure of the two experiments was identical except for the way in which participants responded higher or lower. In Experiment 1, participants responded by using their right hand to move a joystick forward to indicate higher or backward to indicate lower. In Experiment 2, participants pressed one of two keys on a computer keyboard.

The joystick was chosen for Experiment 1 because the forward/backward movement is similar to the movement required of trombonists to change slide position on their instrument. This made it possible to manipulate the congruence of response direction (forward or back) and slide direction (forward or back) when playing the two notes in sequence. A bimanual keypress response was selected for Experiment 2 in order to retain the spatial mapping between slide position direction and response direction on a similar plane to that used with the joystick response, while also reducing the movement required to respond, thus minimizing the likelihood of movement congruency effects.

The task of identifying whether pitches were higher or lower was chosen for two reasons. First, the task is easy enough that it can be done by non-musicians with little or no previous
exposure to musical notation. Second, there was no a priori reason to expect that musicians trained on different musical instruments would perform differently on this task. If trombonists show a movement congruity effect, as expected, it will suggest that the effect is a product of sensory-motor learning specific to the trombone, a kind of instrument specificity effect (Drost et al., 2007). The use of the trombone also made it possible to counterbalance response direction and interval direction (rising or falling); these could be varied independently because pitch on the trombone is a function of slide position, lip tension (embouchure), and air velocity.

I expected trombonists to respond faster when response and slide direction were congruent and more slowly when they were incongruent. Such a movement congruency effect would suggest that seeing the notes engaged the motor system. Such a congruency effect for musical notation would be analogous to the action-sentence compatibility effect for language (Glenberg and Kaschak, 2002). In the latter case, the effect suggested that reading a sentence engages the motor system in a fashion consistent with the action described by the sentence. In the present case, a movement congruency effect for musical notation would suggest that reading a sequence of notes engages the motor system in a fashion consistent with the actions required to play them.

I expected to find a congruency effect for trombonists but not for musicians who play other instruments (non-trombonist musicians). Such an instrument effect would strengthen the inference that the movement congruity effect for trombonists was due to the way in which trombonists manipulate their instrument. The trombone is unique among musical instruments in being the only instrument on which changes in pitch are achieved by forward/backward movements of the right hand. While the response times of non-trombonist musicians may also be influenced by movement congruity, no effect of congruity was expected for this group of
musicians. Since the stimuli presented were selected to vary movement congruity on the trombone, it was unlikely that they would also elicit congruity effects from non-trombonist musicians, because movement congruity effects should be specific to each instrument. An instrument effect would be analogous to the instrument-specificity effects reported by Drost and colleagues (Drost et al., 2005; Drost et al., 2007). In Drost’s studies, hearing incongruent musical pitches interfered with playing when the incongruent pitches shared the same timbre as the instrument played by the participant. These effects suggest that for experienced musicians, musical sounds that are produced by the type of instrument they play engage the motor system in a fashion consistent with the actions required to produce them. In the present study, a movement congruency effect would likewise suggest that the motor system was engaged, but by reading musical notation rather than by hearing musical sounds. Instrument specificity, in the present study, refers to the movement used to produce the sound rather than to the timbre of the sound, as in Drost’s studies. A movement congruity effect in the present study would, thus, be a new kind of instrument specificity effect. It would also extend instrument specificity effects to a new class of musical instruments since Drost’s studies have demonstrated instrument specificity effect for the guitar and piano but not for brass instruments.

**Materials**

The stimuli were assembled by first creating a list of all possible interval pairs within an octave (i.e. distances spanning between one and 11 semitones—Minor 2\textsuperscript{nd} through Major 7\textsuperscript{th}s) between one ledger line below the staff to two ledger lines above. This range was chosen as it encompasses a range shared by other instruments that play in the baritone register, e.g., bassoon, euphonium, cello. Common enharmonic spellings were also included. For example, the interval pair Db to Eb was also represented as C# to D#. Each interval pair was then coded with its (a) distance in semitones, (b) quality (major, minor, perfect, augmented/diminished), (c) size
(second, third, fourth, fifth, sixth or seventh), (d) direction (whether the second note was lower or higher than the first), (e) slide direction (in, out, or null—whether a trombonist would need to move the slide in, out, or not at all in order to play the second note after the first), (f) range (whether the interval pair resided in the lower, middle or upper third of the total pitch distribution) and (g) movement congruency, also referred to as congruency below. As described above, *congruent* pairs were those for which the direction required to move the joystick in order to provide a correct response was the same as the direction in which a trombonist would move the slide in order to play the second note after the first. *Incongruent* pairs were those for which the direction required to move the joystick in order to provide a correct response was in the opposite direction. For interval size, *small* intervals included all 2nds and 3rds, *medium* intervals included all 4ths and 5ths and *large* intervals included all 6ths and 7ths.

The initial set of possible combinations yielded over 600 interval pairs, including enharmonic respellings. From this set were deleted all pairs which contained notes most often played in either one of two alternate positions using the F trigger on the trombone (specifically, the second space C or B#, and the second line B natural or Cb, using the bass clef). These were removed so that there would be no ambiguity as to slide position and thus to slide direction. Also removed were all pairs in which slide direction was *null* (i.e. there was no slide movement required to perform the interval pair), leaving 517 stimuli to choose from.

I then selected stimuli so that equal numbers of stimuli would be in each bin representing congruency, interval size, direction and range. For each of twelve interval distances (minor 2\(^{nd}\) through major 7\(^{th}\), with augmented 4\(^{th}\) and diminished 5\(^{th}\) treated as separate intervals), three interval pairs were chosen for each of the four conditions: (a) rising congruent, (b) rising incongruent, (c) falling congruent and (d) falling incongruent, resulting in 144 interval pairs (12
x 3 x 4). Rising and falling conditions were equivalent in the complete set, in that for each two-note rising condition item, the same two notes were used in a falling condition item. Equal numbers of interval pairs were chosen from the low, medium and upper range. A complete list of all 144 interval pairs, along with their coding in condition is included in Appendix A.

The 144 interval pairs were each presented twice, making 288 stimuli in total. For presentation, the 288 stimuli were divided into six blocks of 48 stimuli each, with each block containing three of each interval distance type (Minor 2nd through Major 7th). No interval pair repeated in the same block. The order of presentation of items within blocks was random. Blocks were presented sequentially and participants in each group were randomly assigned (without replacement) to begin in one of the six blocks. With 12 participants in each group (non-musicians, trombonists, non-trombonist musicians), there were two participants from each group who started on each block.

Procedure

Participants were seated at a computer with either a joystick (Experiment 1) or computer keyboard (Experiment 2) between them and the computer screen (see Appendix B). The computer program E-prime was used to display the stimuli and collect responses. On each trial, participants saw two notes, displayed one at a time in succession with a mask in between. The first note appeared for 750ms, followed by a 850ms masking image of the same size as the note display area, consisting of a box filled with the letter “x”. This was followed by the second note. The second note remained in view until the participant responded. Participants were asked decide whether the second note was higher or lower than the first and to indicate their decision using either a joystick (Experiment 1) or keyboard (Experiment 2) to identify. There was a 1000 ms interval between trials.
Two place-cards with the words *lower* or *higher* written in black two-inch lettering were placed on the table to indicate which response indicated which decision. In Experiment 1, in which participants responded using a joy-stick, the “lower” card was placed between the participant and the joystick and the “higher” card was placed between the joystick and the computer screen. If the second note was higher than the first note, participants responded by moving the joystick away from themselves in the direction of the word “higher”. If the second note was lower than the first, they responded by moving the joystick toward themselves in the direction of the word “lower”.

In Experiment 2, participants responded on a computer keyboard, using the 8 and m keys on which they rested the middle finger of each hand. Participants were randomly assigned so that half of those in each group used their left hand for 8 and their right hand for m. The place cards were placed with *lower* in between the participant and the keyboard, indicating the m key response in the bottom row of the keyboard and *higher* between the keyboard and the monitor indicating the 8 key in the top row of the keyboard.

**Analyses**

Differences in mean reaction times were assessed using mixed analyses of variance (ANOVA) in which *instrument* was a between groups factor (*non-musicians, trombonists and non-trombonist musicians*) and within group factors included *congruency, interval size* (small, medium and large) and *interval direction* (rising or falling).
Chapter Five: Experiment 1

Participants viewed pairs of musical notes and indicated whether the second note was higher or lower than the first note by moving a computer joystick forward, to indicate higher, or backward, to indicate lower. The experiment tested the hypothesis that response time would be affected by congruency between the direction of movement of the joystick and the movement of the trombone slide when playing the two notes and that the congruency effect would occur for trombonists but not for non-trombonists. A congruity effect would suggest that visually perceiving music notation engages the motor systems of expert musicians in ways that are specific to the instrument they play. 

Participants

Participants included trombonists, non-trombonist musicians and non-musicians. There were 12 participants in each group, N=36. Musicians were all professional musicians, active in their professions and with a minimum of 10 years of serious study on their instrument. Each participant received a $10 gift card for their participation.

Materials and Procedure

The experiment was divided into a practice phase and a test phase. None of the 144 unique item pairs from the test phase were viewed during practice. Instead, participants saw 40 random pairs from the remaining pool of possible two-note pairs. The task was to indicate, using the joystick, whether the second note was higher than the first. Participants were encouraged to answer as quickly as possible while maintaining accuracy.

Results

Response times and error rates were analyzed separately using a mixed ANOVA design with one between-subjects factor of instrument (3 levels) and three within-subjects factors:
congruency (2 levels), interval size (3 levels) and interval direction (2 levels). For within-subjects effects, the reported $p$ and $F$ values were adjusted using the Greenhouse-Geisser correction.

Congruent responses were faster than incongruent responses for trombonists, but not for non-trombonist musicians or for non-musicians (see Figure 1). Congruent responses were 181 ms faster than incongruent responses for trombonists and only 6 ms and 2 ms faster for non-trombonist musicians and non-musicians respectively. This interaction between instrument and congruency was significant, $F(2,33)=26.95$, $p<.001$. There was also a main effect of congruency, $F(1,33)=23.43$, $p<.001$, but not for instrument, $F(2,33)=1.87$, $p>.05$.

![Figure 1](image-url)

*Figure 1.* Mean response times for congruent and incongruent pairs for participants of each instrument type.

Responses were slower to small intervals than to medium and large intervals, $F(2,66)=39.74$, $p<.001$. The effect was larger for trombonists than for the other two groups resulting in a significant interaction between interval size and instrument, $F(4,66)=5.03$, $p<.01$ (Figure 2). Post-hoc comparisons using Bonferroni adjustments showed that responses to small
intervals (M=668 ms) were slower than to medium (M=632 ms) or large intervals (M=627 ms), p<.001, and that the difference between medium and large intervals was not significant.

Pairwise comparisons showed that for the trombonists the differences between small, medium and large intervals were all significant; small intervals were 60 ms slower than medium, p<.001, and 71 ms slower than large intervals, p<.001, and medium intervals were 11 ms slower than large intervals, p<.05. For the non-musicians, responses to small intervals were significantly slower than responses to medium (29 ms) and large intervals (30 ms), p<.01. For the non-trombonist musicians, responses to small intervals were significantly slower than responses to large intervals (22 ms), p<.05.

The congruity effect for trombonists (shown in Figure 1 above) was larger for small intervals than for medium or large intervals, resulting in the three-way interaction of Congruency x Interval Size x Instrument, F(4,66)=10.72, p<.001, shown in Figure 3. Post-hoc comparisons revealed that for trombonists responding to small intervals, congruent pairs (M=579 ms), were
233 ms faster than incongruent pairs (M=812 ms), \( p<.001 \). For medium intervals, congruent pairs (M=564ms), were 142 ms faster than incongruent pairs (M=707ms), \( p<.001 \). For large intervals, congruent pairs (M=541ms) were 168ms faster than incongruent pairs (M=708ms), \( p<.001 \).

![Graph showing mean response time as a function of congruency and interval size for each instrument type.](image)

**Figure 3.** Mean response time as a function of congruency and interval size for each instrument type.

There was a main effect of interval direction with faster responses to falling intervals (M=623 ms) than to rising intervals (M=662 ms), \( F(1,33)=67.294, p<.001 \). The congruity effect for trombonists was larger for rising than for falling intervals, resulting in a Congruency x Direction x Instrument interaction, \( F(2,33)=22.56, p<.001 \) (see Figure 4). For trombonists, the congruency effect was 230 ms for rising intervals and 132 ms for falling intervals, both \( p<.001 \). There were no such differences for non-musicians and non-trombonist musicians.
The four-way interaction between congruency, direction, interval size and instrument did not reach significance, $F(4,66)=2.45, p>.10$.

Another possible influence on trombonists is slide distance, that is, the distance between notes on the trombone slide between positions where each note is played. An items analysis was performed to determine whether any of the effects for trombonists were influenced by slide distance. The distance between the first and second note for this set of stimuli could range from 3.5-14.5 inches measured in terms of change of position along the trombone slide. For the stimuli in this study, any interval pair could be 1, 2, 3 or 4 positions apart. The items analysis was a 4-way between subjects ANOVA with RT as the dependent variable and items as the subjects. The between subjects factors included congruency (2 levels), interval size (3), direction (2) and slide distance (4). There was no effect of slide distance indicating that item response times did not
differ as a function of slide position distance. Slide position was not included in subsequent analyses.

Error rates in stimulus-response compatibility studies generally co-vary with reaction times, and this was the case here. Throughout, I report error rates as percentage of total responses that were incorrect. Overall error rate was 1.2%. Trombonists had a slightly higher error rate (1.9%) than the other two groups (both .9%) resulting in a main effect for instrument, $F(2,33)=6.57$, $p<.01$. There was no main effect for congruency $F(1,33)=2.21$, $p>.10$ or direction, $F(1,33)<1.0$.

Trombonists had lower error rates in the congruent condition (1.0%) compared to incongruent (2.8%), $p<.01$. This Instrument x Congruency interaction was significant, $F(2,33)=5.92$, $p<.01$ (Figure 5).

![Figure 5. Error rate as a function of congruency for each instrument type.](image)

Responses to small intervals (2.4%) had higher error rates than to medium (0.9%) or large intervals (0.5%), both $p<.01$, resulting in a main effect for interval size, $F(2,66)=32.37$, 


This difference was greater for trombonists than for the other two groups of non-trombonists resulting in an interaction of Interval Size x Instrument, $F(4,66)=4.57, p<.01$ (Figure 6).

*Figure 6* Error rate as a function of interval size for each instrument type.

The effect of congruency on error rates was larger for small intervals than for medium or large intervals resulting in an interaction of Congruency x Interval size, $F(2,66)=4.16, p<.05$. This interaction between congruency and interval size was larger for trombonists than for the other two groups, resulting in an interaction of Instrument x Congruency x Interval Size, $F(4,66)=3.54, p<.05$ (see Figure 7).
Figure 7. Error rate as a function of interval size and congruency for each instrument type.

For trombonists, when responding to small intervals, incongruent pairs had higher error rates (5.5%) than congruent pairs (2%), $p<.001$.

**Discussion**

Trombonists’ responses to music notation were different from those of non-trombonist musicians and non-musicians. Trombonists showed a movement congruity effect, while non-trombonists did not. For trombonists the forward and backward movement of the joystick resembles similar movements made with the trombone slide when performing the same notes on trombone. When there was a mismatch between these two sets of movements, trombonists’ responses were slower than when the movements were congruent. This result suggests that musicians are sensitive to information about potential actions implied by music notation. Non-trombonists did not show the same movement congruity effect.

The instrument congruity effect for trombonists extends the instrument-specificity effects of Drost et al. (2007) in three ways. First, the instrument congruity effect for trombonists did not
involve actually playing the instrument. The movement was similar to moving a trombone slide, but participants moved a computer joystick rather than playing an instrument. Second, the instrument congruity effect for trombonists did not involve auditory distractors, as in Drost’s experiments. Third, the present results extend instrument-specificity effects from keyboard and string instruments to a brass instrument.

As discussed earlier, irrelevant task information can influence response times when they share a common dimension with task-relevant information. In this case, the irrelevant information was the direction one would move a trombone slide in order to perform any given two-note pair. The task-relevant information of relative location to initial stimulus is assumed to be the same for musicians and non-musicians. However, the irrelevant information of the actions used to perform notated music is presumably only recognized by the musicians. In the current experiment the response to both the relevant and irrelevant information is similar for the trombonist group, but not for the non-trombonist groups, because non-trombonists (whether they are musicians or not) presumably do not have experience moving trombone slides.

There are two alternative explanations for the movement congruity effect for trombonists. One would be that the effect was due to the spatial mapping of stimulus onto response arrays. This is in line with a traditional approach to spatial compatibility effects like those seen by Fitts and Seeger (1953) and Simon and Rudell (1969). Trombonists’ responses may be affected by the spatial mapping of slide position direction (relative to the starting note) on to direction of joystick position for correct response.

Alternatively, if cognition is affected by bodily processes as suggested by a general embodied view of cognition, then trombonists may be affected by the mapping of the actions required to play the trombone and to slide the joystick. In responding with the joystick,
trombonists may be affected by bodily states built up over years of playing and tuning in to information about playing notes from musical notation. On this explanation, the movement congruity effect is due to the action involved rather than to the disembodied mapping of spatial location. Experiment 2 was designed to dissociate the spatial hypothesis from the action hypothesis.

The effect of interval size and the interactions involving interval size are consistent with results in perceptual studies where participants make faster judgments for extreme location than for centrally located stimuli (e.g., Clark & Brownell, 1975). Clark and Brownell had participants view arrows pointing up or down at various heights inside a rectangle. The higher an arrow pointing up was in the rectangle, the faster the responses were. Similarly, arrows pointing down elicited faster responses the farther down they were in the rectangle. This congruity effect in spatial discrimination is analogous to what is seen with interval size in the current experiment. Larger intervals in both directions elicited faster responses than smaller intervals.

With respect to interval direction, responses to rising intervals were slower than they were to falling intervals across all groups. However, for trombonists, the congruity effect was larger when presented with rising intervals than with falling intervals by approximately 100 ms. In the face of two incongruent mappings, the interference of incongruity was larger for rising than falling intervals. Alternative to using the congruity effect to explain this difference in interval direction, some other aspect of pitch direction and how it relates to trombone playing may be another irrelevant stimulus dimension that trombonists are somehow tuned in to but is not captured in this data.

One method of controlling for interval direction in the current experiment would have been to counterbalance higher and lower response locations. A decision was made when piloting
the experiment to not counterbalance the direction of the *higher* and *lower* responses due to the difficulty participants had with getting used to responding to the opposite mapping of *near* responses for *higher* and *far* responses for *lower* See General Discussion for a discussion of future experimental paradigms designed to avoid this issue.
Chapter Six: Experiment 2

Experiment 2 asked whether the instrument specificity effects found in Experiment 1 would appear on a task which mimicked the spatial mapping in Experiment 1 but did not involve the actions required to play the trombone. Similar to the movement of the joystick in Experiment 1, the higher responses in Experiment 2 involved pushing a button that was farther away from the body (the 8 key) and the lower responses required pushing a button nearer the body (m key). In this way, the spatial mappings of higher for away and lower for near were retained by selecting response keys located, one directly above the other, in the top and bottom rows of the keyboard. However, the movement for trombonists implied by the note pairs was absent. Participants used the middle finger of each hand to press the response buttons and so made no gross motor movement.

The results of Experiment 1 suggested that experience with a particular musical instrument interfered with reaction time in a perceptual task when that task involved the same movements required in playing that instrument. One explanation for the effect, suggested by a traditional cognitive approach to stimulus-response compatibility, is that it was due to the dimensional overlap between the response dimension (far vs near on the joystick) and the irrelevant stimulus dimension of slide position (far vs near on the trombone slide). According to this account, the compatibility effect found in Experiment 1 should be replicated in Experiment 2 when the response method was changed from a joystick to button presses, because the mapping of response location remained the same. Locations on the keyboard in Experiment 2 were far or near and retained the same spatial mapping of position onto position of the trombone slide as in Experiment 1.
An alternative explanation for the movement congruity effect, suggested by the embodied approach to cognition, is that the dimensional overlap in Experiment 1 was between the response movement (forward or backward in the sagittal plane) and the irrelevant stimulus dimension of movement of trombone slide. On this view, the effect in Experiment 1 was due to action-effect coupling of learned movements of the trombone slide in response to musical notation. According to this account, the movement compatibility effect from Experiment 1 should go away when the response is changed to bi-manual button pressing in Experiment 2. For button pressing, there is no mapping between the pressing movements required and the movements of the trombone slide and so there should be no movement congruity effect.

**Participants**

Participants included non-musicians, non-trombonist musicians, and trombonists. There were 12 participants in each group, N=36. Musicians were all professional musicians with a minimum of 10 years of serious study on their instrument and actively engaged in their profession. Each participant received a $10 gift card for their participation in the study.

**Materials and Procedure**

The same materials from Experiment 1 were used in the current experiment. The procedure was also the same, with the exception that instead of using a joystick to respond *higher or lower*, participants responded with button presses on a computer keyboard. Participants rested the middle finger of one hand on the 8 key (for *higher* responses) and the middle finger of the other hand on the m key (for *lower* responses). Participants were randomly assigned to one of two groups having their right hand respond with either the 8 or with the m. This control manipulation was included in the analysis, where it is referred to as *hand*. As in Experiment 1,
participants were encouraged to answer as quickly as possible while maintaining accuracy, and participants began with 40 practice trials.

Results

Response times and error rates were analyzed using a 3 x 2 x 2 x 3 x 2 mixed ANOVA with two between-subjects factors: instrument (3 levels: non-musician, non-trombonist musician, and trombonist) and hand (2 levels: Right on 8 for higher; Right on m for lower), and three within-subjects factors: congruency (2 levels: congruent, incongruent), interval size (3 levels: small, medium, large) and interval direction (2 levels: rising, falling). For within-subjects effects, the reported p and F values were adjusted using the Greenhouse-Geisser correction.

As predicted by the action hypothesis vs the spatial hypothesis, there was no movement congruity effect and the Instrument x Congruency interaction did not reach significance, $F(2,30)=2.86, p=.073, ns$. There was, however, a trend toward an interaction with trombonists being marginally faster (7 ms) when responding to congruent pairs than incongruent pairs, $p<.05$. This marginal effect was much smaller than that found in Experiment 1 where trombonists were 181 ms faster for congruent pairs.

Similar to Experiment 1, responses to small intervals (427 ms) were slower than to medium intervals (422 ms), which were, in turn, slower than large intervals (416 ms), $F(1.44,43.16)=9.57, p=.001$. The effect was larger for trombonists than for the other two groups resulting in a significant interaction between interval size and instrument, $F(2.88,43.16)=8.13, p<.001$ (see Figure 8). Comparisons revealed that responses to small intervals (407 ms) were slower than to medium (389 ms) or large intervals (378 ms), both $p<.001$, and responses to medium intervals were slower than to large intervals, $p<.001$. 
There was also a Direction x Instrument interaction, $F(2,30)=9.64, p<.01$ (shown in Figure 9). Trombonists responded faster to falling intervals (386 ms) than to rising intervals (398 ms), as in Experiment 1, $p<.05$. For non-musicians, the effect was in the opposite direction: rising intervals (463 ms) were faster than falling intervals (475 ms), $p<.01$. 

*Figure 8.* Mean response time (ms) as a function of interval size, for each instrument type.
There was a three-way interaction of Congruency x Direction x Hand, $F(1,30)=4.55$, $p<.05$ (Figure 10). The interaction is weak and only one post-hoc comparison survived: the non-significant trend among participants in the right hand = lower group, for falling interval responses to be faster for congruent (419 ms) than incongruent (425 ms) pairs, $p=.052$. In view of the small size of the effect and the small number of data points contributing to each mean, it is possible that this unexpected effect was due to Type I error.

*Figure 9* Mean response times (ms) for rising and falling intervals for each instrument type.
Figure 10. Mean response times for rising and falling intervals in the congruent and incongruent conditions, separately for participants using the right hand to respond “higher” or “lower”.

Accuracy in Experiment 2 was at near ceiling (overall error rate = 1.2%) and analysis of error rates revealed no main effects and only one interaction between instrument and interval size, $F(4,60)=5.20, p<.001$ (Figure 11). For non-musicians, small and medium intervals elicited lower error rates (both 1.0%) than large intervals (2.0%), $p<.05$. For non-trombonist musicians, small intervals had lower error rates (0.7%) than medium (1.6%) and large intervals (1.7%), $p<.05$. For trombonists, small intervals had higher error rates (1.9%) than medium and large (both 0.6%), $p<.01$
Discussion

According to the action hypothesis, the expected result for Experiment 2 was that the interaction between instrument and congruency found in Experiment 1 would be eliminated, or at least greatly reduced. This was the case. It was predicted that changing the response from one that incorporated actions similar to playing the trombone to one that did not would eliminate this instrument-specificity for action result found in Experiment 1. This is similar to the results of Glenberg and Kaschak (2002) which showed that the action-sentence compatibility effect depends on action and not spatial mapping of responses. If the result from Experiment 1 was due to trombonists’ mapping of response location with forward and backward slide position locations, then a similar effect should be evident in Experiment 2. This was not the case.

The spatial hypothesis was weakly supported by these results in that there was a non-significant trend toward an interaction of instrument and congruity. Since the way of responding in Experiment 2 did not require gross motor movements with the right hand and arm, similar to playing the trombone, this remaining trend (6.5 ms advantage for congruent pairs among
trombonists) can be attributed to the similar dimensional overlap resulting from response location between experiments: the mapping of response location to slide position location for trombonists (away or near) along the sagittal plane.

The Interval Size x Instrument interaction was similar to that of Experiment 1, except that differences were only seen in the trombonist group. In Experiment 1, this difference was also driven by the congruity effect for trombonists (see Figure 4). Since in Experiment 2 this congruity effect was not found we can interpret that some of the difference found between interval sizes is due in part to a discrimination effect: that smaller intervals were harder to discriminate than larger ones for trombonists, reflecting a potential change in strategy between the two experiments for the non-trombonists.

Interestingly, the error rates for the interaction between instrument and interval size appear to deviate from the pattern of Experiment 1. In this case, trombonists showed higher errors on smaller intervals, as expected. However, non-musicians and non-trombonist musicians showed higher error rates on larger intervals than smaller ones. This was not expected and may reflect a difference in strategy for the two non-trombonist groups as a result of changing the response from joystick to bimanual button press.

The Instrument x Direction interaction also suggested that trombonists differed from the other two groups. In Experiment 1, all three groups exhibited shorter RTs for falling intervals than rising ones. However, in Experiment 2, the non-musicians showed a reversal of this effect, while trombonists remained the same and other musicians exhibited no advantage for rising or falling intervals. Again, this suggests that the two non-trombonists groups used a different strategy from Experiment 1, while the trombonists employed a similar strategy. It is possible that for the non-trombone groups in this bimanual task, the direction of higher or lower was assigned
to the hand corresponding to those responses, and so responses became a choice between left
hand or right hand response versus a spatial correspondence of far hand for higher and near hand
for lower.

The Hand x Direction x Congruency interaction is puzzling (Figure 10). The direction of
the congruity effect changed for participants responding with their right hand to make rising
responses (right hand away from the body). This difference did not, however, survive post-hoc
analysis. The only post hoc comparison to approach significance was a trend for congruent
responses to be faster than incongruent responses for participants using their right hand in the
lower position to respond to falling intervals. This interaction may be driven by the relatively
large (20 ms) advantage for falling intervals found among trombonists only in that right-hand
falling response condition. The effect was small ($\eta_p^2=.174$), and since the number of data points
contributing to each mean was small, may have been due to Type I error.
Chapter Seven: General Discussion

The current findings support the view that music cognition, at least as it relates to reading notated music, is grounded in the perceiver’s abilities to create the sounds implied by the notation. When actions that would be required to perform two consecutive notes are in opposition with the motor response to perform the experimental task, this conflict resulted in a movement congruity effect. In Experiment 1, holding the joystick and moving it along the sagittal plane like a trombone slide was similar enough to playing the trombone (for trombonists) to cause interference between two possible motor responses: one for answering the task question, and one implicit, automated response for performing the notes. In Experiment 2, however, this interference was not present when the response switched from joystick to bimanual button pressing. This difference greatly diminished the movement congruity effect for trombonists. The decrease suggested that the effect in Experiment 1 was due to the congruency of the actions involved in moving the joystick and the trombone slide rather than to the congruency of the spatial mapping of the joystick and trombone slide positions.

The small remaining effect of movement congruity in Experiment 2 could, however, be attributed to spatial mapping. Response locations on the sagittal plane with one hand farther away and one hand near the body map onto the irrelevant stimulus dimension of slide positions (away or near on the same plane). Response times were, thus, affected by both action congruity and spatial congruity. The effect of action congruity was, however, the larger of the two effects by an order of magnitude.

Similar to the action-related responses to objects in Tucker and Ellis (1998), for musicians, the ability to play the notes evoked goal-directed motor codes to perform them. However, Phillips and Ward (2002) and Lyons (1996) would argue that visual “affordances” like those described here (and in Tucker and Ellis, 1998) evoke abstract spatial codes. Using Tucker
and Ellis stimuli, Phillips and Ward showed that left and right responses with feet provided the same effect as those made with the hands. Lyons found similar correspondence for grasping as Tucker and Ellis, but for non-graspable objects. Lyons argues that his findings supported spatial S-R compatibility, like a Simon effect, over an action-compatibility account. But these results are in contrast to those claims.

The interval size effect, where small intervals elicited slower responses in both experiments, may be attributed to a discrimination effect (e.g. Clark & Brownell, 1975). The interaction between interval size, instrument and congruency in Experiment 1, highlights the multiplicative effects of interference of automated motor responses for playing trombone when presented with incongruent response information. In Experiment 2, with no conflicting movement incongruency, trombonists exhibited only the discrimination effect of smaller intervals eliciting longer RTs.

The present study accomplished five goals. First, the data demonstrates that the motor system is activated when reading music notation, even when the task is divorced from music performance. Second, the data also demonstrate that extensive experience with a musical instrument provides the basis for how the motor system will be engaged during note-reading in ways that are related to music performance—that is, notated music provides different affordances for different musicians. Third, the results extend previously established instrument-specificity effects for musicians (Drost et al., 2005, 2007; Repp & Knoblich, 2007, 2009) in three directions: a) they establish an instrument-specificity effect for musicians without actually using their instruments, b) they extend the findings from string and percussion instruments to wind instruments, and c) they demonstrate that instrument-specificity interference effects can be achieved without auditory distractor information. Fourth, the data provide a parallel domain to language for the study of the perception of symbols and meaning as being grounded in action.
Finally, I have described the place of studies of instrument specificity effects in musicians in the larger framework of research on stimulus-response compatibility, explaining how the effects of actions and action goals can be viewed in terms of stimulus-response dimensional overlap.

On the first and second points, I have demonstrated that when trombonists view consecutive notes, a motor plan is activated for movement in the same direction as the notes imply for performance on a trombone. The same is not true for other instrumentalists or for non-musicians. Each two-note sequence in the study afforded a specific action trajectory that, when violated by the required response trajectory, caused differences in reaction times among trombonists between congruent conditions and incongruent conditions. Since the required response in both experiments was on a forward/backward plane, the trombonists were affected while the non-trombonist musicians, who presumably had acquired different action representations for the two-note sequences, were not. This is similar to the effects reported by Repp et al., (2007, 2009) who found that pianists responded differently than non-pianists on a left-right movement when making judgments about ambiguous tones.

On the third point, previous behavioral studies on instrument-specificity effects have been limited in two ways: first, by focusing primarily on pianists, with one study also including guitar, (Drost et al., 2007), and second by using multi-modal tasks that do not separate the effects of seeing and hearing. The current study demonstrates, first, that the instrument-specificity effect extends to wind instruments, which use complex movements and coordination of muscle groups including arms, fingers, diaphragm, facial muscles surrounding the embouchure and tongue. The one EEG study (Behmer & Jantzen, 2011) which did include a brass instrument was non-behavioral and while demonstrating differences between musicians and non-musicians, failed to detect differences between violinists and trumpet players. Second, previous studies on
instrument-specificity have relied on multi-modal tasks that make use of both auditory and visual perception processes to produce the hypothesized interference effects. The current study draws on the learned associations of expert musicians to produce sensorimotor interference effects for visual stimuli alone, and provides evidence for motor interference related to playing the instrument even without the instrument present.

On the fourth point, language studies have been a traditional domain for studying the role of sensorimotor processes during cognition, for example, sentence comprehension (Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006) and speech perception (Liberman & Mattingly, 1985; Galantucci, Fowler, & Turvey, 2006; Fowler & Dekle, 1991. Music, like language, offers a rich landscape of properties of perception to study: abstract symbols, meaning, emotion, production, memory, visual symbol recognition, semantic relations of musical properties, pitch, rhythm and melody perception, etc. Additionally, expertise in specific musical domains (e.g. an instrument, genre or style) can offer ways to study learned associations and acquired skills, compared with others in a general population in ways that might be more difficult with language-based materials. The current study extends the findings of the action-sentence compatibility effect (Glenberg & Kaschak, 2002) to the domain of music by treating notated music like action sentences in that the comprehension of the meaning of musical symbols (for musicians only) affords an action response. Moreover, the afforded response is modulated by the experience of the perceiver in ways that are specific to the instrument they play.

Fifth, the movement congruity effect for trombonists can be understood as a Stroop effect (see Lu & Proctor, 1995 for review). For the trombonists, there was dimensional overlap between the irrelevant and relevant stimulus dimension as well as the response dimension. The irrelevant stimulus dimension was the direction of slide movement required to play the two notes
in sequence. The relevant dimension was the direction of the second note in the display relative to the first note (higher or lower). The response dimension was the direction of joystick movement required to make a correct response, higher or lower. The direction of movement required to respond overlapped with both the relevant and irrelevant stimulus dimensions. For non-musicians and non-trombonist musicians, in contrast, the same irrelevant stimulus dimension was meaningless, as they had no experience playing the trombone.

It is important to note that these results, while supporting the view that cognition is embodied cognition (e.g. Glenberg & Kaschak, 2002) or grounded (e.g., Barsalou, 2008), are also consistent with a more strictly ecological view of behavior. Indeed, the framework for the current view of embodied cognition borrows much from the ecological perspective, particularly with respect to affordances. On the ecological view, the information that connected the participants of the current study to their environment was qualitatively different for the three groups. The differences in RTs for trombonists between congruent and incongruent intervals occurred because the intervals afforded two opposing movements at the same time. The latency difference did not occur for non-trombonist musicians because of the available task-relevant responses, none afforded playing the notes on their instrument. For non-musicians, the information about visual features and spatial relationships only afforded responding correctly to the task (accomplishing a goal).

Future Direction

In pilot work for this study, when the labels for higher and lower were counterbalanced between participants in the joystick experiment, all groups had difficulty in producing consistent, quick and accurate responses. This was likely due to a natural tendency to equate higher and lower responses to forward and backward joystick movements, respectively. This is consistent
with experimental results manipulating directional mapping of cursor movements (Phillips, Triggs & Meehan, 2005). For this reason the location of these labels was not counterbalanced in the current study. Future experiments might avoid this issue by switching to a same/different paradigm in which correct responses could be same/different instead of higher/lower. For example, in addition to the current visual stimuli, the addition of note pairs in which the second note is the same as the first note, and the task is to respond whether they were same or different. Response direction could then be manipulated between subjects without a speed/accuracy tradeoff.

In addition to replicating the results of the current study, another area of interest would be to examine the role of modality-specific information on interference in stimulus-response compatibility with musicians. For example, would trombonists exhibit a similar 180 ms difference for congruent intervals with additional, concurrent auditory information? Would confirming auditory information disambiguate the interval size differences at small interval sizes to shorten response latencies? The evidence from Drost et al. (1995, 1997) suggests that it would, but possibly only if presented in the instrumental timbre which the musician has the most experience producing.

**Conclusions**

I have demonstrated that the motor system of musicians is engaged when perceiving musical stimuli in ways that are specific to that musician’s instrument. The perceptual systems of musicians are tuned to information from the environment that prepares them for action. When presented with musical stimuli, each musician is readied through implicit processes for a response that relates to that musician’s ability to create sound on their instrument. I have also shown that instrument specificity effects among musicians can be found not only for auditory distractor stimuli, but for visually presented musical notation. When musicians perceive musical
features, they perceive the effects of those features and therefore the actions required to produce those effects.
References


Appendix

**Appendix A.** Pitch range used for experiment, notated in American Standard Pitch Notation, followed by table of all stimuli used in experimental trials. Each item is a pair of intervals showing start and end notes (given in American Standard Pitch Notation—see music staff at top for reference notes), *interval size* (small=2nds and 3rds, medium=4ths and 5ths, large=6ths and 7ths), *congruency*, *interval direction* (second note higher or lower than the first), *slide movement* (“in” towards the body or “out” away from the body relative to starting note), and *slide distance* in terms of how many positions away the second note is from the first (1–4).

American Standard Pitch Notation labels for range of notes used in experiment.

<table>
<thead>
<tr>
<th>Start Note</th>
<th>End Note</th>
<th>Direction</th>
<th>Interval Size</th>
<th>Congruency</th>
<th>Slide Movement</th>
<th>Slide Distance</th>
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<td>Small</td>
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<td>OUT</td>
<td>4</td>
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<tr>
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Appendix B. Experimental setup (top panel) and procedure for Experiment 1. Lower left panel displays a sample congruent condition and lower right panel displays a sample incongruent condition.