Speech and non-speech measures of audiovisual integration are not correlated

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Abstract

Many natural events generate both visual and auditory signals, and humans are remarkably adept at integrating information from those sources. However, individuals appear to differ markedly in their ability or propensity to combine what they hear with what they see. Individual differences in audiovisual integration have been established using a range of materials including speech stimuli (seeing and hearing a talker) and simpler audiovisual stimuli (seeing flashes of light combined with tones). Although there are multiple tasks in the literature that are referred to as “measures of audiovisual integration,” the tasks themselves differ widely with respect to both the type of stimuli used (speech versus non-speech) and the nature of the tasks themselves (e.g., some tasks use conflicting auditory and visual stimuli whereas others use congruent stimuli). It is not clear whether these varied tasks are actually measuring the same underlying construct: audiovisual integration. This study tested the convergent validity of four commonly-used measures of audiovisual integration, two of which use speech stimuli (susceptibility to the McGurk effect and a measure of audiovisual benefit), and two of which use non-speech stimuli (the sound-induced flash illusion and audiovisual integration capacity). We replicated previous work showing large individual differences in each measure, but found no significant correlations between any of the measures. These results suggest that tasks that are commonly referred to as measures of audiovisual integration may not be tapping into the same underlying construct.

Keywords: *Audiovisual integration, individual differences, convergent validity*

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Integrating auditory and visual information facilitates stimulus identification and speeds responses (Stein & Stanford, 2008). Audiovisual integration has been studied extensively using behavioral tasks (e.g., McGurk & MacDonald, 1976; Shams et al., 2000), neuroimaging paradigms (e.g., Beauchamp et al., 2004; Calvert et al., 2000), and even single-cell recordings (Stein et al., 1976). It has been tested using a range of materials including simple stimuli such as flashes of lights and tones (Shams et al., 2000) as well as naturally-occurring complex stimuli such as audiovisual speech (Sumby & Pollack, 1954). In some cases, stimuli in one modality may increase the perceptibility of stimuli in another (e.g., Sommers et al., 2005; Van der Burg et al., 2008). In other cases, perception in one sensory modality is led astray by stimuli in a different modality (e.g., the sound-induced flash illusion; Shams et al., 2000; the McGurk effect, McGurk & MacDonald, 1976).

In recent years, there has been a burgeoning field of research examining factors contributing to individual differences in audiovisual integration (e.g., Brown et al., 2018; Gurler et al., 2015; Van Engen et al., 2017). This work has generally progressed in parallel in the speech and non-speech literatures, with little overlap between the two (but see Conrey & Pisoni, 2006; Stevenson et al., 2012). However, given that individual differences have been observed for multisensory integration across a wide variety of stimuli, it is possible that individuals who tend to show greater integration in one context also show greater integration in other contexts. That is, audiovisual integration may represent an underlying ability that is not specific to a particular stimulus category (see Huang et al., 2012 for an analogous claim in the attention literature).

Seeing a talker's face not only improves speech intelligibility relative to hearing alone ("audiovisual benefit"; Erber, 1972; Sommers et al., 2005; Sumby & Pollack, 1954), but

incongruent visual cues can also alter perception of aurally presented syllables (the “McGurk effect”; McGurk & MacDonald, 1976). Although these general trends are robust at the population level, individuals differ markedly in the extent to which intelligibility improves when they can see the talker (Grant & Seitz, 1998; Tye-Murray et al., 2016), and susceptibility to the McGurk effect also varies dramatically across individuals (Basu Mallick et al., 2015; Brown et al., 2018). However, despite the fact that measures of audiovisual benefit and McGurk susceptibility both rely on audiovisual processing of speech, it is not clear that they are served by similar mechanisms. In fact, performance on congruent audiovisual speech and McGurk tasks appear to be uncorrelated (Van Engen et al., 2017; though see Grant & Seitz, 1998).

Audiovisual integration of non-speech materials has been assessed in multiple ways, including the pip and pop effect (Van der Burg et al., 2008, 2011), the ventriloquist effect (Alais & Burr, 2004; Bertelson et al., 2000; Vroomen et al., 2001), the sound-induced flash illusion (Shams et al., 2000), and audiovisual integration capacity (Wilbiks & Dyson, 2016, 2018). However, just as research in the speech literature has found little evidence that multiple measures of integration rely on the same underlying mechanisms, evidence for a general integration factor in the non-speech literature also remains elusive. Matthews and colleagues (2016) demonstrated that temporal order judgements, which require that participants report which of a pair of auditory and visual stimuli was presented first, are uncorrelated with explicit simultaneity judgements, in which observers are asked to report whether two stimuli were presented simultaneously (Petrini et al., 2009; Zampini et al., 2005). This is notable given that both tasks are used as measures of integration, and more specifically, they are both used to establish the point of subjective simultaneity. In addition, performance on audiovisual spatial and temporal binding tasks are not

related (Noel et al., 2018). However, there is some evidence suggesting that spatial localization and audiovisual synchrony perception may be related (Meyerhoff & Gehrler, 2017).

Given the variety in measures used to assess audiovisual integration and the relatively small body of work assessing intercorrelations among these measures, a question arises as to whether audiovisual integration of speech and non-speech stimuli relies on the same underlying mechanisms. Is it the case that individuals with strong propensities to integrate non-speech auditory and visual stimuli also show high levels of integration on audiovisual speech tasks?

Conrey and Pisoni (2006) showed that performance on a non-speech audiovisual synchrony task (identifying whether a visually-presented circle coincided with a pure tone) was related to audiovisual sentence recognition in noise. However, performance on the non-speech audiovisual synchrony task also predicted accuracy on audio-only sentence recognition, so it is possible that the measure of synchrony detection is related to a general feature of speech processing rather than integrating auditory and visual information. There is also some evidence that susceptibility to the sound-induced flash illusion and the width of the right side of the audiovisual temporal binding window (i.e., audio lag) predict McGurk susceptibility (Stevenson et al., 2012). Intriguingly, however, those correlations are *negative*, indicating that individuals with larger temporal binding windows and those who are more susceptible to the sound-induced flash illusion are *less* susceptible to the McGurk effect. Thus, these results may reflect individual differences in sensitivity to the timing of audio and visual synchrony, but do not provide evidence for an audiovisual integration ability that is unified across speech and non-speech tasks.

The Current Study

The current research assessed the convergent validity of multiple measures of audiovisual integration by testing intercorrelations among two speech (McGurk susceptibility and

audiovisual benefit) and two non-speech (sound-induced flash illusion and audiovisual integration capacity) tasks that are commonly used to assess audiovisual integration. Each pair of tasks included one task in which a stimulus in one modality leads to an illusory perception in the other (speech: the McGurk task; non-speech: the sound-induced flash illusion task) and one task in which a stimulus in one modality is boosted into greater perceptibility by a stimulus in the other (speech: audiovisual benefit; non-speech: audiovisual integration capacity). Although all four tasks have been described as measures of audiovisual integration, there is little evidence in the literature that they are tapping into the same underlying construct, and previous correlational research in the audiovisual integration literature tends to use sample sizes that are too small to reliably detect the effects of interest (e.g., see Yarkoni, 2009). Thus, we predicted the measures would not be correlated.

Method

The pre-registration document, raw data, analysis code, and stimuli are available at <https://osf.io/e92yr>.

Participants

Previous work has shown that susceptibility to the McGurk effect is correlated with some measures of lipreading ability at $r = .29$ (Brown et al., 2018) and $r = .32$ (Strand et al., 2014). To ensure that we could detect effects of that size, we opted to include a sample of 150 participants, which can reliably detect an effect of $r = .26^1$. To reach the intended number, we collected data from 158 participants with self-reported normal hearing and normal or corrected-to-normal vision. Seven participants experienced technical difficulties and could not complete the study,

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¹ Note that we preregistered a sample size of 150 but with an incorrect justification (that it would enable us to detect an effect size of $r = .17$ rather than $r = .26$). However, we have collected data from the number of participants originally stated.

and one participant withdrew from the experiment. Participants were recruited from an undergraduate research participant pool at the University of New Brunswick Saint John. Participants were compensated with a bonus point to be used in an undergraduate psychology course. The 150 participants included in the analysis (116 male, 34 female) had a mean age of 21.7 years ($SD = 6.4$). All recruitment and experimental practices were approved by the Research Ethics Board at the University of New Brunswick Saint John.

McGurk Stimuli

All speech stimuli were taken from Brown and Strand (2019). Speech was produced by a female native speaker of American English without a strong regional accent speaking consonants followed by “a.” Video files displayed her head and shoulders on a white background. Stimuli consisted of six different tokens of each of four different McGurk stimuli ($A_{ba}V_{ga}$, $A_{ba}V_{fa}$, $A_{ma}V_{ta}$, $A_{pa}V_{ka}$). Each token was repeated four times, for a total of 96 McGurk stimuli. Those stimuli were intermixed with 44 congruent filler stimuli: 4 tokens each of 11 different syllables (“ba”, “da”, “fa”, “ga”, “ka”, “ma”, “na”, “pa”, “ta”, “ða”, and “va”) produced by the same talker. After each syllable, participants were asked to report what they perceived by typing it in a text box and pressing enter. After entering their response, there was a 500 ms interstimulus interval before the next trial.

Audiovisual Benefit

The congruent speech task included the same 44 congruent stimuli used in the McGurk task, and were intermixed with audio-only presentations of the same 44 stimuli (during which a blank screen was presented). Each stimulus was presented twice for a total of 176 trials. Speech stimuli were presented in a continuous stream of speech-shaped noise, generated in Praat to match the long term average spectrum of the syllables (Winn, 2018). The signal-to-noise ratio

was -8 dB to avoid ceiling-level performance in the audiovisual condition and floor-level performance in the audio-only condition. Participants responded to each trial by typing what they perceived in a text box (with a 500 ms interstimulus interval).

Sound-Induced Flash Illusion

The method for the sound-induced flash illusion was adapted from Shams and colleagues (2000). A white fixation cross measuring $1^\circ \times 1^\circ$ was presented in the center of a black display. The visual stimulus consisted of a single white circle (diameter = 2°) presented with its centre 5° below the fixation cross for 17 ms. The auditory stimuli consisted of sine tones at 3.5 kHz frequency, with a length of 7 ms and an intensity of 95 dB(C). Each trial consisted of either one or two tones presented with a single disc.

On trials in which two tones occurred, one tone was always presented with its onset simultaneous with the onset of the visual stimulus. On “lead” trials, the first tone in a pair occurred before the disc was presented (therefore the second tone was simultaneous with the disc), and on “lag” trials, the first tone was simultaneous and the second tone occurred after the disc was presented. Stimulus onset asynchronies for the lead and lag trials included $\pm 25, 50, 70, 100, 125, \text{ and } 150$ ms. On trials in which only a single tone was presented, the auditory and visual stimuli were always presented synchronously. Those trials were included to ensure that even the most susceptible participants still would have trials on which they only perceived one flash. Each of the 13 timing conditions was presented twice to form a block of 26 trials. Participants completed six blocks, for a total of 156 trials, 144 of which (those with two flashes) were included in the final analysis.

Participants were asked to maintain fixation on the cross while attending to the area below it (where the disc would appear). They were asked to attend to both auditory and visual

stimuli, and after each trial, participants indicated the number of discs they believed they saw by pressing the left button on a Cedrus RB-540 button box if they saw one disc, and the right button if they saw two discs. Participants were asked to prioritize accuracy over speed.

Audiovisual Integration Capacity

The audiovisual integration capacity task was adapted from a task used in previous studies (e.g., Wilbiks & Beatteay, 2020). In this task, participants were presented with eight dots 1.5° in diameter presented on a grey background. The dots were randomly assigned to be black or white and were arranged in a circle 13° in diameter with a 0.15° fixation dot in the center. After an initial presentation of the dots, between one and four of the dots changed polarity from white to black (or vice versa) repeatedly, 10 times total, at 400 ms per switch. Although previous research (Van der Burg et al., 2013; Wilbiks & Dyson, 2018; Wilbiks et al., 2020) has varied the presentation rate to examine effects of stimulus variation on audiovisual integration capacity, given that we used this task for purposes of comparison to other measures of integration, we used a single presentation rate of 400 ms. The particular dots that changed were randomly assigned for each polarity switch, with no restriction on which dots switch at any time..

The penultimate switch was accompanied by an auditory stimulus consisting of a 500 Hz sine tone presented for 60 ms (with 5 ms onset and offset ramps), which was presented at an intensity of approximately 74 dB(C). Participants were instructed to keep track of which dots were changing throughout the trial, and were told to note which dot(s) changed in synchrony with the tone. After a 1000 ms retention interval in which only the fixation dot was presented, the final array of dots was displayed again along with a 1° diameter red dot overlaid on one of the dots. Participants were asked to make an unspeeded response as to whether the dot at that location changed at the same time as the tone by pressing the number 1 on a keyboard if the dot

did not change at the same time as the tone, and by pressing the number 2 if the dot did change at the same time as the tone. No feedback was provided, and the subsequent trial began 500–1,500 ms (randomly in increments of 100 ms) after the response was entered. The probe had a validity of 50%, meaning that half the time the red dot indicated the correct answer and half the time it indicated an incorrect answer, and invalid probe locations were randomly assigned to any invalid location. An experimental block contained 24 trials: three presentations of each number of dots (1, 2, 3, 4) by stimulus validity (valid, invalid) crossing. Each participant completed three blocks, for a total of 72 trials.

Procedure

The four tasks were administered to each participant in the order in which they appear above. All tasks were administered in a dimly lit, quiet room. Visual stimuli were presented on a Dell 2407 WFP monitor at a viewing distance of approximately 57 cm. Auditory stimuli were presented binaurally through Sennheiser HD 280 Pro headphones. Stimulus presentation and data collection were controlled by Superlab (Version 5; Cedrus) for the speech tasks and by Presentation (Version 21.0, Neurobehavioral Systems) for the non-speech tasks.

Results

All data were cleaned, analyzed, and visualized in R version 4.0.4 (R Core Team, 2020) using the following packages: *tidyverse* version 1.3.0 (Wickham et al., 2019), *broom* version 0.7.5 (David Robinson et al., 2021), *psychometric* version 2.2 (Fletcher, 2015), *ggpubr* version 0.4.0 (Kassambara, 2020), *data.table* version 1.14.0 (Dowle & Srinivasan, 2021), *psych* version 2.0.12 (Revelle, 2021), *Hmisc* version 4.5-0 (Harrell, 2021), *BayesFactor* version 0.9.12-4.2 (Morey, 2018), and *bayestestR* version 0.8.2 (Makowski et al., 2019).

McGurk Syllables

McGurk fusions were defined using the criteria from Brown and Strand (2019). The following responses were scored as fusions: for $A_{ba}V_{ga}$, “da” or “tha”; for $A_{ba}V_{fa}$, “va”; for $A_{ma}V_{ta}$, “na”; and for $A_{pa}V_{ka}$, “ta” or “tha.” The rationale for these criteria was that the fusion incorporates elements of both the auditory and visual stimuli. For each participant, McGurk susceptibility was defined as the proportion of McGurk trials on which they reported a fusion response. Some previous work (Stevenson et al., 2012) has normalized McGurk susceptibility relative to accurate identification of audio-only tokens to ensure that any fusion responses are not the result of poor quality audio. We opted against that in this study because the audio-only tokens were pre-screened for high intelligibility (Brown & Strand, 2019). Replicating previous work (e.g., Basu Mallick et al., 2015), there was large variability in the extent to which participants were susceptible to the McGurk effect, with fusion scores ranging from 0%–99% ($M = 55\%$, $SD = 29\%$).

Audiovisual benefit

We first calculated mean accuracy on the audio-only and audiovisual trials separately for each participant. Audio-only syllable identification accuracy ranged from 14%–73% ($M = 53\%$, $SD = 10\%$) across participants, indicating that the signal-to-noise ratio was successful at keeping performance off the ceiling and floor. Audiovisual syllable identification accuracy ranged from 43%–95% ($M = 81\%$, $SD = 7\%$) across participants, with an average of increase of 28% in the audiovisual relative to the audio-only condition, consistent with previous research (e.g., Sommers et al., 2005).

We then calculated audiovisual benefit for each participant using the equation $(AV - A)/(1 - A)$, which normalizes improvement from seeing the talker relative to the amount each participant could possibly improve (see Grant & Seitz, 1998; Sommers et al., 2005). Audiovisual

benefit scores ranged from 0.23 to 0.89 ($M = 0.60$, $SD = 0.12$), indicating substantial variability in how much individuals benefited from seeing the talking face. For example, two participants identified 45% of the audio-only syllables correctly, but one of them correctly identified 85% of audiovisual syllables (benefit = 0.73) whereas another identified only 61% of audiovisual syllables (benefit = 0.29).

Sound-Induced Flash Illusion

For each condition in which two tones were presented (ranging from 150 ms lead to 150 ms lag, in 25 ms intervals), we calculated the proportion of trials on which the participant reported perceiving multiple flashes. The pre-registered analysis plan called for a calculation of the width of the susceptibility threshold—that is, the range of stimulus onset asynchronies for which an individual participant reported seeing two flashes at least 50% of the time. However, in our data we observed 95 participants who never exceeded 50% susceptibility. We therefore opted to follow a method used in previous research (Hirst et al., 2019; Shams et al., 2000) to calculate the average susceptibility to the illusion across all timepoints for each participant. Individuals varied substantially in their susceptibility to the illusion, with scores ranging from 0%–100% ($M = 44\%$, $SD = 24\%$).

Audiovisual Integration Capacity

One participant did not complete the task correctly (they consistently responded prior to the presentation of the red probe dot), so were excluded from analyses involving this task. Estimates of audiovisual integration capacity were calculated by fitting the raw data to a variant of Cowan's K (Cowan, 2001; see Van der Burg et al., 2013; Wilbiks & Beattie, 2020 for examples of the same approach) This model assumes that an individual's performance (p) is a function of the number of objects to be integrated (n) and their integration capacity (K), and can

be modeled with the equation: $p = K/2n + .5$. Thus, if an individual's capacity is equal to or greater than the number of objects to be integrated on a given trial, their performance will be optimal (i.e., if $K \geq n$, $p \approx 1$). An estimate of audiovisual integration capacity is obtained for each participant by finding the value of K that minimizes the root-mean-square error between the raw data (proportion of trials in which they correctly identified whether a given dot changed polarity) and the model predictions. Curve fitting for each participant was performed using four points, each representing the average performance across all trials for a particular dot-changing condition (1–4 changes). The model encountered convergence issues for one participant, so that participant was assigned a K value of 0 (the model with convergence issues had a K estimate of approximately 0). Audiovisual integration capacity ranged from 0.00 to 1.37 ($M = 0.55$, $SD = 0.42$).

Correlational Analyses

Correlation coefficients and scatter plots comparing the four measures are shown in Figure 1. As predicted, we did not find significant correlations between any of the measures. Given the null findings, we also calculated Bayes Factors to assess the magnitude of the evidence for the null hypothesis (note that this exploratory analysis was not pre-registered). BF_{01} values were all above 2.20, indicating that the observed patterns of data are at least twice as likely to emerge under the null as compared to the alternative hypothesis.

Figure 1.*Correlations among measures*

Discussion

The purpose of this experiment was to assess the convergent validity of tasks commonly used to measure audiovisual integration in speech and non-speech realms. Using a well-powered

design, we did not find evidence that any of these measures were correlated; the null hypothesis was 2.20 to 5.26 times more likely than the alternative for all task pairs. The lack of correlations can not be attributable to restriction of range, as the ranges reported here are comparable to those reported elsewhere, and all tasks showed substantial inter-individual variability.

The lack of correlation between McGurk susceptibility and audiovisual benefit is in line with the results of Van Engen and colleagues (2017), who found no correlation between the two when using syllable stimuli for the McGurk task and sentence stimuli for the audiovisual benefit task. However, syllable identification accuracy is only weakly correlated with sentence identification accuracy for congruent materials (Grant & Seitz, 1998), so it is possible that a correlation would be more likely to emerge in this study, in which both the McGurk task and the audiovisual benefit task used the same kind of stimuli (syllables). We did not find evidence for this, however, strengthening the claim that McGurk susceptibility and audiovisual benefit are not measuring the same underlying ability.

As with the speech tasks, we did not find any evidence that susceptibility to the sound-induced flash illusion was related to performance on the audiovisual integration capacity task. This finding is consistent with previous work showing that audiovisual temporal order judgments are unrelated to explicit audiovisual simultaneity judgments (Matthews et al., 2016; see also Vatakis et al., 2008). As with the results of the speech measures, these findings pose a challenge for the claim that multiple measures of “audiovisual integration” are tapping into the same construct.

Given the lack of correlations within speech tasks purported to measure audiovisual integration and within non-speech tasks, it is not surprising that the speech and non-speech measures were also uncorrelated. Our results are inconsistent with one study showing a negative

correlation between McGurk susceptibility and both the right side of the audiovisual temporal binding window and susceptibility to the sound-induced flash illusion (Stevenson et al., 2012). The cause for this discrepancy is not clear; although there were slight methodological differences between our experiment and the previous study (e.g., the previous study used a single McGurk token whereas we used multiple tokens), there is not a clear mechanistic explanation for why any particular methodological choice would lead to a correlation in Stevenson et al. (2012) but not in our experiment. The current study was powered to detect effects at the lower bound of the 95% confidence interval around Stevenson's correlation ($r = .30-.84$; calculated using the *psychometric* package in R), so the lack of correlation does not appear to be an issue of statistical power.

Overall, our findings suggest caution in assuming that multiple tasks are tapping into the underlying construct without providing validity evidence for this claim. Thorndike (1904) described this issue as the *jingle fallacy*, wherein researchers believe that certain tools measure the same construct because they share a name (e.g., “audiovisual integration measures”; see Strand et al., 2021 for other examples of jingle in the speech literature). Given that the tasks appear to be measuring different constructs, we recommend that researchers carefully consider which tasks are most appropriate for the purposes of their study. For example, there is debate about whether individual differences in measures of “integration” reflect differences in the process of integrating information from multiple modalities, or instead reflect differences in unisensory abilities (Strand et al., 2014; Tye-Murray et al., 2016). Thus, if the goal of the study requires assessing integration rather than unisensory abilities, it would be advantageous to identify tasks that are relatively insensitive to individual differences in unisensory ability, or to measure and statistically control for those differences. In addition, incongruent stimuli (such as

those used in the McGurk task) may be processed differently than congruent ones (Beauchamp et al., 2010; Calvert et al., 2000), because they may require detecting and resolving conflict between the auditory and visual inputs or trying to assign poor exemplars to discrete phoneme categories (see Brown & Strand, 2019). We also recommend that researchers conduct additional validation work to attempt to better understand what our measures are actually tapping into. Doing so would contribute to an ongoing effort to improve measurement practices in all areas of psychology (Flake & Fried, 2020).

Acknowledgements

This work was supported by a National Institutes of Health grant via the National Institute on Deafness and Communication Disorders awarded to Julia Strand (R15-DC018114), a Discovery Grant from the Natural Sciences and Engineering Research Council of Canada awarded to Jonathan Wilbiks (RG-2020-04291), and the National Science Foundation through a Graduate Research Fellowship awarded to Violet Brown (DGE-1745038). Many thanks to Kimberly Mazerolle and Michaela Ritchie for their assistance with data collection.

Open Practices Statement

The experiment, data analysis plans, and hypotheses were pre-registered prior to data collection.

All raw data, analysis code, stimuli, and the pre-registration document are available on the Open

Science Framework at <https://osf.io/e92yr>.

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