Journal of Autism and Developmental Disorders
https://doi.org/10.1007/s10803-021-05074-w

ORIGINAL PAPER

Relations Between the McGurk Effect, Social and Communication Skill, and Autistic Features in Children with and without Autism

Jacob I. Feldman[1,2,3] · Julie G. Conrad[4,5] · Wayne Kuang[4,6] · Alexander Tu[4,7] · Yupeng Liu[4,8] · David M. Simon[9] · Mark T. Wallace[1,2,9,10,11,12,13] · Tiffany G. Woynaroski[2,3,9,10]

Accepted: 9 May 2021

Abstract

Children with autism show alterations in multisensory integration that have been theoretically and empirically linked with the core and related features of autism. It is unclear, however, to what extent multisensory integration maps onto features of autism within children with and without autism. This study, thus, evaluates relations between audiovisual integration and core and related autism features across children with and without autism. Thirty-six children reported perceptions of the McGurk illusion during a psychophysical task. Parents reported on participants' autistic features. Increased report of illusory percepts tended to covary with reduced autistic features and greater communication skill. Some relations, though, were moderated by group. This work suggests that associations between multisensory integration and higher-order skills are present, but in some instances vary according to diagnostic group.

Keywords Multisensory integration · McGurk · Autism spectrum disorder · Communication skill · Social skill

Autism is defined by differences in social and communication skill and by the presence of broader features such as restricted, repetitive patterns of behavior, interests and activities that emerge in early childhood (American Psychiatric Association, 2013). Children with autism also display differences in sensory function that are now recognized as "core" characteristics of the condition. Sensory first accounts of autism posit that sensory function is foundational, and that disruptions in sensory processing may produce cascading effects on social and communication development and broader behavior, ultimately yielding the constellation of symptoms associated with autism (Cascio et al., 2016; Robertson & Baron-Cohen, 2017). One area of sensory processing that has been particularly well studied in persons with autism is audiovisual integration. The purpose of this study was to replicate prior findings of reduced audiovisual

✉ Jacob I. Feldman
j.i.feldman@vumc.org

1 Department of Hearing and Speech Sciences, Vanderbilt University, MCE 8310 South Tower, 1215 21st Avenue South, Nashville, TN 37232, USA

2 Frist Center for Autism & Innovation, Vanderbilt University, Nashville, TN, USA

3 Department of Hearing and Speech Sciences, Vanderbilt University Medical Center, Nashville, TN, USA

4 Neuroscience Undergraduate Program, Vanderbilt University, Nashville, TN, USA

5 Present Address: College of Medicine, University of Illinois, Chicago, IL, USA

6 Present Address: College of Osteopathic Medicine of the Pacific, Western University of Health Sciences, Pomona, CA, USA

7 Present Address: College of Medicine, University of Nebraska Medical Center, Omaha, NE, USA

8 Present Address: Washington University School of Medicine, Washington University in St. Louis, St. Louis, MO, USA

9 Vanderbilt Brain Institute, Vanderbilt University, Nashville, TN, USA

10 Vanderbilt Kennedy Center, Vanderbilt University Medical Center, Nashville, TN, USA

11 Department of Psychology, Vanderbilt University, Nashville, TN, USA

12 Department of Psychiatry and Behavioral Sciences, Vanderbilt University Medical Center, Nashville, TN, USA

13 Department of Pharmacology, Vanderbilt University, Nashville, TN, USA

Published online: 08 June 2021

integration (as indexed by a phenomenon known as the McGurk effect) in children with autism relative to neurotypical peers, and to evaluate how audiovisual integration relates to core and related features of autism in children who are and are not on the autism spectrum.

A recent systematic review and meta-analysis of the literature on audiovisual integration conducted by Feldman et al. (2018) indicated that individuals with autism display differences in audiovisual multisensory integration compared to non-autistic peers that are more pronounced in childhood than later in life. Alterations in multisensory integration were present across a range of stimulus types that have been employed in prior work, but differences in the integration of social multisensory stimuli, audiovisual speech in particular, were associated with autistic features, including indices of social and communication skill (e.g., Woynaroski et al., 2013) and overall level of autistic features (e.g., Mongillo et al., 2008; Smith et al., 2017). These results lend some empirical support to the cascading effects hypothesis in children with autism.

One tool that has been used frequently to measure multisensory integration of audiovisual speech in children with autism is the McGurk effect (see Zhang et al., 2019 for a review), wherein incongruent multisensory speech (e.g., concurrent presentation of an auditory "ba" and visual "ga") often leads to the perception of a fused percept (i.e., "da" or "tha"; McGurk & MacDonald, 1976). Children with autism may perceive significantly fewer illusory percepts in response to McGurk stimuli compared to non-autistic peers (e.g., Bebko et al., 2014; Irwin et al., 2011; Stevenson et al., 2014; Taylor et al., 2010), reflecting reduced visual influence on auditory speech perception or diminished multisensory integration, but these differences have not been consistently observed across the extant literature (e.g., Keane et al., 2010; Saalasti et al., 2011; Stevenson et al., 2018; Woynaroski et al., 2013).

In a meta-analysis of the McGurk effect in individuals with autism, Zhang et al. (2019) found that the marked heterogeneity across previous studies was explained in part by study-level factors such as the mean age of the participants (younger samples perceive the McGurk effect less frequently; e.g., McGurk & MacDonald, 1976; Sekiyama & Burnham, 2008) and the manner in which the researchers scored participant responses [i.e., whether studies utilized the number of visual tokens (e.g., "ga") reported or the number of fusions (e.g., "da" or "tha") reported]. Yet, despite this known heterogeneity, only a few investigations to date have attempted to explain the variance *within* studies. Such studies have found that decreased perception of the McGurk effect is correlated with increased autistic features in children with autism (Mongillo et al., 2008), children with and without autism (Bebko et al., 2014), and non-autistic adults (e.g., Donohue et al., 2012; Ujiie et al., 2015, 2018).

However, at present there is limited evidence that multisensory integration as indexed by perception of the McGurk effect is related to autistic features in non-autistic children and, more broadly, limited understanding of the extent to which the sensory first account extends to non-autistic children. It has been suggested that core and related autistic features (e.g., social communication skill, presence of restricted and repetitive interests and behaviors) lie on a continuum ranging from "normality" to clinically significant (Baron-Cohen et al., 2001). Audiovisual integration has been hypothesized to be a mechanism that underlies this continuum (Donohue et al., 2012; Irwin et al., 2017), such that early differences in multisensory integration cause proportional differences that underlie both autism and the broader autism phenotype (Bailey et al., 1995). Therefore, it is important to assess whether relations between indices of multisensory integration and autistic features are specific to children with autism or are present to the same degree in non-autistic peers. Although some previous work has investigated correlations between metrics of multisensory integration and autism symptomatology in combined clinical and nonclinical samples (Bebko et al., 2014; Feldman et al., 2019), no study to our knowledge has statistically tested whether the theorized associations of interest significantly vary in magnitude according to (i.e., are moderated by) diagnostic group.

The present study, therefore, evaluates the extent to which multisensory integration for audiovisual speech, as indexed by perception of the McGurk effect, relates to concurrent measures of social and communication skill and broader autistic features in children with and without autism matched on chronological age and biological sex. Specific research questions were: (a) Do children with autism report fewer fusions of mismatched audiovisual speech (i.e., McGurk stimuli) on average compared to non-autistic peers, as previously observed?; (b) Is perception of the McGurk effect associated with parent-reported indices of social and communication skill and broader autistic features?; (c) Does the magnitude of the aforementioned relations vary according to diagnostic group?

Methods

The Vanderbilt University Institutional Review Board approved the recruitment and study procedures. Parents provided written informed consent, and participants provided written assent prior to participation in the study. All families were compensated for participating.

Participants

Participants were 18 children with autism (16 males, $M_{age} = 12$ years, 7 months) and 18 children without autism (13 males, $M_{age} = 11$ years, 8 months). Participants did not significantly differ on age, sex, or nonverbal IQ (p values ≥ 0.2; see Table 1). The present study sample partially overlaps with prior reports from our laboratories (Feldman et al., 2020a; Noel et al., 2018).

Eligibility criteria for inclusion in the study were: (a) chronological age between 8 and 17 years; (b) normal hearing and normal or corrected-to-normal vision per parent report; (c) no history of seizure disorders, and (d) no diagnosed genetic disorders (e.g., Fragile X, tuberous sclerosis).

An additional eligibility criterion for children with autism was diagnosis of autism spectrum disorder according to DSM-5 criteria (American Psychiatric Association, 2013), independently confirmed by research-reliable administrations of the Autism Diagnostic Observation Schedule (ADOS-2; Lord et al., 2012) and clinical judgment of a licensed clinician. No eligibility criteria related to cognitive functioning were imposed on children with autism; nonverbal intelligence was assessed using the Test of Nonverbal Intelligence (TONI-4; $n = 15$; Brown et al., 2010) or the Leiter International Performance Scale (Leiter-3; $n = 3$; Roid et al., 2013).

Additional eligibility criteria for children without autism included: (a) parent report of autistic features below the screening threshold on the lifetime version of the Social Communication Questionnaire (SCQ; Rutter et al., 2003); (b) no immediate family members with autism; (c) no history of neurological conditions; (d) no prior history or present indicators of psychiatric conditions; (e) no diagnosed learning disorders; and (f) average nonverbal intelligence (i.e., standard scores ≥ 80) on the TONI-4 or Leiter-3.

McGurk Effect

The experimental task was completed in a sound- and light-attenuated room (WhisperRoom Inc., Morristown, TN, USA). Stimulus presentation was managed by E-prime software, and responses were recorded using the keyboard (i.e., "b" for "ba", "g" for "ga", "d" for "da", "t" for "tha"). Visual stimuli were presented on a 22 inch flat-screen Samsung SyncMaster CM22WS LCD PC monitor. Auditory stimuli were presented via Sennheiser HD558 circumaural headphones.

Stimuli have been used and validated previously in our laboratories (i.e., Dunham et al., 2020; Feldman et al., 2020b). Videos of a young woman speaking two CV syllables (i.e., "ba", "ga") at a natural rate and volume with neutral affect were recorded against a white background using a digital camera. The visual and auditory tracks were separated using Adobe Premiere, and the visual "ga" stimulus was combined with the auditory "ba" stimulus, such that the auditory stimuli began at the natural visual offset observed for the visual "ga." The metric derived from this task was the proportion of trials on which participants reported McGurk fusion: the amount of times the participant reported hearing a fused percept (i.e., answered "da" or "tha") divided by the total number of McGurk trials presented.

During each run of the task, 70 trials were presented: 20 matched audiovisual trials (i.e., 10 audiovisual "ba" and 10 audiovisual "ga"), 20 auditory-only trials (i.e., blank screen with auditory "ba" and "ga"; 10 trials of each), 20 visual-only trials (i.e., lip-reading; 10 trials of each), and 10 McGurk trials.

Clinical Measures

Parents reported their children's social and communication skill and broader autistic features on a series of previously developed and validated questionnaires. Social and communication skill was measured via the Vineland Adaptive Behavior Scales, second edition (VABS; Sparrow et al.,

Table 1 Means, standard deviations, and group differences of selected variables by group

	Autism *M (SD)*	Non-autism *M (SD)*
Age (years; months)	12;7 (40.0 months)	11;8 (29.1 months)
Biological sex	16 male; 2 female	13 male; 5 female
Nonverbal IQ	105.8 (13.2)	111.4 (13.2)
VABS Communication standard score	83.2 (20.5)	109.4 (11.6)
VABS Socialization standard score	72.7 (17.1)	109.5 (10.8)
Autistic feature aggregate	0.85 (0.64)	−0.85 (0.19)

Nonverbal IQ measured by the Test of Nonverbal Intelligence (Brown et al., 2010) or the Leiter international performance scale (Roid et al., 2013)

VABS Vineland Adaptive Behavior Scales, second edition (Sparrow et al., 2005), *Autistic Feature Aggregate* average of z-scores from the Social Responsiveness Scale, second edition (Constantino & Gruber, 2012) and the Social Communication Questionnaire (Rutter et al., 2003)

2005), a standardized, norm-referenced parent questionnaire. Two indices of interest were derived from the VABS: the communication domain standard score, which indexes receptive, expressive, and written communication abilities, and the socialization domain standard score, which indexes social communication, play and friendship skills, and adaptive coping skills.

Two parent reports were used to quantify the core features of autism—the Social Responsiveness Scale, second edition (SRS; Constantino & Gruber, 2012) and the SCQ (Rutter et al., 2003). Given that the total scores from these measures were highly correlated ($r = 0.908$), a single aggregate of autistic features was calculated by averaging their total scores, following z-score transformation (Rushton et al., 1983).

Analysis

The missForest package (Stekhoven & Bühlmann, 2012) in R (R Core Team, 2020) was used to impute missing data (ranging from 0 to 8.3% across variables used in analyses). Compared to traditional methods for dealing with missing data (e.g., listwise deletion, single imputation), multiple imputation reduces bias, improves parameter estimates, and preserves statistical power to detect effects of interest (Enders, 2010). Prior to imputation, all variables were evaluated for normality, specifically for skewness >|1.0| and kurtosis >|3.0|.

An independent samples *t* test was carried out to examine (anticipated) between-group differences in magnitude of multisensory integration as indexed by the rate of reported McGurk percepts. A series of multiple regression analyses was subsequently conducted, wherein the predictor (rate of reported McGurk percepts), group, and group*predictor product terms were entered into models testing theorized associations for multisensory integration with social and communication skill and autistic features across groups and evaluating whether the aforementioned associations varied according to diagnostic group. Cook's D was utilized to monitor for undue influence throughout modeling.

Results

Between Diagnostic Group Differences in Illusory Perceptions

Means and standard deviations for each trial type by group are presented in Table 2.

There was a significant difference in the proportion of reported McGurk fusions according to group in the present sample, $t\ (34) = -2.273$, $p = 0.029$, Cohen's $d = 0.76$. Children with autism reported fewer illusory percepts ($M = 38.82\%$, $SD = 31.91\%$) than their TD peers ($M = 64.44\%$, $SD = 35.64\%$). This effect was moderate to large in magnitude.

Table 2 Means, standard deviations, and group differences of variables derived from McGurk task by group

	Autism *M (SD)*	Non-autism *M (SD)*	Cohen's d
AV accuracy[a]	0.93 (0.12)	0.95 (0.06)	0.03
A accuracy[a]	0.90 (0.12)	0.92 (0.08)	0.01
V accuracy	0.64 (0.20)	0.59 (0.18)	− 0.27
Rate of McGurk fusion	0.39 (0.32)	0.64 (0.36)	0.76

Accuracies were averaged across trials for "ba" and "ga" stimuli

AV audiovisual condition, *A* auditory-only condition, *V* visual-only condition

[a]Means and standard deviations for these variables represent back-transformed values

Table 3 Zero-order correlations between rate of McGurk fusion and clinical measures across and within groups

	Rate of McGurk fusion		
Clinical measure	Overall	Autism	Non-autism
VABS communication standard score[a]	0.449**	0.510*	0.023
VABS socialization standard score	0.304	0.101	−0.062
Autistic feature aggregate	−0.418*	−0.330	−0.052

VABS Vineland Adaptive Behavior Scales, second edition (Sparrow et al., 2005), *Autistic Feature Aggregate* average of z-scores from the Social Responsiveness Scale, second edition (Constantino & Gruber, 2012) and the Social Communication Questionnaire (Rutter et al., 2003)

[a]Association was significantly moderated by group, *$p < 0.05$, **$p < 0.01$

Links with Social and Communication Skill and Autistic Features

The rate of McGurk fusion was positively correlated with communication skill as reported by parents on the VABS across groups (zero-order correlation = 0.449, $p = 0.006$; see Table 3). This association, however, was moderated by group (p value for group * predictor term in regression model testing moderated effect = 0.050; see Table S1 for full results from multiple regression models), such that communication skill was more strongly associated with the McGurk effect in children with autism ($r = 0.510$, $p = 0.031$) than in children without autism ($r = 0.023$, $p = 0.929$). Increased integration of audiovisual speech stimuli as indexed by the McGurk effect was thus associated with increased communication

abilities, but this finding was specific to children with autism (see Fig. 1).

To further explore this relation, post-hoc analyses were conducted between McGurk fusion and the subscales that comprise the communication scale index of the VABS. These follow up analyses indicated that, in children with autism, perception of the McGurk effect was significantly associated with expressive communication standard (Vscale) scores ($r = 0.505$, $p = 0.032$). The correlations with receptive communication standard scores ($r = 0.453$, $p = 0.059$) and written communication standard scores ($r = 0.453$, $p = 0.059$) in this group similarly trended towards, but did not reach, statistical significance. None of the aforementioned correlations were significant in children without autism ($r = -0.340$, -0.215, and 0.142, respectively).

The rate of McGurk fusion was not significantly correlated with socialization skills as reported by parents on the VABS across groups (zero-order correlation = 0.304, $p = 0.071$). This association additionally was not moderated by group (p value for group * predictor term in regression model testing moderated effect > 0.05).

The rate of reported McGurk fusion was negatively correlated with the aggregate of autistic features, zero-order correlation across groups = −0.418, $p = 0.011$ (see Table 3). Increased integration of audiovisual speech as indexed by the McGurk effect was associated with reduced features of autism (see Fig. 2). This association was not moderated by group.

Post-Hoc Analyses

It is possible that some of the results observed may have been due to accuracy in the unisensory conditions; therefore, a series of post-hoc analyses covaried for visual-only accuracy, auditory-only accuracy, and unisensory accuracy (i.e., each participant's average of visual-only and auditory-only accuracy). All of the results were robust to controlling for all three of the aforementioned variables indexing unisensory accuracy.

We further assessed whether relations between McGurk fusion and variables derived from the VABS (i.e., communication and socialization standard scores) were moderated by autism features as more continuously quantified, as indexed by our autistic feature aggregate. When employing this analytic approach, the relation between McGurk fusion and VABS communication was similarly moderated by autistic features (p value for autistic features * predictor term in regression model testing moderated effect = 0.042), with a nearly identical effect size as observed in the model dichotomizing diagnostic groups (Cohen's $f^2 = 0.13$ and 0.14 for

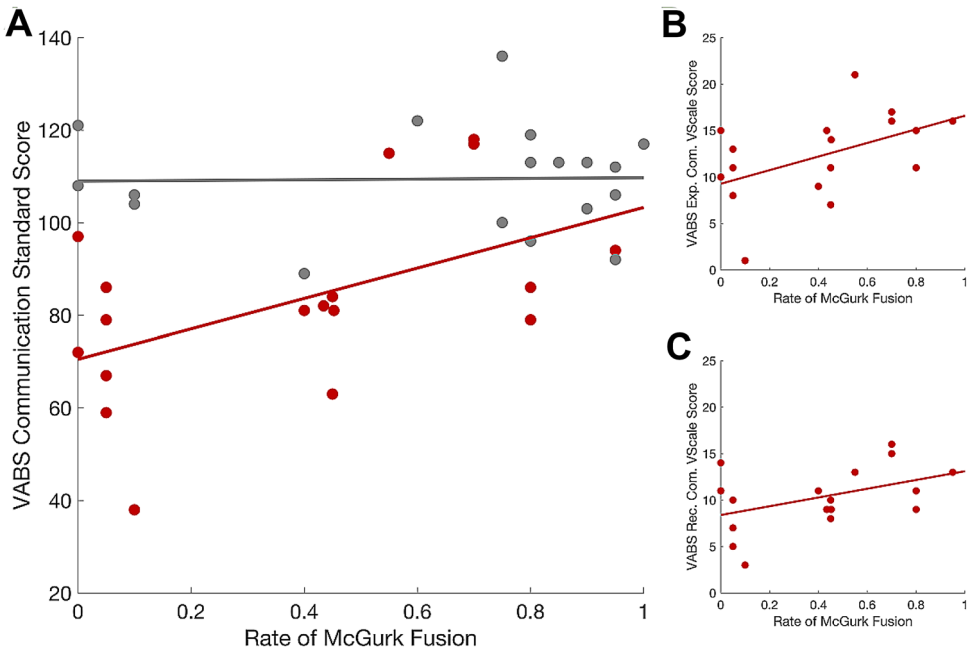

Fig. 1 Associations between rate of McGurk fusion and communication skill as reported by parents on the Vineland Adaptive Behavior Scales, second edition (VABS; Sparrow et al., 2005). Results indicate that: **a** better multisensory integration for audiovisual speech stimuli (i.e., increased report of the McGurk illusion) on average is associated with increased communication skill across children with autism (red dots) and children without autism (grey dots), but this relation is moderated by group, such that it is stronger (and in fact only statistically significant) within the autism group, **b** the relation between the rate of McGurk fusion and VABS expressive communication V-scaled scores was significant in the autism group, and **c** the relation between the rate of McGurk fusion and VABS receptive communication V-scaled scores similarly approached, but did not reach significance in the autism group

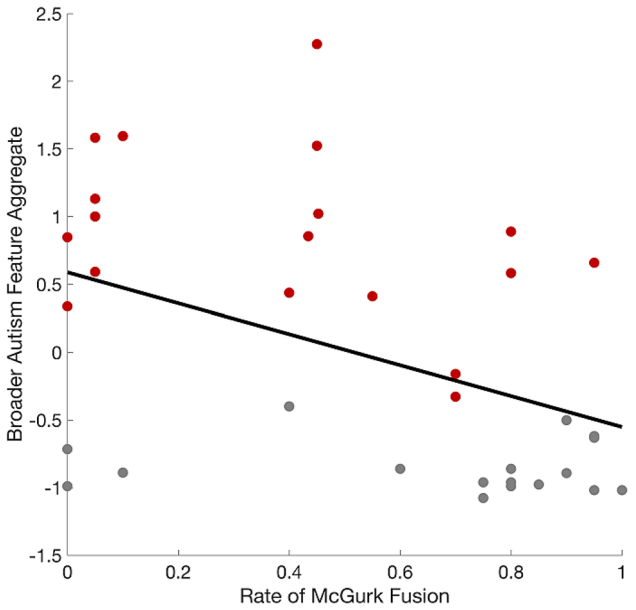

Fig. 2 Association between rate of McGurk fusion and the aggregate index of autistic features, an average of z-scores from the Social Responsiveness Scale, second edition (SRS; Constantino & Gruber, 2012) and the Social Communication Questionnaire (SCQ; Rutter et al., 2003). Results indicate that better multisensory integration (i.e., greater report of the McGurk illusion) is associated with reduced autistic features across groups. Red circles represent children with autism. Grey circles represent children without autism. This relation was not significantly moderated by group

the product terms testing whether the association of interest varied according to feature aggregate and diagnostic group, respectively). The relation between McGurk fusion and VABS socialization was not moderated by autistic features.

Additionally, there is some evidence to suggest that multisensory integration in children with autism may be stronger in females than males (e.g., Ross et al., 2015); therefore, we additionally ran a series of analyses evaluating the influence of biological sex on effects of interest. In a 2 (group) × 2 (sex) ANOVA with reported McGurk fusion as the dependent variable, there was a significant main effect of sex, F (1, 32) = 4.15, p = 0.05, and a marginally significant main effect of group, F (1, 32) = 3.45, p = 0.07. Females, on average across groups, perceived the McGurk effect at a higher rate than males. There was not a significant interaction between group and sex, F (1, 32) = 0.03, p = 0.87. All associations of interest to the present report were robust to controlling for biological sex.

Finally, a series of regression analyses was run to explore associations between other variables that could be derived from the McGurk task (i.e., variables from control conditions indexing unisensory accuracy and accuracy in the identification of matched audiovisual stimuli) and the clinical measures available in this study. None of these exploratory correlations were significant, nor were they moderated by group (see Table S2).

Discussion

This work is among the first to statistically test the difference in relations between multisensory integration and features commonly associated with autism (i.e., social and communication skill and autistic features) across well-matched samples of children with and without autism. Findings suggest that multisensory integration for more complex audiovisual stimuli (i.e., speech, as indexed by the rate of reported McGurk fusion) is linked with communication skill in children with autism and with the features of autism across children with and without autism.

The association between core autism features (as indexed by an aggregate score quantifying the presence of autistic features) and the perception of the McGurk effect was significant, and this association did not significantly vary according to diagnostic group. This finding supports the theory that differences in audiovisual integration may underlie the presence of autistic features across the general population (Baron-Cohen et al., 2001; Donohue et al., 2012), and further accords with previous work demonstrating associations between metrics of audiovisual integration and the presence of autistic features in adults without a diagnosis of autism (e.g., Donohue et al., 2012; Stevenson et al., 2017; Ujiie et al., 2015, 2018; Yaguchi & Hidaka, 2018) and in combined clinical and nonclinical samples (Bebko et al., 2014).

The association between communication skill and integration of audiovisual speech as indexed by perception of the McGurk effect was moderated by group, such that the link between these two constructs was only present in children with an autism diagnosis. This finding is consistent with findings across a large and ever-growing literature (e.g., Mongillo et al., 2008; Patten et al., 2014; Righi et al., 2018; Woynaroski et al., 2013) and provides increased empirical support for the theory that alterations in multisensory function may disrupt communication development in children with autism. We speculate that children with autism who present reduced audiovisual integration (e.g., those with reduced magnitude of audiovisual integration, as indexed by reduced perception of the McGurk illusion) may orient less to audiovisual stimuli in the environment, which are inherently social in nature, which will then lead to reduced social communication and language abilities (Bahrick & Todd, 2012; Baranek et al., 2018; Damiano-Goodwin et al., 2018). Thus, this mounting evidence for a correlation between multisensory function and communication in this clinical population begs for additional work more firmly establishing the directionality and causality of this oft replicated association. Such work will advance us towards translation of findings

from this body of research to clinical practice for persons on the autism spectrum.

Perception of the McGurk effect did not covary with communication abilities in children without autism. This result may be explained by the fact that, unlike the core features of autism, communication deficits are typically not present in the general population (Sparrow et al., 2005). Children without autism did present with a somewhat truncated range of communication abilities (i.e., communication standard scores from 89 to 136) relative to children with autism (i.e., communication standard scores from 38 to 118), which could have contributed to the attenuated association within the non-autism group. Further work is needed to determine the degree to which individual variation in higher-order domains associated with autism, in particular communication and language skill, can be explained by audiovisual multisensory integration in non-autistic individuals across the lifespan.

This study advances our understanding of the degree to which theorized associations between multisensory function and higher-order skills are present within children who do and do not have a clinical diagnosis of autism, but it is not without limitations. First, this report is limited by a somewhat small sample size ($n = 36$). Further, though we did not exclude children according to language and/or cognitive ability, the autism group does represent a relatively cognitively and linguistically able sample of children who were able to attend to and actively report their perception on a psychophysical task for a somewhat extended period of time (~20–30 min to complete the McGurk task). Larger and more diverse samples will allow us to ascertain whether the present results generalize to the broader population of persons with and without autism. It is also unclear whether these results would generalize to individuals with autism matched to non-autistic peers on the basis of full-scale or verbal IQ as opposed to nonverbal IQ. Specifically, further work is needed to determine whether these findings generalize to younger and/or less-linguistically fluent individuals with autism, though passive paradigms that can index multisensory integration, such as those utilizing eye tracking (e.g., Bahrick et al., 2018; Lewkowicz & Flom, 2014; Righi et al., 2018) and electroencephalography (EEG; e.g., Dunham et al., 2020; van Wassenhove et al., 2005), must be developed and validated in order to assess more heterogeneous samples. Future work may also wish to consider using multiple types of McGurk stimuli, particularly those that have been found to be stable and valid in this population (see Dunham et al., 2020). One final limitation of this report is the reliance on parent report to measure social and communication abilities and core autistic features. Future research should consider taking a multi-modal approach to participant characterization that incorporates norm-referenced, standardized observational measures of higher-order skills purported to be impacted by multisensory processing, including those symptoms indexed here, as well as other features commonly co-occurring with autism, such as spoken language impairments.

Conclusion

Children with autism on average reported significantly fewer illusory percepts during the McGurk task employed in this study compared to children without autism, as expected. Considerable individual variation in audiovisual integration, however, was observed across groups. Increased magnitude of multisensory integration for audiovisual speech stimuli, as indexed by the McGurk effect, was correlated with reduced autistic features and increased communication skill. However, relations between the rate of perceived McGurk illusions and communication skills were moderated by group, such that significant associations were only present in children with autism, who were somewhat more variable in their communication ability relative to children without autism. Further work is needed to examine these links using more diverse measures of multisensory integration and clinical tools tapping communication and social skill across children representing the full autism spectrum.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10803-021-05074-w.

Author Contributions JIF, MTW, and TGW posed the research questions and collected data. DMS developed the stimuli and analytic tools. JIF, WK, AT, JGC, and YL scored, entered, and organized the data. TGW and JIF analyzed the data, interpreted the results, and drafted the manuscript. All authors read and approved the final manuscript.

Funding The work described was supported by NIH U54 HD083211 (PI: Neul), NIH/NCATS KL2TR000446 (PI: Woynaroski), NIH/NIDCD R21 DC016144 (PI: Woynaroski), and NSF NRT Grant DGE 19-22697 (PI: Wallace).

Declarations

Conflict of interest The authors declare no competing interests.

Ethical Approval All procedures were performed in accordance with the ethical standards of the Vanderbilt University Institutional Review Board and with the 1964 Declaration of Helsinki and its later amendments.

Informed Consent The parents of all participants provided written informed consent. All participants provided written assent prior to their participation.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders-5*. American Psychiatric Association.

Bahrick, L. E., & Todd, J. T. (2012). Multisensory processing in autism spectrum disorders: Intersensory processing disturbance

as atypical development. In B. E. Stein (Ed.), *The new handbook of multisensory processes.* (pp. 657–674). MIT Press.

Bahrick, L. E., Todd, J. T., & Soska, K. C. (2018). The multisensory attention assessment protocol (MAAP): Characterizing individual differences in multisensory attention skills in infants and children and relations with language and cognition. *Developmental Psychology, 54*(12), 2207–2225. https://doi.org/10.1037/dev0000594

Bailey, A., Le Couteur, A., Gottesman, I., Bolton, P., Simonoff, E., Yuzda, E., & Rutter, M. (1995). Autism as a strongly genetic disorder: Evidence from a British twin study. *Psychological Medicine, 25*, 63–77. https://doi.org/10.1017/S0033291700028099

Baranek, G. T., Woynaroski, T. G., Nowell, S., Turner-Brown, L., DuBay, M., Crais, E. R., & Watson, L. R. (2018). Cascading effects of attention disengagement and sensory seeking on social symptoms in a community sample of infants at-risk for a future diagnosis of autism spectrum disorder. *Developmental Cognitive Neuroscience, 29*, 30–40. https://doi.org/10.1016/j.dcn.2017.08.006

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*, 5–17. https://doi.org/10.1023/A:1005653411471

Bebko, J. M., Schroeder, J. H., & Weiss, J. A. (2014). The McGurk effect in children with autism and asperger syndrome. *Autism Research, 7*, 50–59. https://doi.org/10.1002/aur.1343

Brown, L., Sherbenou, R. J., & Johnsen, S. K. (2010). *Test of nonverbal intelligence*. (4th ed.). Pro-Ed.

Cascio, C. J., Woynaroski, T., Baranek, G. T., & Wallace, M. T. (2016). Toward an interdisciplinary approach to understanding sensory function in autism spectrum disorder. *Autism Research, 9*, 920–925. https://doi.org/10.1002/aur.1612

Constantino, J. N., & Gruber, C. P. (2012). *Social responsiveness scale*. (2nd ed.). Western Psychological Services.

Damiano-Goodwin, C. R., Woynaroski, T. G., Simon, D. M., Ibañez, L. V., Murias, M., Kirby, A., Newsom, C. R., Wallace, M. T., Stone, W. L., & Cascio, C. J. (2018). Developmental sequelae and neurophysiologic substrates of sensory seeking in infant siblings of children with autism spectrum disorder. *Developmental Cognitive Neuroscience, 29*, 41–53. https://doi.org/10.1016/j.dcn.2017.08.005

Donohue, S. E., Darling, E. F., & Mitroff, S. R. (2012). Links between multisensory processing and autism. *Experimental Brain Research, 222*, 377–387. https://doi.org/10.1007/s00221-012-3223-4

Dunham, K., Feldman, J. I., Liu, Y., Cassidy, M., Conrad, J. G., Santapuram, P., Suzman, E., Tu, A., Butera, I. M., Simon, D. M., Broderick, N., Wallace, M. T., Lewkowicz, D. J., & Woynaroski, T. G. (2020). Stability of variables derived from measures of multisensory function in children with autism spectrum disorder. *American Journal of Intellectual and Developmental Disabilities, 125*(4), 287–303. https://doi.org/10.1352/1944-7558-125.4.287

Enders, C. K. (2010). *Applied missing data analysis*. Guilford Press.

Feldman, J. I., Dunham, K., Cassidy, M., Wallace, M. T., Liu, Y., & Woynaroski, T. G. (2018). Audiovisual multisensory integration in individuals with autism spectrum disorder: A systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews, 95*, 220–234. https://doi.org/10.1016/j.neubiorev.2018.09.020

Feldman, J. I., Cassidy, M., Liu, Y., Kirby, A. V., Wallace, M. T., & Woynaroski, T. G. (2020a). Relations between sensory responsiveness and features of autism in children. *Brain Sciences, 10*(11), 775. https://doi.org/10.3390/brainsci10110775

Feldman, J. I., Dunham, K., Conrad, J. G., Simon, D. M., Cassidy, M., Liu, Y., Tu, A., Broderick, N., Wallace, M. T., & Woynaroski, T. G. (2020b). Perceptual training in children with autism spectrum disorder: A single-case treatment study. *Research in Autism Spectrum Disorders, 74*, 1–13. https://doi.org/10.1016/j.rasd.2020.101555

Feldman, J. I., Kuang, W., Conrad, J. G., Tu, A., Santapuram, P., Simon, D. M., Foss-Feig, J. H., Kwakye, L. D., Stevenson, R. A., Wallace, M. T., & Woynaroski, T. G. (2019). Brief report: Differences in multisensory integration covary with differences in sensory responsiveness in children with and without autism spectrum disorder. *Journal of Autism and Developmental Disabilities, 49*, 397–403. https://doi.org/10.1007/s10803-018-3667-x

Irwin, J., Avery, T., Turcios, J., Brancazio, L., Cook, B., & Landi, N. (2017). Electrophysiological indices of audiovisual speech perception in the broader autism phenotype. *Brain Sciences*. https://doi.org/10.3390/brainsci7060060

Irwin, J. R., Tornatore, L. A., Brancazio, L., & Whalen, D. (2011). Can children with autism spectrum disorders "hear" a speaking face? *Child Development, 82*(5), 1397–1403. https://doi.org/10.1111/j.1467-8624.2011.01619.x

Keane, B. P., Rosenthal, O., Chun, N. H., & Shams, L. (2010). Audiovisual integration in high functioning adults with autism. *Research in Autism Spectrum Disorders, 4*, 276–289. https://doi.org/10.1016/j.rasd.2009.09.015

Lewkowicz, D. J., & Flom, R. (2014). The audiovisual temporal binding window narrows in early childhood. *Child Development, 85*, 685–694. https://doi.org/10.1111/cdev.12142

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, 264*, 746–748. https://doi.org/10.1038/264746a0

Mongillo, E. A., Irwin, J. R., Whalen, D., Klaiman, C., Carter, A. S., & Schultz, R. T. (2008). Audiovisual processing in children with and without autism spectrum disorders. *Journal of Autism and Developmental Disorders, 38*, 1349–1358. https://doi.org/10.1007/s10803-007-0521-y

Noel, J. P., De Niear, M., Lazzara, N. S., & Wallace, M. T. (2018). Uncoupling between multisensory temporal function and nonverbal turn-taking in autism spectrum disorder. *IEEE Transactions on Cognitive and Developmental Systems, 10*, 973–982. https://doi.org/10.1109/TCDS.2017.2778141

Patten, E., Watson, L. R., & Baranek, G. T. (2014). Temporal synchrony detection and associations with language in young children with ASD. *Autism Research and Treatment*. https://doi.org/10.1155/2014/678346

R Core Team. (2020). R: A language and environment for statistical computing. In (Version 4.0.2) Vienna, Austria. Retrieved from, https://www.R-project.org/

Righi, G., Tenenbaum, E. J., McCormick, C., Blossom, M., Amso, D., & Sheinkopf, S. J. (2018). Sensitivity to audio-visual synchrony and its relation to language abilities in children with and without ASD. *Autism Research, 11*, 645–653. https://doi.org/10.1002/aur.1918

Robertson, C. E., & Baron-Cohen, S. (2017). Sensory perception in autism. *Nature Reviews Neuroscience, 18*, 671–684. https://doi.org/10.1038/nrn.2017.112

Roid, G. H., Miller, L. J., Pomplun, M., & Koch, C. (2013). *Leiter international performance scale*. (3rd ed.). Western Psychological Services.

Ross, L. A., Del Bene, V. A., Molholm, S., Frey, H. P., & Foxe, J. J. (2015). Sex differences in multisensory speech processing in both typically developing children and those on the autism spectrum. *Frontiers in Neuroscience, 9*, 1–13. https://doi.org/10.3389/fnins.2015.00185

Rushton, J. P., Brainerd, C. J., & Pressley, M. (1983). Behavioral development and construct validity: The principle of aggregation. *Psychological Bulletin, 94*, 18–38. https://doi.org/10.1037/0033-2909.94.1.18

Rutter, M., Bailey, A., & Lord, C. (2003). *The social communication questionnaire*. Western Psychological Services.

Saalasti, S., Tiippana, K., Kätsyri, J., & Sams, M. (2011). The effect of visual spatial attention on audiovisual speech perception in adults with asperger syndrome. *Experimental Brain Research, 213*, 283–290. https://doi.org/10.1007/s00221-011-2751-7

Sekiyama, K., & Burnham, D. (2008). Impact of language on development of auditory-visual speech perception. *Developmental Science, 11*(2), 306–320. https://doi.org/10.1111/j.1467-7687.2008.00677.x

Smith, E. G., Zhang, S., & Bennetto, L. (2017). Temporal synchrony and audiovisual integration of speech and object stimuli in autism. *Research in Autism Spectrum Disorders, 39*, 11–19. https://doi.org/10.1016/j.rasd.2017.04.001

Sparrow, S. S., Cicchetti, D. V., & Bella, D. A. (2005). *Vineland adaptive behavior scales*. (2nd ed.). Pearson.

Stekhoven, D. J., & Bühlmann, P. (2012). MissForest—Non-parametric missing value imputation for mixed-type data. *Bioinformatics, 28*, 112–118. https://doi.org/10.1093/bioinformatics/btr597

Stevenson, R. A., Segers, M., Ncube, B. L., Black, K. R., Bebko, J. M., Ferber, S., & Barense, M. D. (2018). The cascading influence of multisensory processing on speech perception in autism. *Autism, 22*, 609–624. https://doi.org/10.1177/1362361317704413

Stevenson, R. A., Siemann, J. K., Woynaroski, T. G., Schneider, B. C., Eberly, H. E., Camarata, S. M., & Wallace, M. T. (2014). Brief report: Arrested development of audiovisual speech perception in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 44*, 1470–1477. https://doi.org/10.1007/s10803-013-1992-7

Stevenson, R. A., Toulmin, J. K., Youm, A., Besney, R. M., Schulz, S. E., Barense, M. D., & Ferber, S. (2017). Increases in the autistic trait of attention to detail are associated with decreased multisensory temporal adaptation. *Scientific Reports, 7*, 1–10. https://doi.org/10.1038/s41598-017-14632-1

Taylor, N., Isaac, C., & Milne, E. (2010). A comparison of the development of audiovisual integration in children with autism spectrum disorders and typically developing children. *Journal of Autism and Developmental Disorders, 40*, 1403–1411. https://doi.org/10.1007/s10803-010-1000-4

Ujiie, Y., Asai, T., & Wakabayashi, A. (2015). The relationship between level of autistic traits and local bias in the context of the McGurk effect. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.00891

Ujiie, Y., Asai, T., & Wakabayashi, A. (2018). Individual differences and the effect of face configuration information in the McGurk effect. *Experimental Brain Research, 236*(4), 973–984. https://doi.org/10.1007/s00221-018-5188-4

van Wassenhove, V., Grant, K. W., & Poeppel, D. (2005). Visual speech speeds up the neural processing of auditory speech. *PNAS, 102*, 1181–1186. https://doi.org/10.1073/pnas.0408949102

Woynaroski, T. G., Kwakye, L. D., Foss-Feig, J. H., Stevenson, R. A., Stone, W. L., & Wallace, M. T. (2013). Multisensory speech perception in children with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 43*, 2891–2902. https://doi.org/10.1007/s10803-013-1836-5

Yaguchi, A., & Hidaka, S. (2018). Distinct autistic traits are differentially associated with the width of the multisensory temporal binding window. *Multisensory Research, 31*, 523–536. https://doi.org/10.1163/22134808-00002612

Zhang, J., Meng, Y., He, J., Xiang, Y., Wu, C., Wang, S., & Yuan, Z. (2019). McGurk effect by individuals with autism spectrum disorder and typically developing controls: A systematic review and meta-analysis. *Journal of Autism and Developmental Disorders, 49*, 34–43. https://doi.org/10.1007/s10803-018-3680-0

Jacob I. Feldman , PhD, CCC-SLP was a PhD student in the Department of Hearing and Speech Sciences at Vanderbilt University at the time that this work was completed and is presently a Research Fellow in the Department of Hearing and Speech Sciences at Vanderbilt University Medical Center.

Julie Conrad , BA, was a undergraduate student at Vanderbilt University at the time this work was completed.

Wayne Kuang , BA, was a undergraduate student at Vanderbilt University at the time this work was completed.

Alexander Tu , BA, was a undergraduate student at Vanderbilt University at the time this work was completed.

Yupeng Liu , BA was a undergraduate student at Vanderbilt University at the time this work was completed.

David Simon , PhD, was a PhD student in Neuroscience at Vanderbilt University at the time this work was completed.

Mark T. Wallace , PhD, is Dean of the Graduate School; Professor in the Department of Hearing and Speech Sciences, Department of Psychological Sciences, and Department of Psychiatry and Behavioral Sciences; Investigator in the Vanderbilt Kennedy Center; Member of the Vanderbilt Brain Institute at Vanderbilt University; and Fellow of the Frist Center for Autism and Innovation at Vanderbilt University.

Tiffany Woynaroski , PhD, CCC-SLP is Assistant Professor in the Department of Hearing and Speech Sciences; Investigator of the Vanderbilt Kennedy Center at Vanderbilt University Medical Center; Member of the Vanderbilt Brain Institute at Vanderbilt University; and Fellow of the Frist Center for Autism and Innovation at Vanderbilt University.