The Impact of Access to Verbal Language on Working Memory: A Study of Working Memory on Profoundly Deaf Adults

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To my parents, who wouldn’t have been surprised.

Abstract

Working Memory, the ability to retain, manipulate and recall small amounts of information is vital for planning, comprehension, reasoning and problem solving. A core concept of Working Memory is the exercise of the phonological loop and sub-rehearsal. Studies have suggested Deaf individuals suffer by comparison with their hearing counterparts on Working Memory tasks. Tests using core elements of verbal language, e.g. digit spans or narrative discourse may create a bias against profoundly deaf individuals who have never heard verbal language. This current study uses the Corsi test on deaf and hearing participants recruited through social media. A one-way ANOVA examined the relationship between hearing status and Working Memory as measured by scores on the Corsi test. Findings did not support a relationship between hearing status and Working Memory. A two way between groups ANOVA was used to examine the possibility that hearing status, access to language inside participants own modality and Working Memory was correlational. Access to language was operationalised by participants parents primary language matching their own. There was no significant relationship found. It is this researchers opinion that and examination of the validity of Working Memory tests in use on Deaf participants be conducted.

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The Impact of Access to Verbal Language on Working Memory:

A Study of Working Memory on Profoundly Deaf Adults

The Deaf Community in Ireland is estimated to be approximately 5000 people (Citizens Information Board, CIB, 2017). A wider community encompassing Deaf and Hard of Hearing is estimated to comprise 2.2% (103,676) of the population of Ireland, (CIB, 2017; *Census of Population 2016 – Profile 9 Health, Disability and Carers*, 2016). 8% of the adult population of Ireland have a permanent acquired hearing loss of a significant degree, rising to 50% in those aged over 70 years of age (*National Audiology Review*, 2011). While debate continues on what exactly constitutes the Deaf Community in Ireland, for the purpose of this study it is defined as those who are Deaf and whose have chosen primary language is sign language (SL). While the Deaf community is internally vibrant, as a linguistic minority they are exposed to possible discrimination, marginalisation and isolation from the larger community (Andrews, 2022; Bosco Conama, 2013), with 23% of this population reporting difficulties in the areas of occupation and attending school or college. 28% of the Deaf or Hard of Hearing population reported difficulties interacting outside the home in situations such as shopping alone or visiting a doctor (*Census of Population 2016 – Profile 9 Health, Disability and Carers*, 2016).

Research into the Deaf Community in Ireland is limited, however, what is available indicates that 90-95% of Deaf people are educated in mainstream settings (Leeson, 2018), have lower levels of educational attainment compared with their hearing peers and are less likely to attend third-level education (Citizens Information Board, 2017). Central Statistics Office (CSO) statistics indicate that 34% of Deaf people in Ireland left the education system before reaching the age of 15-years-old. This is three time the average for the state as a whole. Only 11% of Deaf people have degree-level qualifications, compared with 26% of people with no disability (*Census of Population 2016 – Profile 9 Health, Disability and*

Carers, 2016). Deaf people show lowered rates of employment compared with the hearing population, a significant contributing factor being Deaf people have markedly lower literacy levels compared with the hearing community (CIB, 2017).

Deafness and the late access to language has been shown to negatively predict Working Memory (WM) scores in traditional language based task such as digit spans and narrative discourse (Marschark, 2006). WM is the capacity to encode, store, manipulate and recall information (Baddeley, 1984). WM uses two main mechanisms of sub-rehearsal: the Phonological Loop (PL) and the Visuospatial Sketchpad (VS) (Baddeley, 1984; Baddeley, 2003 Logie et al., 2020). The VS stores and process information in a visual or spatial form. The PL deals with spoken and written material. Sign Language (SL) is a system by which linguistic information is communicated in the visuospatial modality (Rudner et al., 2009; Wilson & Emmorey, 1997). Deaf Native Signers (DNS) are signers who have been exposed to sign language from birth, most likely due to one or both parents also being Deaf. In this situation children acquire their primary language within normal developmental times (Wilson & Emmory, 1997). Non-Native Signers are Deaf signers who experienced a delay in learning SL. A similar delay is experience by children diagnosed later in childhood, or children and adults who become Deaf through illness or injury.

Visuospatial Sketchpad as a Phonological Loop

Most SLs contain a phonology (patterns and sounds), morphology (internal structure) and syntax (arrangement) as complex as that of most spoken languages, (Becker, 2020). SL is a composition of independent visual-gestural features, communicated through hand-shape, palm orientation, location in space and motion (Zeshan, 2003). Language based tasks constitute a large proportion of WM tasks. Language based tasks are commonly believed to utilise the PL (Baddeley et al., 1998), a sub-rehearsal network which allows the average person to retain seven (± 2) pieces of information in WM. However, when dealing with unnamed objects this drops to five (± 2) (Cowan, 2001; Jou, 2001). The PL had previously been shown through studies of patients such as P.V. by Baddeley in the 1980s, not to be essential for native language comprehension. P.V. had a PL deficit and while he displayed little difficulty on WM tasks in his native language, he had difficulty learning words in previous unlearned languages, indicating the importance of WM in new learning.

Wilson and Emmorey (1997), investigated whether the VS could function as a language-based rehearsal loop, if it was subject to the same constraints as the PL. Baddeley (2003) presumes a relationship similar to that of the PL exists between the VS and visual semantics but to date there has been little research in this area. Wilson and Emmorey (1997) posit that the relationship exists and that any evidence to the contrary is a result of test materials being presented via inappropriate modalities, not creating a truly like-for-like situation. This was further supported when one experiment saw on Deaf adults, native signers pitched against hearing English speakers in speed reading tests and short term memory (STM) span. Each undertook the test inside their own modality, ie signers only received signed stimuli. They found no significant differences in speed or memory span, though comparison across modalities can cause difficulties disseminating data (Boutla et al., 2004).

Language Exposure

A study by Marshall et al., (2005) investigated the impact of language exposure on WM. If language exposure and not deafness predicted results on non-verbal WM tasks, then native signers and typically hearing English speakers (THES) should score alike as both sets of children had theoretically reached their language development goal withing the proper timeframe. Their sample population consisted of children aged between eight and 12-years-old, Deaf native and non-native signers and THES. Their hypothesis was supported with non-native signers scoring significantly lower than both native signers and THES. Native signers and THES showed no significant difference in scores. A preliminary scan of studies has yet to yield test of non-verbal WM on adult Deaf signers who have achieved a level of fluency in their native language as compared with a control group of similarly aged heading adults. Some findings indicate that access to verbal language may actually be a hinderance with congenitally profoundly Deaf individuals benefiting from less reliance less on phonology (Emmorey & Lee, 2021), this study involved a population of skilled adult readers.

Narrative Discourse as a Test of WM

An Italian study conducted by Arfé and Perondi (2008), on both Deaf and hearing students using written narrative discourse, compared referential errors between groups. Written narrative discourse involves writing stories where events are contingent on one another, and which typically have more than one character. While the number of errors produced by both the Deaf and typically hearing participants were similar, the differed in type. Hearing participants transferred speech patterns into written passages. Their errors tool the form of referential ambiguities. The errors created by Deaf students tended towards the opposite. The overuse of nouns resulted in fragmented written discourse. They report this stemmed from the belief that the reader would be unable to follow the discourse without a heavily marked trail. The researchers attributed this to cognitive and linguistic challenges of the task rather than developmental issues. There were no native signers in this experiment to contest their findings.

Three decades earlier, McAfee et al. (1990) raised a warning flag when results of their study into this phenomenon indicated that Deaf children’s difficulties with narrative discourse was pragmatic in nature. They believed it to stem from a lax approach in schools and at home to grammatical rules, particularly as the same errors may not have been as evident in signing. However, research by Candida Peterson (2004) indicated that hearing children scored significantly higher than Deaf non-native signers on Theory of Mind (TOM) tasks. TOM is the ability to attribute mental states, your own and others (Premack &

Woodruff, 1978). Non-native signing children scored equally with autistic children of the same age. Woolfe et al., (2002) suggest that this may be due to non-native signers spending their early years in an environment which, due to their parents lack of SL, resulted in a compromised quality of social interactions.

The validity of WM tests using narrative discourse must come under question when disseminating results between modalities is presents such complex need for qualification. Further research is needed into within-modality situations. At the time of writing, there was an absence of empirical data on adult Deaf signers questioning if life experience could mitigate poor performance on narrative discourse tasks.

Neurology

As previously discussed, sign language and spoken language share the same complex structure and are layered in much the same way (Emmorey & McCullough, 2009). The difference being the modality by which they are transmitted (Rudner et al., 2009). Neurologically, it has been shown that the brains systems involved in speech processing are similar to those involved in conveying visual information though visuospatial means, ie SL (Petitto et al., 2000). This would suggest that modality should not matter (Hickok et al., 1998; Petitto et al., 2000), and that speed and veracity of processing should be consistent between the two modalities. A study of STM in Deaf native signers and THES by Bavelier et al., (2008) asked participants to undergo a verbal recall test while connect to an fMRI machine. There was some belief that the left hemisphere has been shown to effectively annex the motion processing systems for sign language process (Chiarello et al., 1982). However, Bavelier et al., (2008) observed the frontoparietal network activating in both cases. This supports the hypothesis that the same neural network is used in processing language.

Neural networks in the brain for signing and speech appear to be highly similar (Petitto et al., 2000), lending support to the concept of what is virtually an a-modal STM system. However, how the network is utilised at different stages of the process may vary by modality, with Deaf signers relying more heavily on passive memory storage areas during encoding and maintaining (Bavelier et al., 2008). The suggested that Deaf signers also relied more heavily on the executive process areas during retrieval. Deaf signers are less likely to use areas involved in chunking and manipulation during encoding. These areas are important to speech encoding and maintenance but Deaf signers engage these areas during recall to a greater extent than hearing people

Non-verbal WM

Non-verbal WM raises no issues with modality. Deaf people have been shown to perform well on non-verbal WM tasks involving sequential recall or visuospatial memory task such as the Corsi Block Test, typically comparable to or outperforming THES (Capirci et al., 1998; Romero Lauro et al., 2014), in a longitudinal study tested non-verbal WM on school children using the Corsi test in two experimental conditions, before learning sign language and after one year of sign language classes. The found after one year that typically hearing students performed equally with Deaf students, indicating that high scores where a product of training is a visuospatial modality and not as a result of deafness.

The Corsi test is a WM task, essentially a visual digit span (Kessels et al., 2000). In a study conducted by Romero Lauro et al., (2014), using the Corsi test forwards and backwards for the first time on Deaf native signers and a control group of typically hearing, the Deaf outperformed the hearing. Romero Lauro et al., (2014), concurs with Caprici et al. (1998) that the spatial nature of the tool complimented the spatial nature of sign language.

The present study

The aim of this study is to investigate if access to verbal language in an adult population will predict scores on purely non-verbal WM tasks across three populations profoundly Deaf at birth or prior to five years of age (PDP5), profoundly Deaf after the age of five years (PDA5) and typical hearing English speakers (THES). PDP5 have had no access to verbal language; PDA5 may have heard verbal language prior to becoming Deaf; THES typically use verbal language as their primary method of communication. To date tests have predominantly used written or spoken WM tasks such as digit spans and narrative discourse and many previous studies of WM have been conducted on children. Young age, delayed diagnosis and late access to SL tuition would suggest they may not have achieved fluency in either SL or speech at this point (Emmorey & Lee, 2021). Difficulties disseminating data across modalities can lead to unreliable results and may indicate an uncertainty of validity in the measures used. Using the singular modality of non-verbal WM on an adult population should yield data which can be easily disseminated. The non-verbal nature of the Corsi test will remove test bias.

Research question: Deafness and late access to language has been shown to negatively predict WM scores in traditional language based tasks such as digit spans and narrative discourse. Under these conditions, across modalities and generally compared against the hearing population, the Deaf have suffered by comparison. This study asks, is experience of verbal language essential to optimum WM or in WM tasks with a singular non-verbal modality, will Deaf adults score equally with adult hearing participants?

Hypothesis 1: There is a significant relationship between hearing status and WM as quantified by scores of a sample of profoundly Deaf adults and THES on the Corsi test, a sequential test of non-verbal WM. Access to verbal language will impact scores.

Hypothesis 2: There is a significant relationship between access to language inside participants own modality, as operationalised by corresponding parents primary language, and WM as measured by scores on the Corsi test. There will be a significant difference in scores between PDP5 and PDA5 and THES, when parents primary language is accounted for.

Methodology

A quantitative cross-sectional study was carried out to investigate the impact of access to verbal language on WM.

Participants

182 participants were recruited through advertising on social media platform or by personal invitation through direct messaging via website and email contact portals. A description of the study was included in the post. Social media sites used to target participants came from Facebook, Instagram, LinkedIn, Twitter. Direct contact was made with Irish Deaf Society, Deaf Ireland, Chime, Cork Deaf Association, Kerry Deaf Association, Deaf Village Ireland, IrishDeaf.com, Trinity Deaf Studies, Catholic Institute for Deaf, Dublin Deaf Association, Manchester Deaf Association, British Deaf Association. Social media influencers were also contacted by direct messaging over Facebook and Instagram. Direct contact was made with two leading researchers in the Deaf community Dr John Bosco Conama and Dr Elizabeth Mathews. A convenience snowball sampling method was used with participants being asked to share the link with any colleagues, friends and family they considered eligible.

The final sample consisted of 81 (n = 81), between 18-75 years old. Of this number 22.2% (n = 18) were PDP5 and did not wear a cochlear implant; 8.6% (n = 7) were PDA5 but did not wear a cochlear implant; 29.6% (n = 24) reported mild or moderate hearing loss (MMHL). 39.5% (n = 32) participants self-reported having no hearing impairment and were THES. Data was excluded if participants did not progress from the initial survey into the experiment stage, the Corsi block test (n = 100). This high attrition rate may be due to the lack of mobile responsiveness of the experiment. One further participant selected 'Other' as their hearing status and was also excluded.

Measures/Materials

Materials. A single page WordPress site was generated by the researcher to host a brief explanation of the research study along with written English instructions and a link to the survey and experiment. Literacy levels in the Deaf community are reportedly low for verbal English (Citizens Information Board, 2017) and on the advice of the Irish Deaf Society the verbal English used was simple, easy understand and presented in a visual form. They advised that the addition of and ISL translation would be highly beneficial. This was not possible due to the ongoing need for ISL translators during the pandemic and the low number of available qualified signers.

Demographics. In a short self-description questionnaire, participants were asked to indicate their hearing status, primary language, age, highest level of education, parents hearing status, and parents primary language. The questions were presented as multiple choice questions. The complexity of the levels of deafness saw this experiment listing only three levels of deafness: Profoundly Deaf prior to five years old, no cochlear implant (PDP5); Profoundly Deaf after the age of five years old, no cochlear implant (PDA5); Mild or moderate hearing loss (MMHL); hearing (THES); and other. Other was an acknowledgement of the diversity of hearing impairment and levels, however only one participant chose to self-report as other and was excluded from the final sample. Parental hearing status was grouped as follows: Both parents Deaf; both parents hearing; One parent Deaf & one hearing; one parent Deaf and one parent hearing; single parent family - Deaf parent; single parent family - hearing parent. Participants were also asked to self-report their highest academic achievement, the range spanned Junior Certificate to Post Doctorate.

Experiment. Upon completion of the demographic survey participants were prompted in the next link to take the online Corsi test. Participants are advised that they will need a computer keyboard and mouse or trackpad to complete the experiment, both on the home screen and at this stage of the experiment. The Corsi test is hosted by psytoolkit.org, an online bank of psychological experiments. The online test presents a set of nine purple blocks which change colour to yellow and back to purple in varying sequences. The tasks begins with two blocks changing colour and progresses to the maximum level of nine depending on the participants competency. The participant is asked to replicate this sequence using their mouse or track pad. The block span or Corsi Span is defined as the longest sequence a participant can correctly repeat. Kessels et al (2000), carried out a study on participants with some form of brain damage and a control group of no evidence of brain damage. Evidence suggested that a healthy adults had an average block span of 6.2 blocks (SD = 1.3), between five and seven blocks. It is considered a reliable measure of WM (Morales et al., 2013).

Design

The present study use quantitative experimental conditions (experimental versus control). This study investigated group differences in WM performance between typically hearing participants and those with hearing impairments. To investigate hypothesis 1: a between-participant design was used. The independent variable is hearing status (PDP5, PDA5, Hearing). The dependent variable is score on the Corsi test. To investigate hypothesis 2: a correlational design was used. The predictor variable was indicated by the self-report hearing status with scores on the Corsi block test used as the criterion variables. Scores were compared for each group. Response times were not considered in this experiment as the verbal prompt generated by the Corsi test was not equally available to all participants. A pilot study of two individuals was carried out. One participant was typically hearing and one profoundly Deaf prior to 5 years of age with no cochlear implant. This data was deleted prior to commencement of final data collection.

Procedure

Participants were prompted to take part in this experiment through a range of social media platforms and direct contact as specified, but not limited to, those listed in the Participants section (see Appendix A). Email contact details were listed on both social media posts and experiment website homepage. Comments were enabled on all posts and the researcher responded to all queries. These queries were not linked to participation in the experiment so anonymity was not compromised. Participants were instructed to conduct this experiment on a desktop computer or laptop as they would need a mouse or track pad to complete the Corsi test.

Once participants clicked though to the experiment site they were provided with a short description of working memory, an abbreviated version of the research question in simplified language, a brief description of the Corsi test. Participants were once again reminded that they would need a keyboard, mouse and track pad. This was communicated in both verbal English and also with the use of imagery and icons. Participants were also advised that this test could be taken by both typically hearing and Deaf individuals. Participants were prompted to click a large brightly coloured button to take the test. This button was hyperlinked to a Psytoolkit survey and experiment page (see Appendix B).
The current study was approved by the NCI ethics committee and upon clicking the test button, participants were presented with the informed consent details, researcher contact details and supervisor details. Participants were advised of the average time needed to take the experiment. Participants were informed of the particular areas of interest and the need for participants to be over 18 years of age page (see Appendix C).

Informed consent was obtained by a ‘required click’ radio button. Participants were asked to click a box to confirm willingness to take part in the study and that they understood the conditions of the study. Participants were also informed that they could exit the study at any time and that by not finishing the experiment they ensured that their data would not be analysed. Using a function within Psytoolkit to excluded incomplete surveys ensured the researcher could accommodate this choice. Participants were advised that they would not be asked for their names or any identifying details. Participants were supplied with contact details for both researcher and supervisor and advised that they would both be available to contact if the participant had any concerns.

The survey contained 6 questions (see Appendix D). Upon completion of the survey the participant is presented with the opening screen of the Corsi test and are asked to press the space bar to continue. The next screen once again advises of the need for a real keyboard and outlines instructions for completing the test. A verbal prompt to ‘go’ after the test sequence has been shown is not referenced in these instructions as reaction times are not a feature of this experiment and not all participants will be able to hear this verbal prompt. Participants are given a visual 3, 2, 1 countdown to the start of the experiment.

Initially two of the nine purple blocks presented on screen change colour to yellow and back to purple in rapid sequence. Participants use their mouse or trackpad to click on the blocks onscreen, replicating the sequence. Once answered correctly the sequence increases to 3, 4 and so on. Participants were advised of their score at the end of the Corsi test and prompted to exit the experiment. The participant is redirected to the home screen where the researchers contact details were once again made available.

Analysis

SPSS was used to run descriptive and inferential statistics. Descriptive statistics were used to explore the distribution of the population, frequencies in hearing status, primary language, age, highest educational qualification attained, parents hearing status and parents primary language. Descriptive statistics were prepared examining the relationships between hearing status, and participants primary language and also between hearing status and parents primary language. Descriptive statistics were also used to illustrate the relationships between highest education qualification attained and hearing status and finally mean scores on the Corsi test by hearing status.

Inferential statistics were used to further examine the relationship between hearing status and scores on the Corsi test. A one-way between-groups analysis of variance was conducted to explore the impact of hearing status on WM, as measured by scores on the Corsi test. A two way between groups ANOVA was conducted to explore the impact of hearing status and parental primary language on WM, as measured by their scores on the Corsi test. Checks that the assumptions of normality, linearity, homoscedasticity and multi collinearity have not been violated were conducted.

Results

Descriptive Statistics

A sample of 182 participants were recruited. Of this number 100 did not begin the Corsi test and were excluded. One participant identified hearing status as other and was also excluded. The final sample consisted of 81 participants (n = 81). Descriptive statistics are presented in Table 1. Ages ranged from 18-75 (M= 43.83). The majority of participant defined themselves as Typically Hearing English Speakers (THES) (n = 32, 39.5%), the next largest grouping was Mild/Moderate Hearing Loss (MMHL) (n =24, 29.6%). The profoundly

Deaf made up a combined total of 25 (n = 25, 30.8%) and was comprised of two groups Profoundly Deaf Prior to 5yrs of age (PDP5) (n = 18, 22.2%) and Profoundly Deaf After 5yrs of age (PDA5) (n = 7, 8.6%). Descriptive statistics for primary language, parents hearing status, parents primary language and highest education qualification attained are also displayed in Table 1.

Table 1

Descriptive statistics for Hearing Status; Primary Language; Parents Hearing Status; Parents Primary Language; Highest Education Qualification Attained (n = 81)

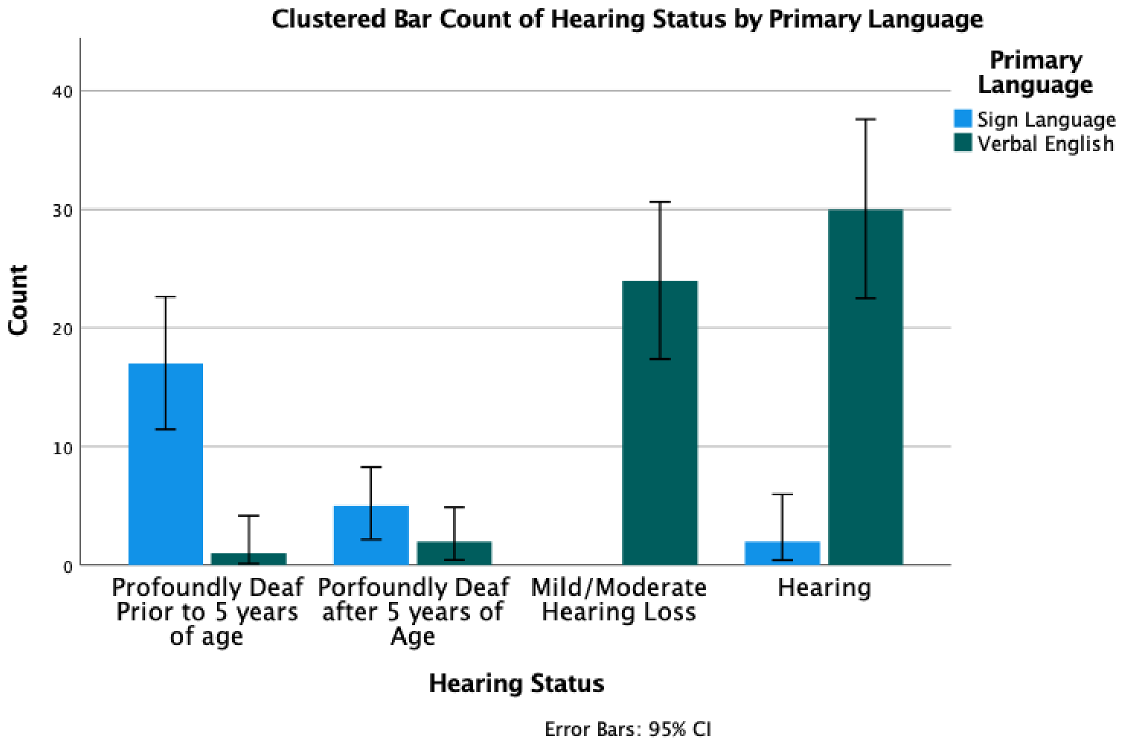
Variable	Frequency	Valid %
Hearing Status		
Profoundly Deaf prior to 5 years of age	18	22.2%
Profoundly Deaf after 5 years of age	7	8.6%
Mild/moderate hearing loss	24	29.6%
Typically hearing English speaker	32	39.5%
Primary Language		
SL	24	29.6%
VE	57	70.4%
Parents Hearing Status		
Both Deaf	10	12.3%
Both Hearing	63	77.8%
One Hearing One Deaf	3	3.7%
Single Parent Deaf	1	1.2%
Single Parent Hearing	4	4.9%
Parents Primary Language		
SL	10	12.5%
VE	70	86.4%

Highest Education Qualification Attained		
Intermediate/Junior Cert	5	6.2%
Leaving Cert	35	43.2%
Diploma	15	18.5%
Degree	14	17.3%
Masters	10	12.3%
Doctorate	1	1.2
Post Doctorate	1	1.2

Preliminary analysis indicates sign language is the preferred primary language among the two Profoundly Deaf populations sampled (PDP5 and PDA5) with verbal English being the preference for MMHL and THES, see Figure 1.

Figure 1.

Primary language preferences



Across all categories of hearing status, participants reported their parents primary language as predominantly verbal English, see Table 2. for descriptive statistics on hearing status and parents primary language, see Figure 2 for histogram. In the PDP5 group 2 participants reported their parents as having SL as their primary language. This would mean they are Deaf Native Signers. 16 PDP5 reported their parents primary language as VL. This would mean they are Deaf Non-Native Signers.

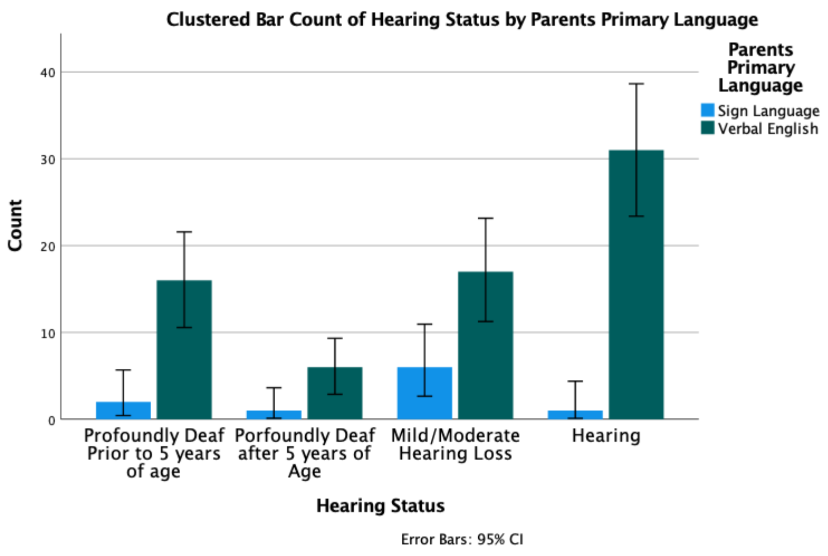
Table 2

Descriptive statistics for parents primary language categorised by participants hearing status

Hearing Status	**Parents Primary Language**		
	SL	VL	TOTAL
PDP5	2	16	18
PDA5	1	6	7
MMHL	6	18	24
Hearing	1	31	32
Total	10	71	81

Figure 2

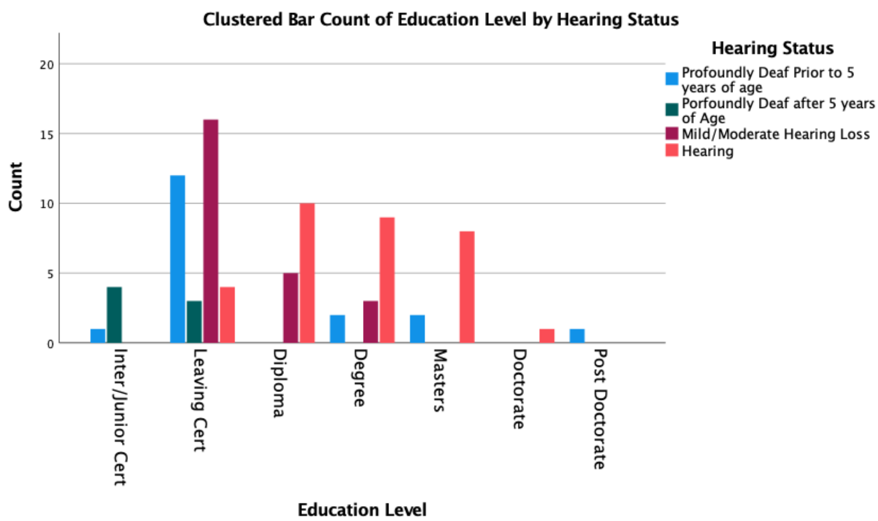
Parents primary language categorised by participants hearing status



Participants reported their highest level of education attained, see Figure 3. The PDP5 group are represented across the full span of education qualifications, though in fewer numbers than those with MMHL or THES. In the PDP5 the self-reported highest level of education attained were: 5.6% (n = 1) Inter/junior cert; 66.7% (n = 12) Leaving cert; 11.1% (n = 2) Degree; 2 11.1% (n = 2) masters and 5.6% (n = 1) post doctorate. In the PDA5 the self-reported highest level of education attained were: 57.1% (n=4) Inter/junior cert; 42.9% Leaving cert. This contrasts with THES participants who were represented in higher number in the more advance educational categories: 12.5% (n = 4) Leaving cert; 31.3% (n = 10) Diploma; 28.1% (n = 9) Degree; 25.0% (n = 8); 3.1% (n = 1) Doctorate. Those with MMHL report their highest level of educational qualification as: 66.7% (n = 16) Leaving cert; 20.8% (n = 5) Diploma; 12.5% (n = 3) Degree. While the PDP% is represented across the full spectrum of educational qualifications, PDA5 peals at Leaving Certificate level. No other group reports Inter/Junior cert as their highest level of educational achievement.

Figure 3

Highest educational achievement attained, categorised by hearing status



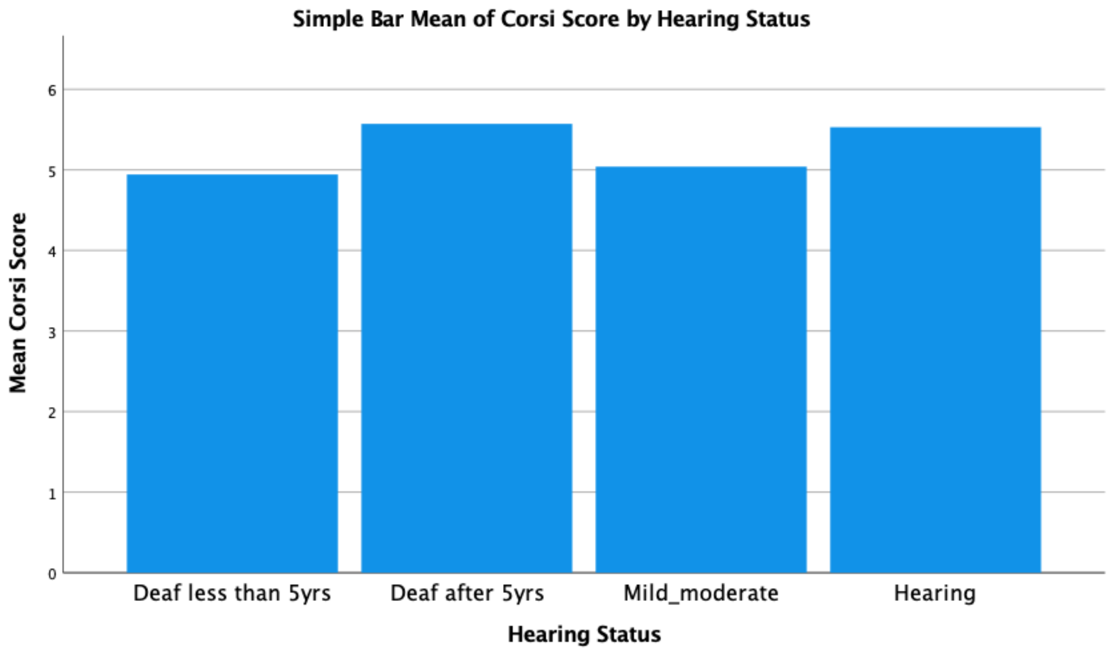
Scores on the Corsi test were examined and descriptive statistics are displayed below in Table 3. A maximum score of 9 was available in this test. Results indicate a mean score of 5.26, minimum score 1 and maximum score of 8. This is visually represented in Figure 3.

Table 3

Descriptive statistics for Corsi test scores, participants (n=81)

Variable	Minimum	Maximum	Mean	Std. deviations
Scores	1	8	5.26	1.170

Figure 4 Mean of Corsi Score by Hearing Status



Inferential Statistics

Hypothesis 1

A one-way between-groups analysis of variance was conducted to explore the impact of hearing status on WM, as measured by scores on the Corsi test. Participants self-reported into one of 4 groups based on their hearing level. Group 1: Profoundly Deaf Prior to 5yrs of age (PDP5); Group 2: Profoundly Deaf After 5yrs of age (PDA5); Group 3: Mild/Moderate Hearing Loss (MMHL); Group 4: Typically Hearing English Speakers (THES). Categories of interest were PDP5, PDA5 and THES. There was no statistically significant difference at the $p < .05$ level in Corsi scores for the five groups: F (3, 80) = 1.47, p = .227, see Table 4. The effect size, calculate using eta squared was .054. Post hoc comparisons using the Tukey HSD test confirmed no statistically significant differences.

Table 4

One-way Analysis of Variance of scores on the Corsi test across three Hearing Status'

	PDP5			**PDA5**			**THES**			**df**	**F**	**p**	**Partial eta squared**
Variable	**n**	**M**	**SD**	**n**	**M**	**SD**	**n**	**M**	**SD**				
Corsi Scores	18	4.94	1.349	7	5.57	.535	32	5.53	.950	3, 80	1.479	.227	.054

Hypothesis 2

A two way between groups ANOVA was conducted to explore the impact of hearing status and parental primary language on WM, as measured by their scores on the Corsi test. Participants were divided into 4 groups according to hearing status. Group 1: Profoundly Deaf Prior to 5yrs of age (PDP5); Group 2: Profoundly Deaf After 5yrs of age (PDA5); Group 3: Mild/Moderate Hearing Loss (MMHL); Group 4: Typically Hearing English Speakers (THES). Categories of interest were PDP5, PDA5 and THES. Levene's test indicated that the assumption of homogeneity of variance were not violated there was no statistically significant interaction effect between hearing status, parents primary language and scores on the Corsi test F (3, 73) = 2.049, p = .115 (partial Eta squared = .078). There was no significant main effect for parents primary language F (1, 73) = 1.259, p = .265 (partial Eta squared = .017), accounting for only 1.7% of the variance. There was no significant main effect for hearing status language F (3, 73) = 2.205, p = .095, though it showed a medium effect size of 8.3% (partial Eta squared = .083). Post-Hoc comparisons using the Tukey HSD test confirmed that the mean scores for the Group 1 PDP5 (M = 4.94, SD = 1.35) and Group 2 PDA5 (M = 5.57, SD =.535) was not significantly different from the Group 4 THES (M = 5.53, SD = .950). Parental primary language does not have a statistically significant impact on scores on the Corsi test for Group 1, 2 and 3.

Discussion

The aim of the current study was to investigate if access to verbal language impacted scores on the Corsi test, a sequential test of WM. There exists a data gap in the knowledge of WM in Deaf adults, with the bulk of previous studies having been conducted on children. This study aimed to address the data gap by recruiting from and adult population above 18-years-old with a broad span of educational qualifications. This would address any bias which may exist when testing on a college student population, or on children. The knowledge to be gained from a population who have no access to spoken language could yield valuable information and highlight hidden biases in our understanding of the processes involved in WM. Previous research indicates that participants who were profoundly Deaf prior to five years of age have not performed as well as THES on tests of working memory (Hoffman et al., 2014). Typically these studies have contained core components of verbal language, in the form of narrative discourse or digit spans. When tested inside their own modalities it has been shown that adult Deaf native signers perform equally with hearing people across cognitive, behavioural and neurological domains (Arfé & Perondi, 2008; Boutla et al., 2004; Capirci et al., 1998; Marshall et al. 2005; Romero Lauro et al., 2014; Wilson & Emmorey, 1997). However, testing inside separate modalities presents difficulties when disseminating data. This study sought to explore the performance of profoundly Deaf adults both Deaf native signers and non-native signers under almost non-verbal conditions. It was believed that the sensory modality of non-verbal working memory tasks will eliminate test bias. Through this research, three hypothesis were designed to address the objectives for this study.

Hypothesis 1 explored the relationship between access to VL and scores on the Corsi Block test, a sequential test of non-verbal WM was not support. Those born Deaf or who acquired deafness prior to 5 years of age are have been raised in the absence verbal language. Those who acquired Deafness late than 5 years of age may have had exposure to VL.
One profoundly Deaf participant self-reported VL as their primary language. Age may have been a contributing factor as this participant was 65 years of age and educated under a system of Oralism, prevalent in the State up to 30 years ago (Leeson, 2018). Results indicated no significant relationship between hearing status and scores on the Corsi test. Results indicate a mean score of 5.26, in line with findings by Kessels et al (2000), that a healthy adults had an average block span of 6.2 blocks (SD=1.3), between 5 and 7 blocks.

Hypothesis 2 explored the relationship between access to access to language inside participants chosen modality. No significant relationship was found between access to language inside each participants modality as operationalised by parents primary language, e.g. Deaf child being raised in a home were VL is the primary language vs Deaf child being raised in a home where SL is the primary language. Though the hypothesis is supported, sample sizes are small so further research is needed in this area.

With such a small sample size it is difficult to attach certainty to these results. However early trends would support the hypotheses that no relationship exists between hearing status and WM as operationalised by scores on the Corsi test. This would raise questions the validity of tests using VL when measuring WM in Deaf.

WM has been viewed consistently as a portal for long term memory and vital for learning, problem solving and concept formation (Cowan, 2013; Hartshorne & Makovski, 2019), which in turn are vital for creativity and innovation (Vandervert et al., 2007). Previous studies have suggested that Deaf individuals suffer by comparison with their hearing counterparts on WM tasks (Wilson & Emmorey, 1997). Decisions based on an individual's capacity to learn may contribute to a lack investigation of barriers to education and reinforce low expectations of achievement in academia and learning (Leeson, 2018). The presumption that a person could have a mind less capable of complex concept formation or understanding may in turn impact the level of information that is imparted to the individual. This can heavily influence outcomes in, but not limited to, medical, occupational and educational settings.

Large amount of WM studies of the hearing are conducted on student populations, both children and at college/university level. This largely leaves the Deaf community excluded as THES are ten times more likely to progress to 3rd level education, therefore research is ten times more likely to be tailored to this population. More worryingly the data gap created means results are more likely to be interpreted from a narrower perspective. Availability sampling of this nature continues to see the bulk of testing of the Deaf being conducted on children this leaves the psychological community open to a bias in that the foundations of their presumptions are not appropriately measured. Adult participants for this study were recruited through social media and spanned the full range of educational qualifications, though there is evidence to support previous research into engagement in further education with 67% of PDP5 and 42.9% of PDA5 reporting leaving Certificate as their highest educational qualification. PDA5 group saw 57.1% reporting Inter/Junior Cert as their highest qualification.

If the capacity to learn is not an obstacle then investigation of such low engagement in further education is needed. A root cause could lie in the lack of primary school teachers who are fluent in ISL. Mathews (2020), cites the needed for linguistic modelling to be addressed. Barriers exist for Deaf students to take places in the Irish Primary School systems as many Deaf students are exempt from learning Gaelige, a prerequisite for many teacher training programmes. The absence of fluent signing teachers leaves children open to two options, one of which is signed interpreted in the classroom. This from of mediated learning is less effective than learning direct from a teacher or lecturer (Mathews, 2019). Research has shown Deaf students comprehend on average 60-65% of an interpreted lecture (Marschark, 2005). The National Council for Special Education (NCSE) as early as 2011 has highlighted the right of for all Deaf and HoH children to be provided with opportunity 'to acquire fluent language skills while engaged in meaningful activity with capable users of the language' (NCSE, 2011). However, despite the Sign Language Act of 2017 placing a statutory obligation on all public bodies to provide free interpretation services for all statutory services including education, investment was only ringfenced for this service since February 2022.

Delay in diagnosis and language acquisition have been suggested as possible reasons for impaired social development in Deaf children. Deaf children present with greater instances of behavioural problems (Barker et al., 2009; Netten et al., 2015), experience more conflict with their peers (de Giacomo et al., 2013; Terlektsi et al., 2020), have less social competence (Hoffman et al., 2014). Deficits in WM and its relationship with executive function has been offered as an explanation for this discord. The suggestion could be made that we move away from the medical model of deafness, with its focus on fixing an impairment and encourage the general hearing population to recognise the Deaf as a community with a common language, cultural norms, values and history. If you feel the need to fix something then you are starting from the view that the item in question is broken. Growing and learning as Deaf child in a hearing world may lead to high levels of frustration. Psychosocial stress has also been shown to impair WM as there exists an association between cortisol levels and memory retrieval (Oei et al., 2006). Lack of understanding of this community may lead to several misunderstandings, one of which may be the impact of moving the bulk of Deaf education into mainstream schools. Deaf students are now largely dispersed among a hearing community with less access to interaction with Deaf peers and hence social isolation. Longitudinal research in to the relationship between WM and levels of psychosocial stress and a social model of Deafness would greatly benefit understanding of this community.

Limitations and further research

While there are limitations to most studies it must be acknowledged that engaging with this particular population proved to be extremely difficult. Presuming a homogeneity of aims and values inside this community is a naïve error. In addition, the nuances and complexity of levels of hearing impairment meant terminology of categories was somewhat exclusionary. The inclusion of a ‘other’ category however was only used by one participant.

The lack availability and costliness of translation services made translation from verbal or written English into ISL unmanageable. The low number of qualified services and the impact of the ongoing need for translators for public service broadcast resulting from the ongoing pandemic saw no translator available despite an offer to pay the market rate. This was a barrier to securing the previously offered collaboration of the Irish Deaf Society (IDS). The society could not host the experiment without the ISL translations to run alongside the written verbal English. Vlog style sign language videos would not be accepted as the IDS required that the video process also be monitored by a registered sign language interpreter.

Had this been available a wider population would have been accessed for sampling. The same limitation occurred with the British Deaf Society who were keen to host the experiment but required translation into British Sign Language and the Americans requiring American Sign Language.

Mobile responsive experiments are needed to further research this community. The high level of attrition on this experiment would indicate an appetite to continue with the experiment had the test been mobile-friendly and available to run on smart phones.

While the lack of engagement is disappointing it is encouraging that all groups contacted recognised the value of the research, with many acknowledging that they had never questioned the impact of the absence of spoken language on the working memory of the profoundly Deaf. Research in this area is fraught with difficulties, political divides, cultural divides and literacy levels. This however should not be a barrier. Funding and time are needed to facilitate further research in this area.

Conclusion

WM is the ability to retain, manipulate and recall small amounts of information in order to facilitate planning, comprehension, reasoning and problem solving. A core concept of WM is the exercise of the phonological loop and sub-rehearsal. Previous research has indicated a deficit in the WM of Deaf children, in some cases reporting measures of Theory of Mind similar to those of children on the Autism spectrum. In the majority of cases these tests have used the core elements of verbal language, eg digit spans or narrative discourse. The VL element of these tests may create a bias against profoundly Deaf individuals who have never heard VL. This current study used the Corsi test on a sample of Deaf and hearing participants recruited through social media. A small sample size (n = 81) showed indications that a relationship between hearing status and WM is not supported as operationalised by scores on the Corsi test. The relationship between scores on the Corsi test and hearing status was also explored when accounting for parents primary language. There was no significant relationship found. It is this researchers opinion that an examination of the validity of WM tests in use on Deaf participants be conducted, new tools developed to address this bias. Identifying barriers to education, resourcing training for all primary school teachers and reducing the amount of mediated learning where possible could see members of the Deaf community motivated to continue with in education. This will in turn lead to a more in-depth knowledge of the community.

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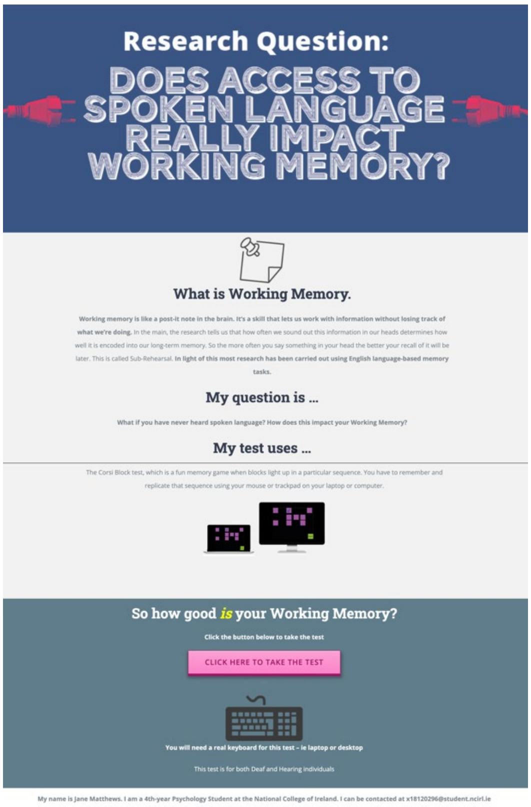
Appendices

Appendix A

Sample Social Media post targeting Deaf pages and associations

Appendix B

Sample Social Media post targeting Deaf pages and associations



Appendix C

Informed Consent

You will require a real keyboard for this test, ie laptop, desktop.

This study aims to investigate the relationship between hearing and working memory. Working memory is the ability to maintain and manipulate chunks of information in your mind before encoding it to long-term memory. Research tells us that the quality of long-term memory is improved when you sub-rehearse or sound out that information in your head. My research asks what if you have never heard language, how does that impact memory. There is a data gap in this area.

What will this study involve?

You will be asked to complete a short demographic questionnaire of 4 questions. No personal details will be collected. The survey and test will be completely anonymous. Once completed you will be prompted to carry out the memory test. The test is a fun, short memory test called The Corsi Block Test.

1. You will see nine blocks arranged on screen
2. Some of these blocks will light up in a particular sequence
3. You need to tap the blocks, in the same order. It gets harder as you level up
4. The average time including survey is 2 minutes (unless you're really good)

Who can take part?

- You can take part in this study if you are aged over 18.
- The study is open to both Deaf (all categories) and Hearing.
- My area of interest is Congenitally Deaf Individuals and individuals who became Deaf at an early age and my control group is Hearing individuals 18+ years.
- You should not take part in this study if you have been told by a doctor that you have a diagnosis of dementia.

Do I have to take part?

- Participation in this research is voluntary; you do not have to take part.
- You can withdraw from participation at any time simply by exiting the web page
- No data will be recorded unless you finish the experiment.
- Once you have submitted your test, it will not be possible to withdraw your data from the study, because the questionnaire is anonymous and I will not be able to identify your response.

Data & Privacy

- You will not be asked for your name or any identifying details.
- The anonymous data will be stored by NCI for a period of 5 years.
- If you feel that these questions may cause you distress, you can choose not to take part in the study.
- You can contact the researcher on x18120296@student.ncirl.ie

Researcher: Jane Matthews, National College of Ireland

Contact Email: x18120296@student.ncirl.ie

Supervised By: Rocio Galan Megias

Contact Email: rocio.megias@ncirl.ie

Please be advised that the study is anonymous, all data is anonymised and therefore I will be unable to tell which was your response, give scores or feedback on individual performance

Appendix D

Survey Questions

I am

1. Profoundly Deaf since birth or prior to 5 years of age. (Cannot hear below 90dB, no cochlear implant)
2. Profoundly Deaf after 5 years of age (Cannot hear below 90dB, no cochlear implant)
3. I have Mild or Moderate hearing loss
4. Hearing
5. Other

My Primary Language is
1. Sign Language
2. Verbal Language

My Age is ___

My Family Hearing History
1. Both Parents Deaf
2. Both Parents Hearing
3. One Parent Deaf & One Parent Hearing
4. Single Parent Family - Deaf Parent
5. Single Parent Family - Hearing Parent

My Parents Primary Language

1. Sign Language
2. Verbal Language

My Highest Level of Educational Qualification Attained

1. Intermediate/Junior Certificate
2. Leaving Certificate
3. Diploma
4. Degree
5. Masters
6. Doctorate
7. Post Doctorate