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Movement is part of the meaning of music notation: A musical Stroop effect for trombonists

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Abstract

Does seeing music notation activate the motor systems of expert musicians in preparation for playing, even when they do not have an instrument to play? Trombonists, non-trombonist musicians, and non-musicians were asked to indicate whether the second note of a visually presented two-note sequence was higher or lower than the first note. Participants responded by moving a joystick forward for "*higher*" and backward for "*lower*" or by pressing a button in the top or bottom row, respectively, of a computer keyboard. We examined response time as a function of whether the direction of movement required by the task was the same (*congruent*) or different (*incongruent*) from the direction of movement of a trombone slide when playing the same notes on the trombone. For trombonists, responses were faster for congruent than for incongruent trials for the joystick, but not for the keyboard. There was no effect of congruency for non-trombonists for joystick or keyboard responses. The *trombone congruency effect* is a new kind of musical Stroop effect. Learning to play a musical instrument links the motor and perceptual systems so that seeing musical notes automatically primes playing them.

Keywords

embodied cognition, Stroop effect, instrument specificity, congruency, automatism

When talking about a piece of music, musicians sometimes gesture as though playing, as if their movements expressed their musical ideas (Hostetter & Alibali, 2019). Similarly, musicians' swaying movements during performance reflect their musical interpretations (Demos, Chaffin, & Logan, 2017), and listeners move spontaneously in response, entraining more with the performer as their appreciation of the music increases (Demos & Chaffin, 2018). These

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relationships between movement and music are examples of embodied music cognition (Eitan & Timmers, 2010; Larson, 2012: 33–36; Leman & Maes, 2014; Maes, 2016; Zbikowski, 2011). The embodied cognition framework was a reaction to early claims by cognitive psychologists that cognition can be understood as manipulation of abstract, amodal symbols (Barsalou, 1999; Boroditsky & Prinz, 2008; Galantucci, Fowler, & Turvey, 2006; Glenberg & Kaschak, 2002; Pezzulo et al., 2011). Although criticized for being vague and misdirected (Goldinger, Papesh, Barnhart, Hansen, & Hout, 2016; Mahon, 2015), the embodied cognition framework has highlighted ways in which cognition is grounded in context, including the modal, sensory-motor systems of the human body (Barsalou, 2010; Wilson, 2002).

The training and practice required to perform music creates automatic links between perception, thought, and action (Lisboa, Demos, & Chaffin, 2018; Palomar-García, Zatorre, Ventura-Campos, Bueichekú, & Ávila, 2017). As a result, musicians' music-producing actions affect their perception of musical sounds. For example, pianists perceive the second of two octave-ambiguous tones as higher than the first when the order of key presses they use to produce the tones on a keyboard is left-to-right and as lower when the order of key presses is right-to-left, in accord with the pitch mapping of the piano (Repp & Knoblich, 2009). Likewise, perception of musical sound affects music-producing actions. Pianists respond faster when cued visually to play a chord that is the same as a concurrently sounded (heard) chord than when the two chords are different (Drost, Rieger, Brass, Gunter, & Prinz, 2005). The effects are instrument-specific. Pianists are affected by piano and organ sounds but not by guitar sounds; guitarists are affected by guitar sounds but not by piano or organ sounds (Drost, Rieger, & Prinz, 2007).

Musicians often read through music scores without playing them on an instrument. We hypothesized that when they do so, the motor system automatically prepares for playing, even in the absence of any intention or opportunity to do so. Part of what music notation means to a musician is the actions involved in playing it. To test this, we asked participants (trombonists, other musicians [non-trombonists], and non-musicians) to indicate whether the second of a pair of visually presented notes was higher or lower than the first by moving a joystick backward or forward (*joystick task*), or by pressing one of two response keys located in the top and bottom rows of a computer keyboard (*keyboard task*). We asked whether response time was affected by congruency between the direction of response (*response direction*) and the direction of movement of a trombone slide when playing those two notes in succession (*slide direction*). Congruency was a relationship between the direction of the overt response called for by the task and the *implied movement* of a trombone slide; no actual movement of a trombone slide was required or possible. We expected trombonists to be faster when moving the joystick in the same direction as a trombone slide (*congruent*) and slower when moving the joystick in the opposite direction (*incongruent*). We expected non-musicians to respond correctly on the basis of height on the musical staff. We expected no effect of congruency for non-musicians or other musicians because neither had learned to respond to music notation by moving a trombone slide.

The congruency effect that we expected for the trombonists is an example of stimulus-response compatibility (Proctor & Vu, 2006), specifically a musical Stroop effect. There are many versions of the Stroop task (Schmidt, Hartsuiker, & De Houwer, 2018; for reviews see Lu & Proctor, 1995; MacLeod, 1991; Melara & Algom, 2003). In every version, participants respond to some property of a word or symbol while suppressing a normal response to reading it (Fennell & Ratcliff, 2019). In the classic, color Stroop task, color words are printed in mismatching colors (e.g., "green" printed in red ink). Participants identify either the ink color (ignoring the color word) or the color word (ignoring the ink color). Comparison is made to a neutral condition such as identifying the ink color of squares (Stroop, 1935) or to a congruent condition in which ink color and color word match (Dalrymple-Alford & Budayr, 1966). Identifying the ink color is slowed by a mismatch (incongruent) between the ink color and color word.[1] In contrast, mismatches slow reading of the color word only under special conditions, when it is known as a *reverse Stroop effect* and is smaller than the effect for identifying ink color (Stroop, 1935, Experiment 3; MacLeod, 1991).

In musical Stroop tasks, color is replaced by musical pitch (i.e., pitch chroma), and the participants of interest are musicians; instead of naming colors, participants play notes, and instead of reading color words aloud, participants read the names of notes (Akiva-Kabiri & Henik, 2012; Grégoire, Perruchet, & Poulin-Charronnat, 2013, 2014, 2015; Stewart, Walsh, & Frith, 2004; Zakay & Glicksohn, 1985). Notes of the musical scale are simultaneously indicted in two of several possible ways: name (*do, re, mi*, etc.), height on a musical staff, or fingering. Most often, names of notes are superimposed on a musical staff at heights that either match (congruent) or mismatch (incongruent) the name, for example, *re* (*D*) printed in the note position for "re" (congruent) or in the note position for "mi" (incongruent; Grégoire et al., 2013, 2014, 2015; Zakay & Glicksohn, 1985). As with color, responding is generally slowed by incongruity. In the small number of studies that have looked for both, the Stroop and reverse Stroop effects are more symmetrical for music than for color, occurring whether musicians respond by playing the note or saying it aloud and whether the response is to the printed name or to height on the musical staff (Grégoire et al., 2014; Zakay & Glicksohn, 1985).

Congruity effects in Stroop tasks reflect an inability to suppress processing evoked by symbols (written words or music notation) that has become automatic as a result of extended practice (Cohen, Dunbar, & McClelland, 1990). On incongruent trials in a color Stroop task, the meaning of the color word conflicts with the color of the ink (*stimulus conflict*), and motor activity elicited by the color word conflicts with motor activity elicited by the ink color (*response conflict;* Schmidt et al., 2018).[2] Similarly, musical Stroop effects may result from either stimulus or response conflict, or both. For example, when note names are superimposed on a musical staff, the note name and height on the staff may elicit incompatible ideas of the pitch being referenced (stimulus conflict) or incompatible patterns of motor activity in preparation for playing the note or saying its name aloud (response conflict).

Musical Stroop tasks provide a way of distinguishing response conflict from other sources of conflict, such as stimulus conflict. Playing a musical instrument requires different kinds of movement depending on the instrument. We compared joystick and keyboard responses because the joystick requires playing-type movements similar to those involved in moving a trombone slide, while the keyboard requires a different kind of movement. In the joystick task, participants moved a joystick forward or backward; in the keyboard task, they positioned their hands over two keys, in the top and bottom rows of the keyboard, and pushed downward with one finger. Thus, joystick and keyboard involved moving different effectors (arm vs. finger) in different spatial planes (sagittal vs. vertical). If seeing musical notes automatically activates the motor systems of trained musicians in preparation for playing, then the trombonists will automatically prepare to move their arm in or out along the sagittal plane. A congruency effect for trombonists in the joystick task but not in the keyboard task will indicate that the effect was due to response conflict.

Previous musical Stroop studies have not attempted to examine the contribution of response conflict. Of the three studies that examined playing or playing-type responses, two did not compare different types of response. Stewart et al. (2004) found a congruency effect for pianists executing sequences of five keypresses on a computer keyboard, with the sequence indicated by five digits corresponding to fingers of the right hand (1 = *thumb*, 5 = *little finger*). Responding was 253 ms slower when the number-to-finger mapping was incongruent with the height of the numbers on a musical staff. Grégoire et al. (2013, Expt. 1) found a small (10 ms) but statistically reliable congruency effect for musicians (not selected by instrument) in a go/no-go task in which participants pressed the space bar on a computer keyboard for note names but not for other words. In the only study to compare two types of responses, modeled closely on Stroop's original study (Stroop, 1935), Zakay and Glicksohn (1985) found a congruency effect for pianists playing notes on the piano and reading note names aloud. However, it is not clear whether the 255 ms effect for playing was statistically significant because the effect was not tested separately for each response type (Grégoire et al., 2013).

We expected no effect of congruency for other musicians. Although we expected the other musicians to be affected by their habitual responses to musical notation, as with the trombonists, we expected those effects to cancel out across participants because the other musicians played a variety of different instruments, each with its own set of habitual responses. The trombone is almost unique among Western musical instruments in the sliding motion used to change pitch and so trombonists learn to relate pitch and movement differently from, for example, pianists (cf. Repp & Knoblich, 2009). An effect for trombonists but not for other musicians would show that the trombone congruency effect is instrument-specific (Drost et al., 2005; Drost et al., 2007). We also expected no effect of congruency for non-musicians because they had not learned habitual responses to notes. Non-musicians controlled for the possibility that slide direction might be confounded with some unanticipated spatial property of the stimuli that participants could map onto the spatial direction of the response (cf. Eitan & Timmers, 2010; Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006).

In summary, a congruency effect for trombonists will indicate that, for experienced musicians, reading music notation activates the motor system in preparation for playing, even when there is no intention or possibility of playing. The effect will provide the first evidence that the musical Stroop effect is instrument-specific and occurs for an instrument other than the piano. The effect will also extend the instrument specific effects reported by Drost et al. (2005; Drost et al., 2007) to a new modality (reading vs. hearing), a broader class of actions (non-music producing vs. music producing), and a new class of musical instruments (brass vs. keyboard and string).

Method

Participants

Participants were 12 trombonists, 12 non-trombonist musicians, and 12 non-musicians. Numbers were limited by the availability of professional trombonists. We refer to non-trombonist musicians as "*other musicians*" and we refer collectively to trombonists and other musicians as "*musicians*," and to other musicians and non-musicians as "*non-trombonists*." Musicians were all professionally active, with 10 or more years of serious study on their instrument. Trombonists (eight male and four female) ranged in age from 23 to 59 (mean of 39). Other musicians (seven male and five female) ranged in age from 30 to 59 (mean of 41) and played the bassoon (one), cello (four), doublebass (one), piano (two), euphonium (one) and tuba (three). Non-musicians (seven male and five female) ranged in age from 31 to 59 (mean of 40). Participants were recruited through the professional network of the first author and by advertisements on a university campus. Each participant received a US$10 gift card.

Materials

On the trombone, pitch is a function of three factors: slide position, lip tension (embouchure), and air velocity. The direction of slide movement between notes depends on which pair of consecutive notes (intervals) a trombonist is playing. Some intervals that raise the pitch are played by pushing outward, and some inward. Likewise, for intervals that lower the pitch. There is no absolute association between direction of slide movement and direction of pitch change, although higher pitch is associated with inward slide movement for adjacent pitches produced with the same embouchure and air velocity. Accordingly, slide direction and response direction varied independently in our stimuli.

We selected 72 note pairs from the 372 pairs of notes (pitch chroma) with an interval of less than an octave across the two-octave range from F#2 to F#4, a range common in the trombone repertoire. We excluded note combinations that required no change in slide position, were non-idiomatic, or had commonly used alternative slide positions (many notes on the trombone are commonly played at a single, conventional slide position; we selected notes of this type). We included augmented fourths as well as diminished fifths as they differ visually, despite being the same interval class of a tritone.

Notes were displayed on a bass clef staff. Each note pair was presented twice, once with the lower note first and once with the higher note first (*interval direction*), for a total of 144 stimulus items (listed in the Supplementary Materials). As described below, interval direction and response direction were not counterbalanced. The response option located outward, away from the body, always indicated that the second note was higher than the first. In describing the results, we refer to response direction, not interval direction.

The 72 note pairs included 12 pairs for each of the factorial combinations of slide direction (in/out) and interval size (small/medium/large). Small intervals were notes separated by one to four semitones, medium intervals by five to seven semitones, and large intervals by eight to eleven semitones. For each interval size, pairs were evenly distributed across the two-octave range. Thus, the 144 stimuli represented the factorial combination of response direction (in/out), slide direction (in/out), and interval size (small/medium/large). The 144 stimuli were each presented twice, for a total of 288 trials in each task.

Procedure

Each participant was tested twice, at an interval of approximately 6 months, thus minimizing possible effects of retesting. Half of the participants in each group performed the joystick task first, and the keyboard task 6 months later; the other half performed the two tasks in the opposite order.

Participants viewed pairs of notes on a computer screen and indicated whether the second note was higher or lower in pitch than the first by moving a joystick (Logitech Attack™ 3) forward or backward or by pressing keys in the top and bottom rows of a computer keyboard. In the joystick task, participants moved the joystick in or out from the body along the sagittal plane, as when moving the trombone slide. In the keyboard task, participants positioned their hands over keys in the top and bottom rows of the keyboard. Thus, the response alternatives were located in or out, toward or away from the body, in both tasks. In contrast, the direction of movement was in the sagittal plane in the joystick task and vertically down in the keyboard task.

Response options were labeled the same way in both tasks, by two white index cards bearing the words “higher” and “lower,” in two-inch lettering. “Higher” was located between the

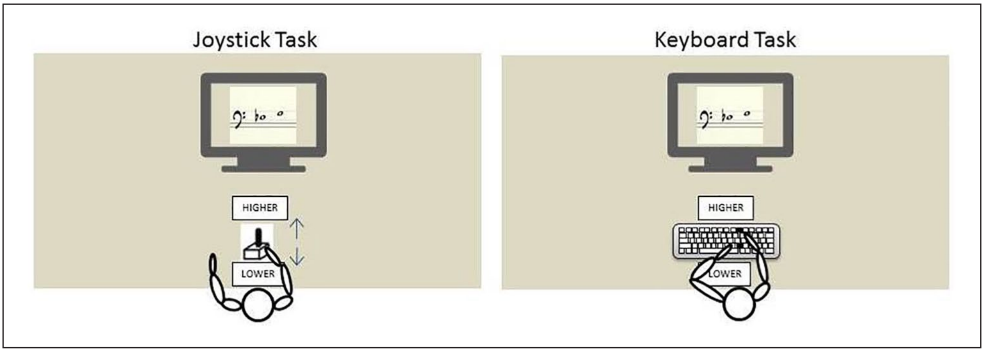

Figure 1. The configuration of computer screen, response labels, and response device in each task.

joystick/keyboard and monitor, "lower" between the joystick/keyboard and the participant (see Figure 1). Thus, the direction of the response options in the sagittal plane (response direction) was not counterbalanced with the direction of the pitch change represented by the stimulus (interval direction). Instead, the option indicating "lower" was always located in, toward the body (*in*), and "higher" was always located out, away from the body (*out*), in both tasks.

In the joystick task, participants held the joystick in their right hand, between the thumb and first two or three fingers, and responded by pushing or pulling the joystick in or out along the sagittal plane from its default, neutral position. The joystick did not provide feedback other than stopping movement at the farthest point forward or backward; instead, participants were instructed to continue pushing or pulling until feedback appeared on the computer screen, as will be described. In the keyboard task, participants positioned one hand over the "8" key (in the top row of the keyboard) and the other over the "M" key (in the bottom row) and responded by pushing down on one key. Half of the participants in each group were randomly assigned to press the "8" key with their right hand and the "M" key with the left hand; for the other half, the assignment was reversed.

Stimuli were prepared using Finale music notation software and displayed on an 18-in. screen using E-Prime. The two notes of each pair were presented successively, in the center of the screen, on a bass clef staff measuring 571 pixels (length) by 200 pixels (height). Each trial began with the first note displayed for 750 ms, followed by an 850 ms mask, consisting of a box, of the same size as the bass staff, filled with the letter "x," followed by the second note, which remained on the screen until the participant responded, at which time the word "correct" or "incorrect" appeared, also in the center of the screen, for 750 ms. There was an inter-trial interval of 1 s. Response time was measured from presentation of the second note. Stimuli were randomly ordered in six blocks of 48 trials, with no note pair repeated within a block and the order of blocks counterbalanced across participants.

Results

We excluded 0.22% of the responses that were faster than 200 ms (4 trials in the joystick task and 28 trials in the keyboard task) or slower than 2,000 ms (14 trials in the joystick task and 0 trials in the keyboard task). Responses were fast and error rates low, and the relationship between the two measures was weakly positive (see Table 1), suggesting that there was no speed/accuracy trade-off.

Table 1. Means and standard deviations (in parentheses) for response time and error rate and the correlation between them, separately for each task.

	Joystick Task	Keyboard Task
Response time (ms)	644 (190)	423 (105)
Error rate (%)	.013 (.028)	.011 (.023)
Point-biserial *r*[1]	.141*	.033*

[1] computed across all responses.
*$p < .01$.

Mean response times for correct responses and number of errors were analyzed separately in 2 × 3 × 2 × 2 × 3 mixed analyses of variance (ANOVAs) with group (trombonists, other musicians, non-musicians), as a between subjects variable and task (joystick, keyboard), slide direction (in, out), response direction (in, out), and interval size (small, medium, and large) as repeated measures variables. For effects which violated the assumption of sphericity, we used the Greenhouse–Geisser correction. Results for reaction time (RT) and errors were similar. Here, we report results for RT. (See Table 2 for a summary. The analysis of errors is summarized in the Supplementary Materials).

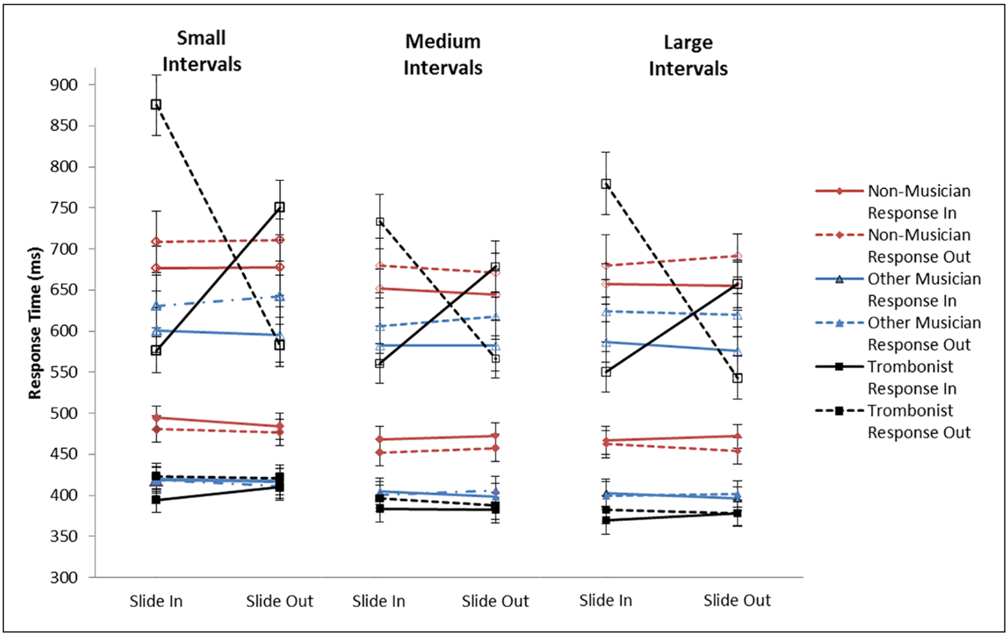

Figure 2. Mean response time for small, medium, and large intervals as a function of group, response direction, slide direction, and task. The joystick task (open markers) appears at the top of each panel, the keyboard task (solid markers) at the bottom. Error bars represent standard error.

As expected, there was a congruency effect for trombonists in the joystick task. The effect is evident in Figure 2 in the X-shaped configuration for trombonists in the top set of functions in each of the three panels. Figure 2 shows mean response time as a function of slide direction and

Table 2. Summary of effects for response time analysis by participants.

Effect	*df*	*F*	Partial η^2
Group	2, 33	4.28*	0.206
Task	1, 33	206.64***	0.862
Slide Direction (SlideDir)	1, 33	23.36***	0.414
Response Direction (ResponseDir)	1, 33	47.47***	0.59
Interval Size (IntervalSize)	1.36, 44.71	74.24***	0.692
Group × Task	2, 33	1.70	0.093
Group × SlideDir	2, 33	18.16***	0.524
Group × ResponseDir	2, 33	5.46**	0.249
Group × IntervalSize	4, 66	6.342***	0.278
Task × SlideDir	1, 33	17.14***	0.342
Task × ResponseDir	1, 33	63.08***	0.657
Task × IntervalSize	1.36, 44.87	5.60*	0.145
SlideDir × ResponseDir	1, 33	24.90***	0.43
SlideDir × IntervalSize	2, 66	1.38	0.04
ResponseDir × IntervalSize	2, 66	2.84	0.079
Group × Task × SlideDir	2, 33	21.49***	0.566
Group × Task × ResponseDir	2, 33	0.14	0.008
Group × Task × IntervalSize	2.72, 44.87	2.11	0.114
Group × SlideDi × ResponseDir	2, 33	29.27***	0.639
Group × SlideDir × IntervalSize	4, 66	0.89	0.051
Group × ResponseDir × IntervalSize	4, 66	1.28	0.072
Task × SlideDir × ResponseDir	1, 33	21.38***	0.393
Task × SlideDir × IntervalSize	2, 66	1.09	0.032
Task × ResponseDir × IntervalSize	2, 66	1.59	0.046
SlideDir × ResponseDir × IntervalSize	1.69, 55.87	10.37***	0.239
Group × Task × SlideDir × ResponseDir	2, 33	24.04***	0.593
Group × Task × SlideDir × IntervalSize	4, 66	3.71**	0.184
Group × Task × ResponseDir × IntervalSize	4, 66	0.75	0.043
Group × SlideDir × ResponseDir × IntervalSize	3.39, 55.87	10.34***	0.385
Task × SlideDir × ResponseDir × IntervalSize	2, 66	5.15**	0.135
Group × Task × SlideDir × ResponseDir × IntervalSize	4, 66	6.87***	0.294

$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$.

response direction with interval size in separate panels. The flat response functions for other musicians and non-musicians indicate the absence of a congruency effect for these groups. Similarly, the flat response functions for all three groups at the bottom of each panel indicate that there was no effect for trombonists in the keyboard task. (Keyboard responses are at the bottom of each panel, indicating that responding was consistently faster in the keyboard than the joystick task.) Unexpectedly, the X-shape of the congruency effect for trombonists is asymmetrical, with level feet and left arm higher than right, reflecting greater slowing for incongruent responses when the implied direction of the trombone slide is in, toward the body. The X-shape is taller and more asymmetrical in the leftmost panel, indicating that the effects of incongruity were larger for small intervals.

The trombonist congruency effect was reflected in a four-way interaction of Task x Group x Slide Direction x Response Direction, $F(2, 33) = 24.039, p < .001, \eta_p^2 = 0.593$. The larger effect for small intervals was reflected in the five-way Group × Task × Slide Direction × Response Direction × Interval interaction, $F(4, 66) = 6.867$, $p < .001$, $\eta_p^2 = 0.294$. The asymmetry of the effect was reflected in the main effect of slide direction, $F(1, 33) = 23.359$, $p < .001$, $\eta_p^2 = 0.414$ and by its two-, three-, and four-way interactions with task, group, and interval size (see Table 2), indicating that the effect of slide direction was limited to trombonists in the joystick task, and was largest for small intervals.

In addition, there were main effects of group, task, and response direction. Non-musicians were 49 ms slower on average than trombonists and 66 ms slower than other musicians, $F(2, 33) = 4.277$, $p = .022$, $\eta_p^2 = 0.206$, perhaps reflecting their lack of familiarity with music notation. Responses were 221 ms faster in the keyboard than in the joystick task, $F(2, 33) = 206.642$, $p < .001$, $\eta_p^2 = 0.862$, perhaps reflecting the smaller movements required on the keyboard. Responses were slower for small intervals than for medium (28 ms; $p < .001$) and large intervals (34 ms; $p < .001$), $F(1.355, 44.712) = 74.239$, $p < .001$, $\eta_p^2 = 0.692$, perhaps reflecting visual discriminability. Responses made inward, toward the body, were faster than responses outward, away from the body, $F(1, 33) = 47.470$, $p < .001$, $\eta_p^2 = 0.590$; the effect occurred in the joystick task (39 ms) but not the keyboard task (<1 ms), $F(1, 33) = 63.075$, $p < .001$, $\eta_p^2 = 0.657$, perhaps reflecting a general advantage of inward over outward hand movements. The interactions between these effects and the congruency effect are summarized in Table 2 and are evident in Figure 2 in the contrast between the flat response functions and the asymmetric X-shape of the congruency effect.

Discussion

Trombonists were faster when the overt movement of the joystick was in the same direction as the implied movement of a trombone slide than when overt and implied movements were in opposite directions. As suggested by the embodied cognition approach, reading music notation automatically activates the motor systems of trained musicians in anticipation of playing, even when there is no opportunity or possibility of doing so (cf. Bach, Griffiths, Weigelt, & Tipper, 2010; Barsalou, 2010; Hommel, 2009). The trombone congruency effect is also consistent with evidence that musical training increases anatomical and functional connections between the auditory and motor systems (Palomar-García et al., 2017).

There was no effect for other musicians or for trombonists in the keyboard task. Thus, the congruency effect was specific to both the instrument the musicians had learned to play and the experimental task they were asked to perform. Learning to play a musical instrument creates instrument-specific links between music notation and sound-producing actions. Previous studies had demonstrated instrument-specific effects of music training on links between actions and their auditory effects (Drost et al., 2005; Drost et al., 2007; Repp & Knoblich, 2009). We have extended instrument specificity to links between visual symbols and action, and from keyboard and string to brass instruments.

The trombone congruency effect is a new kind of musical Stroop effect. Like other Stroop effects, it is due to inability to suppress automatic processing of visual symbols (MacLeod, 1991). Seeing two notes automatically activated trombonists' motor systems in preparation for moving the trombone slide from the position required to play the first note to the position required to play the second. On incongruent trials, this automatic activation conflicted with the activation required to move the joystick in the direction required by the overt response.

Three characteristics of the trombone congruency effect point to response competition as its source: (1) the absence of the effect for trombonists in the keyboard task, (2) the asymmetry of the effect (larger for implied movement of the trombone slide in than out), and (3) its larger size for small intervals. We discuss each characteristic in turn. First, the presence of the effect for trombonists in the joystick task and not in the keyboard task points to anticipatory movement of the trombone slide as its source, since it occurred only when the overt response required by the experimental task was physically similar to the habitual response of moving the trombone slide. Thus, the effect was a product of response rather than stimulus conflict.

Second, the trombone congruency effect was larger when the anticipated movement of the trombone slide was in, toward the body, than when it was out, away from the body. This unexpected asymmetry suggests that anticipatory activation of the implied movement of the trombone slide was subject to the same advantage of inward over outward movement observed for overt movement of the joystick in all three groups. All three groups moved the joystick faster in than out, suggesting a general advantage of inward over outward arm movement. (The effect has not, to our knowledge, been previously reported, perhaps because it is enhanced by music training; it was smallest for non-musicians). If the anticipatory activation elicited by the implied movement of the trombone slide also favored in over out, then suppressing this activity on incongruent trials would take longer when the implied direction was inward. We suggest that this is why trombonists' responses were slowest on incongruent trials when the implied movement of trombone slide was inward.

Third, the trombone congruency effect was larger and more asymmetrical for small intervals; responses were also slower to small intervals for all three groups, in both tasks. Similarly, Rusconi et al. (2006) found a larger congruency effect coupled with slower responding for smaller intervals in a study of spatial-numerical compatibility. Both effects may stem from difficulty in discriminating smaller intervals (Clark & Brownell, 1975). For trombonists in the joystick task, the longer time needed to identify the direction of small intervals may have allowed more time for automatic, anticipatory activation to develop, requiring more time to inhibit it when the activation was incompatible with the overt response.

Our study does not address the question of whether response competition occurred centrally or peripherally. Other studies suggest that competition occurs centrally, during action planning, rather than peripherally, during response execution (Hedge & Marsh, 1975; Lu & Proctor, 1995; Miller, Brookie, Wales, Kaup, & Wallace, 2018). This would explain why there was interference between response direction and slide direction despite the substantial differences between pushing/pulling a joystick and moving a trombone slide. Also, our study does not separate inhibition on incongruent trials from facilitation on congruent trials because we did not include a neutral baseline. Other studies that included a neutral baseline found that inhibitory effects were substantially larger than facilitative effects (Akiva-Kabiri & Henik, 2012; Glaser & Glaser, 1982; see Lu & Proctor, 1995; MacLeod, 1991, for reviews). Thus, it is likely that the trombone congruency effect was largely inhibitory, reflecting slowing of joystick responses by automatic, anticipatory motor activity elicited by the two-note stimulus.

In conclusion, our study provides the first evidence that musical Stroop effects are instrument-specific and the first demonstration of a musical Stroop effect for an instrument other than the piano. Reading music notation automatically activates musicians' motor systems in preparation for playing, even when there is no opportunity or intention to play. This adds one more example to the growing list of ways in which music is embodied (Maes, 2016). More broadly, it supports the central insight of embodied or "grounded" cognition that conceptual representations are grounded in the brain's modal systems for perception and action rather than in independent, amodal data structures (Barsalou, 2010). For trained musicians, part of the meaning of music notation is the movement involved in playing it.

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Supplemental material

Supplemental material for this article is available online.

Notes

1. Identifying ink color is also faster when the ink color and color word match, compared with a neutral baseline condition, but the facilitatory effect for congruent stimuli is much smaller than the inhibitory effect for incongruent stimuli (MacLeod, 1991).
2. Task conflict (e.g., between color naming and word reading) may also contribute when participants perform more than one task (Kalanthroff, Goldfarb, Usher, & Henik, 2013; Kinoshita, de Wit, Aji, & Norris, 2017).

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