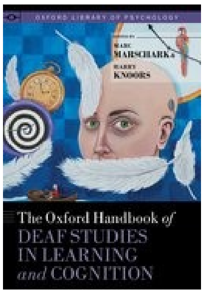

The Oxford Handbook of Deaf Studies in Learning and Cognition
Marc Marschark (ed.), Harry Knoors (ed.)

https://doi.org/10.1093/oxfordhb/9780190054045.001.0001
Published: 2020 **Online ISBN:** 9780190054076 **Print ISBN:** 9780190054045

CHAPTER

20 The Influence of Explicit and Implicit Memory Processes on the Spoken–Written Language Learning of Children with Cochlear Implants

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https://doi.org/10.1093/oxfordhb/9780190054045.013.18 Pages 320–331
Published: 08 June 2020

Abstract

Recent improvements in cochlear implants (CIs) and hearing aid technology are providing deaf children better access to sounds, yet many children with CIs and digital hearing aids continue to experience significant difficulties in verbal language learning, reading, and writing. It has been shown that explicit and intentional memory processes, like verbal rehearsal or semantic organizational strategies, can explain the language and literacy outcomes of CI and hearing aid users. More recently, however, researchers have suggested also an involvement of implicit memory, and particularly implicit sequence learning (SL), in the language and literacy delay of these children. This chapter reviews and discusses studies bringing evidence of the involvement of inefficient explicit memory processes and implicit SL in the language and literacy development of children with CIs. It is argued that the interaction between explicit and implicit memory processes (verbal rehearsal and implicit SL) can better account for CI users' problems with language and literacy acquisition.

Keywords: cochlear implants, implicit learning, working memory, language, literacy
Subject: Educational Psychology, Psychology
Series: Oxford Library of Psychology
Collection: Oxford Handbooks Online

p. 320 Today there is renewed interest into the cognitive bases of prelingually deaf children's learning. Thanks to the spread of universal newborn hearing screening and the new generation of technologies in hearing compensation (i.e., digital hearing aids and cochlear implants [CIs]), the prospects of children with hearing loss are significantly improved (Archbold et al., 2008; Vermeulen, van Bon, Schreuder, Knoors, & Snik, 2007). For a long time, deaf children's learning difficulties have been primarily attributed to their limited access to spoken language (or sign language). Over time, with earlier diagnosis and cochlear implantation as well with the improvements in speech-processing technologies, the spoken-language outcomes of children with CIs have improved significantly (Sarant, Harris, & Bennet, 2015; Spencer, Barker, & Tomblin, 2003;

Spencer, Marschark, & Spencer, 2011). However, studies in the field have suggested that CIs are not a panacea, and even if CIs reduce the gap between hearing and deaf children, greater and better access to spoken language does not eliminate all the learning problems of children born deaf. Indeed, the variability in language and learning outcomes of children with CIs remains very large (Harris & Terletski, 2010; Marschark, Rhoten, & Fabich, 2007; Niparko et al., 2010; Sarant et al., 2015); in some domains, such as reading and writing, the lag between children with CIs and their hearing peers seems even to increase with age (i.e., maturation) and schooling (i.e., experience; Archbold et al., 2008; Arfé, Ghiselli, & Montino, 2016; Harris, 2015; Marschark et al., 2007). Moreover, when studies involving large samples of children with CIs are considered, the results show that at school entrance a significant proportion of children with CIs (i.e., from 42% to 61%) continue to perform below their hearing age-mates also in spoken language (Geers, Moog, Biedenstein, Brenner, & Hayes, 2009).

This chapter discusses findings that refer mainly to deaf children and adolescents who are CI users. In some p. 321 cases, findings related to profoundly or ↳ severely deaf children who use hearing aids are also discussed, as the nature of learning problems related to an early auditory deprivation can be similar in the two groups (Arfé et al., 2016). Spoken and written language learning through a CI or hearing aid is mainly related to the maturation of auditory processes and speech perception.

Why Do Children With CIs Continue to Lag Their Hearing Peers?

With the spread of CIs, audiologists and psychologists put much effort in exploring the factors underpinning the enormous (and largely unexplained) individual variability in the language and literacy outcomes of children who received a cochlear implantation. Researchers and experts in the field agree that factors like treatment choice (bilateral versus unilateral implantation), age at implantation, and duration of implant use play an important role in explaining the variance of spoken and written language outcomes of children with CIs (Archbold et al., 2008; Geers, Tobey, Moog, & Brenner, 2008; Harris, 2015; Sarant et al., 2015). Research shows that children using bilateral CIs achieve significantly higher scores in verbal language and academic skills than children with unilateral CIs (Sarant et al., 2015), and that children receiving the implant early show the largest improvements in spoken language and literacy (Archbold et al., 2008; Arfé et al., 2016; Connor & Zwolan, 2004; Geers et al., 2008, 2009; Sarant et al., 2015). Environmental factors, like family socioeconomic status, birth order, parents' involvement in children's learning activities, time spent reading books, and speech therapy, are also recognized to be important (Marschark et al., 2007; Niparko et al., 2010; Sarant et al., 2015).

Yet, neither age at implantation and duration of implant use nor important environmental factors, such as parent involvement or speech therapy, are systematically associated with academic (reading) outcomes in students with CIs (Marschark et al., 2007).

In addition, after controlling for all these factors, as well as for intelligence (IQ), a large portion of variance (ranging from 31% to 65%) in the learning outcomes of CI users at 8 years continues to remain unexplained (Sarant et al., 2015). As children get older and learning tasks become more complex, the amount of unexplained variance in students' literacy outcomes may increase further, and gaps between hearing and CI children increase too (Arfé et al., 2016; Harris, 2015; Marschark et al., 2007; Thoutenhoofd, 2006). Recent data suggest that at high school, up to 72% of the variance in the literacy outcomes of students with CIs remains unexplained once all crucial child variables (age, duration of deafness, age at first hearing aid fitting, nonverbal IQ) and environmental variables (such as family size and socioeconomic status) are controlled for (Geers & Hayes, 2011). Currently, identifying factors that may explain this large variability represents a priority in research.

The Link Between Early Auditory Deprivation and Explicit and Implicit Memory for Sequences

From the early 21st century onward, the research focus has shifted from auditory and language factors to the neurocognitive underpinnings of auditory and language processes (AuBuchon, Pisoni, & Kronenberger, 2015b; Fagan, Pisoni, Horn, & Dillon, 2007; Kronenberger, Colson, Henning, & Pisoni, 2014; Kronenberger, Pisoni, Henning, & Colson, 2013; see also Kronenberger and Pisoni, this volume). Although it is commonly assumed that earlier implantation automatically leads to better language and literacy skills, current findings suggest that it is more the length of time between hearing loss and implantation and language skills prior to implantation that could explain differences in the language and literacy outcomes of children with CIs (Harris et al., 2013; Marschark, Rhoten, & Fabich, 2007). Such evidence has led researchers to hypothesize that early auditory stimulation has scaffolding effects on the child's brain (Conway, Pisoni, & Kronenberger, 2009). According to this hypothesis, known as the auditory scaffolding hypothesis (Conway et al., 2009), thanks to early auditory stimulation, neuronal cells connect in functional and integrated systems that allow them to efficiently encode, maintain, and retrieve information abstracted from the environment (Kral, Kronenberger, Pisoni, & O'Donoghue, 2016). A sensory impairment from birth may affect the way the neurocognitive networks develop in the brain, with long-term effects on the ability to learn. Since sound has a temporal extension and speech perception involves the ability to encode sequences of speech sounds (i.e., sequences of phonemes), the most severe effects of early auditory deprivation seem to involve the development of neurocognitive processes addressed at encoding and maintain sequential information (Cleary, Pisoni, & Geers, 2001; Conway et al., 2009). Thus, interindividual variation after cochlear implantation may predominantly result from differences in these neurocognitive processes and not just from the technical qualities of the device or from variation in improved auditory skills (Kral et al., 2016).

 In children with congenital deafness, deficits in processing and elaborating sequential information have been observed in visual, auditory-verbal, and motor sequencing domains (Cleary et al., 2001; Conway, Karpike et al., 2011; Conway, Pisoni, Anaya, Karpicke, & Henning, 2011b), suggesting that the effects of early auditory deprivation on sequence learning (SL) are domain-general. Problems with SL seem to involve both the CI children's explicit memory (e.g., the use of strategies to encode and recall sequential information) and implicit memory processes (i.e., automatic encoding and unintentional learning of sequential information; Cleary et al., 2001; Conway, Pisoni et al., 2011). Thus, experts in the field have suggested that different learning and memory mechanisms, from stimuli encoding to storage and maintenance, could represent the missing piece of the puzzle to understand the variability in the spoken language and literacy outcomes of children with CIs (Pisoni & Cleary, 2003; Pisoni, Kronenberger, Chandramouli, & Conway, 2016). Initially, researchers have mainly payed attention to the development of mechanisms of explicit memory that are more closely related to spoken and written language learning, like verbal short-term and verbal working memory (WM; Cleary et al., 2001; Dillon & Pisoni, 2006; Geers, Strube, Tobey, Pisoni, & Moog, 2011; Pisoni & Cleary, 2003; Pisoni, Kronenberger, Roman, & Geers, 2011). More recently, implicit and nonverbal memory processes, such as implicit SL, have become a new focus of interest (Conway, Karpike et al., 2011; Conway, Pisoni et al., 2011). As soon as explicit and implicit memory factors have been taken into account, an additional and significant proportion of the (unexplained) variability in individual language and literacy outcomes of children with CIs has been accounted for (Harris et al., 2013).

The Influence of Explicit (Verbal) Memory Processes in the Language Learning and Literacy of Children With CIs

In exploring the explicit mechanisms of verbal memory, researchers' attention has mainly focused on two memory systems: verbal short-term memory (STM) and verbal WM. Both involve the ability to encode, store, and hold phonological memory traces for short time (a few seconds) in the memory store. However, the WM system involves both storage (maintenance) and elaboration of the information to recall (i.e., greater executive control, necessary to allocate attentional resources between memory processes), whereas STM involves only storage capacity (i.e., the ability to maintain verbal information in memory for a short time; Baddeley, 2003). Verbal storage capacity is typically measured by span tasks, like digit span, corresponding to the largest number of elements (digits) that an individual can store and maintain in STM/WM (Gathercole, Pickering, Ambridge, & Wearing, 2004; Pisoni et al., 2011). Digit span tasks involve two testing conditions: In the first (forward digit span) the child recalls a series of spoken digits in direct (forward) order; in the second (backward digit span), the child recalls a series of digits but in reverse order. Whereas forward digit span is a measure of verbal storage capacity, backward span is assumed to assess the executive control component of verbal WM (i.e., the child's ability to divide her attention between the maintenance and the elaboration demands of inverting digit order). In addition, the backward span condition requires inhibition of forward (direct) repetition, which is often automatic for the (hearing) STM system (Gathercole et al., 2004).

Immediate verbal memory capacity (STM) is, probably, the memory function most widely studied in the field. The ability to store and immediately recall a series of verbal elements (e.g., sounds or letters) is indeed crucial for learning new words (Baddeley, 2003; de Abreu, Gathercole, & Martin, 2011; Gathercole, Service, Hitch, Adams, & Martin, 1999), comprehending spoken and written language (Archibald & Gathercole, 2007; Harris et al., 2013; Swanson & Ashbaker, 2000; Swanson & Howell, 2001), and also organizing words into spoken or written sentences (Arfé, 2015b; Arfé, Rossi, & Sicoli, 2015; Dawson, Busby, McKay, & Clark, 2002; Harris et al., 2013). Problems with the immediate memory of (auditory and visual) serial patterns in children with CIs could substantially affect the child's development at all these levels (Pisoni et al., 2016).

In hearing children, verbal STM and WM develop significantly from 5 to 8 and 9 years, that is, in the early years of schooling, thanks to the development of a mechanism used to refresh the information to hold in memory—verbal rehearsal (Gathercole et al., 2004). Verbal rehearsal is a functional component of the temporary memory store of verbal STM (the phonological loop), and consists of the subvocal repetition (rehearsal) of the memory traces to hold in memory (Baddeley, 2003). Unless refreshed by this component, the memory traces temporarily stored in STM would easily decay. The subvocal rehearsal mechanism is also crucial to register visual information in the store, provided the items to recall can be named. Before the age of 7 years, spontaneous rehearsal does not seem to ↳ occur reliably (Gathercole et al., 2004). After this age, children seem to systematically use rehearsal processes in verbal tasks, and much of the increased verbal STM capacity as children get older seems to result from the increased rate of rehearsal. Faster rehearsal indeed helps the child to retain an increased amount of information in STM.

As a consequence of the development of more efficient rehearsal mechanisms, not only STM for verbal materials, but also for visual materials (e.g., familiar pictures and objects) recodable into phonological form, increases dramatically in hearing children during the early school years (Gathercole et al., 2004). With the augmented verbal STM and WM capacities, hearing children's linguistic knowledge also develops (Baddeley, 2003; Gathercole et al., 1999), and improvements in verbal WM seem also to support the acquisition of reading and writing (Berninger et al., 2010; Swanson & Berninger, 1996).

In many children with CIs, the development of verbal STM and WM systems seems delayed. Children 8 to 9 years old and older children with CIs have been found to be significantly less efficient at encoding and maintaining phonological representations in verbal STM and WM than their hearing peers (AuBuchon, Pisoni, & Kronenberger, 2015a; Cleary et al., 2001; Pisoni & Cleary, 2003). Reduced forward and backward digit spans in comparison to hearing peers have been extensively documented in orally educated children with hearing loss compensated by hearing aids (Arfé, 2015b; Arfé et al., 2015) or cochlear implants (AuBuchon et al., 2015a; Cleary et al., 2001; Harris et al., 2013; Pisoni & Cleary, 2003). Studies in the field have also shown that at the age of 8 to 9 years, the difference between hearing children and children with CIs was more marked in the case of forward digit span, and the difference between forward and backward digit spans was significantly larger in the hearing children than in the children with CIs (Pisoni & Cleary, 2003). These findings suggest that in prelingually deaf children, the mechanisms of verbal WM could develop atypically. Consistent with this hypothesis, Arfé, Nicolini, and Pozzebon (2014) found that in a sample of 34 prelingually deaf children 9 to 14 years old with hearing aids or CIs, more than half (22 children, 65%) scored the same (in backward and forward) or higher in the backward digit span than in the forward condition. Overall, unlike hearing children, prelingually deaf children seem comparatively less disturbed by inverting the digit order in recall tasks. The fact that digit forward and backward tasks in Arfé et al.'s study were administered bimodally (i.e., digits were displayed visually using the fingers while being pronounced aloud) cannot explain these findings, since hearing children (who performed the task bimodally, too) did not show the same trend (Colombo, Arfé, & Bronte, 2012). In addition, this pattern of performance in CI users (relatively greater impairment in forward than in backward span tasks) emerges both in the auditory and in the visual modality (AuBuchon et al., 2015a). A possible explanation of this, apparently paradoxical, effect is that reversing the order of elements has negative effects when children spontaneously use verbal rehearsal strategies to support their memory, as inversion interferes with their automatic (forward) rehearsal procedure (AuBuchon et al., 2015a). That is, school-age children with a prelingual hearing loss, independently of having received a CI, could not make spontaneous (or make less) use of rehearsal strategies that are typically mastered by hearing peers during early elementary school. An exception to these findings comes from a study that involved a small group (about 20) 5- to 11-year-old CI users (Dawson et al., 2002). The authors found no differences between a group of children with CIs and their hearing controls in the ability to immediately reproduce visual hand movements. Yet, in the study, sequences consisted of only two items and thus probably did not stress the child's cognitive system enough to activate supportive (rehearsal) memory strategies.

Consistent with the hypothesis that deficits in verbal rehearsal are the key to understanding the STM and WM difficulties of children with CIs are research findings by Cleary et al. (2001). The authors demonstrated that children with CIs show deficits in comparison with hearing controls in tasks requiring immediate recall of visual sequences (i.e., a sequence of colored lights) and that, unlike hearing controls' performance, their performance does not improve significantly when the stimuli of the visual sequences (lights) are associated with semantic cues (color names; Cleary et al., 2001). Overall, children with CIs seem to benefit less from using verbal encoding strategies and using verbal labels to retain and to recall visually presented sequences.

A few studies have explored the developmental growth of STM and WM of children with CIs (Harris et al., 2013; Pisoni et al., 2011), showing that with age (from 6 and 8 years to 16 years), rehearsal and STM skills improve significantly in these children too, just as they do in hearing peers (Pisoni et al., 2011).
p. 324 Nevertheless, children with CIs fail to ↳ catch up to their hearing peers. Age at implantation and duration of the compensation do not seem to fully account for these delays (Harris et al., 2013). Additionally, for a large percentage of children, either no improvement or a marginal improvement is found (Harris et al., 2011; Pisoni et al., 2011).

Interestingly, a dissociation has been found in the development of phonological STM and WM within the population of children with CIs. Whereas phonological STM skills seem to increase with age relative to norms, on average, WM skills decrease (Harris et al., 2013; Pisoni et al., 2011). The lack of sufficient WM skills to perform complex academic tasks in high school represents an important obstacle to the academic success for prelingually deaf students (Arfé, 2015a).

With the transition from learning to write and to read to reading and writing to learn, reading and writing tasks become cognitively more complex and demanding for the child's verbal WM (Berninger & Swanson, 1994; Pisoni et al., 2011; Swanson & Berninger, 1996). A lack of verbal WM skills in later childhood and adolescence therefore significantly and negatively affects the literacy skills of children with CIs, with long-term effects on their access to knowledge and their social and professional participation in society (Arfé, 2015a; Harris, 2015; Harris & Terlektsi, 2010). Reading and writing may end up being even more demanding for these students than spoken language (Arfé, 2015b). Comparing the spoken and written stories produced by 7- to 15-year-old prelingually deaf or hard of hearing (DHH) children to that of a group of hearing controls, Arfé (2015) found, for example, that the disadvantage of the DHH group appeared to be greater in writing than in spoken-language production. Moreover, the contribution of verbal rehearsal (forward digit span) skills was greater in written language than in spoken-language production (Arfé, 2015b; Arfé et al., 2015). These studies have also shown that the contribution of verbal rehearsal to the spoken and written language of prelingually deaf children can be even greater than that of the executive component of WM (Arfé, 2015b; Arfé et al., 2015). Rehearsal skills explain, for example, elementary and middle school students' ability to generate sentences in spoken and written discourse production (up to 20% variance, after controlling for age and reading comprehension skills) and also contribute to explaining deaf children's ability to produce coherent relations in written stories (26% of variance in story structure; Arfé, 2015b).

What Does Cause CI Users' Failure in Verbal Rehearsal?

To account for the problems prelingually deaf children have with rehearsal, researchers have investigated deaf children's use of rehearsal mechanisms more in depth. Deficits in verbal rehearsal have been explained not only as the effect of a lack of strategic (explicit) use of verbal language to support maintenance of memory traces, but also as the effect of inefficient use of two mechanisms at the basis of the rehearsal process, which are less dependent on the child's intentional effort. One is the efficiency with which the child's cognitive system encodes and parses the phonological (or visual) information to recall. The second is the speed at which this information is refreshed by subvocal rehearsal. As information in the phonological loops is subject to rapid decay, subvocal verbal rehearsal must be rapid enough to prevent the loss of the information to recall (AuBuchon et al., 2015b; Gathercole et al., 2004). Involving both efficient parsing and encoding of phonological information and articulatory control processes, verbal rehearsal can be impaired in children with CIs for whom the phonological input is often degraded and speech output (i.e., articulatory rate) is slowed down (Burkholder & Pisoni, 2003).

Several research findings suggest an impairment in prelingually deaf children's rehearsal speed (e.g., AuBuchon et al., 2015b; Pisoni et al., 2011). Extant studies (e.g., Geers et al., 2011) also show that verbal rehearsal speed is an independent and powerful predictor of early language and literacy skills in CI users of elementary school age, accounting for between 13% and 30% of the variance in early outcomes, and continue to predict CI users' literacy (reading) outcomes at high school. This is interesting, considering that the contribution of rehearsal processes seems more significant in the written than in the spoken language production of prelingually deaf children (Arfé et al., 2015). In writing, where language production is slowed down by handwriting and spelling processes, rehearsal speed—which is assumed to be critical for deaf children (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003)—should have less impact. However, instead of being an advantage for prelingually deaf children, the reduced pace of writing could pose additional demands on their already poor verbal rehearsal skills, as slower production requires the child to refresh verbal information for longer in STM. Another possibility is that rehearsal processes may impact writing
p. 325 through spelling. If spelling is not fully automatic, the child ↳ needs to rehearse letter and sound sequences to spell words in the text, and this could engage verbal WM resources that are necessary for other writing

processes (e.g., sentence construction). In writing, the need to pay attention to spelling during text production affects the storage capacity of the writer's verbal WM system and may result in loss of information during sentence transcription (Arfé et al., 2016; Berninger, 1999).

The Influence of Implicit SL and the Link Between Implicit and Explicit Sequence Memory

Another possible cause of the poor rehearsal processes of prelingually deaf children could be an impairment of the child's implicit learning mechanisms. The efficiency with which the child's mind encodes and parses sequences of information can indeed be related to subconscious and automatic learning mechanisms referred to as implicit statistical learning (Conway, Pisoni et al., 2011). Differently from explicit memory processes, implicit statistical learning, which can be considered an implicit memory process, occurs unconsciously, through repeated exposure to stimuli, even when individuals do not make an explicit effort to maintain or recall information.

As highlighted by Saffran, Aslin, and Newport in their seminal work on implicit (statistical) learning (1996), being able to extract environmental information speedily and accurately from early in development is crucial for the survival of an organism. The neural mechanisms that support this process can in part be independent of experience (experience-independent) and structured at neural level at birth, and in part, be dependent on experience (experience-dependent), that is, developed through interaction with the environment. In their study, Saffran and colleagues (1996) demonstrated that 8-month-old infants were able to extract single pseudowords from 2 minutes of continuous speech stream; the authors concluded that the infants' ability to identify these structural aspects of language was dependent on their sensitivity to the statistical regularities (i.e., the transitional probabilities between syllables, which is higher within than between words) that characterize speech. Saffran and colleagues also argued that this experience-based mechanism could support the acquisition of several other aspects of language.

Subsequent studies confirmed that this statistical learning mechanism occurs in other areas of language acquisition, such as in sentence perception and receptive and expressive grammar learning (Conway, Bauernschmidt, Huang, & Pisoni, 2010; Conway, Karpicke, & Pisoni, 2007), in reading (Apfelbaum, Hazeltine, & McMurray, 2013; Aravena, Snellings, Tijms, & van der Molen, 2013; Pavlidou & Williams, 2014), and in spelling (Hedenius et al., 2013; Ise, Arnoldi, Bartling, & Schulte-Korne, 2012; Jimenez-Fernandez, Vaquero, Jimenez, & Defior, 2011; Steffler, 2001; Treiman & Kessler, 2006). Studies also demonstrated that statistical learning occurs incidentally and without intention through simple exposure to the input. Because of its implicit nature and because, when speech inputs are concerned, it involves sequential structures, some authors called it implicit SL (Conway et al., 2007; Conway, Pisoni et al., 2011; Goschke & Bolte, 2012).

A dysfunction of these subconscious and automatic memory mechanisms has been proposed as one of the causes of the developmental delay and deficits observed in children with dyslexia (Hedenius et al., 2013; Ise et al., 2012; Jimenez-Fernandez et al., 2011; Pavlidou & Williams, 2014), and other developmental disabilities, including prelingual hearing loss (Conway et al., 2009; Conway, Pisoni et al., 2011).

It has been suggested that inefficient implicit SL mechanisms could be the source both of the verbal short-term (i.e., inefficient rehearsal) and spoken-language learning problems of children with CIs (Conway, Pisoni et al., 2011). A lack of early auditory experience (preimplant) could explain the implicit SL deficit of CI users and, consequently, their language-learning problems. In line with Saffran et al.'s (1996) hypothesis of an experience-dependent (implicit) statistical learning mechanism, it has been suggested that exposure to serially ordered events, sound and auditory stimulation (inherently sequential), could scaffold the child's cognitive ability to process sequential patterns of information and extract regularities from it, thus bootstrapping the development of implicit SL: this is the auditory scaffolding hypothesis (Conway et al., 2009). The auditory scaffolding hypothesis predicts that a lack of, or an impoverished, early auditory experience affects the way implicit SL mechanisms are structured in the child's brain (Conway et al., 2009).

Empirical support to this hypothesis comes both from studies comparing implicit SL across modalities (visual, auditory, and tactile) and between individuals with hearing loss and normal hearing. The comparison across modalities has shown an auditory superiority effect in SL for hearing adults, when auditory, tactile, and visual learning of serial patterns were contrasted (Conway & Christiansen, 2005). The

comparisons between hearing and deaf ↳ individuals have further supported these findings, showing impaired visual SL in adults with severe to profound hearing loss (Lévesque, Théoret, & Champoux, 2014) and lower implicit visual SL in serial recall tasks for five to ten year-old prelingually deaf children with CIs in comparison to hearing children of same age (Conway et al., 2009).

These studies seem to demonstrate, on the one hand, that the perceptual modality is critical in implicit SL (i.e,, auditory processes are more critical than other sensorial processes for the development of efficient implicit SL skills; Conway & Christiansen, 2005), and on the other hand, that early auditory deprivation affects SL skills across modalities (showing domain-general effects; Conway, Karpike et al., 2011; Conway, Pisoni et al., 2011 Lévesque et al., 2014).

Pioneering in the field of deaf cognition is the study by Conway, Pisoni et al. (2011). The authors explored whether children with CIs, who experienced a lack of auditory stimulation in their early childhood, showed disturbances in visual implicit SL. The task used in their experiment was the same immediate serial recall task used by Cleary et al. (2001). However, unlike in the experiment by Cleary et al., sequences were generated by an artificial grammar (i.e., a predefined set of rules). Artificial grammar learning (AGL) tasks are commonly used to assess implicit learning (Ise et al., 2012; Pavlidou & Williams, 2014; Samara & Caravolas, 2017; van Witteloostuijn, Boersma, Wijnen, & Rispens, 2017). In AGL, participants experience patterns of information (in this case visual sequential patterns) generated according to unfamiliar (artificially determined) regularities or transition probabilities (e.g., the probability that A or C follows B in a letters string) and are asked to immediately recall these patterns. After this "learning phase," a new series of (sequential) patterns is presented and participants are again asked to recall them immediately after presentation. Half of the patterns are generated following the same regularities experienced during the learning phase, whereas the other half are generated following a different artificial grammar (set of regularities) or at random. This second phase of AGL tasks is called "test phase." The extent to which participants are better at recalling sequences generated according to the same artificial grammar experienced in the learning phase (than by a different one) is considered a measure of their implicit learning. Implicit learning thus involves the ability to extract and generalize the regularities experienced to new sets of stimuli generated according to the same rules. Learning is considered implicit because participants are not aware of the regularities underlying the learning phase and test phase sequences.

Like Cleary et al. (2001), Conway et al. studied sequences consisting of colored squares (red, blue, yellow, green) appearing one at a time on a touchscreen, and the children's task was to reproduce the sequences on the touchscreen immediately after their presentation. The authors found no differences between the children with CIs and their hearing controls in the immediate serial recall task of the learning phase, but statistically significant differences were seen between the two groups in the test phase. Only the hearing children showed significantly implicit learning (i.e., better recall for sequences following the same grammar trained during the learning phase). Conway et al. also demonstrated that implicit SL correlated significantly with critical variables, such as age at implantation and duration of implant use: Children who were deprived of auditory stimulation for prolonged periods of time appeared to show lower implicit SL scores. Moreover, children's performance in implicit SL correlated significantly with their language outcomes (i.e., sentence formulation and sentence recall subtests of the CELF-4). These correlations remained significant even when children's receptive vocabulary and auditory digit span scores were partialled out. Performance in immediate visual serial recall (learning phase) did not show significant correlations with the language outcomes of the children with CIs.

Despite this latter finding, which seems to corroborate the nonlinguistic and implicit nature of children's learning, one aspect of Conway et al.'s study suggests caution in interpreting these results. As in Cleary et al.'s study (2001), preliminary to the experimental task, Conway et al. asked their participants to identify and name the four colors (yellow, red, green, or blue) used in the experiment. Although these instructions allowed the experimenters to exclude that the participants had problems in perceiving the colors used in the implicit SL tasks, on the other hand, they could have activated the use of rehearsal strategies, at least in the hearing group. That is, the participants could have used the labels (color names) to rehearse (subvocally) the sequences to learn during task execution. Thus, explicit (i.e., verbal) strategies might also have had a role in children's performance.

Conway and colleagues (2009) have offered two possible explanations for the way in which auditory p. 327 deprivation may affect implicit SL. On the one hand, early auditory deprivation may limit the opportunity ↳ to imitate speech sounds in the environment, and therefore the development of verbal rehearsal, that is necessary for developing implicit SL abilities. Thus, it affects the development of implicit SL by affecting rehearsal processes. On the other hand, prelingual hearing loss may directly affect children's opportunity to extract patterns of temporal change and serial order in the environment, which may in turn negatively impact rehearsal processes. In both cases, language learning would be significantly affected.

Subsequent studies have shown that, although statistical learning is ubiquitous, that is, occurs in different sensory modalities (visual, auditory, and tactile; Conway & Christiansen, 2005), differences in sensory processes substantially affect this mechanism and how learning occurs. For example, it has been shown that, in a mature cognitive system, different timing conditions may facilitate the temporal processing of information involved in implicit SL depending on the perceptual modality in which learning occurs (auditory or visual). At faster rates, auditory implicit SL seems superior to visual implicit SL (Emberson, Conway, & Christiansen, 2011). At slower rates, the opposite pattern emerges: visual implicit SL is superior to auditory implicit SL (Emberson et al., 2011).

Studies Not Supporting the Hypothesis of an Implicit SL Impairment in Children With CIs

The hypothesis of an implicit SL deficit in children with CIs has been challenged by findings showing implicit learning effects in this population (see also Hall, this volume). In a recent replication of Conway et al.'s seminal study (Conway, Pisoni et al. 2011), von Koss Torkildsen, Arciuli, Haukedal, and Wie (2018) have retested the hypothesis that early auditory deprivation constrains the development of implicit SL mechanisms in children with CIs. To retest this hypothesis, like Conway et al. they compared the implicit visual SL skills of prelingually deaf children with CIs (7 to 12 years old) to those of hearing children matched on age. However, differently from Conway et al., who assessed implicit SL using sequences of colors (and instructed children to name the colors before the task), von Koss Torkildsen et al. used stimuli that were unfamiliar to the children (cartoonlike figures that did not have well-learned automatized labels) and did not provide participants with explicit instructions to perform the learning task. Their findings showed statistically significant implicit SL taking place in both hearing and CI children and no significant difference in the amount of learning between the two groups. That is, the prelingually deaf children with CIs displayed intact SL at a level comparable to that of age- and gender-matched children with normal hearing.

The different findings between the Conway et al. study and the von Koss Torkildsen et al. study may be partially explained by the different tasks and procedures used by the researchers. In Conway et al.'s experimental task, verbal labels were implicitly emphasized during the instruction phase and children could use verbal rehearsal to recall the colors sequence. In von Torkildsen et al.'s study, this was more difficult, because the participants did not have labels immediately available for the unfamiliar pictures used.

Consistent with these findings are findings obtained by other recent studies (Arfé, Fastelli, Mulatti, Scimemi, & Santarelli, 2017; Hall, Eigsti, Bortfeld, & Lillo-Martin, 2018). Arfé et al. have tested the implicit visual SL and verbal rehearsal skills of 104 hearing children 5 to 7 years old, and those of 29 prelingually deaf children with CIs 5 to 11 years old (compared with 102 hearing controls in the same age range). The researchers replicated the procedure for eliciting implicit SL used by Conway and colleagues (the same artificial grammar was employed), except for the use of unfamiliar and abstract visual stimuli (i.e., unfamiliar mathematical symbols and characters; Arfé et al., 2017). In a first study, the performance of 5-, 6-, and 7-year-old hearing children was compared on verbal rehearsal (forward digit span) and implicit visual SL tasks. The results, consistently with extant knowledge on verbal rehearsal development (Gathercole et al., 2004), showed significant differences between the 5-year-olds and the other two age groups in verbal rehearsal, and a significant effect of implicit SL in the experimental task only for the younger group (5-year-old children). The second study, comparing the 29 prelingually deaf children with CIs to hearing controls, showed significantly better verbal rehearsal skills for the hearing children than for the children with CIs, and implicit SL in both groups, although the performance of the hearing controls was better. In this study, Arfé et al. also examined the contribution of implicit SL and verbal rehearsal skills to children's variance in receptive vocabulary. The results of the study did not reveal any significant contribution of implicit SL to the children's spoken-language vocabulary. Only age and verbal rehearsal skills contributed to accounting for the significant variance in CI children's vocabulary scores. Taken
p. 328 together, the results of these two studies ↳ suggest that SL may not be driven by a single cognitive process, but relies on two distinct mechanisms: an implicit mechanism, which is already active at an early age, and an explicit mechanism, dependent on individual attentional resources (i.e., rehearsal), which develops later, in the years of transition to school. When explicit mechanisms are more efficient, implicit SL could be masked or replaced by the more efficient processes.

Serial reaction time (SRT) tasks have been also used to assess the implicit learning abilities of children with CIs (Hall et al., 2018). SRT tasks involve the ability to predict items or events in a sequence based on their underlying and implicit regularities. By extracting such regularities, individuals become able to anticipate the elements in the sequence, thus reducing reaction times in response to it (Nissen & Bullemer, 1987). With this procedure, too, an implicit SL effect for hearing children as well as for children with CIs has been found (Hall et al., 2018).

On the basis of these contrasting findings, Conway and colleagues have more recently conducted studies to assess the contribution of intentional processes and pattern awareness to implicit SL (Hendricks, Conway, & Kellogg, 2013; Singh, Daltrozzo, & Conway, 2017). These studies, which have used different methodologies (dual task paradigms and self-reports) to assess the contribution of automatic and nonautomatic (intentional) memory processes to AGL tasks, have consistently shown that in hearing adults, AGL involves both automatic and intentional processes. Automatic processes seem more influential in the learning phase, whereas intentional processes seem to play a greater role in the test phases when individuals are requested to express the rule or use strategies to support their performance (Hendricks et al., 2013). In summary, both implicit and explicit learning mechanisms could account for performance on implicit learning tasks.

Conclusions: Implicit and Explicit Memory Processes May Interact in the Language Learning of Children With CIs

The critical review of the literature presented in this chapter suggests the involvement of both implicit and explicit processes (and deficits) in SL and, more so, in the verbal language learning of prelingually deaf children with CIs. While some findings have suggested the existence of an impairment in implicit learning mechanisms as the basis of the poor verbal short-term memory skills and language outcomes of children with CIs (Conway et al., 2007; Conway, Karpike et al., 2011; Conway, Pisoni et al., 2011), other research suggests that the problems of children who experience a prelingual hearing loss lie instead in the inefficient use of explicit memory mechanisms, such as verbal rehearsal (Arfé et al., 2016, 2017; Pisoni & Cleary, 2003), which affects spoken language development (vocabulary and grammatical development), reading, and writing (Arfé, 2015b; Arfé et al., 2015, 2016; Harris et al., 2013; Kronenberger, Pisoni, Harris, et al., 2013). However, verbal rehearsal processes could be not fully explicit, and some mechanisms underlying efficiency in rehearsal can be partially subconscious, such as the speed of rehearsal and visual or auditory parsing.

Furthermore, in the wider field of implicit learning studies, the hypothesis of a "pure" implicit learning deficit as the basis of neurodevelopmental disorders is much discussed. Although much of the literature is consistent in showing impaired implicit SL in populations with language-learning problems (Hedenius et al., 2013; Jimenez-Fernandez et al., 2011), there are also some contrasting findings (Staels & Van den Broeck, 2017; West, Vadillo, Shanks, & Hulme, 2018), and the existence of a publication bias in favor of studies confirming the implicit learning hypothesis has been recently suggested (van Witteloostuijn et al., 2017).

A way to reconcile conflicting findings emerging from the literature is to consider that individual differences in the spoken-language outcomes of the children with CIs might derive neither from implicit learning nor from explicit learning mechanisms alone, but from the interplay of implicit and explicit memory processes. This is a promising avenue that researchers in the field have started to explore (Hendricks et al., 2013; Singh et al., 2017). Such a hypothesis would be in line with current models of neurodevelopment, such as the representation redescription model (RR model; Karmiloff-Smith, 1992).

According to the RR developmental model, the expression of implicit statistical learning skills could change with age and across populations through a representation redescription (RR) mechanism, by which the child redescripts knowledge representations progressively from implicit to fully explicit. At the beginning, information is implicitly encoded in a procedural data-driven format. The child has no consciousness of the knowledge representations and is unable to verbalize them. For instance, the child may be able to recall a string of letters (e.g., f-i-l-l) without being conscious of the rule underlying its generation. By abstracting information (i.e., rules) from the environment to understand the world, the child redescripts the initial
p. 329 implicit representation in a more ↳ explicit form, until the knowledge representation becomes fully explicit and can be consciously accessed and verbalized. At this point, the child is aware that the doubled "ll" never occurs at the beginning of a word, and l-l-i-f is thus not a legal string. The child is also able to apply the rule to other words (e.g., *call, fall*). As the child progresses through these levels of redescription, his or her learning mechanisms could also change, becoming progressively more supported by explicit memory skills (e.g., the use of memory strategies). However, when the cognitive system is put under stress (e.g. when task demands increase) or other cognitive tasks interfere with the child's explicit memory mechanisms (e.g., the child is asked to recall a series of digits or a sentence while also performing a secondary task), implicit statistical learning may again appear and sustain learning (Arfè et al., 2017; Hendricks et al., 2013; Singh et al., 2017).

Further studies are necessary to understand how the mechanisms underlying implicit and explicit memory processes interact in children with CIs, as well as to explore how they modulate the different processes and components of children's verbal language performance. Finally, the role played by rehabilitation and educational (school and home) settings and strategies needs also to be explored in depth. Factors like attending public or private schools, socioeconomic status, or mode of communication in education (spoken, manual, bimodal) are largely insufficient to account for changes in implicit and explicit basic memory processes. In-depth longitudinal and observational studies that explore in detail how instructional or rehabilitation interventions are delivered are necessary to understand the impact of the learning environment on the development of these basic and important mechanisms. Such studies will further contribute to basic knowledge as well as to inform the instructional and educational practices addressed to children with prelingual deafness.

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