Schizotypal Personality Traits and Multisensory Integration: An Investigation Using the McGurk Effect

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Abstract

Multisensory integration, the process by which sensory information from different sensory modalities are bound together, is hypothesized to contribute to perceptual symptomatology in schizophrenia, in whom multisensory integration differences have been consistently found. Evidence is emerging that these differences extend across the schizophrenia spectrum, including individuals in the general population with higher levels of schizotypal traits. In the current study, we used the McGurk task as a measure of multisensory integration. We measured schizotypal traits using the Schizotypal Personality Questionnaire (SPQ), hypothesizing that higher levels of schizotypal traits, specifically *Unusual Perceptual Experiences* and *Odd Speech* subscales, would be associated with decreased multisensory integration of speech. Surprisingly, *Unusual Perceptual Experiences* were not associated with multisensory integration. However, *Odd Speech* was associated with multisensory integration, and this association extended more broadly across the Disorganized factor of the SPQ, including *Odd or Eccentric Behaviour*. Individuals with higher levels of *Odd or Eccentric Behaviour* scores also demonstrated poorer lip-reading abilities, which partially explained performance in the McGurk task. This suggests that aberrant perceptual processes affecting individuals across the schizophrenia spectrum may relate to disorganized symptomatology.

Keywords: multisensory integration, schizophrenia spectrum disorders, schizotypy, audiovisual, McGurk effect

Public Significance Statement

This study shows that people with many schizotypal traits are more likely to combine a voice they hear and a speaker's mouth movements when they do not match. When their brains incorrectly combine what they see and hear, this may lead to issues that we often see on the schizophrenia spectrum, such as hallucinations or other unusual perceptions. Some of these problems may also be caused by difficulty reading lips.

Schizotypal Personality Traits and Multisensory Integration: An Investigation Using the McGurk Effect

Multisensory integration is the process by which the brain combines sensory information from multiple modalities, for example auditory and visual information, into coherent, unitary percepts. This ability is crucial to everyday perception, as the majority of sensory experiences are multisensory. As a result of multisensory integration, individuals are better at detecting (Lovelace, Stein, & Wallace, 2003; Stein & Wallace, 1996), localizing (Nelson et al., 1998; Wilkinson, Meredith, & Stein, 1996), and have faster response times to stimuli in the environment (Diederich & Colonius, 2004; Hershenson, 1962). Multisensory integration also aids with speech perception (Ross, Saint-Amour, Leavitt, Javitt, & Foxe, 2007) and identification of ambiguous stimuli (Green & Angelaki, 2010). While multisensory integration does not require conscious effort, one must determine which sensory inputs originate from the same external event and thus should be integrated, and which should be processed independently (Stevenson, Ghose, et al., 2014). This is a computationally difficult cognitive feat to achieve given the overwhelming amount of sensory information entering each sensory system at any given moment. There are a number of different types of information embedded within the sensory inputs themselves that can be used as cues to bind, the most salient of which are the temporal and spatial coincidence of information across different sensory modalities (Stein & Meredith, 1993). In short, the more temporally and spatially coincident two sensory inputs are, the more likely they originated from the same external event, and thus the more likely that they should be integrated. Temporal processing abilities vary quite drastically between individuals in both clinical and nonclinical groups (Wallace & Stevenson, 2014), and within these individual differences, multisensory temporal precision has been directly associated with the frequency and accuracy of multisensory integration (Ferri et al., 2017; Martin, Giersch, Huron, & van Wassenhove, 2013; Stevenson, Zemtsov, & Wallace, 2013).

With multisensory integration being so important for normal perception of the world, it follows that alterations in one's multisensory integration abilities might contribute to atypical perceptual experiences, such as those observed across the schizophrenia spectrum (Stevenson et al., 2017; Wallace &

Stevenson, 2014; Wallace, Woynaroski, & Stevenson, 2020). Indeed, individuals with schizophrenia have been shown to have decreased multisensory integration as well as impairments in perceptual processes that underlie multisensory integration, such as temporal processing. Altered temporal processing in schizophrenia has been found in both unisensory (Capa, Duval, Blaison, & Giersch, 2014; de Boer-Schellekens, Stekelenburg, Maes, Van Gool, & Vroomen, 2014; Giersch et al., 2009; Lalanne, Van Assche, Wang, & Giersch, 2012; Tenckhoff, Tost, & Braus, 2002) and multisensory processing (Foucher, Lacambre, Pham, Giersch, & Elliott, 2007; Martin et al., 2013; Stevenson et al., 2017; Zhou et al., 2018). Since multisensory temporal precision has been directly associated with the frequency and accuracy of multisensory integration (Ferri et al., 2017; Martin et al., 2013; Stevenson et al., 2013), it is not surprising that individuals with schizophrenia who have temporal deficits also have altered multisensory integration (de Jong, Hodiamont, Van den Stock, & de Gelder, 2009; White et al., 2014; Williams, Light, Braff, & Ramachandran, 2010, but see Martin et al., 2013; Romero et al., 2016). These multisensory integration deficits in schizophrenia have been found specifically in the realm of audiovisual speech integration (de Gelder et al., 2002; Pearl et al., 2009; Ross, Saint-Amour, Leavitt, Molholm, et al., 2007; Stekelenburg, Maes, Van Gool, Sitskoorn, & Vroomen, 2013, but see Surguladze et al., 2001).

Individuals on the less severe end of the schizophrenia spectrum appear to share these multisensory integration and temporal processing deficits. The schizophrenia spectrum ranges from minor levels of schizotypal traits in the general population (schizotypy) to schizotypal personality disorder, early or prodromal psychosis, and at the extreme, schizophrenia. Schizotypal traits are personality characteristics that occur along a continuum from healthy, imaginative states to psychosis, a continuum referred to as the schizophrenia spectrum. While individuals across this spectrum experience similar symptoms, they differ greatly in severity of these symptoms. For example, evidence from work on cognition, perception, and motor control, as a whole, reveals that individuals who have more schizotypal traits tend to have deficiencies in performance that are similar but attenuated to those seen in individuals with schizophrenia (Ettinger, Meyhöfer, Steffens, Wagner, & Koutsouleris, 2014). While schizotypy is not a clinically diagnosable condition, individuals exhibiting higher levels of schizotypal traits in the

general population are at an elevated risk of developing schizophrenia and other psychotic illnesses (Kwapil, Gross, Silvia, & Barrantes-Vidal, 2013). Like schizophrenia, the features of schizotypy can be organized into three groups: positive (experiences of illusions, unusual perceptual experiences, bizarre or magical thinking, depersonalisation, and derealisation), negative (anhedonia, avolition, reduced emotional expression, and social isolation) and disorganized (odd behaviour, thought, and speech) (Raine, 2006; American Psychiatric Association, 2013).

Within the positive symptom dimension, “unusual perceptual experiences” is a common symptom across the schizophrenia spectrum. This symptom is likely related to differences in sensory processing. Several sensory deficits in both schizotypy and schizophrenia have been reported. Like schizophrenia, deficits in auditory pitch discrimination (Bates, 2005), sensory gating (Park, Lim, Kirk, & Waldie, 2015), sensory prediction (Teufel, Kingdon, Ingram, Wolpert, & Fletcher, 2010), prepulse inhibition (Wan, Thomas, Pisipati, Jarvis, & Boutros, 2017), and olfactory scent identification (S. Park & Schoppe, 1997) have been noted in schizotypy. Considering the significant overlap between schizophrenia and schizotypy found through retrospective, longitudinal, family, genetic, environmental, cognitive, and neurobiological investigations (Ettinger et al., 2014), it is not surprising that these similarities in altered sensory processing have been found.

There is a scarcity of investigation into multisensory integration in schizotypy, but early findings have indicated alterations in temporal processing and multisensory integration in individuals with schizotypal traits in the general population. Specifically, individuals with higher schizotypy tend to have stronger responses to visual-tactile (Asai, Mao, Sugimori, & Tanno, 2011; Germine, Leigh, Cohen, & Lee, 2013) and audiovisual illusions (Ferri, Venskus, Fotia, & Cooke, 2018). Individuals with higher schizotypy also tend to have poorer tactile-proprioceptive (Ferri, Ambrosini, & Costantini, 2016) and audio-tactile temporal processing (Ferri et al., 2017). These findings together indicate that temporal processing and multisensory integration appear to be altered in individuals with higher schizotypal traits.

Here, we assessed the relationship between multisensory integration and schizotypal traits. To assess multisensory integration, we used the McGurk effect (McGurk & MacDonald, 1976). Participants

were presented with a speaker uttering the auditory syllable “ba” coincidentally with the speaker visually articulating the syllable “ga”. Participants commonly report perceiving the speaker saying “da” or “tha”, a syllable that is not present in either of the unisensory stimuli, and a percept that is thus strong evidence of integration. We measured schizotypal traits through the Schizotypal Personality Questionnaire (SPQ; Raine, 1991), with the hypothesis that higher levels of schizotypal traits would be associated with reduced perception of the McGurk effect. In particular, we predicted that the McGurk effect would be related to the *Unusual Perceptual Experiences* and *Odd Speech* subscales of the SPQ.

Materials and Methods

Participants

105 adult participants (60 female, mean age = 18.60, SD = 1.99, range = 17 to 35) completed the current experiment. Seven additional participants were excluded, six participants who did not complete the multisensory McGurk task, and one participant who did not complete the unisensory task. Experimental protocols were approved by Western University’s Non-Medical Research Ethics Board. All individuals self-reported normal hearing and normal or corrected-to-normal vision. All participants reported that English was the first language they learned. Participants were recruited via the undergraduate research participation pool. All participants included in data analysis (N = 105) completed both multisensory and unisensory versions of the McGurk task, and the SPQ (Raine, 1991).

Stimuli

McGurk Task.

All stimuli throughout the study were presented using MATLAB 2018a (MATHWORKS Inc., Natick, MA) software with the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Audio stimuli were presented binaurally through BOSE QuietComfort 35 noise-cancelling headphones.

The videos used for the McGurk task have been used previously in studies of the McGurk effect (Quinto, Thompson, Russo, & Trehub, 2010; Stevenson, Siemann, et al., 2014). Stimuli consisted of one audiovisual clip of a female speaker saying either the syllable “ba” or “ga”, at a normal rate and volume with a neutral facial expression. Auditory stimuli were delivered at a comfortable level (calibrated to

approximately 72 dB SPL) presented through noise-cancelling headphones. Visual stimuli were cropped to square, down-sampled to a resolution of (400 × 400 pixels) spanning 11.8 cm per side or 11.23 degrees of visual angle and converted from color to grayscale. Presentations were shortened to 2 s, and each presentation included the entire articulation of the syllable, including pre-articulatory gestures.

Stimuli included visual-only, auditory-only, and congruent audiovisual presentations of the phoneme “ba” or “ga,” and the McGurk stimuli, a visual “ga” presented with an auditory “ba”. All presentations were temporally synchronous.

Schizotypal Personality Questionnaire.

The Schizotypal Personality Questionnaire (SPQ; Raine, 1991) is a 74-item questionnaire frequently used in the general population. Each item requires either a “Yes” or “No” answer, with the total score summing up “Yes” responses. The items of the SPQ can be reliably broken down into nine subscales: *Ideas of Reference*, *Excessive Social Anxiety*, *Odd Beliefs or Magical Thinking*, *Unusual Perceptual Experiences*, *Odd or Eccentric Behavior*, *No Close Friends*, *Odd Speech*, *Constricted Affect*, and *Suspiciousness*. A widely-replicated three-factor model of the SPQ groups the nine subscales into three factors that match the three areas impacted in both schizophrenia and schizotypal personality disorder: Cognitive-Perceptual, Disorganized, and Interpersonal (Badcock & Dragović, 2006; Chen, Hsiao, & Lin, 1997; Fossati, Raine, Carretta, Leonardi, & Maffei, 2003; Raine, Lencz, Scerbo, & Kim, 1994; Reynolds, Raine, Mellingen, Venables, & Mednick, 2000; Wuthrich & Bates, 2006). High sampling validity has been reported for the SPQ, as well as high internal reliability (0.91), test-retest reliability (0.82), convergent validity (0.59 to 0.81), discriminant validity, and criterion validity (0.63, 0.68) (Raine, 1991).

Procedures

McGurk Task.

Participants sat approximately 60 cm from the monitor, in a sound- and light-controlled room. A researcher sitting next to the participant monitored the participant to make sure his/her eyes remained on the screen. The task was divided into two separate runs, a multisensory and a unisensory run, always

presented in that order. All stimulus presentations included a female actor speaking a single syllable. The audiovisual run included congruent “ba”, congruent “ga”, and the McGurk stimulus, an auditory “ba” paired with a visual “ga”. The unisensory run included random visual and auditory presentations of “ba” and “ga”.

Both runs began with a screen instructing them to identify what syllable the speaker said in modality-neutral wording (“What did she say?”). Each trial began with a fixation screen that randomly jittered from 0.5 to 1.5 seconds, and multi-speaker babble which ramped up linearly for 500 ms and continued during the stimulus presentation. After the stimulus presentation, the visual frame was removed (except for the auditory condition). The multi-speaker babble continued on its own for another 500 ms with a linear ramp down, and each trial was concluded by an additional 250 ms fixation screen. After each presentation, participants were shown a response screen that asked them to report what the speaker said by pressing one of four keys, “b,” “g,” “d,” or “t,” representing “ba,” “ga,” “da,” and “tha,” respectively. Immediately after the response, the fixation screen for the subsequent trial was presented.

In the multisensory run, participants were presented with a total of 60 trials, with each audiovisual condition presented 20 times in random order. The unisensory run began in the same manner as the multisensory run, and trial structures were identical with the exception of stimulus presentations. Each unisensory condition was presented 10 times, for a total of 40 trials. Unisensory conditions included auditory and visual “ba” and “ga” presentations.

Schizotypal Personality Questionnaire.

The SPQ was completed online through Qualtrics prior to each study visit.

Analysis

McGurk Task

For each of the seven conditions, an accuracy score was calculated for each participant. This was calculated as the proportion of trials the participant accurately identified as the syllable that was presented. For the McGurk trials, accuracy was defined as the proportion of trials the participant reported having perceived “da” or “tha”. Average visual accuracy was calculated as the average proportion of

visual-alone trials perceived correctly as “ba” or “ga”. Average auditory accuracy was calculated as the average proportion of auditory-alone trials perceived correctly as “ba” or “ga”.

Schizotypal Personality Questionnaire

Overall SPQ total scores, and SPQ subscale scores were calculated for each participant. Four participants missed a small number of items. Three participants missed one item, and one participant missed four items. Missing data points were replaced based on the participants’ average responses to the other items within that subscale.

A Priori Analyses

Pearson correlations were first conducted between the McGurk effect and two subscales of the SPQ that were expected *a priori* to correlate negatively with the McGurk effect: *Unusual Perceptual Experiences* and *Odd Speech*. *Unusual Perceptual Experiences* was hypothesized to be correlated since altered multisensory integration, as measured by the McGurk effect, is thought to contribute to altered perceptual experiences (Stevenson et al., 2017). *Odd Speech* was predicted to be correlated because the McGurk effect is a speech-related task.

If significant relationships were found between the McGurk effect and a subscale, Pearson correlations were then run between both average auditory and average visual accuracy and that subscale to account for the possibility that individual differences in the perception of the unisensory speech components may influence the perception of the McGurk effect. In the case of subscales correlating with both the McGurk effect and unisensory accuracy, a two-stage hierarchical multiple regression was conducted to assess whether the relationship between that subscale and the McGurk effect may be accounted for by differences in unisensory perception as opposed to multisensory integration. Perceived McGurk effect was entered in Model 1, and unisensory accuracy in Model 2 in order to assess whether the relationship between the McGurk effect and the subscale could be accounted for by unisensory accuracy.

For significant correlations between the McGurk effect, unisensory accuracy, and a subscale or factor, mediational analyses were conducted. The subscale or factor was entered as the dependent

variable, and McGurk effect and unisensory accuracy entered as both mediators and predictors to test directionality of the mediation.

Exploratory Analyses

Exploratory analyses were performed in which the remaining subscales were related to speech perceptions using Pearson correlations. Analyses were identical to that with planned comparisons above, however, initial correlations were subjected to a Benjamini-Hochberg correction for multiple comparisons ($q = 0.05$), and follow-up testing was only conducted where correlations survived correction for multiple comparisons.

Results

McGurk Task

The proportion of phonemes perceived for congruent audiovisual “ba” ($M = 0.99$, $SD = 0.02$) and “ga” ($M = 0.99$, $SD = 0.02$), incongruent audiovisual “da” ($M = 0.49$, $SD = 0.34$), unisensory auditory “ba” ($M = 0.93$, $SD = 0.11$) and “ga” ($M = 0.99$, $SD = 0.03$), and unisensory visual “ba” ($M = 0.99$, $SD = 0.04$) and “ga” ($M = 0.63$, $SD = 0.29$) presentations are shown for each individual in Figure 1.

Schizotypal Personality Questionnaire

The total SPQ scores ($M = 22.81$, $SD = 13.36$) ranged from 2 to 54. The possible scores for the SPQ can range between 0 and 74. Using the 10% high and low cut-offs reported for the original validation of the SPQ of 41 and 12, respectively (Raine, 1991), 15 individuals, or 14.29%, met the high cut-off, and 22 individuals, or 21.90%, met the low cut-off. As such, the current sample filled a wide range of the scale.

Factor scores are as follows: Interpersonal ($M = 10.96$, $SD = 6.94$, range = 0 to 27), Cognitive-Perceptual ($M = 7.29$, $SD = 5.44$, range = 0 to 23), Disorganized ($M = 4.57$, $SD = 3.47$, range = 0 to 13). Factor scores met the entire range of possible scores for each factor.

Subscale scores are as follows: *Ideas of Reference* ($M = 3.68$, $SD = 2.56$, range = 0 to 9), *Excessive Social Anxiety* ($M = 3.68$, $SD = 2.52$, range = 0 to 8), *Odd Beliefs or Magical Thinking* ($M = 1.14$, $SD = 1.47$, range = 0 to 7), *Unusual Perceptual Experiences* ($M = 2.47$, $SD = 1.86$, range = 0 to 9),

Odd or Eccentric Behavior ($M = 1.48$, $SD = 1.86$, range = 0 to 7), *No Close Friends* ($M = 2.62$, $SD = 2.31$, range = 0 to 8), *Odd Speech* ($M = 3.09$, $SD = 2.08$, range = 0 to 8), *Constricted Affect* ($M = 2.10$, $SD = 1.83$, range = 0 to 8), and *Suspiciousness* ($M = 2.56$, $SD = 2.17$, range = 0 to 8). Subscale scores met the entire range of possible scores for each subscale.

A Priori Results

The proportion of trials on which the McGurk effect was perceived was expected *a priori* to negatively correlate with two subscales of the SPQ: *Unusual Perceptual Experiences* and *Odd Speech*. Surprisingly, perceived McGurk effect was not significantly correlated with scores on the *Unusual Perceptual Experiences* subscale, $r(103) = .086$, 95% CI = [-0.107, 0.273], $p = .382$ (Figure 2). Perceived McGurk effect was significantly positively correlated with scores on the *Odd Speech* subscale, $r(103) = .229$, 95% CI = [0.039, 0.403], $p = .019$ (Figure 3A).

Given the significant correlation between McGurk perceptions and *Odd Speech*, further analysis was conducted to investigate whether this effect was specifically multisensory. As auditory and visual perception may influence performance on the audiovisual McGurk effect, Pearson correlations were conducted between both auditory and visual accuracy and the *Odd Speech* subscale. There was not a significant correlation between auditory accuracy and *Odd Speech*, $r(103) = .061$, 95% CI = [-0.132, 0.250], $p = .537$ (Figure 3C). There was, however, a significant negative correlation between visual accuracy and *Odd Speech*, $r(103) = -.206$, 95% CI = [-0.383, -0.015], $p = .035$ (Figure 3D).

To assess whether the relationship between the McGurk effect and the *Odd Speech* subscale could be influenced by visual speech perception, a two-stage hierarchical multiple regression was conducted with *Odd Speech* subscale scores as the dependent variable. Perceived McGurk effect was entered in Model 1, and visual accuracy in Model 2. Perceived McGurk effect and average visual accuracy were significantly intercorrelated, $r(103) = -.519$, 95% CI = [-0.646, -0.364], $p < .001$ (Figure S1), however, collinearity statistics (VIF = 1.369, Tolerance = 0.730, Minimum Tolerance = 0.730) suggest that this intercorrelation did not impact the regression. Detailed regression statistics are reported in Table 1.

The hierarchical multiple regression revealed that in Model 1, the McGurk effect contributed significantly to the regression model and accounted for 5.2% of the variance in *Odd Speech*. Introducing average visual accuracy explained an additional 1.0% of the variance in *Odd Speech*, a change in R^2 that was not significant. While the McGurk effect was a significant predictor of *Odd Speech* and the addition of visual accuracy did not significantly add to the model predicting *Odd Speech*, the McGurk effect itself was no longer significant as an individual predictor in Model 2, suggesting that the relationship between visual perception and *Odd Speech* may account, at least partially, for the relationship between multisensory integration, as indexed by the McGurk effect, and *Odd Speech*.

Mediational analyses for the *Odd Speech* subscale (Tables S1 & S2) and the Disorganized factor (Tables S3 & S4) revealed that neither average visual accuracy (Figure 3B) nor the McGurk effect were mediators.

Exploratory Results

While specific *a priori* predictions were made and tested for the *Unusual Perceptual Experiences* and the *Odd Speech* subscales, exploratory analyses were performed in which Pearson's correlations were conducted between the McGurk effect and total SPQ scores, the three factors of the SPQ (Interpersonal, Cognitive-Perceptual, and Disorganized), and the subscales within each of these factors. Total SPQ scores were not significantly correlated with the McGurk effect (Figure S2). The Interpersonal factor was also not significantly correlated with the McGurk effect (Figure S3). Within the Interpersonal factor, the *Excessive Social Anxiety* subscale was not significantly correlated with the McGurk effect (Figure S4), nor was the *Constricted Affect* subscale (Figure S5), or the *Suspiciousness* subscale (Figure S6). The relationship between the McGurk effect and *No Close Friends* approached significance, but did not survive corrections for multiple comparisons (Figure S7). The Cognitive-Perceptual factor was not significantly correlated with the McGurk effect (Figure S8). Within the Cognitive-Perceptual factor, *Ideas of Reference* subscale (Figure S9) and *Odd Beliefs or Magical Thinking* (Figure S10) were not significantly correlated with the McGurk effect. The Disorganized factor was significantly correlated with the McGurk effect (Figure 4). Within the Disorganized factor, the *Odd or Eccentric Behaviour* subscale

was significantly correlated with the McGurk effect following corrections for multiple comparisons (Figure 5A). See Table 2 for detailed statistics of Pearson's correlations.

The positive, significant relationship between the *Odd or Eccentric Behaviour* subscale and the McGurk effect was investigated further. As with the *Odd Speech* subscale, auditory and visual accuracy were examined to determine whether they played a role in how the McGurk effect was related with the *Odd or Eccentric Behaviour* subscale. Pearson correlations were conducted between both auditory and visual accuracy and the *Odd or Eccentric Behaviour* subscale. There was not a significant correlation between auditory accuracy and *Odd or Eccentric Behaviour*, $r(103) = .146$, 95% CI = [-0.047, 0.328], $p = .137$ (Figure 5C). There was, however, a significant negative correlation between visual accuracy and *Odd or Eccentric Behaviour*, $r(103) = -.322$, 95% CI = [-0.484, -0.139], $p = .001$ (Figure 5D). The influence of visual accuracy on the McGurk effect's relationship with *Odd or Eccentric Behaviour* was investigated further with a hierarchical multiple regression.

To assess whether the relationship between the McGurk effect and the *Odd or Eccentric Behaviour* subscale could be accounted for by the relationship between visual speech perception, a two-stage hierarchical multiple regression was conducted with *Odd or Eccentric Behaviour* subscale scores as the dependent variable. Perceived McGurk effect was entered in Model 1, and visual accuracy in Model 2. Perceived McGurk effect and average visual accuracy were significantly intercorrelated, $r(103) = -.519$, 95% CI = [-0.646, -0.364], $p < .001$ (Figure S1), however, collinearity statistics (VIF = 1.369, Tolerance = 0.730, Minimum Tolerance = 0.730) suggest that this intercorrelation did not impact the regression. Detailed regression statistics are reported in Table 3.

The hierarchical multiple regression revealed that in Model 1, the McGurk effect contributed significantly to the regression model and accounted for 8.6% of the variance in *Odd or Eccentric Behaviour*. Introducing average visual accuracy explained an additional 3.9% of the variance in *Odd or Eccentric Behaviour*, a significant change in R^2 . Together, perceived McGurk effect and average visual accuracy predicted 12.5% of the variance in *Odd or Eccentric Behaviour*. However, while the overall

model including the McGurk effect and visual accuracy significantly predicted *Odd or Eccentric Behaviour*, neither remained significant at the individual variable level.

Mediational analyses revealed that average visual accuracy fully mediated the relationship between the McGurk effect and *Odd or Eccentric Behaviour* (Table 4; Figure 5B). When McGurk effect was entered as the mediator and average visual accuracy as the predictor, no mediation effect was found (Table S5).

Discussion

This study is the first to investigate the relationship between schizotypal traits and perception of the McGurk effect, a measure of multisensory integration. We hypothesized that individuals with higher levels of schizotypal traits would perceive the McGurk effect at lower rates. Surprisingly, the opposite was found, in that higher schizotypy was associated with increased perception of the McGurk effect. Specifically, we found a novel relationship between the McGurk effect and the Disorganized factor of the SPQ, including the two subscales: *Odd Speech* and *Odd or Eccentric Behaviour*. Interestingly, the relationship between the McGurk effect and *Odd or Eccentric Behaviour* was fully mediated by visual accuracy, suggesting that these results may be a result of broader sensory issues including visual and multisensory processing.

The finding of higher schizotypy being associated with increased McGurk perception is in contrast to investigations of the McGurk effect in individuals with schizophrenia. This literature has found that there is either no difference in McGurk perception compared to controls (Martin et al., 2013; Romero et al., 2016), or decreased perception of the McGurk effect compared to controls (de Gelder et al., 2002; Pearl et al., 2009; White et al., 2014). The reason for the current opposing findings is not entirely clear, but they do align with findings in schizophrenia of increased proneness to other perceptual illusions that rely on multisensory integration. Specifically, individuals with schizophrenia are more prone than controls to perceiving the double-flash or fission illusion, in which one visual flash presented with two auditory beeps results in the perception of two visual flashes (Haß et al., 2017). Individuals with schizophrenia also experience the rubber hand illusion stronger and faster than controls (Peled, Ritsner,

Hirschmann, Geva, & Modai, 2000). In the rubber hand illusion, brushstrokes are applied to one's hidden hand synchronously to a visible rubber hand, resulting in a feeling that the rubber hand belongs to one's body. Asynchronous stroking of the rubber hand usually leads to lower perceptions of the illusion (Botvinick & Cohen, 1998), but individuals with higher schizotypy do not have lower perceptions of the rubber hand illusion when asynchronous stroking is applied (Asai et al., 2011). This suggests that high schizotypy individuals have altered multisensory temporal processing, such that they do not recognize that the stroking has become asynchronous. This is seen across the schizophrenia spectrum, with individuals with higher levels of schizotypal traits showing less precise multisensory temporal processing (Dalal, Muller, & Stevenson, 2020). It also suggests that high schizotypy individuals are more permissive of the binding together of incongruent stimuli, which in an asynchronous rubber hand illusion would be a temporal mismatch of visual and tactile information. The McGurk effect is inherently incongruent, in that it requires individuals to bind mismatching auditory and visual information. Notably, the syllabic incongruence in the McGurk effect is different from the temporal incongruence in the asynchronous rubber hand illusion. Nevertheless, if individuals within the schizophrenia spectrum are less restrictive with binding incongruent stimuli broadly speaking, this could explain the higher perception of the McGurk effect and other perceptual illusions. It has also been found that individuals across the schizophrenia spectrum have increased openness to experience (Chmielewski, Bagby, Markon, Ring, & Ryder, 2014), a personality trait describing increased imagination, broad-mindedness, and curiosity (Woo, Saef, & Parrigon, 2015). It is possible that greater openness to experience makes these individuals less skeptical of and more easily susceptible to perceptual illusions. It is also possible that there is a non-linear relationship between schizotypal traits and multisensory integration, and that multisensory integration is not linearly impacted across the schizophrenia spectrum.

As with overall schizotypal traits, *Odd Speech* positively correlated with the McGurk effect as opposed to the predicted negative correlation. While not in the predicted direction, this association between a speech-based task and a subscale of *Odd Speech* makes intuitive sense. This relationship was not confined to *Odd Speech*, but was found throughout the Disorganized factor. From a conceptual

standpoint, one can imagine how increased McGurk effect perception may be related to disorganized symptomatology, which spans across speech (characterized by difficulty maintaining a train of thought, rambling, jumping from topic to topic, using words in unusual ways, etc.) and behaviour (characterized by lack of impulse control, difficulty completing tasks, and unusual mannerisms, habits, and appearance) (Raine et al., 1994). If visual perceptions are less reliable, and audiovisual stimuli are being integrated erroneously, this impacts how speech is perceived, therefore impacting reciprocal communication. Similarly, it is entirely possible that a less reliable perceptual system may impact behaviours, as perceiving one's environment unreliably could alter one's interactions with the environment, perhaps leading to unusual behaviours. Future work should further investigate the relationship between sensory processing generally, and multisensory integration specifically, and disorganized schizotypal traits.

Individuals who had higher Disorganized factor scores not only had higher rates of McGurk effect perception, but they also tended to be worse lip-readers. Poorer lip-reading was significantly associated with increased perception of the McGurk effect. Poorer lip-reading mediated the relationship between the McGurk effect and *Odd or Eccentric Behaviour*, but not between the McGurk effect and *Odd Speech* or the Disorganized factor more broadly. The current finding of poorer lip-reading abilities among high schizotypy individuals aligns with previous research into speech perception in schizophrenia, in which these individuals show less speech perception improvement from visual speech input compared to controls, suggesting either poorer lip-reading abilities or poorer multisensory integration, or a combination of both (Ross, Saint-Amour, Leavitt, Molholm, et al., 2007), though without a visual-only condition in this previous study it is unknown whether lip-reading abilities were actually poorer in individuals with schizophrenia. Individuals with schizophrenia may also be poorer at lip-reading sentences (Myslobodsky, Goldberg, Johnson, Hicks, & Weinberger, 1992) and single words (Schonauer, Achtergarde, & Reker, 1998). Individuals with schizophrenia also show less neural activation compared to controls in response to silent visual speech, specifically with less activation in the posterior inferior temporal cortex, occipital cortical areas, temporal areas, and the inferior frontal gyrus being found (Surguladze et al., 2001). Taken together, the current results and previous literature on visual speech

perception in schizophrenia suggest that individuals with schizophrenia may have impaired lip-reading abilities, and that this may extend to individuals with higher disorganized schizotypal traits.

In contrast to our hypotheses, *Unusual Perceptual Experiences* were not associated with the McGurk effect. It was predicted that they would be associated because the McGurk effect is a measure of multisensory integration, and multisensory integration abnormalities are thought to contribute to *Unusual Perceptual Experiences*, such as hallucinations or less severe perceptual anomalies (hallucination-like experiences). This is because multisensory integration and temporal processing, which are altered in individuals with schizophrenia and vary based on the level of schizotypal traits (Dalal, Muller, & Stevenson, 2020), are crucial for accurate everyday perceptions, such as audiovisual speech (Stein & Meredith, 1993). Considering that the majority of hallucinations experienced by individuals with schizophrenia are audiovisual in nature (Lim et al., 2016; McCarthy-Jones et al., 2017), and often speech-based (Hugdahl & Sommer, 2018), it is possible that these anomalies are partially arising from the mis-binding of visual and auditory stimuli (Stevenson et al., 2017), such as the mis-binding of inner auditory speech with external visual sources (Jones & Fernyhough, 2007).

In sum, the present study suggests increased multisensory integration in individuals with high levels of schizotypal traits. Specifically, individuals with high levels of Disorganized factor traits had an increased proneness to the McGurk effect. Individuals with higher levels of schizotypal traits also showed poorer lip-reading abilities, which mediated susceptibility to the McGurk effect for only one of the schizotypal traits (*Odd or Eccentric Behaviour*). This work provides further support for the conceptualization of schizotypal traits as a broad spectrum, and suggests that individuals with higher levels of these traits have different sensory experiences and perhaps receptive communicative abilities compared to individuals with lower levels of these traits.

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Figure 1. Proportion of phonemes perceived for congruent audiovisual “ba” and “ga”, incongruent audiovisual “da”, unisensory auditory “ba” and “ga”, and unisensory visual “ba” and “ga” presentations.

Dashed lines indicate group means.

Figure 2. Scatterplot showing correlations between the McGurk effect and *Unusual Perceptual Experiences* subscale score ($N = 105$).

Figure 3. (A) Scatterplot showing correlation between the *Odd Speech* subscale and McGurk effect. (B) Summary of mediational analysis for perceived McGurk effect predicting *Odd Speech* subscale scores with average visual accuracy as a mediator. (C) and (D) Scatterplot showing correlations between *Odd Speech* subscale and average auditory and visual accuracy, respectively ($N = 105$).

Figure 4. Scatterplot showing correlations between perception rate of the McGurk effect and the Disorganized factor ($N = 105$).

Note. The Disorganized factor includes the *Odd or Eccentric Behaviour* and *Odd Speech* subscales.

Figure 5. (A) Scatterplot showing correlation between the *Odd or Eccentric Behaviour* subscale and McGurk effect. (B) Summary of mediational analysis for perceived McGurk effect predicting *Odd or Eccentric Behaviour* subscale scores with average visual accuracy as a mediator. (C) and (D) Scatterplot showing correlations between *Odd or Eccentric Behaviour* subscale and average auditory and visual accuracy, respectively ($N = 105$).

Table 1

Summary of hierarchical regression analysis for perceived McGurk effect and average visual accuracy predicting Odd Speech subscale scores

Predictor	B (unstandardized coefficient)	Partial correlation (<i>pr</i>)	<i>p</i> -value
Step 1: $R^2 = .052$, $F(1,103) = 5.692$, $p = .019$			
McGurk effect	1.411	.229	.019
Step 2: $R^2 = .063$, $F(2,102) = 3.416$, $p = .037$			
McGurk effect	1.029	.146	.140
Average visual accuracy	-1.643	-.105	.290

Table 2

Pearson's correlations between the McGurk effect and total SPQ scores, the three factors of the SPQ (Interpersonal, Cognitive-Perceptual, and Disorganized), and the subscales within each of these factors

	r(103)	95% CI	p-value	Adjusted p-value
Total SPQ	.122	[-0.071, 0.307]	.216	.475
Interpersonal	.121	[-0.072, 0.306]	.218	.400
<i>Excessive Social Anxiety</i>	.064	[-0.129, 0.253]	.513	.705
<i>Constricted Affect</i>	.102	[-0.091, 0.288]	.298	.468
<i>Suspiciousness</i>	.026	[-0.166, 0.217]	.789	.868
<i>No Close Friends</i>	.188	[-0.004, 0.366]	.055	.202
Cognitive-Perceptual	-.042	[-0.232, 0.151]	.671	.820
<i>Ideas of Reference</i>	-.152	[-0.334, 0.041]	.121	.333
<i>Odd Beliefs or Magical Thinking</i>	-.022	[-0.213, 0.170]	.823	.823
<i>Unusual Perceptual Experiences</i>	.086	[-0.107, 0.273]	.382	.382
Disorganized	.295	[0.110, 0.461]	.002	.022
<i>Odd or Eccentric Behaviour</i>	.293	[0.107, 0.459]	.002	.011
<i>Odd Speech</i>	.229	[0.039, 0.403]	.019	.038

Table 3

Summary of hierarchical regression analysis for perceived McGurk effect and average visual accuracy predicting Odd or Eccentric Behaviour subscale scores

Predictor	B (unstandardized coefficient)	Partial correlation (<i>pr</i>)	<i>p</i> value
Step 1: $R^2 = .293$, $F(1,103) = 9.682$, $p = .002$			
McGurk effect	1.611	.293	.002
Step 2: $R^2 = .353$, $F(2,102) = 7.306$, $p = .001$			
McGurk effect	0.948	.156	.114
Average visual accuracy	-2.848	-.208	.034

Table 4

Summary of mediational analysis for perceived McGurk effect predicting Odd or Eccentric Behaviour subscale scores with average visual accuracy as a mediator

Mediation Estimates

Effect	Label	Estimate	SE	Z	p	% Mediation
Indirect	$a \times b$	0.663	0.323	2.053	0.040	41.133
Direct	c	0.948	0.587	1.616	0.106	58.867
Total	$c + a \times b$	1.611	0.513	3.142	0.002	100.000

Path Estimates

	Label	Estimate	SE	Z	p
McGurk Effect → Average Visual Accuracy	a	-0.233	0.037	-6.225	<.001
Average Visual Accuracy → Odd/Eccentric Beh	b	-2.848	1.310	-2.174	0.030
McGurk Effect → Odd/Eccentric Beh	c	0.948	0.587	1.616	0.106

Supplementary Materials to:

Schizotypal Personality Traits and Multisensory Integration: An Investigation Using the McGurk Effect

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Figure S1. Scatterplot showing correlation between average visual accuracy and McGurk effect ($N = 105$).

Figure S2. Scatterplot showing correlation between the McGurk effect and the Total SPQ score ($N = 105$).

Figure S3. Scatterplot showing correlation between the McGurk effect and the Interpersonal Factor score ($N = 105$).

Figure S4. Scatterplot showing correlation between the McGurk effect and the *Excessive Social Anxiety* subscale score ($N = 105$).

Figure S5. Scatterplot showing correlation between the McGurk effect and the *Constricted Affect* subscale score ($N = 105$).

Figure S6. Scatterplot showing correlation between the McGurk effect and the *Suspiciousness* subscale score ($N = 105$).

Figure S7. Scatterplot showing correlation between the McGurk effect and the *No Close Friends* subscale score ($N = 105$).

Figure S8. Scatterplot showing correlation between the McGurk effect and the Cognitive-Perceptual Factor score ($N = 105$).

Figure S9. Scatterplot showing correlation between the McGurk effect and the *Ideas of Reference* subscale score ($N = 105$).

Figure S10. Scatterplot showing correlation between the McGurk effect and the *Odd Beliefs or Magical Thinking* subscale score ($N = 105$).

Table S1

Summary of mediational analysis for perceived McGurk effect predicting Odd Speech subscale scores with average visual accuracy as a mediator

Mediation Estimates

Effect	Label	Estimate	SE	Z	p	% Mediation
Indirect	$a \times b$	0.382	0.359	1.064	0.287	27.089
Direct	c	1.029	0.682	1.509	0.131	72.911
Total	$c + a \times b$	1.411	0.586	2.409	0.016	100.000

Path Estimates

	Label	Estimate	SE	Z	p
Average Visual Accuracy → McGurk Effect	a	-0.233	0.037	-6.225	< .001
McGurk Effect → Odd Speech	b	-1.643	1.521	-1.080	0.280
Average Visual Accuracy → Odd Speech	c	1.029	0.682	1.509	0.131

Table S2

Summary of mediational analysis for average visual accuracy predicting Odd Speech subscale scores with perceived McGurk effect as a mediator

Mediation Estimates

Effect	Label	Estimate	SE	Z	p	% Mediation
Indirect	$a \times b$	-1.192	0.813	-1.467	0.142	42.050
Direct	c	-1.643	1.521	-1.080	0.280	57.950
Total	$c + a \times b$	-2.835	1.314	-2.157	0.031	100.000

Path Estimates

	Label	Estimate	SE	Z	p
Average Visual Accuracy → McGurk Effect	a	-1.159	0.186	-6.225	< .001
McGurk Effect → Odd Speech	b	1.029	0.682	1.509	0.131
Average Visual Accuracy → Odd Speech	c	-1.643	1.521	-1.080	0.280

Table S3

Summary of mediational analysis for perceived McGurk effect predicting Disorganized factor scores with average visual accuracy as a mediator

Mediation Estimates

Effect	Label	Estimate	SE	Z	p	% Mediation
Indirect	$a \times b$	1.045	0.596	1.752	0.080	34.575
Direct	c	1.977	1.102	1.794	0.073	65.425
Total	$c + a \times b$	3.022	0.957	3.158	0.002	100.000

Path Estimates

	Label	Estimate	SE	Z	p
McGurk Effect → Average Visual Accuracy	a	-0.233	0.037	-6.225	< .001
Average Visual Accuracy → Disorganized Factor	b	-4.490	2.460	-1.825	0.068
McGurk Effect → Disorganized Factor	c	1.977	1.102	1.794	0.073

Table S4

Summary of mediational analysis for average visual accuracy predicting Disorganized factor scores with perceived McGurk effect as a mediator

Mediation Estimates

Effect	Label	Estimate	SE	Z	p	% Mediation
Indirect	$a \times b$	-2.291	1.329	-1.723	0.085	33.781
Direct	c	-4.490	2.460	-1.825	0.068	66.219
Total	$c + a \times b$	-6.781	2.134	-3.177	0.001	100.000

Path Estimates

	Label	Estimate	SE	Z	p
Average Visual Accuracy $\rightarrow$ McGurk Effect	a	-1.159	0.186	-6.225	< .001
McGurk Effect $\rightarrow$ Disorganized Factor	b	1.977	1.102	1.794	0.073
Average Visual Accuracy $\rightarrow$ Disorganized Factor	c	-4.490	2.460	-1.825	0.068

Table S5

Summary of mediational analysis for average visual accuracy predicting Odd or Eccentric Behaviour subscale scores with perceived McGurk effect as a mediator

Mediation Estimates

Effect	Label	Estimate	SE	Z	p	% Mediation
Indirect	$a \times b$	-1.099	0.703	-1.564	0.118	27.841
Direct	c	-2.848	1.310	-2.174	0.030	72.159
Total	$c + a \times b$	-3.946	1.133	-3.483	<.001	100.000

Path Estimates

	Label	Estimate	SE	Z	p
Average Visual Accuracy → McGurk Effect	a	-1.159	0.186	-6.225	<.001
McGurk Effect → Odd/Eccentric Beh	b	0.948	0.587	1.616	0.106
Average Visual Accuracy → Odd/Eccentric Beh	c	-2.848	1.310	-2.174	0.030