



# Inferencing Abilities of Deaf College Students: Foundations and Implications for Metaphor Comprehension and Theory of Mind

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## Abstract

Understanding nonliteral language requires inferencing ability and is an important but complex aspect of social interaction, involving cognitive (e.g., theory of mind, executive function) as well as language skill, areas in which many deaf individuals struggle. This study examined comprehension of metaphor and sarcasm, assessing the contributions of hearing status, inferencing ability, executive function (verbal short-term/working memory capacity), and deaf individuals' communication skills (spoken versus signed language, cochlear implant use). Deaf and hearing college students completed a multiple-choice metaphor comprehension task and inferencing tasks that included both social-emotional (i.e., theory of mind) and neutral inferences, as well as short-term memory span and working memory tasks. Results indicated the hearing students to have better comprehension of nonliteral language and the ability to make social-emotional inferences, as well as greater memory capacity. Deaf students evidenced strong relationships among inferential comprehension, communication skills, and memory capacity, with substantial proportions of the variance in understanding of metaphor and sarcasm accounted for by these variables. The results of this study enhance understanding of the language and cognitive skills underlying figurative language comprehension and theory of mind and have implications for the social functioning of deaf individuals.

**Keywords** Metaphor · Sarcasm · Inferencing · Deaf · Cochlear implant

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## Introduction

### Figurative Language and Theory of Mind: Development and Cognitive Processes

The use of figurative, nonliteral language is extensive in both everyday conversations and literary works, ranging from idioms, similes and metaphors to hyperbole, litotes, sarcasm and irony. Each can be used to emphasize aspects of the speaker's utterance/statement or express meaning not directly conveyed by the words themselves. Understanding such figurative language involves verbal inferencing that demands semantic knowledge, verbal working memory and perceptual integration, as well as social and cultural knowledge. It is also influenced by overall intellectual ability, executive functions, concept formation ability, and reasoning skills (Gibbs Jr and Colston 2012; Giora 2003). Understanding of metaphors and sarcasm, in particular, is dependent on the need to activate relevant and suppress irrelevant information in working memory (Chiappe and Chiappe 2007). However, comprehension of sarcasm additionally requires social-emotional understanding, as readers/listeners must be sensitive to the mental state of the writer/speaker, enabling them to infer intended meaning (Olkoniemi et al. 2016).

A number of authors have explored the possibility that underlying the ability to understand metaphors and sarcasm is the capacity to correctly infer the speaker's state of mind or mental state – having a “theory of mind” (Happé 1993; Mo et al. 2008; Norbury 2005). Happé (1993), for example, argued that similes, metaphors and irony (of which sarcasm is a negative, verbal form) vary in the degree to which the speaker's intention must be inferred in order to interpret the expression correctly. They proposed that, of these, only irony requires second-order theory of mind (i.e., understanding what a second person thinks about a first person's thoughts or perspective) for its comprehension. This conceptualisation of metaphor and sarcasm comprehension as *dependent* on or even a consequence of theory of mind understanding diverges from one in which authors regard sarcasm as an *aspect* of theory of mind understanding. In this case, sarcasm is seen as the most advanced level of a theory of mind scale that starts with the understanding of diverse desires and beliefs (O'Reilly et al. 2014; Peterson et al. 2012; Wellman and Liu 2004).

A number of cognitive processes have been investigated as contributing to theory of mind development. In preschool age children, significant relationships have been found between executive function abilities, such as working memory and inhibitory control, and theory of mind tasks, in typically developing and clinical populations (Fahie and Symons 2003; Mutter et al. 2006). Keenan et al. (1998) suggested that concurrent growth in working memory may be responsible for the developmental change when the ability to pass first-order false belief tasks occurs, at around four years of age, a view supported by the findings of Mutter et al. (2006). In older, school-aged children, empirical evidence indicates that such cognitive abilities are also important for advanced theory of mind understanding, including second-order false belief, white lies, double bluff, and sarcasm (Austin et al. 2014; Cantin et al. 2016; Kouklari et al. 2018).

Several longitudinal studies, employing cross-lagged designs, have sought to establish the direction of causal relationships between executive function and theory of mind. Findings of Lecce et al. (2017), Marcovitch et al. (2015), and Austin et al. (2014) favored executive function skills, predominantly working memory, attention shifting

and inhibition, as precursors of later theory of mind abilities, but not the reverse. However, the evidence is mixed, with other investigations yielding non-significant relationships between earlier executive function skills and later theory of mind, over periods of up to four years (Devine et al. 2016; McAlister and Peterson 2013).

Metaphor comprehension also follows a developmental trajectory and is dependent on a variety of cognitive abilities, including concept formation and analogical reasoning, as well as executive functions such as working memory and attention processes (Carriedo et al. 2016; Gibbs Jr and Colston 2012; Giora 1999; Olkonemi et al. 2016). Working memory in particular is thought to be important for metaphor comprehension, since it is needed to activate and simultaneously keep in mind multiple different possible interpretations (literal versus figurative) while processing the metaphor. Greater working memory capacity thus has been found to be associated with faster and more accurate metaphor interpretation as well as quality of metaphor production (e.g., Chiappe and Chiappe 2007; Monetta and Pell 2007;). Iskandar and Baird (2014) used digit span tasks to explore the relationship between cognitive processes and metaphor comprehension. They asked 40 young adults to provide explanations for 20 metaphors, categorising answers into four types based on the extent to which they reflected abstract rather than concrete/literal interpretations of the metaphors. They found that short-term memory span, but not working memory or divided attention, contributed significantly to the ability to produce the most sophisticated (“abstract”) responses. Olkonemi et al. (2016) investigated the processing of both metaphors and sarcasm in story contexts using an eye-tracking task, finding that individual differences in working memory capacity, as assessed by a reading span task, were related to the processing of both sarcasm and metaphor. They interpreted this result as suggesting that working memory is important for simultaneously holding more than one possible interpretation in mind and suppressing salient, more readily accessed literal meanings.

Although much of the empirical literature to date on the comprehension of nonliteral language has focussed on typically-developing individuals, useful insights have been derived from a variety of clinical populations, a common link between many of them being in their difficulties in social and emotional understanding, social communication and the pragmatic use of language. This brings us to the focus of the current study: the impact of deafness on the inter-relationships between inferencing ability, sarcasm and metaphor comprehension, and working memory capacity.

Children and adults with hearing loss are a population who are at risk of delays or deficits in a wide variety of language and cognitive domains (Houston et al. 2020; Marschark and Knoors 2020). They frequently fall behind their hearing peers in terms of reasoning and executive function skills, inference-making, working memory and theory of mind development (Coppens et al. 2013; Marschark et al. 2019; Marschark et al. 2016). The next sections thus examine studies exploring the impact of deafness on the understanding of figurative, nonliteral language, theory of mind and inferential comprehension, and those cognitive skills most influential in their development.

## **Deafness and Figurative Language**

The traditional view that deaf children are concrete in their thinking and have difficulty in understanding nonliteral and abstract language was challenged in early studies by Marschark and colleagues, who demonstrated that when assessed on creative story

tasks using sign language, deaf children produced at least as much figurative language as their hearing peers did in spoken English, and more of some types of creative expressions (e.g., Marschark and West 1985; Marschark et al. 1986). Iran-Nejad et al. (1981) suggested that deaf children and adolescents are able to understand written metaphorical language but do not spontaneously “look” for metaphorical interpretations if the task does not explicitly demand it, and they are not prompted to do so. Orlando and Shulman (1989) asked deaf adolescents and young adults to provide the meanings of metaphors. The responses of the deaf youngsters were significantly more literal as compared with hearing peers, but they became more abstract with age and reading ability.

To our knowledge, since these early investigations, just three studies have explored metaphor understanding by deaf individuals. Nicastrì et al. (2014) tested the ability of 31 deaf, six to 15-year-old cochlear implant (CI) users with age-appropriate language skills on their ability to explain the meanings of spoken metaphoric sentences, comparing verbal and nonverbal response modes. The children performed significantly worse than age-, gender- and language ability-matched hearing peers only when a verbal response was required. Younger age at implantation was associated with better performance on the verbal task. Comparing hearing and deaf adults, some of whom had CIs, Gold and Segal (2017) reduced metaphors to four types of word pairs in order to minimize the potential influence of contextual and other factors: literal (e.g., smooth fur), conventional metaphoric (e.g., bright student), novel metaphoric taken from poetry (e.g., wilting hope) and unrelated (e.g., disputable tiger). Results indicated that the two groups were equally accurate in their ability to evaluate whether each pair type was “meaningful”, but that the deaf adults’ judgements for the novel metaphors took longer than those of the hearing adults, suggesting that they were processed differently in some way. Finally, Bahrami et al. (2018) compared the performance of school-aged children with CIs with age-matched hearing children, using six unfamiliar metaphors based on the emotions of anger, happiness and fear embedded in stories. Visual response options included images depicting a correct metaphor interpretation, a literal interpretation and an irrelevant one. The deaf children gave significantly fewer correct responses than hearing peers, favoring literal interpretations over the metaphorical.

Conclusions to be drawn from these studies are necessarily tentative and limited. However, clarification of the processes involved in deaf individuals’ difficulties in the comprehension of nonliteral language may be aided by examining metaphor and sarcasm comprehension in relation to other abilities such as general inferencing ability, or to specific executive function skills, that are known to pose significant problems for many deaf individuals.

### **Deafness and Inferencing**

Two possible contributory factors to the difficulties faced by deaf individuals in understanding theory of mind lie in problems with concept formation and making inferences, both from spoken utterances and written text (Castellanos et al. 2014; Li et al. 2019). Evidence from typically developing and clinical populations indicates that making literal inferences is further related to language ability and working memory (Cain et al. 2004; Karasinski and Weismer 2010). With regard to deaf learners, there is a paucity of research on their difficulties at the level of text comprehension (rather than

visual word recognition or phonological skills) (Kyle and Cain 2015). The available studies, reviewed by Kyle and Cain, suggest that deaf learners are generally less efficient than their hearing peers at drawing inferences from text, difficulties that are evident into early adulthood. In their study, Kyle and Cain compared different types of inferences (excluding mental-state ones): literal, local cohesion inferences at the text level, and global coherence inferences requiring knowledge beyond the text. They found that deaf children's ability to make global coherence inferences and to integrate world information with the information in the text was particularly impaired compared to local cohesion inferences, with even poorer comprehension than would be expected given their word-level reading skills relative to age-matched hearing peers.

In apparently the only study to link working memory ability with inferential comprehension in deaf individuals, Garrison et al. (1997) employed computerized digit span and complex working memory (arithmetic) tasks, tests of word and world knowledge, and a reading comprehension test that required the ability to integrate information within and across text paragraphs to arrive at correct inferences. Complex working memory span predicted inferential comprehension after accounting for a composite of word and world knowledge, but only for within-paragraph inferences, and accounted for only a relatively small amount of the variance (7%). The authors suggested that working memory capacity operates as a "general executive system" (i.e., is a domain-general ability) that differentiates good from poor deaf readers.

## Deafness and Theory of Mind

The development of theory of mind abilities in deaf individuals from infancy to adulthood has received extensive attention over the past 25 years (see Marschark et al. 2019; Peterson 2020; Tucci and Easterbrooks 2020, for reviews). Put simply, the key conclusions to be drawn are: (a) that many deaf children are at risk of delays in the acquisition of theory of mind understanding, and (b) that even in adulthood difficulties in understanding advanced aspects of mental state inferencing such as second-order false belief, white lies, double bluff, and sarcasm remain apparent. Using a task that involved anticipating the search actions of a cartoon character that held a false belief about an object location, Meristo et al. (2012) found that the developmental trajectory of theory of mind understanding in deaf individuals diverged from that of hearing counterparts as early as the second year of life. At the other end of the age spectrum, Marschark et al. (2019) tested the advanced theory of mind abilities of deaf college students, around half of whom used CIs, and 62% of whom stated sign language was their preferred mode of communication. They found no significant differences between the deaf CI users and nonusers in understanding second-order false belief, double bluff or sarcasm, but both groups performed significantly more poorly than hearing peers on each of the tests.

Between these two ends of the age spectrum, numerous studies have evidenced the detrimental impact of hearing loss on mental state inferencing. A wide range of factors has been associated with these delays, including signed versus spoken communication, language ability and pragmatic skills, educational strategies, and the quality of social relationships, all associations that are frequently suggested as being reciprocal (Peterson 2020; Stanzione and Schick 2014; Tucci and Easterbrooks 2020). Two different, but not mutually exclusive, alternatives have emerged in the literature to

explain these persistent delays or deficits in theory of mind understanding: conversational and executive function accounts. The present study explored the second of these, since it has received comparatively little attention to date.

### **Executive Function Contributions to Theory of Mind Delays in Deaf Individuals**

The absence of auditory stimulation in prelingual deafness alters the development of the central nervous system and neurocognitive processes both directly through stimulation, as well as indirectly through impacts on language acquisition, parent-child interactions and social experiences (Kral et al. 2016). In particular, executive function is a cognitive domain clearly affected by auditory deprivation, including components such as attention, working memory, inhibition, shifting and emotional control (Edwards and Isquith 2020; Kronenberger and Pisoni 2020). However, the extent that auditory deprivation per se, as opposed to the impact of language delay (or a combination of the two), is responsible for observed differences in executive function between deaf and hearing individuals is not clear: some studies, for example, suggest that when there is no language deprivation or delay (as in the case of native signers), there is no impact on executive function (e.g., Hall et al. 2017). This difference may be at least in part accounted for by the way in which executive function ability was assessed – by parent report of behavior rather than objective, performance measures.

The strongest evidence for the impact of hearing loss on executive function is for delays in verbal memory abilities, with numerous studies documenting reductions in short-term memory capacity and working memory across a wide age range that are only partially remediated by the use of CIs (e.g., Bharadwaj et al. 2015; Edwards and Isquith 2020). Three studies have included measures of both theory of mind and working memory, two in the context of other tests of executive function, and one in relation to reading comprehension. Holmer et al. (2016) tested a small group of seven to 14-year-old children using a Swedish Sign Language (SSL) version of the Wellman and Liu (2004) theory of mind scale, as well as tests of visuo-spatial working memory and reading comprehension. Notably, in the context of a clear delay in theory of mind development there was a significant correlation between the theory of mind measure and both nonverbal working memory and reading comprehension, but not between theory of mind and sign language comprehension. In an earlier study that exclusively involved sign language users, Meristo and Hjelmquist (2009) also found relationships between performance on a working memory capacity task—signed digit span backwards—and second-order false belief and other advanced theory of mind tasks. Neither educational background (bilingual versus orally-education) nor sign language usage (native versus late signers) influenced the executive function abilities of the participants. Finally, Liu et al. (2018) tested 36 young children with CIs aged three to six years who were exposed only to aural-oral instruction. Measures of executive function focused on switching and inhibitory control rather than memory, with inhibitory control predicting 67% of the variance in a composite theory of mind measure. Together these studies support the assertion that executive functioning (and particularly working memory) processes play a central role in theory of mind understanding in deaf youngsters.

## Study Rationale and Aims

The studies described above convey a picture of substantial delays in theory of mind development and working memory in a large proportion of deaf individuals, along with preliminary evidence for more universal difficulties making inferences and understanding figurative language such as metaphors. Yet to be explored is the relationship between difficulties in making inferences generally, as well as those related to inferring mental states, and memory capacity. Thus in addition to measures of verbal memory capacity, sarcasm and metaphor comprehension, the present study included measures of the ability to make inferences from texts where the inferences required either general world knowledge or the ability to infer emotions in social scenarios. The distinction between these “neutral” inferences and “social-emotional” mental state inferences was made to differentiate the possible negative impact of hearing loss on inferences in the social-emotional domain, where developmental delays are well documented (Calderon and Greenberg 2011; Tucci and Easterbrooks 2020; Ziv et al. 2013) from those observed in the context of reading (Coppens et al. 2013; Li et al. 2019). Specific research questions were:

1. Is there a difference in the ability of deaf college students to comprehend metaphors compared with their hearing peers?
2. Is the previously observed deficit in understanding of sarcasm among deaf college students due to a problem with making inferences generally, or specifically with mental state inferences?
3. Is there a relationship among comprehension of metaphors, sarcasm, mental state inferring, communication/language, and working memory capacity in deaf and hearing students?

## Method

### Participants

Participants were 74 deaf students, 32 of whom were CI users, and 38 hearing students. All were volunteers attending a university in a northeastern state of the United States, more than 95% of whom were aged between 18 and 24 years. They were recruited via posters and word of mouth, and were paid for their participation. There were no specific inclusion or exclusion criteria, other than that the participants were enrolled on one of the university’s programs of study. The mean age of first or only cochlear implantation was 6.5 years ( $SD = 5.23$ ). While these ages are relatively late by current standards, they accurately represent the present college-age cohort of CI users in the United States. In the CI group, six participants reported also using a hearing aid and of the 42 non-CI users, 10 said that they did not use one. Thirty-four percent of the CI users and 31% of the nonusers reported starting to learn sign by three years of age, the remainder later. Hearing students were not asked about sign language skills. Communication skills of the deaf participants were assessed using a brief self-report questionnaire described below, but no other demographic information was available with regard to either the deaf or hearing participants.

## Measures

### Communication Questionnaire

Deaf participants were asked how well most hearing people understand their speech on a 5-point Likert scale from “Nothing” to “Everything I say” (i.e., expressive spoken language ability). Their understanding of speech (i.e., receptive spoken language ability) was also rated on a 5-point scale from “Nothing” to “Everything people say”. Expressive sign language ability was assessed by rating their signing (production) skills on a similar scale, from “I don’t know sign language” to “Excellent”. Finally, receptive sign language skill, how well they understand when people sign to them, was rated from “Nothing” to “Everything people sign”, again on a 5-point scale. The CI users were asked at what age they had received their first (or only) implant and how often they used it from “Not often” to “All of the time” on a 4-point Likert scale. All the deaf participants were asked if they used a hearing aid and if so how often, again from “Not often” to “All of the time”. Finally, they were asked whether “Sign language” or “Speaking/listening” was their best form of communication. These language self-ratings have been used extensively with this population in previous studies, demonstrating that responses are consistent with objective assessments of sign language and spoken language abilities among deaf university students with and without CIs as well as with behavioral outcomes (e.g., Marschark et al. 2018; Spencer et al. 2018). Table 1 presents a summary of the participants’ responses to the communication questions.

### Sarcasm Task

Four short stories from Marschark et al. (2019, see Appendix) tested understanding of sarcasm. As the participants were all college students, adequate reading levels for these texts and the other measures were assumed. The task was untimed and, in order to minimize working memory load, the stories remained visible while participants answered the questions. For each vignette a single yes/no “control” question checked for comprehension of the story content (e.g., “Did Matt think Joe played well?”) followed by a “test” question which asked why a character had made the target comment (e.g., “Why did Matt say that Joe played really well in the game?”). The test questions were scored according to the descriptions provided by O’Reilly et al. (2014, Appendix A) as either correct (=1) or incorrect (=0).

### Metaphor Task

The metaphor comprehension task was drawn from Iskandar (2014). Each metaphor was of the format “An X is a Y” or “Xs are Ys”. The measure comprised 17 multiple-choice format items, each with four response options categorized as Abstract Complete reflecting a full explanation of the metaphor using a superordinate category pertinent for both X and Y components of the metaphor; Abstract Partial providing an abstract explanation that was incomplete or involved a superordinate category that was correct but tangential to the underlying concepts of the metaphor; Concrete reflecting concrete thinking (e.g., physical similarities between X and Y, providing a literally true statement that did not explain the functional similarity); and Other containing clearly wrong

**Table 1** Mean scores on communication variables for cochlear implant (CI) users ( $n = 32$ ) and deaf non-CI users ( $n = 42$ )

	CI users		Deaf non-CI users	
	Mean	SD	Mean	SD
Age at cochlear implantation (years)	6.59	5.2	n/a	n/a
	Range 1 - 20			
Age started to learn sign language (years)	9.93	7.0	7.67	6.5
	Range 1 - 19		Range 0 - 19	
Frequency of cochlear implant use <sup>a</sup>	3.41	1.1	n/a	n/a
Hearing Aid user	$n = 6$		$n = 32$	
Frequency of Hearing Aid use <sup>b</sup>	2.50	1.1	2.78	1.3
Spoken language – receptive <sup>c</sup>	2.72	0.9	1.83	1.1
Spoken language – expressive <sup>d</sup>	3.09	0.9	2.38	1.1
Sign language – receptive <sup>e</sup>	2.94	0.9	3.24	0.9
Sign language – expressive <sup>f</sup>	2.63	0.9	3.07	0.9
Best form of communication				
Spoken language	$n = 21$	(66%)	$n = 15$	(36%)
Sign language	$n = 11$	(34%)	$n = 27$	(64%)

<sup>a,b</sup> Scored 0 = “Not often” to 4 = “All of the time”

<sup>c</sup> Scored 0 = “Nothing” to 4 = “Everything people say”

<sup>d</sup> Scored 0 = “Nothing I say” to 4 = “Everything I say”

<sup>e</sup> Scored 0 = “Nothing” to 4 = “Everything I sign”

<sup>f</sup> Scored 0 = “I don’t know sign language” to 4 = “Excellent”

interpretations of the metaphor, but not obviously due to concreteness. The metaphor “The mind is a sponge,” for example, included the response choices: Abstract Complete – The mind can absorb a lot of information; Abstract Partial – The mind loves knowledge; Concrete – The mind has holes; Other – The mind is interesting. Responses were scored Other = 1, Concrete = 2, Abstract Partial = 3 and Abstract Complete = 4.

### Inference Making Tasks

Vignettes to assess the ability to make neutral and social-emotional mental state inferences from written text were taken from the Test of Problem Solving 2, Adolescent version (TOPS-2; Bowers et al. 2007). Because the participants in this study were beyond the age range of available norms, raw scores were used for analysis.

Eight passages were selected from the TOPS-2 that included questions from the Making Inferences and Interpreting Perspectives subscales, along with 12 of the 31 questions associated with them. The questions were chosen so that half required making a social-emotional inference, that is, asked what a person would feel in the particular situation described (i.e., tapping theory of mind), and half did not. The passages were presented one at a time, with the questions underneath, such that the participant was able to re-read the passage if they wished. Responses to the questions

were scored according to the instructions in the TOPS-2 manual as either correct (=1) or incorrect (=0).

## Memory Tasks

Two tests of verbal memory were used: forwards digit span and backwards digit span. Both were based on the Wechsler Adult Intelligence Scale (WAIS) format of presenting digits, one at a time, at the rate of one per second, but they were presented visually, on a computer screen, rather than aurally. In the forwards digit span task (FDS), a measure of short-term memory, participants saw sequences of digits of increasing length and, after each sequence, were asked to type into a response box the digits in the order presented. Testing continued with two trials at each sequence length starting with two, until the sequence length reached nine digits. FDS was operationally defined as the maximum number of digits the participant recalled correctly on at least one of the two trials. Due to programming constraints imposed by the software program, no ceiling/stop rule was applied; participants attempted every sequence length up to the maximum for each task. Therefore the possible range of scores on this task was 0 to 9. A participant could potentially fail both trials at one length (a common point for a stop rule in this type of task), but correctly respond at a subsequent length: In this scenario, the participant would receive credit at the longer sequence length.

Backwards digit span (BDS) provided a measure of verbal working memory capacity, again following the format of the WAIS. Participants were instructed to input the numbers into a response box on the laptop screen in the reverse order to that in which they were presented. For this task, they were given two practice trials of sequences of two digits, before proceeding to the test items, and the longest sequence of digits was eight. The BDS score was the maximum number of digits correctly recalled in reverse order on either of the two trials of a particular sequence length.

## Procedure

Participants were tested in a laboratory setting, individually or in groups of up to six students. Each student completed the tasks independently on a laptop, with measures presented in written format through the Qualtrics<sup>XM</sup> on-line survey platform. Participants entered their responses either by selecting a response option using a mouse or entering text using the keyboard. If clarification of the instructions was required, this was provided taking into account participants' communication preferences (sign language, spoken language, or both) through the availability of a sign language interpreter during testing. No further help was given.

## Results

### Group Comparisons of Task Variables

First, performance on each of the measures was compared across the three groups: CI, CI nonusers (hence “deaf non-CI”), and hearing, with a series of one-way ANOVA. Means, standard deviations and results of Bonferroni-adjusted post hoc comparisons for these analyses are presented in Table 2. Consistent with the methodology of

**Table 2** Results of post hoc, between-groups comparisons on each of the test variables

Test and Group	Mean	SD	Post Hoc Comparisons	
			Cochlear Implant	Deaf, non-Cochlear Implant
<i>Sarcasm</i>				
Cochlear Implant	0.75	0.32		
Deaf, non-Cochlear Implant	0.69	0.33	NS	
Hearing	0.89	0.15	$p = 0.17$	$p < 0.01$
<i>Metaphors</i>				
Cochlear Implant	9.59	2.28		
Deaf, non-Cochlear Implant	8.95	2.42	NS	
Hearing	11.37	1.84	$p < 0.01$	$p < 0.001$
<i>Neutral Inferences<sup>1</sup></i>				
Cochlear Implant	3.47	1.54		
Deaf, non-Cochlear Implant	3.55	1.55	NS	
Hearing	4.50	1.00	$p < 0.001$	$p < 0.001$
<i>Social-Emotional Inferences<sup>1</sup></i>				
Cochlear Implant	4.09	1.35		
Deaf, non-Cochlear Implant	3.52	1.33	NS	
Hearing	5.18	1.94	$p < 0.05$	$p < 0.001$
<i>Forwards Digit Span</i>				
Cochlear Implant	5.84	1.25		
Deaf, non-Cochlear Implant	5.36	1.65	NS	
Hearing	7.24	1.50	$p < 0.01$	$p < 0.001$
<i>Backwards Digit Span</i>				
Cochlear Implant	5.03	1.20		
Deaf, non-Cochlear Implant	5.00	1.61	NS	
Hearing	6.39	1.35	$p < 0.001$	$p < 0.001$

<sup>1</sup> Test of Problem Solving 2

Marschark et al. (2019) individuals' sarcasm test scores included only those items for which they had passed the corresponding control questions. This resulted in reduced sample sizes for the sarcasm task of 21, 31 and 36 for the CI, deaf non-CI and hearing groups respectively. The one-way ANOVA nevertheless revealed a significant effect of group,  $F(2,85) = 4.96$ ,  $p < 0.01$ . The Bonferroni adjusted post hoc comparisons indicated that only the deaf non-CI and hearing groups differed from each other.

For the test of metaphor comprehension, the total number of Abstract Complete responses was calculated for each participant. The one-way ANOVA on these scores again indicated a significant difference among the groups,  $F(2,109) = 12.66$ ,  $p < 0.001$ . Bonferroni-adjusted post hoc tests revealed that the hearing participants scored significantly higher than both groups of deaf participants, which did not differ from each other.

The total number of correct responses made by participants on the neutral and social-emotional inference questions were similarly subjected to one-way ANOVA. The main

effect of group was significant for both:  $F(2,109) = 13.97$ ,  $p < 0.001$ , and  $F(2,109) = 11.40$ ,  $p < 0.001$ , respectively. Finally, longest FDS and BDS scores were subjected to between-subjects ANOVA. Again, these analyses indicated significant differences among the groups,  $F(2,109) = 16.67$ ,  $p < 0.001$ , and  $F(2,109) = 11.98$ ,  $p < 0.001$ , respectively. The same pattern of post-hoc comparison results was found for each measure as was evidenced for metaphors (Table 2).

The aim of the last between-subjects analysis was to explore whether deaf and hearing individuals differed in the *type* of responses they selected in answering the multiple choice metaphor items. Since participants' scores on the response types were not independent of each other, four separate ANOVAs, one for each metaphor response type compared the frequency with which participants in the three groups chose each type of response. These analyses indicated significant differences among the groups for the Abstract Complete,  $F(2,109) = 12.66$ ,  $p < 0.001$ , Concrete,  $F(2,109) = 15.71$ ,  $p < 0.001$ , and Abstract Partial responses,  $F(2,109) = 3.22$ ,  $p < .05$ . Bonferroni-adjusted post hoc comparisons revealed that significantly more hearing than deaf participants (with or without CIs) selected the Abstract Complete interpretations of the metaphors, whereas the Other interpretations were chosen significantly more frequently by both deaf groups compared to the hearing group. The hearing participants also were more likely than the deaf students without CIs to choose Abstract Partial interpretations of the metaphors, whereas there were no differences between the deaf participants with and without CIs, or between the hearing group and CI group.

Given the lack of significant differences between the two deaf groups on every task where the score reflected the number of correct responses as well as in the final ANOVA reported above, their data were combined for all subsequent analyses. These examined the relationships among the communication measures, inferencing ability and memory capacity.

### **Relationships between Communication Variables and Inferential Comprehension Tests**

Pearson product-moment correlations were calculated for the deaf participants between each of the variables derived from the communication questionnaire and the tests of inferencing ability. As indicated in Table 3, significant correlations were found between all of the self-rated indices of receptive and expressive spoken and sign language ability and scores indicating understanding of both sarcasm and metaphors, such that better spoken language skills were associated with better performance. In contrast, self ratings indicating stronger receptive and expressive signing ability were associated with poorer understanding of sarcasm and metaphor. Receptive sign language ability was also negatively correlated with the ability to make both neutral and social emotional mental state inferences. Furthermore, deaf participants who reported their best form of communication to be spoken language performed better than those who communicated best using sign language on the social-emotional inference questions. Short-term memory, assessed by the longest FDS, was significantly related only to self-rated receptive sign language ability, as participants who reported better understanding of what others sign to them had shorter FDSs. Neither the age at implantation, nor the age at which participants started to learn sign language was related to any of the inferential comprehension or memory span measures.

**Table 3** Correlations between communication variables, self-report language skills, and scores on sarcasm, metaphor, inference comprehension, and memory tasks in deaf participants

	Sarcasm	Metaphors	Neutral Inferences <sup>1</sup>	Social-Emotional Inferences <sup>1</sup>	FDS <sup>2</sup>	BDS <sup>3</sup>
Age at Cochlear Implantation	-0.181	-0.272	-0.170	0.067	-0.017	0.065
Age started to learn sign language	0.127	0.020	0.176	0.133	0.163	0.000
Frequency of Cochlear Implant use	0.138	0.337	0.131	0.320	0.001	-0.058
Frequency of Hearing Aid use	0.090	0.059	-0.095	-0.066	-0.190	0.011
Spoken language – receptive	0.238*	0.365**	0.134	0.178	0.098	0.203
Spoken language – expressive	0.355**	0.358**	0.115	0.223	0.171	0.198
Sign language – receptive	-0.478**	-0.315**	-0.283*	-0.277*	-0.255*	-0.043
Sign language – expressive	-0.325**	-0.278*	-0.194	-0.162	-0.175	0.052
Best form of communication	0.353**	0.411**	0.204	0.286*	0.119	0.085

\*  $p < 0.05$ , \*\*  $p < 0.01$

<sup>1</sup> Test of Problem Solving 2, <sup>2</sup> Forwards Digit Span, <sup>3</sup> Backwards Digit Span

### Relationships between Inferential Comprehension and Memory Capacity

Considering the deaf and hearing participants separately, Pearson product-moment correlations were calculated among the sarcasm, metaphor, neutral and social-emotional inference questions and longest FDS and BDS scores. None of the correlations were significant in the hearing group. Table 4 shows the relationships among these variables for the deaf participants. Significant positive correlations were evidenced between every combination of variable pairs, with the exception of the longest FDS score and total number of Abstract Complete responses on the metaphor test. With this exception noted, better performance on the tests of understanding of sarcasm, metaphors, and in the ability to make inferences was associated with greater immediate memory span and working memory capacity.

**Table 4** Correlations among scores on tests of sarcasm, metaphor, inference comprehension, and memory capacity in deaf participants

	Metaphors	Neutral inferences <sup>1</sup>	Social-Emotional inferences <sup>1</sup>	FDS <sup>2</sup>	BDS <sup>3</sup>
Sarcasm	0.639**	0.614**	0.618**	0.419**	0.445**
Metaphors		0.479**	0.510**	0.210	0.454**
Neutral inferences			0.568**	0.288*	0.362**
Social-emotional inferences				0.434**	0.478**
FDS					0.447**

\*  $p < 0.05$ , \*\*  $p < 0.01$

<sup>1</sup> Test of Problem Solving 2, <sup>2</sup> Forwards Digit Span, <sup>3</sup> Backwards Digit Span

## Predicting Inferential Comprehension Ability

A series of stepwise multiple regression analyses was conducted to examine factors that might underlie the observed difficulties of deaf students in understanding figurative language and making inferences. Analyses first examined the role of communication/language factors in making neutral and mental state inferences from text. In order to maximize power of the analyses, only those variables that did not exclude any of the deaf participants (e.g., age at implantation would have excluded all the nonusers) were entered as predictors, and sarcasm, metaphor, neutral and mental state inferences served as criterion variables. Thus the five predictor variables included were self-rated receptive and expressive spoken language ability, self-rated receptive and expressive sign language ability, and best form of communication.

Analysis of the deaf participants' sarcasm scores yielded only receptive sign language ability as a significant predictor,  $R^2 = 0.22$ ,  $\beta = -0.48$ ,  $F(1, 72) = 21.32$ ,  $p < .001$ , as better self-rated understanding of sign language predicted poorer understanding of sarcasm. The ability to grasp the most abstract interpretation of metaphors (Abstract Complete responses) was predicted by the participants' best form of communication, such that those who reported speaking/listening as their best language were more able to interpret metaphors abstractly,  $R^2 = 0.16$ ,  $\beta = 0.41$ ,  $F(1, 72) = 14.62$ ,  $p < 0.001$ . Analysis of the ability to make neutral inferences from text also yielded only one significant predictor: again, self-reported receptive sign language skills, with better understanding of sign language predicting poorer ability to make neutral, non-mental state inferences,  $R^2 = 0.07$ ,  $\beta = -0.28$ ,  $F(1, 72) = 6.29$ ,  $p < 0.05$ . Finally, making inferences in social-emotional contexts was associated with the deaf participants' best form of communication, such that self-reported greater proficiency in spoken language predicted stronger ability to make mental state inferences,  $R^2 = 0.07$ ,  $\beta = 0.23$ ,  $F(1, 72) = 6.39$ ,  $p < 0.05$ .

Two further regression analyses examined the prediction of sarcasm and metaphor comprehension using variables selected based on previous findings reported in the literature and those required specifically to address the aims of the study. Table 5 presents the results of a stepwise multiple regression analysis with self-rated receptive spoken and sign language skills, best form of communication, social-emotional mental state inferences, neutral inferences, and longest BDS as predictor variables, and sarcasm as the criterion variable. The ability to make social-emotional mental state inferences was the strongest predictor of sarcasm understanding, accounting for 38% of the variance in sarcasm scores. Poorer self-reported understanding of sign language, the ability to make neutral inferences and working memory, in that order, each contributed additional significant variance to the understanding of sarcasm, with the full model accounting for 56% of the variance in sarcasm scores.

Finally, a parallel stepwise regression analysis with the same independent variables was conducted with the ability to make fully abstract interpretations of metaphors (Abstract Complete scores) as the criterion variable (Table 6). Again, making social-emotional mental state inferences predicted the greatest proportion of variance (26%), with the remaining three significant predictors contributing a further 17.6% of variance. However, in this instance, after the ability to make social-emotional inferences, the deaf participants' best form of communication (spoken over sign language) was the strongest predictor, followed by working memory capacity, which contributed 6.5% to the variance accounted for in metaphor scores. Neutral, non-mental state inferences, while making a significant contribution to the model, accounted for only 3.4% of additional variance.

**Table 5** Stepwise multiple regression analysis predicting sarcasm understanding from self-report communication, neutral and social-emotional inferencing, and working memory variables

Predictor	R <sup>2</sup> (adjusted)	Standardized $\beta$	F (change)	Significance of F (change†)
Mental state inferences	0.382	0.618	44.534	0.000†
Mental state inferences	0.484	0.526	14.026	0.000†, 0.000
Sign language - receptive		-0.332		0.000
Mental state inferences	0.558	0.349	11.683	0.000†, 0.001
Sign language - receptive		-0.287		0.001
Neutral inferences		0.334		0.001
Mental state inferences	0.586	0.267	4.699	0.034†, 0.011
Sign language - receptive		-0.310		0.000
Neutral inferences		0.304		0.002
Backwards Digit Span		0.194		0.034

## Discussion

This study aimed to extend understanding of inferencing abilities and possible processing mechanisms underlying these abilities in deaf college students. On all the measures of the ability to make inferences, with the exception of sarcasm, both groups of deaf students (CI users and nonusers) were significantly outperformed by their hearing counterparts, but the two deaf groups did not differ from each other. This latter finding is consistent with the growing body of evidence that the benefits of CIs to language acquisition, cognitive development, social communication and psychological well-being that have been documented in the preschool and primary school years are attenuated or have disappeared by secondary and college level education, for a variety of reasons (Marschark and Knoors 2019; Marschark et al. 2015). The late age at which the implant users received their first (or only) CI might be thought to contribute to the present inferencing results but, consistent with a variety of other studies, age at implantation was not a significant predictor of cognitive performance in any of the regression analyses. Similarly, although a number of the students who reported being CI users also reported that they used the device only infrequently, frequency of CI use was not a significant predictor of performance. Alternatively, the absence of significant differences between the two groups of deaf students may derive from the functioning of the implant device itself. The auditory signal provided by CIs is comparatively degraded relative to normal hearing, potentially contributing to delays in the development of linguistic and cognitive skills (e.g., Nittrouer et al. 2014). This is particularly relevant in the case of understanding spoken nonliteral language such as sarcasm and irony, where recognition of the emotional qualities of an utterance through prosodic cues may not be readily accessible to CI users (Chatterjee et al. 2015; Most and Aviner 2009). Thus while long-term CI use may support the development of good language skills in many recipients, grasping the more subtle, nuanced aspects of social interactions

**Table 6** Stepwise multiple regression analysis predicting metaphor understanding from self-report communication, neutral and social-emotional inferencing, and working memory variables

Predictor	R <sup>2</sup> (adjusted)	Standardised $\beta$	F (change)	Significance of F (change $\dagger$ ),
Mental state inferences	0.260	0.510	25.316	0.000 $\dagger$
Mental state inferences	0.337	0.428	8.918	0.006 $\dagger$ , 0.000
Best form of communication		0.289		0.006
Mental state inferences	0.402	0.283	7.699	0.007 $\dagger$ , 0.012
Best form of communication		0.305		0.002
Backwards Digit Span		0.292		0.007
Mental state inferences	0.436	0.171	4.149	0.045 $\dagger$ , 0.159
Best form of communication		0.293		0.003
Backwards Digit Span		0.265		0.013
Neutral inferences		0.226		0.045

is likely to remain a challenge. If this is the case for spoken language it is conceivable that the understanding of these pragmatic aspects of language are equally hard to identify in written text.

### Differences between Deaf and Hearing Students

The significant differences evidenced between the deaf students and their hearing counterparts on all of the inferencing and memory measures were not entirely unexpected in view of previous research in deaf children and young adults (Marschark et al. 2019; Marschark and Knoors 2019). It is unlikely that domain-general influences such as overall intellectual ability or fluid reasoning skills can account for these differences, given that all were attending university and therefore could be assumed to be functioning at a level associated with this educational stage. Instead, explanations for these delays or deficits in abilities across the range of inferencing tasks employed in this study may variously draw on the relationships between auditory deprivation and language acquisition, early conversational access and neurocognitive processes (Kral et al. 2016; Peterson 2020). While the first two of these have proved popular viewpoints, they cannot fully account for the difficulties deaf individuals experience in mastering inferential comprehension.

The present study included four different measures of inferencing ability varying in the extent to which they tapped the ability to understand mental state, or theory of mind inferences. Despite being college students, consistent with the conclusions of Kyle and Cain (2015), the deaf participants in this study were poorer than their hearing peers at providing appropriate responses to questions requiring inferences about everyday situations and past events. Therefore it appears that even at this basic level, hearing loss is associated with difficulty drawing conclusions not explicitly stated from information contained in texts. Thus the problems experienced by deaf individuals in making mental state inferences apparently do not reflect a domain-specific difficulty,

but rather a more general difficulty in concept formation and representational understanding (Castellanos et al. 2014).

Another task focused on social-emotional inferences. Despite the apparent simplicity of this task, reflecting as it did only first-order theory of mind understanding, the deaf participants evidenced significant difficulty naming socially conventional emotional states compared with their hearing peers. Previous research findings are mixed, but studies where the deaf participants were on a par with their hearing peers in emotion recognition (e.g. Ziv et al. 2013) focused on a limited range of “basic” emotions – typically happiness, sadness, anger, fear, and disgust. In contrast, the task in the present study demanded a more sophisticated understanding of emotional states, correct responses including terms such as, “shy”, “self-conscious”, “guilty”, and “nervous”.

A third task indicated that the ability to recognize the use of sarcasm in everyday social contexts was more problematic for the deaf students relative to their hearing peers. This is consistent with previous studies of both children and young adults (Marschark et al. 2019; O’Reilly et al. 2014) and confirms the more general finding that hearing loss is associated with delayed development of advanced theory of mind abilities (Peterson 2020). While lack of exposure to rich and diverse conversational input about mental states early in life may play a significant role in the delays in theory of mind development evident in deaf children and adolescents, later exposure to the typical social interactions of young adults, including those with similar communicative abilities and preferences in a college setting, does not appear to have been sufficient to ameliorate the deficit observed in college-age students.

In this study metaphors were also poorly understood by the deaf college students, a result consistent with Orlando and Shulman (1989), who found that explanations of metaphors provided by deaf children were more likely to be literal (i.e., concrete) than those provided by hearing peers. The present findings indicated that the deaf participants were more likely to select partially abstract or literal/irrelevant interpretations than their hearing counterparts, whereas the hearing participants were more likely to select the most abstract interpretations for the metaphors. Relatedly, the Gold and Segal (2017) study suggested that deaf adults had difficulty in interpreting novel poetic metaphors as compared to more conventional metaphors, although that finding may have resulted from a confounding of metaphor type and familiarity (see Gold and Segal 2017, Appendix A) or vocabulary knowledge. Whether these differences are more a function of language abilities (signed or spoken) or experience with nonliteral language remains to be determined. The only pertinent variables available for the purposes of this study were self-reports of deaf participants’ expressive and receptive language skills, neither of which (in either mode) speaks to the vocabulary, problem solving, and metacognitive abilities necessary for metaphor comprehension.

Finally, verbal memory span and verbal working memory capacity were significantly smaller in the deaf students compared with their hearing counterparts, irrespective of CI use, consistent with a large body of previous evidence (Kronenberger and Pisoni 2020; Pisoni et al. 2011). Many causes of congenital deafness are likely to influence the development of the auditory pathways of the brain before birth, with further impacts of the lack of spoken language input on the development of a functional brain connectome, from birth through to adulthood (Kral et al. 2016). Thus despite

remarkable brain plasticity, especially during the first few years of life, it is possible that lack of auditory stimulation has affected the neural pathways that support executive function abilities such as verbal working memory, if not before the influence of reduced language input then concurrently with it.

### **Relationships between Understanding Inferences and Communication Abilities**

Perhaps the most noteworthy aspect of these results lies in the contrast between the ability to comprehend sarcasm and metaphors by deaf students who rated themselves as having good receptive and expressive spoken language skills versus those who rated their equivalent proficiency in sign language as good. Among the deaf participants, better spoken language skills were associated with better understanding of sarcasm and metaphors. However the opposite was true for sign language skills: Students who rated themselves as having a higher level of sign language ability, both in terms of understanding sign and making themselves understood, showed *poorer* understanding of sarcasm and metaphors, the reverse of what the conversational account of theory of mind theory of mind delays would predict. Those results are consistent with a variety of recent findings indicating that by secondary school and college age, deaf students' spoken language skills are positively related to a variety of academic outcomes, while their sign language skills are negatively related or independent of such outcomes (Crowe et al. 2017; Marschark et al. 2015).

The most likely explanation for the present findings can be found in the nature of the tasks employed. Both sarcasm and metaphor require a more sophisticated, advanced level of mental state inferencing than the first and second order false belief tasks that have typically been the focus of studies finding an advantage to theory of mind understanding in deaf children who are proficient in sign language (for reviews, see Marschark et al. 2019; Peterson 2020). This interpretation is supported by the significant correlations between performance on the three tasks that required mental state inferencing (social-emotional inferences, sarcasm and metaphors) and the deaf students' self-reported best mode of communication – spoken or sign language. Those students whose strongest language was spoken English performed better on all three of the tasks requiring the ability to attribute mental states. The fact that this relationship was not found for the ability to make neutral inferences based on world knowledge, further points to the special status of mental state inferencing and communication modality in deaf individuals. Importantly, this is not to suggest that sign language has a negative impact on social-emotional inferencing per se. Rather, it reflects the relatively greater utility of spoken language for the complex functioning required by the present tasks. As such, it is consistent with findings from a variety of recent studies indicating that at secondary and college levels, deaf students who rely primarily on spoken language demonstrate a variety of cognitive, academic, and social-emotional advantages over those who rely primarily on sign language (see Marschark and Knoors 2020; Marschark et al. 2015; for reviews).

### **Relationships between Understanding Inferences and Memory Capacity**

Strong and consistent relationships were evidenced between the tests of short-term memory and working memory, and all four of the tests of inferential comprehension:

Having greater short-term and working memory capacities was found to support the comprehension of nonliteral, figurative language in text. This result supports the findings of Iskandar and Baird (2014), that working memory contributed to hearing college students' ability to generate abstract (rather than concrete or irrelevant) explanations for metaphors, a process likely to be dependent on the ability to simultaneously hold and evaluate multiple possible interpretations of the metaphors. Additionally, our results are consistent with a number of previous studies involving both hearing and deaf individuals that have reported associations between working memory and inferential comprehension, first- and second-order as well as advanced theory of mind abilities, and metaphor interpretation (Cain et al. 2004; Carriedo et al. 2016; Chiappe and Chiappe 2007; Holmer et al. 2016; Meristo and Hjelmquist 2009; Olkonieni et al. 2016). Individuals with longer working memory spans would have greater processing resources to devote to inhibitory control needed to suppress the literal interpretations of figurative language (Chiappe and Chiappe 2007).

One of the most interesting, and perhaps most surprising aspects of these correlational analyses was the complete dissociation of outcomes between the deaf participants and their hearing counterparts, with no significant relationships between verbal memory and inferential comprehension in the hearing students. Although a number of studies have evidenced such associations in hearing children and adults (e.g., Carriedo et al. 2016; Chiappe and Chiappe 2007), some, more commonly in clinical or other neuro-atypical populations including those with hearing loss, have found equivalent or related dissociations between groups (Ozonoff et al. 1991; Peterson 2015). Other studies provide an alternative approach to understanding this dissociation by dividing participants into groups based on their working memory capacity, finding that those with poorer working memory are also inferior at processing or producing metaphorical language (Monetta and Pell 2007; Chiappe and Chiappe 2007). Similarly, Carriedo et al. (2016) separated their healthy, neuro-typical participants into groups based on whether they were "more efficient" or "less efficient" metaphor processors: Working memory was only related to metaphor comprehension in the less efficient group.

Another strength of the current study relates to the common complaint when this kind of dissociation is found, which suggests that hearing samples do not show sufficient variability in the variables tested for correlation. This clearly is not the case in this study. It is evident from Table 2 that the standard deviations for the hearing group were well within the ranges of those for the two deaf groups on both digit span measures and social-emotional inferences. Furthermore, the standard deviations for the hearing group appear quite large for the metaphor comprehension task as well. It is possible that the standard deviations for the hearing group on the sarcasm task produced a restricted range, but this one marginal finding does not explain the complete lack of significant correlations within the hearing group. Future research might therefore investigate similarities and differences in the distributions of scores on inferencing, memory, and nonliteral language tests in groups of deaf and hearing populations.

Taken together, along with the longitudinal studies of the relationship between executive function and theory of mind development (e.g., Austin et al. 2014), these studies support the contention that for deaf young adults, adequate

working memory ability is a pre-requisite for making inferences, including mental state inferences, and the understanding of nonliteral language such as sarcasm and metaphors.

### **Predicting Understanding of Sarcasm and Metaphor**

Building on the findings of Marschark et al. (2019) this study aimed to further determine the extent to which a range of cognitive, language, and communication factors contribute to the difficulties experienced by deaf college students in interpreting sarcastic comments. Almost 40% of the variance in sarcasm comprehension was accounted for by the ability to infer emotions to others in social contexts, a first-order theory of mind ability. This is not surprising given that understanding sarcasm requires an appreciation of the social context and the speaker's emotional state. The outcome thus is consistent with the results of Olkonemi et al. (2016) who included a measure of participants' ability to use emotional information for decision-making in their investigation of processing of sarcasm and metaphors in written texts. A further 10% of the variance in performance on the sarcasm task was accounted for by students' self-rated receptive sign language skills, with better skills predicting poorer understanding of sarcasm. This may simply reflect the nature of the sarcasm task used in terms of tapping advanced theory of mind understanding rather than first-order false mental state inferences. However, recent studies have demonstrated that deaf college students' receptive sign language skills are not as good as they think they are (e.g., Spencer et al. 2018; Walton et al. 2019), and it thus may be that, aside from a few native signers, participants who rated their skills higher simply may have been incorrect in their self-assessments. Alternatively, it is also possible that the result reflects a more subtle, complex picture of the interplay between sign language skill and advanced higher-order understanding of mental states (e.g., metacognition) that warrants further exploration.

The remaining two variables that contributed significant variance to the prediction of sarcasm comprehension were the ability to make neutral, non-mental state inferences, and working memory, which together accounted for another 10% of the variance. Thus deaf college students' difficulties in several cognitive domains may disrupt the comprehension of nonliteral language as it does for the higher order comprehension of other verbal material (Marschark and Knoors 2020). Consistent with this suggestion is the role of working memory as an important cognitive process in aiding the processing of sarcasm, probably through enhanced ability to simultaneously hold in mind (and inhibit) alternative interpretations of an utterance while processing and perhaps re-processing the context.

As with sarcasm, and consistent with the hypothesis that interpreting figurative language requires making inferences about the mental state of the trope producer, the primary predictor of participants' scores on the metaphor comprehension was their scores on the social-emotional inferencing task. This may be a reflection of the nature of the metaphors, the subject of many of which was either directly about an emotion (e.g., "Love is a flower"), or suggested a social perspective (e.g. "Alcohol is a crutch", "A judge is a balance"). In addition, both participants' spoken language ability—as reflected in their indicating speech to be their best form of communication—and working memory capacity accounted for significant portions of variance in metaphor

comprehension scores. As Carriedo et al. (2016) pointed out, especially in the absence of context as in this task, understanding metaphors requires relatively high levels of cognitive processing involving relational reasoning, cognitive inhibition, and working memory. These findings further emphasize both the complexity of metaphor comprehension and its reliance on both language and cognitive abilities.

## Implications and Future Directions

Many authors have indicated the importance of age-appropriate theory of mind understanding for normal development of social interactions and social competence. Variations in capacity on theory of mind tasks should therefore lead to variations in scores on assessments of social competence, and this has been found to some extent in hearing preschool and school-age children (Banerjee et al. 2011; Devine et al. 2016). Recent studies by Peterson et al. (2016a) and Peterson et al. (2016b) also demonstrated links between theory of mind mastery and social skills such as leadership, coping with frustration in interactions with peers and peer popularity in deaf children up to around 13 years of age. However, it is during adolescence and beyond that the use of metaphors, and in particular advanced theory of mind abilities such as irony and sarcasm, become of increasing importance. The current study confirmed that in many deaf individuals difficulty recognising that an utterance is intended to be sarcastic and not taken literally persists into early adulthood. Results also revealed clear difficulty in the ability to make mental state inferences attributing socially appropriate emotions. A valuable next step would be to clarify whether within this age range such difficulties impact upon social skills and peer relationships, either directly or moderated by another factor such as CI use, communication mode or communication efficacy.

A number of studies have highlighted the importance of executive function skills for social-emotional development. Several studies have explored this relationship both in terms of correlations between the constructs (e.g., Hintermair 2013) and the impact of interventions to promote social-emotional competence that focus, for example, on impulse control, social problem solving, awareness and regulation of feelings, and the accurate perception of the perspectives of others (Riggs et al. 2006). One limitation of our study was the lack of objective test of inhibition (impulse control). Given previous research demonstrating significant associations between inhibitory control and theory of mind ability in young children, including those with hearing loss and CIs (Austin et al. 2014; Cantin et al. 2016; Kouklari et al. 2018; Liu et al. 2018; Mutter et al. 2006) inclusion of such a measure is likely to have further strengthened the proposition that executive function skills continue to play an important role later in the development of deaf individuals, influencing advanced theory of mind abilities such as the comprehension of sarcasm and metaphors.

Finally, one issue yet to be resolved is the long-term influence of CIs on the capacity of deaf individuals to develop age-appropriate mental state inferencing skills in adolescence and beyond. As yet firm conclusions cannot be drawn regarding the potential facilitation of this audiological intervention on mental state (and indeed world knowledge) inferential understanding. Thus, future research could usefully explore in detail the developmental trajectories of advanced mental state inferencing ability and executive function in adolescence and early adulthood in youngsters who received their implants very early in life.

In conclusion, from a theoretical perspective this study supports a biopsychosocial conceptualisation of the difficulties experienced by deaf students in making inferences and, in particular, mental state inferences. The experiences of deaf children are arguably more diverse and unique to each child than those of their hearing counterparts, their hearing losses impacting language exposure, parent-child interactions, educational opportunities and approaches, and more. Influences of these factors on theory of mind development are likely to be bi-directional and recursive to a greater or lesser extent dependent on the particular factor(s) in question. While the conversational account of delays in theory of mind development in deaf children has provided a convincing starting point (Peterson 2020), it is not the whole story and other factors undoubtedly play a role (Tucci and Easterbrooks 2020). Neurocognitive, domain-general influences such as working memory are clear contenders in further explaining the great variability between deaf individuals in their theory of mind development, and in particular their ability to understand sarcasm and metaphors.

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## Compliance with Ethical Standards

**Conflict of Interest** The authors declare no conflicts of interest.

**Ethical Approval** All procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed Consent** Informed consent was obtained from all participants in the study.

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<sup>1</sup> Throughout this paper “deaf” should be understood to refer to deaf and hard-of-hearing individuals.

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