Working memory and referential communication—multimodal aspects of interaction between children with sensorineural hearing impairment and normal hearing peers

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LANGUAGE AND COMMUNICATION IN CHILDREN WITH SNHI

LANGUAGE
The language development of children with sensorineural hearing impairment (SNHI) with hearing aids and/or cochlear implants has, at a group level, repeatedly been shown to depart from the typical trajectory. Several studies have found approximately half of preschool children with SNHI to exhibit substantial language problems, as compared to approximately 5% in the general population (Gilbertson and Kamhi, 1995; Hansson et al., 2004; Sahlén and Hansson, 2006), with particular deficits in phonological processing (Briscoe et al., 2001; Sahlén et al., 2004; Wake et al., 2006; Wass et al., 2008) and vocabulary (Mayne et al., 1998a,b; Hansson et al., 2004), whereas results are mixed regarding grammar (Norbury et al., 2001; Hansson et al., 2007). While basic language skills can normalize with age, children with SNHI have been found not to close the gap to normal hearing (NH) peers regarding complex language functioning, for example, oral and written narrative ability (Asker-Árnason et al., 2010; Reuterskild et al., 2010). Intrinsic (cognitive) and extrinsic (audiological and linguistic intervention, quality and quantity of input, feedback and teaching) factors, in complex interaction, likely contribute to the substantial heterogeneity in language outcome.

COMMUNICATION
Whereas the primary purpose of language is communication, language ability—at least narrowly defined as the capacity to form linguistically coherent messages—is merely one tool necessary for successful communication. Verbal and non-verbal modalities are integrated with contextual factors to shape our ability to interact with others (Perkins, 2007). Interlocutors continuously merge the verbal message with information gathered from the partner’s speech, voice, posture, field of vision, gaze direction and gestures, as well as contextual information, for example, knowledge of the world, the context and the topic of the conversation. Consequently, intra- and inter-individual linguistic, cognitive, and socio-cognitive systems interact in communication. A hearing impairment may lead to misallocation of resources with negative effects on listening ability and understanding.

While studies often include protocols or checklists considered to capture social and communicative abilities there are surprisingly few experimental studies of children with SNHI interacting with others in everyday communicative settings. Most et al. (2010) analyzed aspects of pragmatic ability in 6 to 9 year-old children with severe-to-profound SNHI (using hearing aids and/or cochlear implants) from video recorded spontaneous conversation with a speech-language pathologist. Although not consistently impaired, the children with SNHI showed particular...
problems continuing the topic of the partner, and adding relevant
information. Most et al. (2010) argued that the problems observed
in the children with SNHI are caused by a delayed language
development and limited linguistic input, resulting in an inexperi-
ence with various pragmatic behaviors and restricted perspective-
taking. Compatible with a delayed language development, Toe
and Paatsch (2010) presented results showing 7 to 12 year-old
children with mild-to-profound SNHI to request repetition and
clarification of questions to a significantly higher extent than NH
peers. Similar results have been presented by our own research
group using referential communication tasks, first introduced by
Glucksberg and Krauss (1967), providing a compromise between
experimental control and ecological validity, and designed to tap
the communicative ability used in everyday activities such as
giving instructions, describing things or events to a listener, and
asking questions. In our studies, the referential communication
tasks were designed to resemble communication between peers in
structured classroom activities, rather than spontaneously occur-
ring interaction.

REFERRERAL COMMUNICATION—METHODOLOGY
Apart from providing details on typical communicative develop-
ment, studies of referential communication have added to our
knowledge of the communicative competence of individuals with
a range of disabilities. In a referential communication task, the
speaker is provided with an array of referents (pictures or physical
objects), arranged in a predetermined pattern. The speaker’s task
is to describe each picture/object, and its position, to enable the
listener to arrange his/her array in the same way. Referential com-
munication tasks allow investigation of the participants’ ability to
produce (when in the “speaker” role), perceive and understand
(when in the “listener” role) spoken messages (see Figure 1).
Specifically, the task seeks to investigate whether the speaker can
form contextually relevant messages, providing the listener with
necessary information, without providing unnecessary details.
The listener is evaluated on the ability to detect and resolve
ambiguities through his/her use of questions. If, for example,
the speaker describes a picture of a face as “It’s a man with a
beard” this would provide sufficient information if all other
referents lacked these characteristics. However, if the competing
referents included other men with beards the listener would have
to request additional information, for example “Is he wearing
glasses?”

Referential communication requires a basic level of linguistic
skills but also a range of cognitive capacities. The linguistic infor-
mation must be processed and maintained until a referent has
been chosen, requiring working memory capacity (WMC), the
demands on which are likely to vary depending on the description
provided (Dahlgren and Dahlgren Sandberg, 2008). Finally, in
order for the speaker to provide an adequately detailed descrip-
tion, and for the listener to adjust his/her questions appropriately,
both interlocutors must be able to take the perspective of the
conversational partner.

REFERRERAL COMMUNICATION—FINDINGS
In a range of studies we have used an adapted version of the
referential communication task, as a complement to linguistic and
cognitive assessment, to investigate the communicative abilities of
Swedish speaking children and adolescents with varying degrees
of SNHI. While conducting the experiments under optimal
acoustic conditions, with rigid experimental control, participants
were instructed to choose a friend with whom to complete the
task, thereby maintaining ecological validity. In the first study,
Ibertsson et al. (2009a) found 11 to 19 year-old adolescents with
severe-to-profound SNHI and cochlear implants to request more
information than NH peers to resolve ambiguities caused by
inaccurate or insufficient information from the conversational
partner. The participants showed an increased use of requests
for confirmation (yes/no questions, for example, “Does she have
blonde hair?”), as compared to requests for elaboration (“What
color is her hair?”). This use of questions was interpreted as a
conversational strategy aimed at limiting the number of possible
responses from the partner and thereby reducing the risk of
misunderstanding. This conversational strategy was found to be
related to complex WMC (Ibertsson et al., 2009b). Participants
with SNHI and reduced WMC were found to use requests for
confirmation of information mentioned earlier in the conver-
sation (“Did you say he had a beard?”) whereas participants
with greater WMC requested confirmation of new information
to a greater extent, more clearly driving the conversation for-
ward (Ibertsson et al., 2009b). Responses to the requests have
not been shown to differ between the groups (Sandgren et al.,
2011).

In an effort to obtain a fuller picture of the communicative
exchanges during referential communication—both speech
and body communication—we recently fitted interlocutors with
mobile eye trackers (Sandgren et al., 2012, 2013, 2014). We were
able to show that moments of mutual gaze, in which the listener
looks at the speaker, showed a tight temporal connection with
important parts of the spoken message (Sandgren et al., 2012).
Questions, back-channeling responses, and statements, directed

![Figure 1](Sketch of the experimental setting showing the speaker
(on the left) describing pictures of faces, and the listener (on the right)
requesting additional information. Adapted from Sandgren et al. (2012).)
from the listener to the speaker, were all associated with higher probability of listener gaze to the speaker’s face. The results indicate that the spoken message is emphasized by the gaze exchanges, even to the point of making the content of the spoken message relevant. In a recurring example from the data, questions remained unanswered when not accompanied by a gaze to the respondent’s face (Sandgren et al., 2012). In a comparison between 10 and 15 year-old children with mild-to-moderate SNHI (mean age 12.6; SD 2.0; mean better ear pure-tone average 33.0 dB HL, SD 7.8) and NH same-age peers, the gaze behavior was found to be accentuated in the participants with SNHI, showing greater odds (ORs 1.2–2.1) for gaze to the speaker’s face than NH peers (Sandgren et al., 2014).

Since other factors than hearing differ between children with and without hearing impairment, we went on to investigate group differences in the probability of gaze to the speaker’s face while adjusting for individual performance on receptive grammar, expressive vocabulary, complex WMC, and phonological short term memory (PSTM; Sandgren et al., 2013). In the collected sample (cf. Sandgren et al., 2014 above), children with SNHI performed significantly below NH controls on non-word repetition (measuring phonological processing and PSTM) and expressive vocabulary, while non-significant differences were found for receptive grammar and complex WMC.

The group difference in gaze behavior remained significant despite adjustment for receptive grammar, expressive vocabulary, and complex WMC, but not non-word repetition, revealing an interaction between SNHI and PSTM capacity. Participants with SNHI with lower scores on non-word repetition (>1.25 SD below NH mean) showed a twofold increase in the probability of gaze to the speaker’s face, whereas those with higher scores had a reduced probability of looking at the conversational partner (Sandgren et al., 2013).

CONCLUSIONS AND IMPLICATIONS

To summarize, request strategies and gaze behavior in children with SNHI during referential communication represent control and validation mechanisms which go above and beyond what is explained by the hearing impairment alone, and the results highlight WMC and PSTM capacity as driving forces behind the effect. While active and competent conversational partners, the participants with SNHI exhibit conversational strategies distinct from those of NH peers despite optimal conditions (clear task objectives, known conversational partner, no time limit, and silent surroundings). The findings affect clinical and school-based management of hearing impairment as well as our theoretical assumptions of the course of development of hearing impairment and its consequences. Speech-language pathologists, audiologists, psychologists and teachers working with children with SNHI should be aware of an increased likelihood of language deficits, which require intervention and adaptations to ensure academic attainment. This is equally relevant for younger school-aged children, whose language deficits may be easy to detect, and for later school years, when language profiles may have changed and previously sufficient coping strategies are challenged as school demands increase and learning is expected in adverse listening conditions (Bishop, 2014). Relevant for all is a comprehensive and continual evaluation of communicative functioning, including formal assessment of language, cognition, and interaction.

Our findings support the notion of WMC and PSTM playing important roles in the integration of auditory and visual information during speech production and perception. As suggested by the Ease of Language Understanding model (Rönberg et al., 2013), a mismatch between input and long term memory representations will evoke extrinsic processing of the acoustic signal, requiring cognitive effort and strategic use of multimodal information, in this case possibly increased use of questions and gaze behavior during conversation. Future studies should evaluate individual variability in these memory capacities in relation to contextual multimodal challenge and support in the search for an explanation for the heterogeneity in language and communication outcome for children with SNHI. This should also provide an answer to whether the changes in request strategies and gaze behavior are, indeed, compensatory. The need for thorough and systematic studies of communication in children with SNHI should, however, not preclude prompt implementation of effective interventions based on current theories of language learning in typical and atypical populations.

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