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RUNNING HEAD: Subject-verb number agreement awareness

Agreeing to disagree: Deaf and hearing children's awareness of subject-verb number agreement.

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Abstract

This study investigated deaf adolescents' implicit and explicit awareness of subject-verb number agreement. In Experiment 1, a self-paced reading task, the reading times of deaf and hearing children (matched for reading and chronological age, mean 8;3 and 13;10 years) increased when sentences contained disagreeing subject-verb number markers. However, deaf adolescents' slowing occurred later in the sentence compared to both groups of hearing children. The same deaf adolescents were unable to detect-and-correct subject-verb agreement errors in Experiment 2, whereas both groups of hearing children performed well on this task. Thus, deaf adolescents demonstrated implicit awareness of agreement in the absence of explicit knowledge. Moreover, this nascent awareness was below that expected on the basis of their (substantially delayed) reading ability. Therefore, grammatical difficulties could be a significant impediment to deaf children's literacy. Future research should examine whether this is a result of late or incomplete learning of English, bilingualism or another factor.

Keywords: Deaf; literacy; reading; morphology; grammar

Deaf and hearing children's awareness of subject-verb number agreement

Severe literacy impairments are well documented within the deaf population. At 16, the average deaf school leaver has a reading-age equivalent to a 9-year-old hearing child (Conrad, 1979; Powers, Gregory, & Thoutenhoofd, 1998). The received view is that this is a result of phonological awareness limitations (Aaron, Keetay, Boyd, Palmatier, & Wacks, 1998; Musselman, 2000; Sterne & Goswami, 2000), a key factor in reading and spelling development for hearing children. But these limitations might not be the only ones that contribute to their literacy impairment. Reading education typically shifts from single word decoding to sentence comprehension at around age 9 (Gaustad & Kelly, 2004), which interestingly coincides with the age that deaf adolescents frequently fail to progress (Allen, 1986; Musselman & Szanto, 1998). Therefore, apart from phonological challenges at the word level, another type of challenge for reading arises at the level of morpho-syntax.

Syntactic awareness of deaf children

Previous research has indicated that deaf children do have difficulties with (morpho)-syntactic processing. Quigley conducted two large-scale research programmes during the 1970s examining the knowledge of various syntactic structures in several hundred deaf children. This research culminated in the design and norming of the Test of Syntactic Abilities (Quigley & King, 1980). It was found that deaf children from mixed educational backgrounds (10 to 18-years-old from USA, Canada and Australia) demonstrated the same general pattern of difficulty across different syntactic structures as hearing children. However, deaf children were substantially delayed. 18-year-old deaf children performed significantly worse than 8-year-old hearing children on every type of syntactic structure (Quigley & King, 1980). Over the past 40 years there have, of course, been numerous changes to the education of children who are deaf, which may affect their performance on such tasks. Nonetheless, more recent evidence suggests that deaf college students' morphological skills can remain incomplete (e.g., Gaustad & Kelly, 2004).

The importance of morpho-syntactic processing for reading is evidenced in the finding that (orally educated) deaf children's performance on the Test of Syntactic Abilities correlates with their reading-age (Waters & Doehring, 1990). Furthermore, for the hearing population it has been found that reading comprehension ability correlates with morphological awareness and does so to a greater degree than single-word reading (Deacon & Kirby, 2004; Mahony, Singson, & Mann, 2000). Thus, morphological and morpho-syntactic awareness plays an important role in reading development.

Subject-verb number agreement

One example of morpho-syntactic information is subject-verb number agreement. In English, this refers to the fact that number markers on the subject and verb of a sentence must match. For example, in the sentence "*the* ***apples grow*** *on the tree"* the plural marker +<s> on the noun informs us that there is more than one apple, while the lack of a +<s> suffix on the verb also indicates that more than one thing is growing. It is worth noting that morphological agreement in English is in opposition to phonological agreement, unlike, for example, gender and number agreement in a Romance language like Italian, where phonological agreement is a sign of morphological agreement (*l**e** perl**e** bell**e**, l**a** perl**a** bell**a**; the beautiful pearls, the beautiful pearl*). Attaching the same suffix to both words in English results in morphological disagreement (e.g., *the* ***apples grows*** *on the tree*).

Another notable feature of subject-verb agreement knowledge is that it is not governed by adjacency. Even though subject nouns and verbs are often adjacent, it is not the noun and verb that are closest that agree, but the head noun and verb. For example, in *The keys to the cabinet remain on the table* or *The key to the cabinets remains on the table,* "remain" is closest to "cabinet" (the local noun) but needs to agree with "key" (the head noun). This indicates that agreement depends on a hierarchical representation of syntactic structure, which allows items in the same clause to be related even if a subordinate phrase intervenes (e.g., [$_1$The key [$_2$to the cabinets] remains on the table]).

These aspects of agreement may be why English subject-verb agreement appears to be relatively difficult to acquire and vulnerable to disruption. For example, monitoring for agreement errors is disrupted by a cognitive load more than monitoring for problems with word order or local plural agreement (e.g. two boys/one boy; McDonald, 2008), subject verb agreement is specifically disrupted in specific language impairment and dyslexia (Rice & Oetting, 1993; Rispens and Been, 2007; Leonard, Bortolini, Caselli, McGregor & Sabbadini, 1992), and acquisition of tense and number agreement is relatively late compared to other function morphemes (Brown, 1973; Menyuk, 1969; Cazden, 1968).

Despite these theoretical considerations, which are most relevant to understanding how learners *produce* the correct forms, it has been noted (Pearlmutter, Garnsey, & Bock, 1999) that it would not be surprising if the comprehension system *ignored* number agreement, since agreeing forms are infrequent and are rarely needed to interpret sentences correctly (only third person present tense forms are marked for number). However, Pearlmutter et al.'s (1999) data showed that number *did* influence comprehension in hearing readers, despite being infrequent. In self-paced reading paradigms, Pearlmutter et al. (1999, Experiments 1&3) and Deevy (2000) showed that mature hearing readers showed increased reading times for disagreeing sentences. These were not only observed on the verb where the anomaly was initially apparent, but also on the word immediately after. These spill-over effects demonstrated that mature readers continued processing syntax in the background while reading on.

In order for subject-verb agreement to influence on-line reading, readers must have learned how words are marked for number (+<s> for plural nouns, +<s> for singular verbs) as well as the distributional properties of agreement – which words in a phrase are systematically marked for number. In addition, they must hold number information in memory while processing the sentence and relate subject and verb during syntactic integration.

Importantly, subject-verb number agreement is primarily a grammatical phenomenon, as it relates words on a grammatical level. However, agreement also has a semantic aspect. Grammatical number and semantic number usually go hand in hand, even though they are not the same. This is most apparent with collective nouns or mass nouns, which refer to groups of objects or people but from a grammatical perspective are singular and take singular verb forms[2], such as *team* or *furniture* which can take singular verb forms (e.g., *The team is preparing for the big match*).

In oral/aural language, grammatical/distributional aspects of subject-verb number agreement seem to be acquired earlier than some of the semantic aspects, especially those related to the verb. Preferential looking paradigms have demonstrated that distributional sensitivity is present at age 3 (Brandt-Kobele & Höhle, 2010) and even at 1;4 (Soderstrom, 2008; Soderstrom, White, Conwell, & Morgan, 2007). In contrast, picture pointing tasks requiring semantic interpretation of number in response to auditory presented stimuli suggest that children fail to use number information on the verb until they are older, at around 5 or 6 years (Brandt-Kobele & Höhle, 2010; Keeney & Wolfe, 1972; Johnson, de Villiers, & Seymour, 2005). By school age (6-12 years) children have developed explicit awareness of number agreement enabling them to perform grammaticality judgments on aurally presented stimuli (Wulfeck, 1993). Therefore, even the most conservative estimate would suggest that

[2] Collective nouns in British English can take singular or plural verb forms depending on whether one wants to refer to the group as a whole or to the group members. In American English collectives always take singular verb forms.

hearing children have pre-existing knowledge of agreement from speech which they can apply when learning to read.

Deaf children's knowledge of agreement

British Sign Language (BSL) has its own rules of number agreement, which differ markedly from English. Number marking itself is far less regular and more complex than in English. Number on nouns can be represented by changing the whole sign, repeating or adding a quantifier before/after or within the sign. Number marking on verbs can be shown in the sign movement, by using a pronoun or through repetition (see Sutton-Spence & Woll, 1999). Moreover, BSL has some verbs that require agreeing object and subject marking and others that do not require agreement at all (see Sutton-Spence & Woll, 1999). Nonetheless, despite the additional complexities of verb agreement in BSL, Morgan et al. (2006) demonstrated that a deaf child born to native deaf signing parents acquired productive use of verb person agreement in BSL by around 3 years. Therefore, if an L1 BSL child learns English at school, he/she will have understanding of agreement in BSL. Due to the large differences in agreement systems in BSL and English it seems unlikely that understanding from BSL will be directly and transparently transferable to English.

Limited previous research has examined awareness of English agreement in the literacy of deaf children. Quigley, Montanelli, & Wilbur (1976) examined a large sample of American deaf children's responses to a grammaticality judgement and correction task (part of the norming for the Test of Syntactic Abiltities). They demonstrated that deaf children had difficulties with English agreement. However, their study investigated agreement by combining various types of agreement anomalies. It is therefore difficult to tell whether the deaf children had specific impairments of subject-verb number agreement. In addition, awareness of agreement can take different forms. Explicit awareness of the type necessary to perform grammaticality judgment is not necessarily the same as implicit awareness that is only visible on-line during reading comprehension. It might be that deaf children possess one, but not both of these types of awareness.

Studies in languages other than English that examine deaf participants' writing concur that agreement can be particularly difficult, but conclusions cannot be directly transferred to English. Hebrew deaf children (oral-aural educated with hearing parents - Tur-Kaspa & Dromi, 2001) and second generation Italian deaf native signers (educated orally - Volterra & Bates, 1989; Fabbretti, Volterra, & Pontecorvo, 1998) make syntactic errors in writing that are largely inflectional in nature and point to difficulty with agreement. For example, Volterra and Bates (1989) demonstrated that a highly literate 32-year-old deaf Italian had a particular problem with grammatical morphology, most commonly with omissions or substitutions of free function words and long distance agreement errors in writing. Similarly, Tur-Kaspa and Dromi (2001) found that Hebrew-speaking children with severe-profound hearing loss made more grammatical errors in writing than children with normal hearing of the same age. Failure to agree (subject-verb and noun-adjective) affected around 22% of written clauses. However, the comparison group was hearing children matched for chronological age rather than reading age. Thus differences could reflect general differences in literacy skill rather than effects of deafness. In the present study we carefully matched each deaf child to a reading-age and chronological-age matched hearing child. In general, agreement phenomena in both Hebrew and Italian (where verbs must be marked for number, gender and tense) are considerably more complex than in English (where verbs are marked for number and tense only). This means that agreement may pose a greater challenge for deaf learners of these languages than of English. Also, as we have noted above, effects of agreement in a production task like writing or an explicit judgment task do not determine what will happen during reading comprehension and might underestimate more subtle implicit awareness of agreement.

It also needs to be noted that previous research examining the syntactic abilities of deaf individuals has focused on participants who had an intensive oral/aural education and predominantly communicated using speech. This could have led to relatively good knowledge of agreement. In contrast, profoundly deaf children (without cochlear implants and hearing aids) who primarily communicate using sign language are likely to really learn English once they begin to read and write, at the very least they will have less experience with spoken English than typically developing monolingual English speaking children, especially for contrasts that are very difficult to see on the mouth. Accordingly, these deaf participants may be inclined to ignore number agreement in English because they are likely to have weak information about the +<s> suffix from lip-reading and are learning English as a second language, primarily from its written forms. This may be quite a different experience to that of hearing bilinguals learning two *spoken* languages. The present study is concerned with deaf children from this population.

Data from hearing children learning a written language like French may provide an indication of what to expect for L1 BSL - L2 English deaf readers. In French, number markings on nouns and verbs are both typically inaudible but are spelled differently (verb +<nt>, noun +<s>). Subject-verb number agreement is specific to the orthography. Because final <s> is often invisible during lip-reading, the situation for L1 BSL - L2 English deaf readers is probably very similar. At age 7, French hearing children seem to have a weak grasp on the agreement process in writing, they appeared to be hindered by cognitive load and tend to apply noun number marking indiscriminately to both nouns and verbs. They then learn verb number marking and overgeneralise this to nouns. Finally (aged 10), they apply both morphographic rules effectively, producing adult-like performance and error patterns (Totereau, Barrouillet, & Fayol, 1998; Fayol, Hupet, & Largy, 1999). If the analogy between French hearing children and L1 BSL - L2 English-reading deaf children is correct, then deaf children with a reading age of around 7 years would have a weak grasp of the agreement process and a similar developmental progression might occur. Because English verb number marking is opposite to noun number marking (+<s> forms a plural noun and a singular verb) over-generalisation to both nouns and verbs would result in production of phrases with disagreeing subject-verb number markers.

It has to be mentioned that L1 BSL – L2 English deaf children certainly have one of the pre-requisites for understanding grammatical agreement, namely plural marking on English nouns. They have been shown to outperform their reading-age matched counterparts when spelling regular noun plurals (Breadmore, Olson & Krott, 2012).

Semantic plausibility

As mentioned, subject-verb number agreement does not only have a grammatical aspect, but also a semantic aspect. Readers might therefore experience processing problems when encountering agreement errors due to problems with semantic number integration, not due to problems with grammatical number integration. It is, therefore, important to compare agreement effects against effects of semantic anomaly that do not involve morphological agreement.

Reading time studies suggest that the time course of semantic and agreement effects differ. De Vincenzi et al. (2003) applied self-paced reading to distinguish effects of semantic anomaly from effects of subject-verb agreement in hearing Italian readers. Mature readers demonstrated subject-verb agreement effects on the disagreeing word and the word immediately afterwards, but reading times for semantic anomalies did not increase until two words after the anomaly. Eye-tracking studies also show that semantic anomalies increase reading times in mature hearing readers, but, like self-paced reading, the time course differs from agreement effects (e.g., Ni, Fodor, Crain, & Shankweiler, 1998). Semantic anomalies generally appear more delayed with increasing rates of regressive eye movements. In contrast, agreement has a more immediate effect on initial gaze durations.

The differences in processing of subject-verb number agreement errors and semantic anomalies are also supported by electroencephalography studies (EEG) investigating brain responses to these errors. While agreement errors have led to a left anterior negativity (LAN) at around 250 – 500ms post presentation onset of the verb, followed by enhanced late posterior-parietal positivity at around 600ms (P600, Coulson, King, & Kutas, 1998; De Vincenzi et al., 2003; Osterhout & Mobley, 1995), semantic anomalies are known to elicit central-posterior negativity at around 400ms post-onset, referred to as the N400 effect (De Vincenzi et al., 2003; Kutas & Hillyard, 1983). These effects have also been documented in deaf participants' responses to semantic and syntactic errors in American Sign Language (Capek et al., 2009). The timing difference for agreement and semantic anomalies found in reading studies do therefore not simply mean that they are processed similarly but with a different time course. Instead, these differences are reflections of different types of processes.

Little research has examined processing of semantic anomalies in written language by readers who are deaf. Using an offline measure, Miller (2005, 2010, 2012) has shown that both deaf and hearing readers typically have poorer reading comprehension for semantically implausible sentences than plausible sentences. Moreover, the size of the difference is larger for deaf participants, particularly for younger deaf readers (Miller, 2005). Miller (2005, 2010, 2012) argues that comprehension of semantically plausible sentences is possible through top-down processing alone, by using prior knowledge of content words. In contrast, understanding of semantically implausible sentences requires bottom-up processing, since the reader cannot rely on prior knowledge of the content words to obtain meaning. Accordingly, Miller (2005, 2010, 2012) argues that comprehension of semantically implausible sentences utilises syntactic skills and, therefore, deaf participants' difficulty understanding these sentences may be related to difficulty processing syntax rather than semantics per se.

The present study

We used a self-paced reading task and an error detection/correction task to investigate implicit and explicit awareness of English subject-verb number agreement in deaf and hearing children. In order to decide on the cause of a possible awareness problem, we compared deaf children's (mean chronological age 13;9 years, mean reading age 8;0 years) performance to groups of both reading-age matched (henceforth, RA) and chronological age-matched (henceforth, CA) hearing children. Comparisons between the CA and RA children define the normal developmental trajectory. RA children have the same reading ability as the deaf children but are substantially younger, less cognitively advanced and have received less education. CA children are at the same level with regards to age-determined aspects of cognitive development and have been schooled for the same amount of time as the deaf children, but are more proficient readers. Differences found between deaf participants and CA children that do not occur between deaf participants and RA children could be due to differences in general reading skills or educational experience. Differences found between deaf participants and RA children that do not occur between deaf participants and CA children could be due to differences in cognitive development and schooling experience. However, if deaf participants are different from both RA and CA hearing children, the differences cannot simply reflect differences in cognitive development, educational experience and/or reading ability, but should instead reveal differences in awareness or processing of morpho-syntactic information.

CA children were predicted to have complete awareness of agreement (see Table 1). Previous findings on judgments of aurally presented stimuli (Wulfeck, 1993) suggest that children of this age should have an explicit awareness of agreement that enables them to perform well in the judgment task (Experiment 2). We also expected CA children to show sensitivity to agreement errors in the self-paced reading study in a similar manner to hearing adults – slowing down on the anomaly and the word after (De Vincenzi et al., 2003). Moreover, we anticipated that this grammatical effect would differ from their response to semantic anomalies, as shown in adults (De Vincenzi et al., 2003). It was less clear what level of awareness the RA and deaf children would have.

The RA matched hearing children were much younger and therefore we expected them to still be developing agreement awareness. The findings by Wulfeck (1993) for young school-age children in a grammatical judgment task suggested that hearing children of this age would have implicit awareness of subject-verb agreement. Thus, we expected the RA children to reveal sensitivity to agreement errors in the self-paced reading experiment. However, the time course of slowing may differ, as these younger children read more slowly and in a word-by-word manner. Therefore, these children might only slow down on the word containing the error. One would also expect that their knowledge of semantics would support a distinction between grammatical and semantic anomaly, as shown in adults (De Vincenzi et al., 2003). An implicit awareness of the distributional aspects of agreement might even enable RA matched hearing children to detect erroneous sentences in the explicit judgement task. However, during language development one often finds that implicit knowledge precedes explicit knowledge (Critten, Pine, & Steffler, 2007). Therefore, the younger RA matched hearing children might find the explicit use of agreement required for error corrections much harder, despite showing implicit awareness (see Table 1).

Given deaf children's difficulties with syntactic processing and previous findings for deaf children's awareness of agreement in other languages, we expected that the deaf participants in our study would show at least some impairment of agreement awareness. At the extreme, deaf participants might not show any awareness at all (see Table 1). At this level of syntactic development, deaf children may also have difficulty comprehending implausible sentences (Miller, 2005, 2010, 2012) and therefore there could be no difference in reading times for plausible and implausible sentences. If the deaf participants' awareness of agreement was developing normally but merely delayed by their reading impairments, they might show a pattern similar to that of reading-age matched hearing children – that is, evidence for implicit knowledge but weaker explicit knowledge (see Table 1). Finally, since the deaf participants in the present study were primarily BSL users acquiring English as a second language, they might show a very similar pattern to English second language learners with a spoken L1. Jiang (2004) reported that native Chinese speakers demonstrated explicit awareness of English subject-verb agreement in a written judgment task, but did not demonstrate increased reading times for agreement errors during self-paced reading. Similarly, ERP studies have shown that L2 English-speakers often fail to show components of syntactic anomaly effects (Hahne, 2001; Ojima, Nakata, & Kakigi, 2005; Weber-Fox & Neville, 1996), even though they are sometimes better at noticing agreement anomalies in explicit judgment tasks (Ojima et al., 2005). Thus, deaf children might have explicit knowledge of morphological agreement (derived from instruction) that would allow them to do relatively well on our error detection/correction task, but this knowledge might not play a role during on-line processes such as our self-paced reading task (see Table 1). This might be, for instance, because the rule has to be applied consciously and/or the process is effortful and working memory load during reading does not leave enough capacity (reasons for such an explicit-implicit knowledge discrepancy are also discussed in Pacton & Deacon, 2008).

*** Table 1 about here ***

Experiment 1

The aim of Experiment 1 was to establish evidence of implicit awareness of subject-verb agreement for both hearing and deaf participants, and to compare responses to agreement anomalies to responses to semantic anomalies. A self-paced reading task was utilised to measure reading times on sentences containing agreeing and disagreeing subject-verb number markers and on sentences containing semantically plausible and implausible noun and verb combinations. Good sensitivity to agreement errors in this task means that a participant slows down when encountering errors.

For both groups of hearing children, we expected their agreement awareness to be of grammatical nature and not of semantic nature, especially because hearing children do seem to start off with a distributional knowledge of agreement, not a full semantic knowledge (Soderstrom, 2008; Keeney & Wolfe, 1972). We expected the slowing on agreement errors in the self-paced reading study to be different when the anomalies are based on grammatical versus semantic mismatches, as has been found for adults (Di Vincenzi et al. 2003). If deaf children process agreement like hearing children, then we would expect that their response to agreement anomalies would also be different from their response to semantic anomalies. If, however, they process the noun and verb mismatch as a semantic but not a grammatical phenomenon, then their response to agreement anomalies might not differ from that to semantic anomalies. Finally, if deaf children simply have a generalised problem integrating words for reading comprehension, they would show neither semantic nor grammatical effects, and should also perform poorly on comprehension trials.

Method

Participants

Nineteen deaf children, 19 reading-age and 19 chronological-age matched hearing children took part in the self-paced reading experiment.

Deaf children.

All 19 deaf children (14 male) were profoundly deaf since before they were 3 years old and had no other special educational needs. They had a mean better ear pure-tone threshold average of 109dB (range 93-120dB), a mean reading-age[3] of 8;0 years (range 6;4 – >11) and a mean chronological-age of 13;9 years (range 11;9 – 16;3). None of the children had a cochlear implant. Nine participants reported using two hearing aids, two participants reported using one hearing aid and eight participants reported that they did not use hearing aids. All but one of the children attended a campus comprising of Primary, Secondary and Post-16 specialist day and residential provision for deaf children. They were educated using BSL and English. The remaining child attended a large campus-based mainstream Secondary School, spending at least one day a week within a specialist Hearing Impairment Unit where they were taught by a Teacher of the Deaf using BSL and Sign Supported English.

The parents of participating children were asked to complete a short questionnaire detailing their own hearing status and communication with their child at home. Four parents did not complete this. All other parents reported communicating using BSL (twelve participants) or a combination of BSL and English (three participants). Four of the children had two deaf parents. One child had a mother who was hard of hearing and a hearing father. The remaining children were born to hearing parents.

Hearing children.

Two children with normal hearing were recruited to match to each individual deaf child on the basis of either (a) reading-age or (b) chronological-age. These children were native, monolingual English speakers from four schools in the Midlands and South of

[3] Reading-ages were measured using the NFER-Nelson Group Reading Test II Form B (Group Reading Test, 1997) which has a lower bound of 6 years and an upper bound of 11 years. One deaf child reached ceiling (>11 years) therefore was matched to a hearing child on the basis of their raw score.

England. Parents confirmed that these children had not been diagnosed with any language, learning or literacy impairments.

The 19 reading-age (RA) matched hearing children (seven male) were reading appropriately for their age, had a mean RA of 8;3 years (range 6;4 – >11) and a mean CA of 8;6 years (range 5;11 – 11;2). The 19 chronological-age (CA) matched hearing children (three male) were reading grade appropriately or better (using Gates-MacGinitie Reading Test Form 6S) and had a mean CA of 13;10 (range 12;0 – 16;1).

Stimuli and design

Two types of sentences were presented; 28 to test agreement anomaly and 20 to test semantic anomaly (i.e., plausibility). The anomaly (whether agreement or plausibility) could be detected from the mismatch between the noun and verb. For each of the 28 agreement sentences, four variations were created, fully crossing number markers on the subject and verb (e.g., *the* ***apples grow*** *on the tree, the* ***apple grows*** *on the tree, the* ***apples grows*** *on the tree, the* ***apple grow*** *on the tree*). The twenty plausible sentences designed for the semantic condition were matched to twenty implausible sentences. These plausible-implausible sentence pairs contained identical nouns but differed from the verb onwards (e.g., *the* ***car drives*** *along the road, the* ***car smiles*** *at her mother*). All were grammatically correct. Half of them contained plural nouns and half contained singular nouns.

The disagreeing sentences contained a verb which could be semantically combined with the subject noun but the number marker was incorrect (e.g., *apple – to grow).* In contrast, the implausible sentences contained a verb with idiosyncratic semantic properties preventing its combination with the preceding subject noun (e.g., *car – to smile;* only animate nouns smile). In both cases, the verb was well-formed and a common word. Therefore the anomaly could only be detected by integrating it into the preceding context. For plausibility anomalies, this meant semantic integration. For agreement errors, this meant both semantic and syntactic integration. A complete list of sentences is provided in Appendix A.

All sentences were structured [the] [noun] [verb] [3 – 5 word completion]. The average number of words in the completion was matched between conditions (see Table 2, $p > 0.5$). The subject noun and verb were always morphographically regular (i.e., root+<s>) and the noun, verb and first two words following the verb (henceforth *verb+1* and *verb+2*) were matched between conditions for word frequency[4] (based on the CELEX Database – Baayen, Piepenbrock, & Rijn, 1993, and the CERV – Stuart, Dixon, Masterson, & Gray, 2003) and number of letters (see Table 2, independent sample *t* tests, $p > 0.1$).

** *Table 2 about here* **

Twenty native English-speaking hearing adults educated to degree level or above provided plausibility ratings for the agreeing, plausible and implausible sentences. Ratings were provided on a Likert scale of 1 (unlikely to occur in the real world) to 7 (very likely to occur in the real world). They confirmed that the agreeing and plausible sentences were equally plausible (independent samples *t* tests, $p = 0.1$) and significantly more so than the implausible sentences; agreeing vs. implausible $t(74) = 39.0$, $p < 0.001$; plausible vs. implausible $t(38) = 34.4$, $p < 0.001$.

The 28x4 agreement sentences and 20x2 plausibility sentences were divided into four lists of stimuli, each containing 48 sentences. Across the four lists, all four types of agreement sentence occurred once and each plausibility sentence occurred twice but on each

[4] Frequencies were missing from the CERV (Stuart et al., 2003) for four nouns and three verbs in the agreement sentences, two nouns and two verbs in the plausible sentences and two nouns and two verbs in the implausible sentences. For the remaining words, independent samples *t* tests confirmed that word frequencies in agreement, plausible and implausible sentences did not differ on the noun, verb, verb+1 or verb+2 ($p > 0.1$).

individual list, each sentence occurred in only one version (i.e., only one of the four versions of agreement sentences and only one of the plausible or implausible pairs). Furthermore, within each list the number of trials per condition was controlled such that each list contained 14 agreeing sentences (7 singular), 14 disagreeing sentences (7 singular verbs), 10 plausible sentences (5 singular) and 10 implausible (5 singular) sentences. Participants completed only one list each.

Procedure

Participants were instructed that they would read sentences on the computer screen but would only see one word at a time. They were told to read carefully because sometimes they would have to choose a picture to match the sentence that they had just read. Participants were told that they should use the spacebar to move through the sentence in their own time but that once they moved on from a word they would be unable to see that word again. Deaf and hearing children received instructions in written, spoken and signed formats (as appropriate) and also completed four practice trials (which didn't contain errors and were different from the experimental stimuli), with experimenter support, prior to commencing experimental trials.

An HP Pavilion dv1000 notebook computer ran the experiment using E-prime™ (version 1.1.4.4 SP3, 2002) software to control stimulus presentation and record responses. Background colour was white with text presented in black 16pt Courier New font. Sentences were presented using a non-cumulative word-by-word moving window paradigm (i.e., only one word was visible at any time) that did not permit regressions. Dashes provided a visual placeholder for words that were not currently visible, with one dash replacing each letter in the words. Trial order was randomised and after each picture trial participants viewed a "scoreboard" screen with a score based on the speed and accuracy with which they selected the picture. Thus even incorrect responses were rewarded with points but correct responses gained more points.

On each list, 16 of the sentences (four agreeing, four disagreeing, four plausible and four implausible) were followed by a picture trial, in which participants had to choose the picture which "*best matched the sentence*" using a mouse to select the image. These trials were included to ensure that participants were reading for comprehension. Each picture trial contained two images. For agreement sentences, one image depicted the sentence in its singular form whilst the other depicted the plural. For the plausibility sentences, one image depicted the plausible sentence and the other the implausible sentence[5]. The left-right order of images was counterbalanced between trials. Images included black-and-white and colour photographs and drawings.

Results

Overall, performance on the picture trials confirmed that children were reading for comprehension. On the picture trials for the plausibility sentences, all participant groups performed close to ceiling (see Table 3). For the agreement condition we only inspected agreeing sentences because disagreeing sentences have no correct response. Deaf children's picture choices for agreeing sentences were particularly poor, and they produced significantly fewer correct responses than RA or CA children; $\chi^2(1, N = 152) = 4.7$, $p = 0.03$ and $\chi^2(1, N = 152) = 11.9$, $p = 0.001$. RA and CA children did not differ; $\chi^2(1, N = 152) = 1.8$, $p = 0.2$.

Table 3 about here

[5] The scoreboard after picture trials for disagreeing sentences gave more points if participants selected the picture that matched the number marking on the noun. Note that each participant responded to only four picture trials for sentences containing disagreeing number markers.

Anomalous sentences could not be recognized until the verb, so our analyses focussed on the verb, verb+1 (V+1) and verb+2 (V+2). Because of large individual variation in reading speed, each participant's reading times were converted into z-scores for each word position (i.e., z-scores were calculated separately for each participant on V, V+1 and V+2 independently). For all analyses, trials with z-scores greater than three on the verb, V+1 or V+2 were removed as outliers and the z-scores were then recalculated for the analyses. Mean raw reading times on these words are presented in Table 3. Figure 1 plots the difference in z-scores between agreeing and anomalous sentences for each participant group. In this graph, a negative z-score difference reflects slowing down as a result of anomaly while a positive z-score difference reflects speeding up.

To establish whether the participant groups differed in performance on the self-paced reading task, a split-plot ANOVA with the repeated-measures factors sentence type (agreement vs. semantic), anomaly (normal, anomalous), word (verb, V+1 and V+2) and the between-participants factor participant group (deaf children, RA, CA) was calculated on the z-score reading times. This revealed a significant sentence type*anomaly*word*participant group interaction, $F_1(4,108) = 3.0$, $p = 0.02$, partial $\eta^2 = 0.10$[6]. The four-way interaction was followed up by two analyses. First we asked where the participant groups' behaviour differed and then we asked whether the behaviour on the different sentence types (agreement and plausibility) was distinct for all participant groups.

Figure 1 about here

[6] Partial η^2 indicates the proportion of variance explained by the current factor out of the variance left unexplained by the other factors. Cohen (1969) gives rules of thumb for η^2 sizes (small = 0.01, medium = 0.06, large = 0.14) which, according to Richardson (2011 p141), "*were intended to apply to partial η^2, not to the classical version*".

Where did the participant groups' behaviour differ?

To examine where participant groups differ in behaviour we first examined behaviour on plausibility sentences and then on agreement sentences, conducting separate split-plot ANOVAs on each sentence type with the repeated-measures factors anomaly and word, and the between-participants factor participant group.

Plausibility sentences

Participant groups did not differ in their behaviour on plausibility sentences. None of the participant group interactions were significant by participants (F_1) or item (F_2); anomaly*word*participant group $F_1(4,108) = 0.4$, $p = 0.8$; $F_2(4,114) = 0.3$, $p = 0.9$; anomaly*participant group $F_1(2,54) = 0.4$, $p = 0.7$; $F_2(2,57) = 0.3$, $p = 0.7$; word*participant group $F_1(4,108) = 1.2$, $p = 0.3$; $F_2(4,114) = 0.4$, $p = 0.8$; anomaly*word F_1(1.8, 3.5[7]) = 0.3, $p = 0.7$; $F_2(2,114) = 0.2$, $p = 0.8$. The main effect of participant group was significant by participant but not by item; $F_1(2,54) = 3.2$, $p = 0.048$; $F_2(2,114) = 1.4$, $p = 0.2$. The main effect of word was significant by participant but not by item; $F_1(2,108) = 7.2$, $p = 0.001$, partial $\eta^2 = 0.12$; $F_2(2,114) = 2.5$, $p = 0.09$. Crucially, the main effect of anomaly was significant by both participants and items; $F_1(1,54) = 12.5$, $p = 0.001$, partial $\eta^2 = 0.19$; $F_2(1,57) = 10.4$, $p = 0.002$, partial $\eta^2 = 0.15$. Combined with the lack of an interaction with word, this shows that plausibility anomalies caused similar levels of slowing across each of the word positions in the analysis[8]. In sum, the results show that all participant groups were

[7] Throughout this paper, when Mauchley's Test of Sphericity indicated that the assumption of sphericity had been violated, the more conservative Greenhouse-Geisser *F*-statistics and adjusted degrees of freedom are presented.

[8] Slowing was not significant later in plausibility sentences; verb+3 mean z-score difference -0.07(0.49); $t_1(56) = -1.1$, $p = 0.3$; $t^2(56) = -1.2$, $p = 0.2$; verb+4 mean 0.11 (0.94); $t_1(56) = 0.8$, $p = 0.4$; $t_2(8) = 0.7$, $p = 0.5$; verb+5 mean 0.02 (1.41); $t_1(23) = 0.1$, $p = 0.9$; $t_2(2) = -0.4$, $p = 0.8$. Note that these positions had not been controlled for linguistic features (e.g., word length, frequency, sentence length) and therefore these results should be viewed cautiously. For comparison, equivalent by position paired-samples t-tests gave indications of slowing at the verb, V+1 and V+2, with contrasts reaching significance (bonferroni-adjusted criterion 0.05/3 = 0.0167) on the verb (by items and marginal by participant) and V+2 (by participant); verb mean -0.15 (0.47); $t_1(56) = -2.4$, $p = 0.018$; $t_2(59) = -3.2$, p

sensitive to plausibility anomalies and there was no indication that this sensitivity differed by participant group.

Agreement sentences

In contrast to the null effect of participant group for plausibility sentences, for agreement sentences the three-way interaction was significant both by participants (F_1) and items (F_2); $F_1(4,108) = 6.3$, $p < 0.001$, partial $\eta^2 = 0.19$; $F_2(4,162) = 11.6$, $p < 0.001$; partial $\eta^2 = 0.22$. At the same time, note that the two-way interaction between anomaly and participant group was not significant; $F_1(2,54) = 1.1$, $p = 0.3$; $F_2(2,81) = 1.2$, $p = 0.3$. Participant groups did not differ in the overall magnitude of their slowing down to agreement anomalies (CA mean z-score 0.00, *SE* 0.04; RA mean -0.01, *SE* 0.04; deaf mean 0.02, *SE* 0.04). The three-way interaction was broken down first by word, and then by participant group. The interaction between participant group and anomaly was significant by participant and by item on the verb, and was significant by items on the two words after the verb; verb $F_1(2,54) = 7.5$, $p = 0.001$, partial $\eta^2 = 0.22$; $F_2(2,81) = 10.4$, $p < 0.001$, partial $\eta^2 = 0.20$; verb+1 $F_1(2,54) = 2.2$, $p = 0.1$; $F_2(1,81) = 3.3$, $p = 0.041$, partial $\eta^2 = 0.08$; verb+2 $F_1(2,54) = 2.8$, $p = 0.07$, partial $\eta^2 = 0.09$; $F_2(2,54) = 3.1$, $p = 0.048$, partial $\eta^2 = 0.07$.

Next we examined the time course of the agreement effect in each participant group individually. We present the data for CA children first (see Figure 1.A). For agreement sentences, there was a significant interaction; $F_1(2,36) = 6.0$, $p = 0.006$, partial $\eta^2 = 0.25$; $F_2(2,54) = 12.0$, $p < 0.001$, partial $\eta^2 = 0.31$; and the main effects of both anomaly and word were also significant; anomaly $F_1(1,18) = 10.1$, $p = 0.005$, partial $\eta^2 = 0.36$; $F_2(1,27) = 21.8$, $p < 0.001$, partial $\eta^2 = 0.45$; word $F_1(1.3\ 23.4) = 3.8$, $p = 0.05$, partial $\eta^2 = 0.18$; $F_2(2,54) = 3.3$, $p = 0.043$, partial $\eta^2 = 0.11$. Paired-samples t-tests for each word revealed that the difference

= 0.002; V+1 mean -0.13 (0.45); $t_1(56) = -2.2$, $p = 0.03$; $t_2(59) = -1.9$, $p = 0.07$; V+2 mean -0.19 (0.43); $t_1(56) = -3.3$, $p = 0.002$; $t_2(59) = -2.3$, $p = 0.024$

between agreeing and disagreeing sentences was significant on the verb only, with a significant effect by items (t_2) and non-significant trend by participant (t_1) on V+1 (applying a Bonferroni corrected criterion of 0.05/3 = 0.0167); verb $t_1(18) = -4.7$, $p < 0.001$; $t_2(27) = -5.0$, $p < 0.001$; V+1 $t_1(18) = -2.4$, $p = 0.03$; $t_2(27) = -4.0$, $p < 0.001$; V+2 $t_1(18) = 0.8$, $p = 0.4$; $t_2(27) = 1.1$, $p = 0.3$.

Examining the agreement effect in the RA population (Figure 1.B), the anomaly by word interaction was significant by both participant and item; $F_1(2,36) = 6.7$, $p = 0.004$, partial $\eta^2 = 0.27$; $F_2(2,54) = 11.6$, $p < 0.001$, partial $\eta^2 = 0.30$. The main effect of anomaly was not significant; $F_1(1,18) = 1.1$, $p = 0.3$; $F_2(1,27) = 1.3$, $p = 0.3$. The main effect of word was significant by participant but not by item; $F_1(2,36) = 5.1$, $p = 0.012$, partial $\eta^2 = 0.22$; $F_2(2,54) = 1.1$, $p = 0.3$. Paired-samples t-tests revealed that, when reading sentences containing agreement anomalies, RA children slowed down on the verb only (t_1 by participant, t_2 by item); verb $t_1(18) = -2.8$, $p = 0.012$; $t_2(27) = -3.9$, $p = 0.001$; V+1 $t_1(18) = -0.06$, $p = 1.0$; $t_2(27) = 0.0$, $p = 1.0$; V+2 $t_1(18) = 1.0$, $p = 0.3$; $t_2(27) = 0.9$, $p = 0.4$.

Finally, examining the agreement effect in the deaf population (Figure 1.C) revealed that the anomaly by word interaction was significant, as was the main effect of word; interaction $F_1(2,36) = 5.5$, $p = 0.008$, partial $\eta^2 = 0.24$; $F_2(2,54) = 6.7$, $p = 0.003$, partial $\eta^2 = 0.20$; word $F_1(2,36) = 5.0$, $p = 0.012$, partial $\eta^2 = 0.22$; $F_2(2,54) = 3.5$, $p = 0.003$, partial $\eta^2 = 0.20$. The main effect of anomaly was significant by participant but not by item; $F_1(1,18) = 10.4$, $p = 0.005$, partial $\eta^2 = 0.37$; $F_2(1,27) = 2.9$, $p = 0.10$. When reading sentences containing agreement anomalies, deaf children slowed significantly on V+1 and V+2 (V+2 significant by participant, t_1, but not by item, t_2) but not on the verb[9]; verb $t_1(18) = 1.2$, $p =$

[9] Slowing was not significant later in the sentence; verb+3 $t_1(18) = -0.7$, $p = 0.5$, $t_2(27) = -0.8$, $p = 0.4$; verb+4 $t_1(18) = 0.3$, $p = 0.8$, $t_2(7) = 0.2$, $p = 0.9$; verb+5 $t_1(14) = -0.8$, $p = 0.5$; $t_2(3) = -0.2$, $p = 0.9$

0.3; $t_2(27) = 1.0$, $p = 0.3$; V+1 $t_1(18) = -3.3$, $p = 0.004$; $t_2(27) = -2.8$, $p = 0.008$; V+2 $t_1(18) = -2.7$, $p = 0.014$; $t_2(27) = -2.0$, $p = 0.06$.

To summarise, all participant groups were sensitive to agreement anomalies and there was no difference in the magnitude of this sensitivity. However, the time course with which participants responded to disagreeing subject-verb number markers differed. CA children's reading times increased on the verb with a weak spill-over effect on V+1, RA children's reading times increased on the verb only but deaf children's reading times did not increase until V+1 and V+2.

Did behaviour on plausibility and agreement sentences differ for all participant groups?

We conducted separate 2 (sentence type) x 2 (anomaly) x 3 (word) repeated-measures ANOVAs for each participant group. The three-way interaction was significant for the CA hearing children; $F_1(2,36) = 4.5$, $p = 0.02$, partial $\eta^2 = 0.20$; and marginal for the RA hearing children; $F_1(2,36) = 3.1$, $p = 0.058$, partial $\eta^2 = 0.15$. As we have already seen in the previous analysis, this interaction occurs within the hearing children's data because slowing was distributed across positions in the plausibility condition, but concentrated on the verb (and, to a lesser extent, on V+1 for the CA group) in the agreement sentences.

In contrast to the observation in both groups of hearing children's data, the three-way interaction of sentence type, anomaly, and word was not significant for the deaf children; $F_1(2,36) = 2.3$, $p = 0.1$; nor was the interaction between sentence type and anomaly; $F_1(1,18) = 0.0$, $p = 1.0$; or the main effects of word or sentence type; $F_1(2,36) = 1.0$, $p = 0.4$; $F_1(1,18) = 0.4$, $p = 0.5$. We have previously seen that when the data are divided by sentence types, the anomaly effect is distributed across words for plausibility sentences and concentrates on V+1 and V+2 for agreement sentences. These apparent differences, however, are not strong enough to sustain a significant interaction when they enter together, as they do here, in an overall analysis. The main effect of anomaly; $F_1(1,18) = 9.1$, $p = 0.007$, partial $\eta^2 = 0.34$; the interaction between anomaly and word; $F_1(2,36) = 4.1$, $p = 0.03$, partial $\eta^2 = 0.19$; and the interaction between sentence type and word; $F_1(2,36) = 4.1$, $p = 0.02$, partial $\eta^2 = 0.19$ were significant. This indicates that deaf children slowed down when reading sentences that contained anomalies (agreement or plausibility) compared to normal sentences, without strong evidence for a difference between the two anomaly types agreement and plausibility.

Discussion

In Experiment 1 a self-paced reading task was used to compare reading times on sentences containing agreeing and disagreeing subject-verb number markers to sentences containing plausible and implausible noun-verb combinations. For CA and RA hearing children, agreement anomalies and plausibility anomalies caused children to slow down while reading, but each type of anomaly caused slowing at different times, and there were minor developmental differences between the groups. The agreement effect was immediate and short-lived, with reading times increased on the verb (where the anomaly occurred) and a spill-over effect for CA children on the word following the verb. RA children slowed down on the verb only. They appeared to have read in a word-by-word manner, not only accessing the word meanings, but also integrating number marking on the verb before moving onto the next word. In contrast, the spill-over effect observed for CA children suggests that they have become slightly more proficient readers, starting to perform syntactic integration in the background whilst continuing to process the remainder of the sentence. This result is in keeping with a previous finding that, when writing, mature readers process subject-verb agreement hierarchically while young children process serially (Negro, Chanquoy, Fayol, & Louis-Sidney, 2005). Our result suggests that this might be true for reading as well.

In contrast to the short-lived effect of agreement hearing children showed a weaker, but longer-lasting plausibility effect. Anomalies resulted in general slowing on the verb and on the following two words for both CA and RA children, even if the effect was only marginally significant, and therefore weaker, for RA children. These results are congruent with findings from EEG studies that adults recognize both subject-verb number agreement errors and semantic anomalies very quickly, but that they process them differently (Coulson et al., 1998; De Vincenzi et al., 2003; Kutas & Hillyard, 1983; Osterhout & Mobley, 1995). The present findings add to this research by suggesting that although anomalies may be detected very early, integration might take place later, especially in case of semantic anomalies.

Deaf participants, like hearing participants, were sensitive to agreement errors. This was despite them having very poor performance on the picture trials for agreeing sentences, which one might expect to indicate a lack of sensitivity to number marking (note, however, that each participant only responded to four picture trials after agreeing sentences). Reading times increased when sentences contained disagreeing subject-verb number markers, and the increase was of the same magnitude as in both groups of hearing participants. However, the time course of slowing differed. While hearing children slowed down immediately on the verb of disagreeing sentences, deaf children's slowing was extended in time over the V+1, V+2 period (returning to normal reading times after this). This late and extended slowing was not the result of general reading comprehension problems, since the deaf adolescents performed at ceiling on the picture trials for plausibility sentences. Furthermore, deaf participants appear to slow down in a very similar way for agreement and plausibility anomalies, namely over an extended period.

Experiment 2

Immediately after completing Experiment 1 participants completed a pencil-and-paper judgment task on the agreement sentences that they had viewed in the self-paced reading task. While Experiment 1 suggested implicit awareness of subject-verb number agreement for both hearing and deaf children, the purpose of Experiment 2 was to test explicit awareness of subject-verb number agreement, by examining whether children could judge whether sentences were correct or contained errors and explicitly manipulate subject-verb number markers to correct the error. This methodology is similar to the classic measures of syntactic ability, such as that used in the Test of Syntactic Abilities (Quigley et al., 1976; Quigley and King, 1980).

Method

Participants

The 19 deaf children and their RA and CA matched hearing counterparts from Experiment 1 completed the agreement judgment task.

Stimuli and design

Participants were assigned the same stimulus list of sentences with agreeing and disagreeing subject-verb number markers as in Experiment 1. This ensured that individual participants were not presented with the same sentence in both its correct and anomalous form. Accordingly, participants responded to 28 sentences; 14 with agreeing and 14 with disageeing subject-verb number markers.

Procedure

The agreement judgment task consisted of a list of sentences with tick boxes located to the left of each sentence. Participants were instructed to read the sentences and decide whether they contained an error. If the sentence was incorrect they were to put a cross in the box and, if possible, try and correct the sentence like a teacher would. If the sentence was correct they were to place a tick in the box. The worksheet included a completed example of a sentence containing spelling errors, to avoid drawing attention to semantic or grammatical anomalies.

Results

The first analyses examined the accuracy with which deaf, RA and CA children marked sentences as correct or incorrect. The second analyses examined the changes that participants made to the sentences.

Accuracy

In order to compare accuracy on the agreement judgment task, *d'* values were calculated for each participant from counts of ticks and crosses on sentences containing agreeing and disagreeing subject-verb number markers[10]. Statistical significance was tested using hierarchical log-linear analysis with the factors participant group (deaf, RA and CA), sentence type (agreeing, disagreeing) and response (tick, cross). Sensitivity is indexed by the interaction between sentence type and response (i.e., the tendency for the agreement anomaly to modify response). This analysis revealed that participant group had a significant effect on sensitivity; Participant group*Sentence type*Response; $G^2(2) = 125.72$, $p < 0.001$. CA children demonstrated good sensitivity (mean *d*' 2.21, *SD* 1.14, mean bias -0.28), correctly accepting a mean of 91% of agreeing sentences and correctly rejecting 76% of disagreeing sentences. RA children had significantly less sensitivity than CA children; $G^2(1) = 8.27$, $p =$ 0.004. Furthermore, the RA children demonstrated a general bias to accept the sentences as being correct (mean *d'* 1.57, *SD* 1.01, mean bias -0.61). Nonetheless, although less sensitive than CA children, the RA children were still quite sensitive, correctly accepting a mean of 90% of agreeing sentences and correctly rejecting 56% of disagreeing sentences.

In contrast to the groups of hearing participants, deaf children were not at all sensitive to the agreement anomaly and had a strong bias for accepting sentences (mean *d'* -0.01, *SD*

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[10] One deaf child omitted responses to 16 sentences (6 on disagreeing sentences and 10 on agreeing sentences), while two RA children omitted a single response to agreeing sentences (none of the hearing adults' or CA children's responses were omissions). Because of how *d'* and log-linear analyses are calculated, these omissions were simply removed from this analysis.

0.69, mean bias -0.75; deaf vs. RA: G^2 (1) = 60.53, $p < 0.001$; deaf vs. CA: G^2 (1) = 119.12, $p < 0.001$). They correctly accepted a mean of 73% of the agreeing sentences and correctly rejected a mean of only 27% of the disagreeing sentences. Furthermore, only 6/19 deaf children achieved *d'* values greater than zero (a *d*' of zero indicates no sensitivity to whether or not the sentences contain anomalies, while a negative *d'* would suggest a bias towards giving *incorrect* responses). In contrast, only one RA and two CA children had such low sensitivity. Therefore, only a real minority of deaf children could reliably identify disagreeing sentences.

Corrections to disagreeing sentences

A fully correct response to a disagreeing sentence would be to mark it as incorrect and then to correct the disagreeing subject-verb number markers – this represents explicit awareness of agreement. If participants are unable to correct the sentence or make a change that does not resolve the agreement error (such as changing the completion) this indicates a lack of explicit awareness of agreement. We analysed the corrections that were made to sentences accurately identified as containing incorrect subject-verb number markers (i.e., correct rejections from the previous analyses). Note that the previous analyses already demonstrated that CA children (203/266) made more correct rejections than RA children (149/266) who, in turn, made more correct rejections than the deaf children (71/266). The present analyses examine what children did once they had identified these errors.

Corrections were scored as correct, other and no change. *Correct* responses included any changes that resulted in a well-formed sentence (including tense changes). Responses were categorised as *other* when an alteration had been made that did not resolve the ungrammaticality of the sentence, for example, changing a different part of the sentence rather than the noun or verb. *No change* responses were responses for which the participant had managed to accurately mark the sentence as incorrect but had not attempted to change the sentence in any way.

Table 4 illustrates the rates of each type of correction to disagreeing sentences. CA children correctly changed disagreeing sentences more frequently than RA children (95% and 60% correct respectively); χ^2 (1, N = 352) = 65.5, $p < 0.001$. However, deaf children had more difficulty than either group of hearing children – only 25/71 (35%) of corrections resulted in a grammatically correct sentence; deaf vs. CA χ^2 (1, N = 274) = 115.9, $p < 0.001$; deaf vs. RA χ^2 (1, N = 220) = 12.2, $p < 0.001$; CA vs RA χ^2 (1, N = 352) = 65.5, $p < 0.001$. In fact, an examination of individual data revealed that only 6/19 deaf children *ever* corrected a sentence appropriately. Moreover, note that only two deaf participants who achieved a $d' > 0$ also ever corrected any sentences correctly[11].

Table 4 about here

Table 5 lists the type of response that was made when participants failed to correct the sentence appropriately. We compared participant groups' 'no change' to their 'other' responses. When children accurately marked a sentence as containing an error but did not properly correct the error, deaf children were more likely not to attempt any kind of correction; deaf vs. RA χ^2 (1, N = 105) = 11.5, $p = 0.001$; deaf vs. CA Fisher's Exact Test $p <$ 0.001. RA and CA children did not differ; Fisher's Exact Test $p = 0.1$.

[11] In fact, only one deaf participant could be said to be "good" at the agreement judgement task. This participant was 15;5 years old with a reading-age of 9;1 years and achieved 86% correct rejections of ungrammatical sentences and 79% correct accepts of grammatical sentences, with 12/12 attempted corrections resulting in a grammatically correct sentence. Note that this participant's performance on the self-paced reading study had a similar to the rest of the deaf participants, slowing down on the word after the anomaly (mean z-score difference for agreement sentences on verb 0.55, V+1 -0.47, V+2 0.12).

Table 5 about here

Discussion

In Experiment 2, participants' explicit knowledge of subject-verb number agreement was tested in a paper-and-pencil detect-and-correct error judgment task. CA matched hearing children were able to perform these judgments without great difficulty, detecting the large majority of errors and almost always correcting appropriately. Therefore, CA children revealed solid explicit awareness of subject-verb number agreement.

The RA matched hearing children were less accurate than the older CA children in detecting erroneous sentences, and only 60% of their corrections actually repaired the agreement error. RA children had some explicit awareness of agreement, but this was not fully developed.

Most strikingly, though, deaf children failed to demonstrate any explicit awareness of subject-verb agreement. They showed a strong bias towards accepting any sentence as being correct. Even when deaf children managed to successfully mark ungrammatical sentences as incorrect, they very rarely managed to successfully correct the error. Instead, they usually made no attempt at a correction. The present findings in the agreement judgement task are consistent with previous research using similar methods (e.g., Quigley et al., 1976; Quigley & King, 1980) and yet contrast with the findings from Experiment 1 which indicated an implicit awareness of agreement. In general, deaf children found the judgment task very difficult. Not only were they less successful, they also found it hard to understand what was required of them and needed more encouragement to attempt the entire worksheet. Hearing children did not have these problems.

A potential criticism of the agreement judgment task is that, although the only type of errors that occurred in the sentences were agreement errors, the example provided did not draw attention to morpho-syntactic errors. Instead, the example illustrated a spelling error that had been corrected. This may have led children to simply look for words that were spelled incorrectly rather than to fully process the sentences. However, this explanation seems unlikely since only six corrections produced by deaf children were of this type. More crucially, any limitation inherent in the task was present for all three groups of participants. Therefore the instructions cannot explain the good performance of RA and CA children and the substantial differences in performance demonstrated between deaf and hearing children.

Explicitly asking children to search for agreement anomalies might, possibly, lead to higher level of detections, even in the deaf population. Note that in the present design participants' attention might have been directed to subject-verb agreement because this was the only type of error present. The only way to make this more explicit would be to show an example of an agreeing and a disagreeing sentence, effectively providing the participants with material to derive a rule that they can use for the task of which they did not have any prior (explicit) knowledge. In addition, we were interested in the children's performance in a task that is closer to a natural proof-reading situation that is done without drawing attention to particular errors, because this is the situation where explicit knowledge makes a real difference.

General Discussion

The present study examined deaf and hearing children's implicit and explicit awareness of subject-verb number agreement in reading. In a self-paced reading task, participants read sentences containing disagreeing subject-verb number markers and sentences with implausible subject-verb combinations. In an agreement judgment task, children were asked to detect-and-correct subject-verb number anomalies. Both RA-matched and CA-matched hearing children demonstrated implicit as well as explicit awareness of agreement. They showed clear differences in the time course of agreement and plausibility effects during reading and they were competent at detecting and correcting errors. However, while the two groups showed very similar implicit awareness, older CA matched hearing children demonstrated a much higher explicit awareness of agreement than RA matched hearing children. CA children were much more accurate at detecting subject-verb agreement anomalies in the judgment task and were much more competent at correcting the error. This finding is consistent with previous evidence suggesting that, developmentally, implicit awareness precedes explicit understanding (Critten, Pine, & Steffler, 2007) and that younger hearing children find explicit grammaticality judgment difficult (Wulfeck, 1993).

Deaf participants demonstrated a very different pattern of results compared to hearing children. The findings from the two experiments together suggested that deaf participants had some implicit awareness of subject-verb number agreement without explicit awareness. In the self-paced reading task (Experiment 1), deaf participants slowed down when encountering agreement errors, revealing an implicit awareness of agreement. However, since the deaf participants' slowing response was prolonged compared to that of the two groups of hearing participants the way agreement was processed was different.

In a detect-and-correct judgement task (Experiment 2) deaf participants had a strong bias to mark sentences as grammatically correct regardless of whether an error was present. Even when they successfully marked ungrammatical sentences as incorrect, deaf participants were much less likely than their RA-matched hearing counterparts to attempt to correct the error and very rarely did so effectively.

The combined results from Experiments 1 and 2 therefore suggest that whatever the nature of the agreement awareness evidenced by the deaf participants in the self-paced reading task, this was an implicit awareness that they were not able to use in grammaticality judgment. Perhaps the meta-linguistic nature of the detect-and-correct judgement task was too arduous for the deaf children's fragile agreement awareness. Whatever the cause, it seems clear that the deaf participants' understanding of subject-verb number agreement was much less advanced and stable than that of CA and RA matched hearing children. They appear to demonstrate a nascent awareness of subject-verb number agreement, which generally follows the pattern of typical hearing development – implicit awareness followed by explicit understanding. It is possible that specific differences in the manner in which deaf children learn about English grammar lead to these differences – perhaps because their knowledge is based more heavily on experience with text rather than speech, or because the aural input differs. For example, word-final /s/ is potentially less visible on the lips in connected speech (note that in text <s> is equally transparent for deaf and hearing children). However, the inaudibility argument is not sufficient to explain the data. Previous evidence of hearing children learning inaudible number markers in French suggest that children first over-generalise noun markers to verb and then verb markers to noun (Totereau et al., 1998; Fayol et al., 1999). In English, in both cases this would result in sentences with disagreeing subject-verb number markers (since +<s> markers a plural noun or a singular verb). In which case, the deaf children should have mistakenly believed that the sentences containing agreeing subject-verb number markers were incorrect. While this might explain some of the data, it was not the case for most children – the deaf children correctly accepted 73% of agreeing sentences.

The pattern observed in the deaf participants in the present study is not consistent with ERP evidence from hearing L2 English-speakers who evidenced explicit understanding of agreement in the absence of implicit awareness (Hahne, 2001; Ojima et al., 2005; Weber-Fox & Neville, 1996). This difference might be due to the fact that second language learners tend to undergo explicit training on subject-verb agreement, which allows them to explicitly apply a rule when asked to do so. The deaf participants in our study clearly have not acquired such an explicit rule. Nonetheless, without comparing deaf participants' behaviour to L2 English-speaking hearing children with a similar amount of English language experience and skill, and an L1 with a subject-verb agreement structure comparable to BSL, one cannot tease apart effects of bilingualism, late or incomplete learning of English and/or deafness per se.

Results from our explicit task are particularly compelling given our own previous findings indicating that a very similar population of deaf children demonstrate good understanding of regular plural noun morphology (Breadmore, 2008; Breadmore et al., 2012). Moreover, the deaf participants in the present study also took part in a recognition task in which they successfully matched a morphographically regular singular or plural noun to the appropriate plural or singular picture in 96% of cases (Breadmore, 2008). Therefore, if our deaf participants lack explicit awareness of agreement errors in the present study, this cannot be because of a lack of understanding of singular/plural alternation at the single word level. Nevertheless, our finding is consistent with previous research showing a general impairment in deaf adolescents' syntax and grammar, particularly in tasks demanding explicit detection and correction of disagreement (e.g., Quigley et al., 1976; Quigley & King, 1980) but also from samples of deaf adults' written prose in Hebrew and Italian (Fabbretti et al., 1998; Tur-Kaspa & Dromi, 2001; Volterra & Bates, 1989).

There are several possible interpretations of the present findings. One possibility is that deaf participants' increased reading times on sentences containing disagreeing subject-verb number markers resulted from them processing the semantic error inherent in the agreement anomaly but not the syntactic error. This interpretation is supported by three findings. First, behaviour for disagreeing sentences was not significantly different from that for implausible sentences. Second, the time course of the deaf participants' agreement effect was reminiscent of the plausibility effect observed in hearing participants – instead of slowing down on the verb, like RA and CA matched hearing children, deaf children slowed over an extended period. Third, the exceptionally poor performance of the deaf children on the ‘detect-and-correct’ grammaticality judgment task (Experiment 2) is consistent with this explanation. If the child interprets these errors as semantic errors there may be no clear way to correct them. If the slowing after agreement errors indicates that deaf children are taking longer to *semantically* integrate disagreeing subjects and verbs, then they might have taken the first step in a process that will eventually lead to acquiring agreement as a *grammatical* phenomenon. If the effect is semantic, semantic information plays a strong role. However, there are also arguments that speak against such an interpretation. First, deaf children performed poorly on the agreement picture trials in the self-paced reading task (Experiment 1), suggesting that they have not understood the singular-plural semantics of the sentence. Second, a general *semantics first* account of agreement acquisition is not supported by previous evidence from hearing populations, which shows that understanding the distributional aspects of agreement typically precedes semantics (Keeney & Wolfe, 1972; Soderstrom, 2008). It might, therefore, be that the agreement effect in the deaf is a nascent *grammatical* effect that would sharpen and contract in time as this knowledge is consolidated.

An alternative explanation for deaf children’s poor performance in the detect-and-correct judgement task, is that a generalised deficit causing the deaf participants to fail to integrate words into context. However, there are several arguments against such an explanation. First, it is not consistent with deaf children’s ceiling level performance on the (im)plausible picture trials, indicating that they can and do integrate the semantic aspects of the verbs into the context of the subject. Second, deaf children did respond to agreement anomalies in Experiment 1, indicating that they did integrate information between words. Moreover, the lack of a two-way interaction between anomaly and participant group in the agreement condition indicates that deaf and hearing participants were similarly affected by agreement anomaly: deaf children differed in the time course of the effect, not the size of the effect. Third, RA hearing children were matched with deaf children on their reading ability, meaning that integration of words into context for comprehension does not differ between the two groups.

Finally, it is possible that deaf children are simply in a protracted phase of rule acquisition, developing in the same manner as hearing children but just more slowly and resulting in agreement awareness which is less secure and less automated. This receives some support from the smaller difference between the agreement and plausibility effect in the younger, reading-age matched hearing children compared to the older, chronological-age matched hearing children. However, it does not seem appropriate to claim that the deaf children were simply slower to perform agreement, as this does not explain the difference in performance in the agreement judgement task, where participants had unlimited time to read and re-read the sentences to detect errors and yet deaf children's performance was far below that of much younger, reading-age matched hearing children. Thus, if deaf children are simply delayed in agreement acquisition, this delay is beyond that expected on the basis of their reading age. Moreover, this delay appears to be specific to morpho-syntactic rather than semantic understanding, since deaf children's performance on the plausibility comprehension trials was at ceiling.

While the results do not definitively tell us how the deaf participants processed subject-verb agreement errors, most importantly, they do tell us that they did respond to them. In contrast to previous findings and our own results in Experiment 2, in Experiment 1 deaf adolescents demonstrated implicit awareness of agreement by slowing down after encountering an agreement anomaly in a self-paced reading task.

In terms of practical consequences of the findings of this study, it appears that teaching children how to build on their knowledge of inflection at the single-word level and apply it to sentence comprehension and production could improve their literacy. An implicit awareness of morphology should enable more efficient processing during reading (since number markers are redundant), while an explicit understanding will improve writing by enabling deaf children to prevent and to correct mistakes appropriately. Previous intervention studies have demonstrated the effectiveness of morphological awareness training on the literacy skills of hearing children (Nunes, Bryant, & Olsson, 2003) including those with dyslexia and SLI (Burani, Marcolini, De Luca, & Zoccolotti, 2008; Elbro & Arnbak, 1996; Pawlowska, Leonard, Camarata, Brown, & Camarata, 2008; Tsesmeli & Seymour, 2009). However, there has been a focus on general morphological awareness training at the single-word level, such as teaching segmentation skills and the combination of morphemes in derivation, compounding and inflection. Moreover, there has been a focus on the oral use of these skills, something that is not necessary helpful (or perhaps attainable) for all deaf children. Future interventions should examine the impact of training morpho-syntax in a sentence context. Moreover, future research should examine the extent to which the effects found in the present study with subject-verb number agreement extend to other agreement phenomena, such as tense errors, which cannot be assumed on the basis of the present study. Previous research using detect-and-correct judgement tasks akin to Experiment 2 suggest that deaf children may have generalised problems with syntactic phenomena (e.g., Quigley & King, 1980), however, future research should examine whether deaf children show implicit awareness in more sensitive tasks.

5. Conclusions

To conclude, deaf children demonstrated limited awareness of subject-verb agreement in reading. In a self-paced reading task, deaf adolescents demonstrated implicit awareness. However, the time course of slowing following an agreement anomaly differed from RA and CA matched hearing children. Moreover, deaf participants were unable to explicitly manipulate subject-verb number markers in order to correct disagreeing sentences. Therefore, deaf children might be sensitive to subject-verb agreement implicitly, but they do not appear to have sufficient understanding of subject-verb number agreement as a grammatical phenomenon to prevent or correct errors in their own writing. Our results indicate that grammatical difficulties may be a significant contributor to deaf children's problems with literacy, explaining, in part, why progress in literacy stalls when it does, as the demands of literacy switch from decoding to effective comprehension. Our study has targeted number agreement, but it is unlikely that the grammatical problems of deaf readers will be limited to this domain. Looking beyond the deaf population, our study, along with other recent research (Rispens & Been, 2007; Oakhill, Cain & Bryant, 2003), forces us to consider the possibility that grammatical knowledge is an important contributor to reading success and that problems with grammatical knowledge could also contribute to literacy impairment in other populations, for example in dyslexia. Intervention studies should be performed to test whether training that targets morphological relationships at the level of sentence processing will move levels of literacy forward in deaf learners.

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Appendix A

Stimuli for Experiment 1: Self-paced reading task

Agreement sentences

the balloon(s) float(s) over the lake
the flower(s) die(s) without any water
the whale(s) swim(s) in the sea
the bubble(s) blow(s) over the fence
the apple(s) grow(s) on a tree
the rabbit(s) eat(s) carrots in the garden
the teacher(s) stand(s) by the blackboard
the girl(s) make(s) a sand castle
the star(s) shine(s) in the sky
the stone(s) sink(s) in the water
the doll(s) ride(s) on a toy horse
the bird(s) build(s) a nest in the tree
the monkey(s) swing(s) through the trees
the goat(s) arrive(s) at the farm
the bell(s) hang(s) in the tower
the rat(s) hide(s) from the cat
the tree(s) burn(s) in the fire
the pill(s) roll(s) off the table
the nurse(s) tie(s) the bandage in a bow
the cat(s) feed(s) the young kittens
the shoe(s) fall(s) off the shelf
the fan(s) wave(s) at the pop star
the egg(s) break(s) on the floor
the pig(s) run(s) away from the farmer
the dog(s) lie(s) on the floor
the builder(s) leave(s) the tools on the floor
the gardener(s) plant(s) a tree in the park
the boy(s) look(s) in the box

Plausibility sentences (plausible / implausible)

the frog jumps out of the pond / the frog cooks dinner in the oven
the ball hits the green vase / the ball loves to eat ice cream
the houses flood in the storm / the houses boil on the stove
the car drives along the road / the car smiles at her mother
the stamp sticks to the envelope / the stamp walks through the forest
the lemons taste too sour for me / the lemons dust the shelves above the fire
the puppies sit in the dog basket / the puppies talk to the girl
the planes land at the airport / the planes help the children cross the road
the kittens chase the little mouse / the kittens ski down the mountain
the pens leak on the paper / the pens shut the front door
the river flows down the hill / the river folds in the middle
the ring fits the finger / the ring wears a blue jumper
the horses ride across the field / the horses cycle down the road
the snake attacks the old man / the snake flies towards the flower
the bear follows the path through the forest / the bear types a letter on the computer
the bridges cross the wide river / the bridges dance to the music
the bulls fight in the field / the bulls ring in the busy office
the truck turns at the traffic lights / the truck plays on the stage
the sign points to the toilet / the sign flowers in the summer
the tigers sleep in the shade / the tigers post a birthday card

Table 1: Hypothesised patterns of performance in Experiment 1 and Experiment 2 resulted from different sources of awareness

	Complete awareness.	Implicit but not explicit awareness.	Explicit but not implicit awareness.	No awareness.
Experiment 1: Self-paced reading	Reading times increase in response to agreement errors. Reading times increase on the anomaly, and spill-over effects on next word.	Reading times increase in response to agreement errors. Reading times increase on the anomaly only.	No effect of agreement.	No effect of agreement.
Experiment 2: Agreement Judgement	Detect and correct errors.	May detect but can’t correct errors.	Detect and correct errors.	Unable to detect and correct errors.

Table 2: Matching agreement and plausibility sentences in Experiment 1

Word	Measure	Condition		
		Agreement	Plausible	Implausible
		M (*SD*)	*M* (*SD*)	*M* (*SD*)
Noun	CELEX Frequency	721 (951)	814 (1201)	814 (1201)
	CERV Frequency	70 (96) [a]	83 (132) [b]	84 (131) [c]
	Number of letters	5 (2)	5 (1)	5 (1)
Verb	CELEX Frequency	633 (741)	719 (973)	710 (794)
	CERV Frequency	52 (119) [a]	37 (43) [b]	47 (111) [c]
	Number of letters	5 (1)	5 (1)	5 (1)
Verb+1	CELEX Frequency	314643 (372032)	465633 (447320)	434715 (399625)
	CERV Frequency	3935 (5151)	6919 (7233)	5520 (5689)
	Number of letters	3 (2)	3 (1)	3 (2)
Verb+2	CELEX Frequency	740254 (491914)	684981 (526075)	622901 (538680)
	CERV Frequency	11253 (7933)	10684 (8487)	9871 (8594)
	Number of letters	3 (1)	4 (1)	4 (2)
Plausibility rating		6.4 (1.3)	6.1 (1.5)	1.3 (0.9)
Number of words in completion		3.4 (0.7)	3.3 (0.6)	3.5 (0.8)

Note. CELEX Frequency: Based on 17.9 million token text corpus taken from the CELEX Database (Baayen et al., 1993). CERV Frequency: Based on 268,028 token children’s text corpus taken from the Children’s Early Reading Vocabulary database (Stuart et al., 2003).
[a] CERV frequencies were missing for four nouns and three verbs out of the 56 items for the agreement sentences. [b] CERV frequencies were missing for two nouns and three verbs out of the 20 items in the plausible sentences. [c] CERV frequencies were missing for two nouns and two verbs out of the 20 items in the implausible sentences.

Table 3: Correct responses to picture trials for agreeing and plausibility sentences and overall raw reading times in Experiment 1

	Correct responses to picture trials		Mean (SD) reading times (msec)		
	Agreeing	Plausibility	Verb	Verb+1	Verb+2
deaf	41/76 (53.9%)	137/152 (90.1%)	763.47 (345.8)	670.7 (293.7)	602.5 (281.3)
RA	54/76 (71.1%)	143/152 (94.1%)	942.6 (631.8)	700.1 (298.7)	629.8 (296.9)
CA	61/76 (80.3%)	149/152 (98.0%)	757.1 (397.9)	646.9 (318.6)	554.3 (240.1)

Table 4: Corrections made to disagreeing sentences by deaf, reading-age and chronological-age matched hearing children in Experiment 2

	Participant group		
	CA	RA	deaf
Correct change	193/203 (95%)	90/149 (60%)	25/71 (35%)
Incorrect change	10/203 (5%)	59/149 (40%)	46/71 (65%)

Table 5: Errors made in correcting disagreeing sentences by deaf, reading-age and chronological-age matched hearing children in Experiment 2

	Participant group		
	CA	RA	deaf
No change	3/10 (30%)	35/59 (59%)	41/46 (89%)
Other change	7/10 (70%)	24/59 (41%)	5/46 (11%)

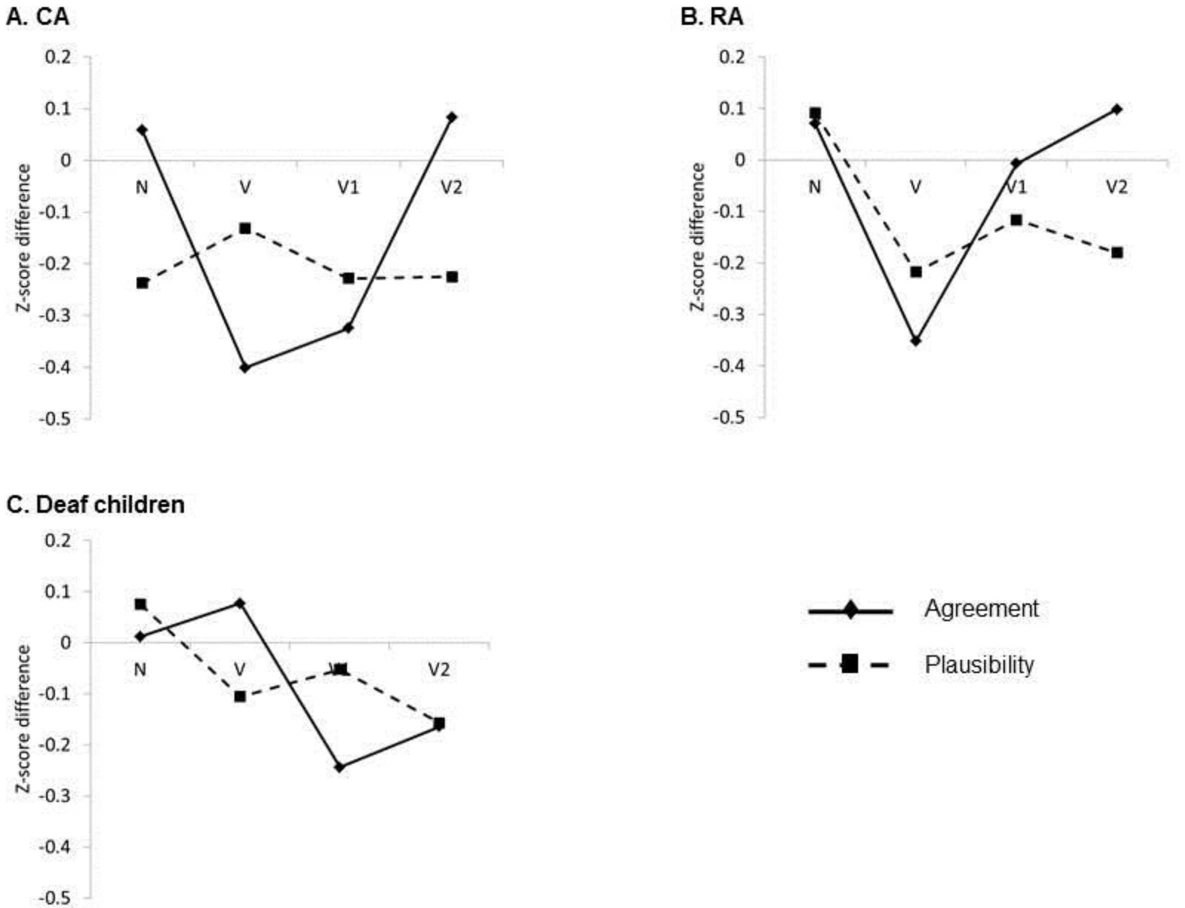

Figure 1: Deaf, reading age (RA) and chronological age (CA) matched hearing children's paired z-score difference reading times (i.e., normal – anomalous)on the noun, verb, verb+1 and verb+2 of agreement and plausibility sentences