Introduction.

The Stroop Interference effect is a psychological phenomenon in which people are more susceptible to making errors when naming the ink color of a word when the word itself is a color that is different from the ink. The original experiment has been expanded in many ways, with Zakay and Glicksohn (1985) introducing the idea of a *musical* stroop effect. In their experiment, 20 participants were exposed to stimuli in which notes were in congruent or incongruent positioning on a musical staff, with either a differently labeled note appearing next to the measure, or the naming of the note (i..e, do, re, mi, etc.) replacing the notation. Subjects were then set to respond verbally, by reading the name of the note, or by manually pressing piano keys. They found that for both congruent and incongruent positioning, verbally response modes had more delayed response times than manual responses when notes were presented. Similarly, manual response modes had more delayed response times when names were presented. This experiment introduced the idea of stimulus-response compatibility (SRC) as determinants of interference within Stroop tasks.

In an audio-centered musical Stroop task executed by Lacey et al. (2020), 24 participants listened to five-note musical phrases with four kinds of visual contours (falling, rising, falling-rising, and rising-falling) that were either congruent or incongruent with their accompanied auditory stimuli. They were then asked whether the final note of the phrase was higher or lower in pitch than the first. The experimenters found that response times were significantly slower in audio-judgment for incongruent trials compared to congruent; therefore, concluding that musical perception may be 'multisensory' - with reliance on both audio and visual sensors.

In Lotze et al. (2003), this multisensory musical perception is also deepened, but with a concentration on audio-motor coactivation. For their experiment, participants (both amateur and professional violinists) were asked to manually execute or imagine playing Mozart's violin Concerto in G Major while their BOLD levels were being examined in an fMRI. Both groups manifested very similar activations during physical execution, with neurological activity being slightly more distributed in the amateurs, but significantly differed in areas of activation for imagined performances. Through the fMRI, they observed that professional musicians generated higher EMG amplitudes during movement execution and showed focused cerebral activations in the contralateral primary sensorimotor cortex, the bilateral superior parietal lobes, and the ipsilateral anterior cerebellar hemisphere. The observations support the notion that musical production involves not only the motor areas, but also other functional systems such as the somatosensory, auditory, emotional, temporal, and memory loops. Specifically, the finding that professionals exhibited higher activity of the right primary auditory cortex during executive may reflect an increased strength of audio-motor associative connectivity for these groups of musicians. Thus, they concluded that 'the motor and auditory systems are coactivated as a consequence of musical training but only if one system (motor or auditory) becomes activated by actual movement execution or live musical auditory stimuli.'

Taken together, these findings suggest that musical perception involves dynamic integration of visual, auditory, and motor systems, with the greatest connectivity reaching trained, professional musicians. Building on these paradigms, my research will examine how different response modalities (verbal vs. manual) affect susceptibility to Stroop-like interference in musical tasks, but when there is an additional audio variable. Specifically, I aim to explore the role of audio-motor interactions in music cognition and relate these findings to broader patterns of Stroop interference in the context of various SRCs. My study will draw on this multisensory framework to examine interference effects in a modified musical Stroop paradigm.

I hypothesize that participants performing manual responses (e.g., pressing piano keys) will exhibit greater Stroop interference than those providing verbal responses when presented with incongruent auditory notes, due to the enhanced involvement and interdependence of auditory and motor systems in music-related tasks. This will be reflected in longer response times as well as greater ratios of inaccuracy. Although Zakay et al. had contradictory findings to my hypothesis, I believe the addition of an auditory variable will outweigh the low stimulus-response compatibility of verbalization and this finding can possibly be irrelevant for this specific study as the Stroop task presented does not include mislabeled notations.

Methods.

Participants. I intend to test about 80-100 trained pianists with similar levels of musical training and educational backgrounds. They will also vary in gender and age, but these characteristics will be noted on a questionnaire administered at the end of the experiment.

Materials. For the experiment, I will use E-Prime on Mac computers running Windows in Bootcamp. There will be a total of seven notes in the key of C Major (C, D, E, F, G, A, B) for both the perfect pitch task as well as the musical Stroop task. For both the perfect pitch task and the musical stroop task, a 6-second audio file will be played using these notes one at a time. For just the musical Stroop task, an image of a G-Clef musical staff with one note in the positioning of the seven notes indicated will appear against a black background (see figure 1.1). My dependent variables will be response time and accuracy, while my main independent variables will be congruency/incongruency and response modality (verbal versus manual).

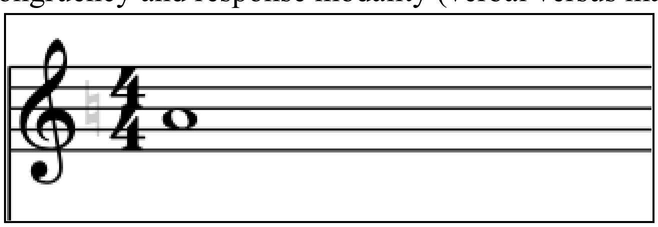

Figure 1.1. The G Clef, or Treble Clef, is the most common clef which is used for high-pitched instruments. The note 'A' in the key of C Major is shown above, which would appear in the Musical Stroop task seven times simultaneously with audio files of congruent or incongruent notes in the same key.

Procedure. The experiment will begin with a screen authorizing the consent of each volunteer in their participation. A Goodbye screen will be displayed at the end of the E-Prime experiment.

Both a perfect pitch task and musical Stroop task will be administered to all participants, however the even-trialed participants will have the perfect pitch task given first, and the musical Stroop task given second, while the odd-trialed participants will have the musical Stroop task given first, and the perfect pitch task given second. This will account for potential learning or memorization which could occur during either task and could reveal differences in task order between participants. If there is no inherent preference or significant difference in results for either order, then this controlled switching could be negligible.

Both the perfect pitch task and the musical Stroop task will include verbal and manual responses within participants. For verbal responses, participants will be asked to state aloud the note (i.e., 'A,' 'B,' 'C,' 'D,' 'E,' or 'F') and then press the SPACEBAR to continue to the next trial. For manual responses, participants will be displayed with specific instructions on how to position their fingers on the piano keyboard rested between themselves and the computer (see figure 1.2). They will then need to respond by either playing the note heard (perfect pitch task) or seen (musical stroop task). Similarly, after each response, they will press the SPACEBAR to continue to the next trial.

Between the perfect pitch task and the musical Stroop task, regardless of ordering, there will be an episode of Popeye the Sailor shown during a ‘break’ of the experiment. This will assist in counterbalancing as well as limiting any potential learning which could occur. It can also aid in brain fatigue as these trials would occur in one sitting.

Figure 1.2. Instructions provided to participants during the manual response sections of either experiment on how to position their fingers on the piano keyboard in front of them.

Perfect Pitch Task Procedure. In this task, a randomized note will be heard in the key of C major and the participant will be prompted to either verbally state or manually play the note they perceived. They will be given instructions on whether to continue the experiment by responding verbally until prompted otherwise, or manually by pressing the corresponding piano key. Each modality will contain seven randomized trials (one for each note) and the order in which the mode-based tasks appear (either verbal or manual) will be randomized within E-Prime. While listening to these audio files, the participant will only see a black fixation screen to limit any visual interference.

Musical Stroop Task Procedure. In this task, E-Prime will present participants with a figure of a G-Clef music staff with randomized notes displayed one at a time (refer back to figure 1.1 for an example). A note is displayed and heard simultaneously, with the note in the image and audio file either being congruent or incongruent. Participants will be tasked to either verbally state or play the note they see, not hear. The participant will be given instructions on whether to continue the experiment by responding verbally until prompted otherwise, or manually by pressing the corresponding piano keyboard. Each modality will contain 49 randomized trials (7 notes seen x 7 notes heard) and the order in which the mode-based tasks appear (either verbal or manual) will be randomized within E-Prime.

Expected Results.

For the results, I expect that there will be a high stimulus-response compatibility in the perfect pitch task for manual responses compared to verbal responses. This will look like either faster response times or greater accuracy for this response modality when there is only auditory stimuli present.

For participants with greater accuracy in the perfect pitch task for manual responses instead of verbal responses, they will also have delayed reaction times and/or greater inaccuracy in the Stroop trials for manual responses. There will be a significant relationship between SRCs and the modality in which a participant is more susceptible to Stroop interference; thus, there will be an inverse result between the perfect pitch task and the musical Stroop task but ONLY if the perfect pitch task was relatively accurate. More specifically, for participants with higher accuracy in the perfect pitch task overall, they will have worse reaction times and accuracy percentages in comparison to participants who did not do well on the task. This is because participants who did well on the perfect pitch task are more likely to experience interference as they are more sensitive to auditory stimuli, while participants who did not do well on the perfect pitch task can do a better job at ignoring the irrelevant accompanying audio.

Across participants, there will be higher levels of Stroop interference for manual responses in the musical Stroop task compared to verbal responses. Ultimately, these results will support my hypothesis.

Discussion.

My hypothesis may compete with other conflicting factors that are not necessarily accounted for in the original experiment, such as old age. Although it is crucial that all the musicians used in the study started their musical development and training around similar ages, older participants may be more prone to interference due to the neurological changes which occur later in life. In a study conducted by Tremblay et al. (2017) on the cognitive effects of aging, fMRI results revealed 'extensive age differences in the relationship between BOLD signal and [movement time],' with longer and more variable MT results in older participants, 'within and outside the sensorimotor system.' It is significant to note that there was no main effect on response planning or motor control accuracy.

Thus, this motor-slowing in older adults may combat my hypothesis that there will be greater SRC for manual responses, as response times will most likely be delayed in elders compared to young adults. This can also be determinant on how often an older adult plays the piano, as they may not maintain the frequency of playing in which they once did while undergoing music lessons. If this motor deficiency is significant across this group, then not only will there be an inverse result in the perfect pitch task, but the audio-motor connectivity may not be as prominent for those who are older in age or lacking in formal practice. Therefore, SRC and Stroop-like interference may depend on the identity of the participant equally as much as it depends on their musical proficiency.

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