Navigating the world of emotions: Social Information processing in children with and without hearing loss

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APPENDICES

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S2.1. Analyses Excluding Children with a Hearing Aid

Table S2.1.1. Fixed and random effects in the generalized linear mixed models of gaze patterns and physiological arousal, after excluding children with only a hearing aid (n = 5).

	Fixation ratios within AOIs				**Fixation ratios within entire faces**				**Physiological arousal (pupil dilation)**			
	Predefined category		**Interpreted category**		**Predefined category**		**Interpreted category**		**Predefined category**		**Interpreted category**	
Fixed/random effect	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI
Intercept	**.18**	[.17, .20]	**.19**	[.18, .20]	**.96**	[.95, .97]	**.97**	[.97, .98]	**.13**	[.09, .17]	**.14**	[.12, .17]
Age	*ns*		*ns*		*ns*		*ns*		*ns*		*ns*	
Group	*ns*		*ns*		*ns*		*ns*		.03 (.08)	[-.03, .10]	*ns*	
Category(AN)	-.00 (.01)	[-.01, .01]	*ns*		**.01** (.10)	[.00, .02]	*ns*		.01 (.03)	[-.03, .05]	*ns*	
Category(FE)	**.01** (.05)	[.00, .02]	*ns*		**.02** (.13)	[.01, .02]	*ns*		-.01 (.04)	[-.06, .03]	*ns*	
Category(HA)	.01 (.02)	[-.01, .02]	*ns*		**.01** (.08)	[.00, .02]	*ns*		.03 (.08)	[-.01, .07]	*ns*	
AOI(Eyes)	**.27** (1.08)	[.26, .28]	**.27** (1.08)	[.26, .28]	--		--		--		--	
AOI(Nose)	**-.07** (.27)	[-.08, -.06]	**-.07** (.27)	[-.08, -.06]	--		--		--		--	
Category(AN) x Group	*ns*		*ns*		*ns*		*ns*		-.00 (.01)	[-.06, .07]	*ns*	
Category(FE) x Group	*ns*		*ns*		*ns*		*ns*		-.02 (.04)	[-.08, .05]	*ns*	
Category(HA) x Group	*ns*		*ns*		*ns*		*ns*		**-.08** (.21)	[-.15, -.02]	*ns*	
AOI x Group	*ns*		*ns*		--		--		--		--	
Variance(Intercept)	.002	[.002, .003]	.002	[.002, .003]	.001	[.001, .001]	.001	[.001, .001]	**.015**	[.01, .02]	**.014**	[.01, .02]
Residual	.061	[.060, .063]	.062	[.060, .063]	.013	[.012, .013]	.013	[.012, .013]	**.131**	[.13, .14]	**.132**	[.13, .14]
N included	14727		14727		4909		4909		50925		53405	

Note: Group was coded as -1 = DHH, 1 = TH (reference). Category (i.e., predefined/interpreted emotion category) was coded as -2 = anger (AN), -1 = fear (FE), 1 = happiness (HA), 2 = neutral emotion (reference). Area of interest (AOI) was coded as -1 = eyes, 0 = nose, 1 = mouth (reference). An "*ns*" indicates that the variable was removed from the final model due to insignificance. A "—" indicates that the variable was not included in the full model. Significant values ($p < 0.05$) are bolded. Coef = unstandardized coefficient; CI = confidence interval. Δ = standardized effect size, calculated by dividing fixed coefficient by the square root of the sum of Level 1 (residual) and Level 2 (intercept) variances (formula suggested by Raudenbush and Liu, 2000). *N* included = number of cases included in the analysis.

Table S2.1.2. Results of multivariate analyses of variance on accuracy Hu scores and misinterpretation tendencies, after excluding children with only a hearing aid.

Effect	Accuracy	Misinterpretation
Group	$F(1, 123) = .80$, $\eta_p^2 = .01$	$F(1, 123) = .56$, $\eta_p^2 = .004$
Category	$F(3, 372) = 64.42^{***}$, $\eta_p^2 = .34$	$F(3, 372) = 15.62^{***}$, $\eta_p^2 = .11$
Category x Group	$F(3, 372) = 1.09$, $\eta_p^2 = .01$	$F(3, 372) = 7.77^{***}$, $\eta_p^2 = .06$
Post-hoc results	HA > NE > AN = FE (*t*s > 5.11, *p*s < .001 for the differences)	*Between-group* AN: DHH > TH ($t = 2.08^{*}$) FE: DHH = TH ($t = 1.73$) HA: DHH = TH ($t = -.90$) NE: DHH < TH ($t = -3.32^{**}$) *Within-group* DHH: AN > FE = NE > HA (*t*s > 2.86, *p*s < .007 for the differences) TH: AN = NE > FE = HA (*t*s > 3.14, *p*s < .003 for the differences)

Note: DHH = deaf and hard of hearing. TH = typically hearing. AN = angry. FE = fearful. HA = happy. NE = neutral. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

S2.2. Exploratory Analyses on Confusion Patterns between Predefined Emotion Categories

For exploratory purposes, we used four 2 (Group: DHH, TH) x 3 (Misinterpretation: e.g., anger misinterpreted as fear, happiness, or neutral emotion) multivariate analyses of variance to examine how each predefined emotion category was confused with the other emotion categories. Age was included as a covariate. Given the number of analyses we ran, which increased the chance of Type I errors, we adjusted the significance level of all exploratory analyses to $p < \alpha/4 = 0.0125$. See Table S1 for percentages of misinterpretations in the two groups.

When angry faces were presented, we observed a main effect of Misinterpretation, $F(2, 248) = 26.74$, $p < .001$, $= .18$, and an interaction of Group x Misinterpretation, $F(2, 248) = 10.61$, $p < .001$, $= .08$. Pairwise comparisons showed that the TH children more often misinterpreted angry faces as neutral than the DHH children, $t(124) = -3.82$, $p < .001$. Moreover, the DHH children more often misinterpreted angry faces as fearful or neutral than as happy, ts > 3.16, ps < .004. The TH children more often mistook angry faces as neutral faces than as fearful faces, $t(71) = 4.49$, $p < .001$, which were mistaken more often than happy faces, $t(71) = 3.01$, $p = .004$.

When fearful faces were presented, we observed a main effect of Misinterpretation, $F(2, 248) = 23.61$, $p < .001$, $= .16$. Post-hoc tests showed that fearful faces were more often recognized as being angry than as being happy or neutral, ts > 4.40, ps < .001.

When happy faces were presented, we did not observed any effects involved Group and Misinterpretation.

When neutral faces were presented, we found main effects of Group, $F(1, 124) = 7.83$, $p = .006$, $= .06$, and Misinterpretation, $F(2, 250) = 10.62$, $p < .001$, $= .08$. We also observed an interaction of Group x Misinterpretation, $F(2, 250) = 4.56$, $p = .011$, $= .04$. Post-hoc t-tests showed that the DHH children more often misinterpreted neutral faces as angry than the TH children, $t(125) = 2.61$, $p = .010$. Also, the DHH children more often mistook neutral faces as expressing anger than as expressing fear or happiness, ts > 3.07, ps < .004. The TH children did not show a particular pattern for misinterpreting neutral faces.

Taken together, the results of the exploratory analyses indicated that the TH children showed a tendency to interpret angry faces as neutral, while the DHH children showed more confusion between angry, fearful, and neutral faces.

Finally, the misinterpretation of fearful, happy, and neutral faces decreased with Age (for fearful faces: $F(1, 123) = 62.63$, $b = -.002$, $p < .001$, 95% CI [-.002, -.001], $= .34$; for happy faces: $F(1, 123) = 30.75$, $b = -.002$, $p < .001$, 95% CI [-.002, -.001], $= .20$; for neutral faces: $F(1, 124) = 50.33$, $b = -.002$, $p < .001$, 95% CI [-.003, -.001], $= .29$). The misinterpretation of angry faces remained stable across Age.

Table S2.2.1. Confusion matrices of the DHH and TH children. The numbers indicate percentages.

	DHH				**TH**				**Difference DHH - TH**			
	Interpreted Category				**Interpreted Category**				**Interpreted Category**			
Predefined Category	A	F	H	N	A	F	H	N	A	F	H	N
Anger	58	19	8	15	52	14	9	25	6	5	-1	-10
Fear	28	48	12	12	22	49	12	17	6	-1	0	-5
Happy	14	12	65	9	10	9	72	9	4	3	-7	0
Neutral	21	12	10	57	13	10	11	66	8	2	-1	-9

S2.3. Post-Hoc Analyses on Physiological Arousal

Table S2.3.1. Fixed and random effects in the generalized linear mixed models of physiological arousal, using each predefined emotion category as the reference category to examine between-group differences.

	Between-group differences					
	Angry as reference		**Fearful as reference**		**Happy as reference**	
Fixed/random effect	*Coef*	95% *CI*	*Coef*	95% *CI*	*Coef*	95% *CI*
Intercept	**.14**	[.10, .18]	.12	[.08, .16]	.16	[.12, .20]
Age	*ns*		*ns*		*ns*	
Group	.03	[-.04, .09]	.01	[-.05, .08]	-.06	[-.12, .004]
Angry	*ref*		.03	[-.02, .07]	-.02	[-.06, .02]
Fearful	-.03	[-.07, .02]	*ref*		**-.04**	[-.09, -.002]
Happy	.02	[-.02, .06]	**.04**	[.002, .09]	ref	
Neutral	-.01	[-.05, .03]	.01	[-.03, .06]	-.03	[-.07, .01]
Angry x Group	*ref*		.01	[-.05, .08]	**.09**	[.02, .15]
Fearful x Group	-.01	[-.08, .05]	*ref*		**.07**	[.01, .14]
Happy x Group	**-.09**	[-.15, -.02]	**-.07**	[-.14, -.01]	*ref*	
Neutral x Group	-.002	[-.06, .07]	.02	[-.05, .08]	**.09**	[.02, .15]
Variance(Intercept)	.01	[.01, .02]	.01	[.01, .02]	.01	[.01, .02]
Residual	.13	[.13, .14]	.13	[.13, .14]	.13	[.13, .14]

Note: Group was coded as -1 = DHH, 1 = TH (reference). An "*ns*" indicates that the variable was removed from the final model due to insignificance. Significant values ($p < 0.05$) are bolded. *Coef* = unstandardized coefficient; *CI* = confidence interval.

Table S2.3.2. Fixed and random effects in the generalized linear mixed models of physiological arousal within the DHH group, using each predefined emotion category as the reference category to examine differences between predefined emotion categories within the DHH children.

	Within-group differences: DHH group							
	Angry as reference		**Fearful as reference**		**Happy as reference**		**Neutral as reference**	
Fixed/random effect	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*
Intercept	.17	[.12, .21]	.13	[.08, .18]	.10	[.06, .15]	.16	[.11, .21]
Age	ns		ns		ns		ns	
Angry	ref		.04	[-.01, .09]	.07	[.02, .11]	.01	[-.04, .06]
Fearful	-.04	[-.09, .01]	ref		.03	[-.02, .08]	-.03	[-.08, .02]
Happy	-.07	[-.11, -.02]	-.03	[-.08, .02]	ref		-.06	[-.11, -.01]
Neutral	-.01	[-.06, .04]	.03	[-.02, .08]	.06	[.01, .11]	ref	
Variance(Intercept)	.01	[.01, .02]	.01	[.01, .02]	.01	[.01, .02]	.01	[.01, .02]
Residual	.14	[.13, .15]	.14	[.13, .15]	.14	[.13, .15]	.14	[.13, .15]

Note: An "*ns*" indicates that the variable was removed from the final model due to insignificance. Significant values ($p < 0.025$) are bolded. *Coef* = unstandardized coefficient; *CI* = confidence interval.

Table S2.3.3. Fixed and random effects in the generalized linear mixed models of physiological arousal within the TH group, using each predefined emotion category as the reference category to examine differences between predefined emotion categories within the TH children.

	Within-group differences: TH group							
	Angry as reference		**Fearful as reference**		**Happy as reference**		**Neutral as reference**	
Fixed/random effect	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*
Intercept	**.14**	[.10, .18]	**.12**	[.07, .16]	**.16**	[.12, .20]	**.13**	[.09, .17]
Age	*ns*		*ns*		*ns*		*ns*	
Angry	*ref*		.03	[-.02, .07]	-.02	[-.06, .02]	.01	[-.03, .05]
Fearful	-.03	[-.07, .02]	ref		-.04	[-.09, -.003]	-.02	[-.06, .03]
Happy	.02	[-.02, .06]	.04	[.003, .09]	*ref*		.03	[-.01, .07]
Neutral	-.01	[-.05, .03]	.02	[-.03, .06]	-.03	[-.07, .01]	*ref*	
Variance(Intercept)	.02	[.01, .03]	.02	[.01, .03]	.02	[.01, .03]	.02	[.01, .03]
Residual	.13	[.12, .14]	.13	[.12, .14]	.13	[.12, .14]	.13	[.12, .14]

Note: An "*ns*" indicates that the variable was removed from the final model due to insignificance. Significant values ($p < 0.025$) are bolded. *Coef* = unstandardized coefficient; *CI* = confidence interval.

SUPPLEMENTARY MATERIALS CHAPTER 3

S3.1. Sample Size Justification

The sample size for the research project was estimated a priori with a power analysis. Previous studies indicated that a difference in emotion understanding between DHH and TH children could be observed with small-to-medium effect sizes (Torres et al., 2016; Wiefferink et al., 2013). Thus, a minimum sample size of 82 was required to detect a group difference (d = .4; α = .05; power = .90). Note that we planned to use mixed model ANOVAs when estimating sample size a priori and later changed to multilevel models considering the two-level structure in the data.

S3.2. Stimuli

Video Validation

Before the study started, the emotion triggered in the videos were rated by 17 typically developing adults. The consent rate was above 82% for 15 of the 16 videos (M = 90.86%, SD = 6.27). Yet, one video had a low consent rate (58.82%) because some raters mistook the surprised face among the response options as fearful. This face image was replaced by a retaken photo.

Table S3.2.1. Overview of videos. There were two sets of videos, and children were randomly assigned to one of the sets. The first sentence describes the contextual scene. The second sentence (bolded) describes the key-action scene (i.e., the scene included in the analyses).

Trial	Set A	Set B
1§	A woman is crying and a man approaches. **The man gives her a flower.***	A man is enjoying himself (slightly shaking body with a tempo) and a woman approaches. **The woman gives him a well wrapped gift.**
2§	A woman is hurt and a man approaches. **The man does not help her.**	A man is enjoying himself (smoking) and a woman approaches. **The woman shows that he is forbidden to be here.***
3	A woman is happily checking smartphone and another woman approaches. **The second woman gives her a high five.**	A woman is happily checking smartphone and another woman approaches. **The second woman pushes her away with elbow while walking by.***
4	A man is sitting in a cafeteria, looking hungry, and a woman approaches with a pizza. **The woman refuses to share the pizza with him.**	A man is sitting in a cafeteria, looking hungry, and a woman approaches with a pizza. **The woman shares the pizza with him.***
5	A woman is waving with a smile and crossing a road. **A man on the other side of the road pushes her down to the ground.***	A woman is waving with a smile and crossing a road. **A man on the other side of the road gives her a well wrapped gift.**
6	A man is hurt, walking with sticks, and a woman approaches. **The woman shows him a cake.***	A man is hurt, walking with sticks, and a woman approaches. **The woman laughs.**
7	A woman is happily climbing across monkey bars. **She successfully makes it to the end and a man gives her a cold drink.**	A woman is happily climbing across monkey bars. **She falls from it and a man points at her.***
8	A man is riding a bike, almost falling down, and a woman approaches. **The woman holds the bike.***	A man is riding a bike, almost falling down, and a woman approaches. **The woman throws a rock at him.**

§ While in trials 3 to 8 the videos in set A and set B were parallel, the first two trials had a different structure. We designed two videos with conceptually similar, but not the same, contextual scenes (e.g., crying vs. feeling pain) and each ends with an emotion in the opposite valence. These two videos were placed in the same set.
*The video had a twist in the plot, i.e., from positive to negative emotion, or vice versa.

S3.3. Fixation Duration

Table S3.3.1. Fixed and random effects in the generalized linear mixed model of fixation ratios within video frame (binomial distribution, link function = logit).

Fixed and random effect	Coefficient	95% CI	z-value (p-value)
Intercept	5.30	[4.74, 5.86]	18.51 (< .001)
Age	**.04**	[.01, .06]	3.38 (.001)
Group	*ns*		
Valence	**-.46**	[-.76, -.16]	-2.98 (.003)
Valence x Group	*ns*		
Variance - Intercept	1.90	[1.53, 2.37]	

Note: Group was coded as -1 = DHH, 1 = TH. Valence was coded as -1 = negative, 1 = positive. The last category was used as the reference. An "*ns*" indicates that the variable was removed from the final model due to insignificance. CI = confidence interval.

Table S3.3.2. Mean (SD) of fixation duration (ms) and ratio within each area as a function of hearing status, device use, and chronological age.

		Hearing status		**Device use**		**Chronological age**	
Area		DHH (n = 57)	TH (n = 68)	CI (n = 52)	HA (n = 5)	< 6 years (n = 77)	≥ 6 years (n = 48)
Target Head	ms	647.75 (384.83)	845.92 (501.63)	665.43 (382.31)	463.95 (404.28)	634.33 (433.44)	950.02 (441.12)
	ratio[a]	0.15 (0.07)[#]	0.18 (0.08)[#]	0.16 (0.07)	0.11 (0.08)	0.14 (0.07)***	0.20 (0.07)***
Target Body	ms	452.53 (323.29)	494.1 (359.59)	473.34 (323.63)	236.04 (252.29)	503.63 (392.94)	429.43 (238.46)
	ratio[a]	0.13 (0.07)	0.11 (0.08)	0.13 (0.07)	0.10 (0.07)	0.12 (0.08)	0.10 (0.06)
Partner Head	ms	963.97 (598.61)	1077.50 (654.02)	974.10 (598.70)	858.65 (656.87)	872.12 (602.3)	1272.14 (598.29)
	ratio[a]	0.23 (0.11)	0.23 (0.11)	0.23 (0.11)	0.22 (0.13)	0.20 (0.11)***	0.27 (0.10)***
Partner Action	ms	466.10 (292.23)	531.74 (332.46)	482.37 (293.20)	296.91 (245.53)	470.87 (334.45)	551.44 (277.85)
	ratio[a]	0.11 (0.05)	0.11 (0.05)	0.11 (0.05)	0.07 (0.03)	0.10 (0.06)	0.12 (0.05)
Within video	ms	3845.59 (1495.81)	4395.06 (1587.74)	3925.78 (1440.33)	3011.55 (1979.97)	3956.52 (1709.09)	4446.05 (1258.83)
	ratio[a]	0.97 (0.13)	0.96 (0.08)	0.97 (0.14)	0.95 (0.07)	0.95 (0.13)*	0.99 (0.03)*
Within screen	ms	3889.36 (1498.80)	4527.17 (1532.56)	3969.32 (1444.30)	3057.86 (1976.24)	4089.27 (1696.54)	4472.24 (1243.66)
	ratio[b]	0.57 (0.22)*	0.66 (0.22)*	0.58 (0.21)	0.44 (0.28)	0.60 (0.24)	0.66 (0.18)
Off-screen	ms	2987.01 (1591.86)	2311.53 (1530.15)	2910.40 (1549.23)	3783.71 (2001.34)	2779.31 (1756.23)	2363.26 (1249.65)
	ratio[b]	0.43 (0.22)*	0.34 (0.22)*	0.42 (0.21)	0.56 (0.28)	0.40 (0.24)	0.34 (0.18)

Note: DHH = deaf and hard of hearing. TH = typically hearing. CI = cochlear implant. HA = hearing aid.
[a] Ratio against fixation duration within the entire screen. [b] Ratio against the duration of the video (key-action scene).
# $p < .08$; * $p < .05$; *** $p < .001$ for the differences in fixation ratios between the comparison groups according to t-tests (two-tailed).

S3.4. Analyses on Children with Cochlear Implants

When analyses were conducted excluding the children with only a hearing aid (HA), i.e., including only children with a cochlear implant (CI), the directions of results generally remained the same. Below we discuss the differences observed between the analyses on all DHH children and the analyses on children with a CI. See Table S4.1 for the complete final models.

Encoding

Regarding the fixation ratios within the video frame, all results were in line with the previous analyses where the entire DHH group was included.

In the analysis on fixation ratios within the AOIs, all the effects remained the same as previous analyses, except for the interaction of Group x Partner Head. When only children with a CI were included, this effect became marginal, b = .03, 95% CI [-.00, .06], δ = .17. The interaction of Group x Target Body remained significant, b = .04, 95% CI [.01, .07], δ = .23.

Interpretation

All the results were congruent with previous analyses, except that an effect for Valence was observed, b = .06, p = .038, 95% CI [.003, .11], δ = .09. In children with CIs and with TH, negative emotions were interpreted more accurately than positive emotions. No interaction effects were observed, in line with previous analyses.

Effect of Encoding on Interpretation

For nonverbal interpretation, we observed two additional interactions: Group x Target Body, b = -.39, 95% CI [-.68, -.10], δ = .60, and Group x Partner Head, b = -.30, 95% CI [-.56, -.03], δ = .46. These results suggest that, while looking longer at Target Body and Partner Head decreased the nonverbal interpretation scores in the two groups alike, these effects were even stronger in children with a CI.

For verbal interpretation, we observed an additional main effect of Partner Head, b = -.17,95% CI [-.29, -.05], δ = .28. This indicates that longer looking times at Partner Head were associated with lower verbal scores in the two groups. We also observed two additional interactions, Group x Target Head, b = .30, 95% CI [.02, .59], δ = .49, and Group x Partner Action, b = .48, 95% CI [.18, .78], δ = 78. Although looking longer at Target Head increased verbal interpretation scores in the two groups alike, this effect was stronger in the children with a CI. Also, the association between longer looking times at Partner Action and lower verbal scores was observed only in the TH children, but not in the children with a CI.

Discussion

Despite these differences between the analyses on all DHH children and the analyses on only children with a CI, the overall picture derived from the results was similar. DHH children decreased their attention to the target person's head and increased their attention to the target person's body. This finding further supports our claim that DHH children tend to divert their attention away from ambiguous cues to explicit, visually observable information, especially the body cues.

Also, the cues we examined in this study appear to work differently on interpretation in the two groups. DHH children were more easily misled by explicit cues, such as target person's body and interaction partner's head. This is most likely because they did not have adequate social-emotional knowledge to support their use of these explicit cues, as we discussed in the main text. The extra interactions of Group x Target Body and Group x Partner Head we observed in the analyses on only the children with a CI suggest that children with a CI might need even more support for gaining social-emotional knowledge in order to make proper interpretation when encountering social situations.

Considering that we only had five children with a HA, it is hard to draw a conclusion whether different types of amplification or degrees of hearing loss might have an effect. Future research is suggested to look further in this direction.

Table S3.4.1. Fixed and random effects in the generalized linear mixed models excluding children with only a hearing aid (n = 5).

	Fixation ratio				**Interpretation**		**Verbal interpretation**			
	within AOIs		**Video frame**				**Interpretation**		**Effect of encoding**	
Parameters	*b*	95% CI	*b*	95% CI	*b*	95% CI	*b*	95% CI	*b*	95% CI
Intercept	.18	[.17, .20]	.97	[.95, .99]	1.10	[1.03, 1.18]	1.14	[1.07, 1.21]	1.12	[1.05, 1.18]
Age	**.00**	[.00, .00]	**.00**	[.00, .00]	**.01**	[.01, .01]	**.01**	[.01, .01]	**.01**	[.01, .01]
Group	**-.02**	[-.05, -.00]	ns		**-.16**	[-.25, -.06]	**-.18**	[-.28, -.08]	**-.14**	[-.24, -.04]
Valence	*ns*		**-.01**	[-.02, -.01]	**.06**	[.00, .11]	ns		ns	
Group x Valence	*ns*		*ns*		**.07**	[.02, .13]	ns		ns	
Group x Task					ns					
Group x Valence x Task					ns					
TarHead	*ref*		--		ns		--		**.18**	[.02, .35]
TarBody	**-.07**	[-.09, -.05]	--		--		--		-.11	[-.31, .09]
ParHead	**.05**	[.03, .07]	--		--		--		**-.17**	[-.29, -.05]
ParAction	**-.07**	[-.09, -.05]	--		--		--		**-.59**	[-.80, -.39]
Group x TarHead	*ref*		--		--		--		**.30**	[.02, .59]
Group x TarBody	**.04**	[.01, .07]	--		--		--		**-.42**	[-.69, -.15]
Group x ParHead	.03	[-.00, .06]	--		--		--		*ns*	
Group x ParAction	.03	[-.00, .06]	--		--		--		**.48**	[.18, .78]
Var(Intercept)	.00	[.00, .00]	.01	[.01, .01]	--		.07	[.05, .10]	.07	[.05, .09]
Residual	.03	[.02, .03]	.01	[.01, .01]	.05	[.03, .07]	.33	[.32, .35]	.31	[.29, .32]

Note: Group was coded as -1 = DHH, 1 = TH. Valence was coded as -1 = negative, 1 = positive. Task was coded as -1 = nonverbal, 1 = verbal. AOI was coded as -2 = interaction partner's head (ParHead), -1 = interaction partner's action (ParAction), 1 = target person's body (TarBody), 2 = target person's head (TarHead). The last category was used as the reference ("ref"). An "ns" indicates that the variable was removed from the final model due to insignificance. A "--" indicates that the effect was not included in the full model. Significant fixed effects (p < 0.05) are bolded. CI = confidence interval.

SUPPLEMENTARY MATERIALS CHAPTER 4

S4.1. Parent reports

Table S4.1.1. Items in each parent-report measure

Emotion recognition	
1.	Can your child fully acknowledge others' emotions?
2.	Does your child see when you are angry?
3.	Does your child see when you are happy?
4.	Does your child see when you are afraid?
5.	Does your child see when you are sad?
6.	Does your child see when you are having fun?
Empathy (3-5 years old)	
1.	When another child cries, my child gets upset too.
2.	When I make clear that I want some peace and quiet, my child tries not to bother me.
3.	When my child sees other children laughing, he/she starts laughing too.
4.	My child also needs to be comforted when another child is in pain.
5.	When another child starts to cry, my child tries to comfort him/her.
6.	When an adult gets angry with another child, my child watches attentively.
7.	When another child makes a bad fall, shortly after my child pretends to fall too.
8.	When another child gets upset, my child tries to cheer him/her up.
9.	My child looks up when another child laughs.
10.	When another child is upset, my child needs to be comforted too.
11.	When I make clear that I want to do something by myself (e.g. read), my child leaves me alone for a while.
12.	When adults laugh, my child tries to get near them.
13.	When another child gets frightened, my child freezes or starts to cry.
14.	When two children are quarrelling, my child tries to stop them.
15.	My child looks up when another child cries.
16.	When other children argue, my child gets upset.
17.	When another child gets frightened, my child tries to help him/her.
18.	When another child is angry, my child stops his own play to watch.
19.	When another child cries, my child looks away.
20.	When other children quarrel, my child wants to see what is going on.
Empathy (6-10 years old)	
1.	If I am happy, my child also feels happy.
2.	My child understands that a friend is ashamed when he/she has done something wrong.
3.	If a friend is sad, my child likes to comfort him.
4.	My child feels awful when two people quarrel.
5.	When a friend is angry, my child tends to know why.
6.	My child would like to help when a friend gets angry.
7.	If a friend is sad, my child also feels sad.
8.	My child understands that a friend is proud when he/she has done something good.
9.	If a friend has an argument, my child tries to help.
10.	If a friend is laughing, my child also laughs.
11.	If a friend is sad, my child understands mostly why.
12.	My child wants everyone to feel good.
13.	When a friend cries, my child cries himself/herself.
14.	If a friend cries, my child often understands what has happened.
15.	If a friend is sad, my child wants to do something to make it better.
16.	If someone in the family is sad, my child feels really bad.
17.	My child enjoys giving a friend a gift.
18.	When a friend is upset, my child feels upset too.

Table S4.1.1. Continued

Negative emotion expression
1. How often does your child show anger?
2. How intense is this usually?
3. How long does it usually last?
4. Is your child easy to calm down when angry?
5. How often does your child show sadness?
6. How intense is this usually?
7. How long does it usually last?
8. Is your child easy to calm down when he is sad?
Positive emotion expression
1. How often does your child show happiness?
2. How intense is this usually?
3. How long does it usually last?
4. How often does your child show joy?
5. How intense is this usually?
6. How long does it usually last?
Social competence
1. Rather solitary, tends to play alone (R)
2. Has at least one good friend
3. Generally liked by other children
4. Picked on or bullied by other children (R)
5. Gets on better with adults than with other children (R)#
6. Considerate of other people's feelings
7. Shares readily with other children (treats, toys, pencils etc.)
8. Helpful if someone is hurt, upset or feeling ill#
9. Kind to younger children
10. Often volunteers to help others (parents, teachers, other children)
Externalizing behaviors
1. Restless, overactive, cannot stay still for long
2. Constantly fidgeting or squirming
3. Easily distracted, concentration wanders
4. Thinks things out before acting (R)
5. Sees tasks through to the end, good attention span (R)
6. Often has temper tantrums or hot tempers#
7. Generally obedient, usually does what adults request (R)
8. Often fights with other children or bullies them
9. Often lies or cheats
10. Steals from home, school or elsewhere

Note: R = reversely scored; # = removed from the analyses, given the reason provided in the main text.

S4.2. EmQue and EmQue-CA

Table S4.2.1. Correlations of Empathy Questionnaire (EmQue) and Empathy Questionnaire for Children and Adolescents (EmQue-CA) with other study variables (pooled results after multiple imputations)

	Negative emotion expression	Positive emotion expression	Emotion recognition	Social competence	Externalizing behaviors
EmQue	-.199	.182	.475***	.392**	-.236
EmQue-CA	-.028	.065	.589***	.295*	-.351**
Fisher's r to z	-.963	.660	-.885	.611	.699
p (z)[a]	.336	.509	.376	.541	.485

*p < .05; **p < .01; ***p < .001 for correlations between EmQue/EmQue-CA and study variables.
[a] Significance of the z-score after Fisher's r-to-z transformation, which was applied to compare the strength of correlations.

S4.3. Analyses Excluding Children without a Cochlear Implant

Table S4.3.1. Psychometric properties and mean scores (standard deviations) of the questionnaires after excluding the five children without a cochlear implant

	Cronbach's α (*n* sample)	Mean (SD)		*t* value[a]	*p* value[ab]
		DHH	TH		
Emotion recognition	.83 (122)	3.64 (.62)	3.61 (.74)	-.29	.387
Empathy (all children)	--	1.22 (.30)	1.25 (.34)	.40	.346
Empathy (3-5 years)	.79 (58)	1.07 (.26)	1.07 (.28)	-.01	.497
Empathy (6-10 years)	.85 (60)	1.35 (.27)	1.42 (.29)	.98	.165
Negative emotion expression	.80 (123)	2.42 (.55)	2.43 (.54)	.16	.437
Positive emotion expression	.74 (123)	3.65 (.66)	3.63 (.54)	-.27	.395
Social competence	.68 (120)	1.47 (.35)	1.52 (.30)	.67	.252
Externalizing problems	.74 (121)	.72 (.39)	.62 (.30)	-1.50	.066

Note: DHH = deaf and hard of hearing; TH = typically hearing.
[a] Pooled results after multiple imputations.
[b] One-tailed.

Table S4.3.2. Hierarchical regression analyses for emotional functioning measures on social functioning after excluding the five children without a cochlear implant (pooled results after multiple imputations)

	Social competence			**Externalizing behaviors**		
	b	***p***	**95% CI**	***b***	***p***	**95% CI**
Step 1	R^2 = .24**			R^2 = .25**		
Age	< .001	.921	[-.003, .002]	.001	.282	[-.001, .004]
Gender	-.001	.990	[-.11, .11]	.04	.509	[-.07, .15]
Group	-.04	.481	[-.14, .07]	.08	.137	[-.03, .20]
Emotion recognition	.06	.210	[-.03, .15]	-.01	.859	[-.10, .09]
Empathy	**.25**	**.022**	**[.04, .46]**	**-.32**	**.005**	**[-.55, -.10]**
Negative emotion expression	**-.18**	**< .001**	**[-.28, -.08]**	**.21**	**< .001**	**[.10, .31]**
Positive emotion expression	.01	.872	[-.09, .10]	.02	.708	[-.08, .12]
Step 2	ΔR^2 = .05			ΔR^2 = .07*		
Age				.002	.130	[-.001, .01]
Gender				.04	.529	[-.07, .14]
Group				-.61	.188	[-.53, .30]
Emotion recognition				.04	.455	[-.07, .15]
Empathy				**-.51**	**< .001**	**[-.77, -.25]**
Negative emotion expression				.05	.441	[-.08, .19]
Positive emotion expression				.04	.540	[-.09, .17]
Group x Emotion recognition				-.12	.222	[-.32, .07]
Group x Empathy				.38	.072	[-.03, .79]
Group x Negative emotion expression				**.33**	**.002**	**[.12, .54]**
Group x Positive emotion expression				-.05	.638	[-.24, .15]

Note: Gender was coded as 0 = male, 1 = female. Group was coded as 0 = typically hearing, 1 = cochlear implant. 95% CI: 95% confidence interval. *p < .05; **p < .001 for the change in R^2.

S4.4. Comparisons between DHH and TH Children Per Age Group

Table S4.4.1. Mean scores (standard deviations) per age group and comparisons between deaf and hard-of-hearing (DHH) children and children with typical hearing (TH)

	Emotion recognition	Empathy	Negative emotion expression	Positive emotion expression	Social competence	Externalizing behaviors
3-4 years						
DHH (n=18)	3.69 (.75)	1.08 (.24)	2.52 (.78)	3.60 (.60)	1.42 (.43)	.79 (.35)
TH (n=21)	3.62 (.64)	1.07 (.28)	2.46 (.47)	3.73 (.59)	1.48 (.30)	.70 (.31)
t value[a]	-.34	-.11	-.28	.68	.45	-.82
p value[ab]	.366	.457	.390	.250	.327	.208
5-6 years						
DHH (n=19)	3.79 (.73)	1.18 (.34)	2.32 (.41)	3.57 (.57)	1.46 (.31)	.65 (.38)
TH (n=35)	3.62 (.86)	1.25 (.33)	2.41 (.62)	3.56 (.51)	1.54 (.28)	.60 (.26)
t value[a]	-.84	.74	.61	-.24	.94	-.57
p value[ab]	.200	.231	.272	.407	.175	.286
7-10 years						
DHH (n=18)	3.64 (.48)	1.37 (.21)	2.31 (.43)	3.77 (.74)	1.54 (.34)	.71 (.42)
TH (n=18)	3.59 (.63)	1.45 (.30)	2.43 (.44)	3.64 (.56)	1.51 (.32)	.57 (.34)
t value[a]	-.25	.89	.82	-.59	-.22	-1.03
p value[ab]	.402	.187	.208	.278	.415	.152

[a] Pooled results after multiple imputations.
[b] One-tailed.

S4.5. Correlations between Emotional and Social Functioning Measures

Table S4.5.1. Pearson's correlations between all study variables (pooled results after multiple imputations)

	Correlation in all children (in DHH children / in children with TH)					
	1.	**2.**	**3.**	**4.**	**5.**	**6.**
1. Age						
2. Emotion recognition	-.05 (-.07/-.05)					
3. Empathy	**.38** (**.41**/**.38**)	**.45** (**.44**/**.46**)				
4. Negative emotion expression	-.07 (-.12/-.02)	-.12 (-.19/-.06)	-.19 (-.04/-**.30**)			
5. Positive emotion expression	.07 (.12/.01)	**.24** (.24/.24)	.11 (.25/.02)	.18 (.12/.25)		
6. Social competence	.09 (.10/.10)	**.27** (.35/.24)	**.38** (**.36**/**.40**)	**-.36** (**-.50**/-.24)	.02 (.05/-.01)	
7. Externalizing behaviors	-.03 (.02/-.12)	-.18 (-.25/-.14)	**-.33** (-.15/-**.48**)*	**.40** (**.55**/.27)#	.06 (.01/.11)	**-.51** (**-.52**/**-.49**)

Note. Correlations in DHH children and in children with TH are reported separately in the parentheses. Significant correlations are bolded. Given that each variable was tested against the other six variables, Bonferroni correction was applied to adjust significance level to $p < \alpha/6 = .0083$.

*$p = .040$ for the difference in the strength of correlation between DHH children and children with TH, according to Fisher's r-to-z transformation.

#$p = .064$ for the difference in the strength of correlation between DHH children and children with TH, according to Fisher's r-to-z transformation.

SUPPLEMENTARY MATERIALS CHAPTER 5

S5.1. Correlations between Study Variables

Table S5.1.1. Pearson's correlations between study variables.

	1.	2.	3.	4.	5.	6.
1. Age	-					
2. Affective empathy	-.106*	-				
3. Attention to emotions	.026	.350**	-			
4. Prosocial actions	.403**	.150**	.305**	-		
5. Emotion acknowledgment	.195**	.016	.262**	.365**	-	
6. Internalizing behaviors	.222**	.272**	.120*	.042	-.082	-
7. Externalizing behaviors	.095	.094	.067	.025	-.076*	.374**

* $p < .0083$; ** $p < .001$. Significance level was adjusted by the number of correlation analyses on each variable to $p < \alpha/6 = .0083$.

S5.2: Individual Variations

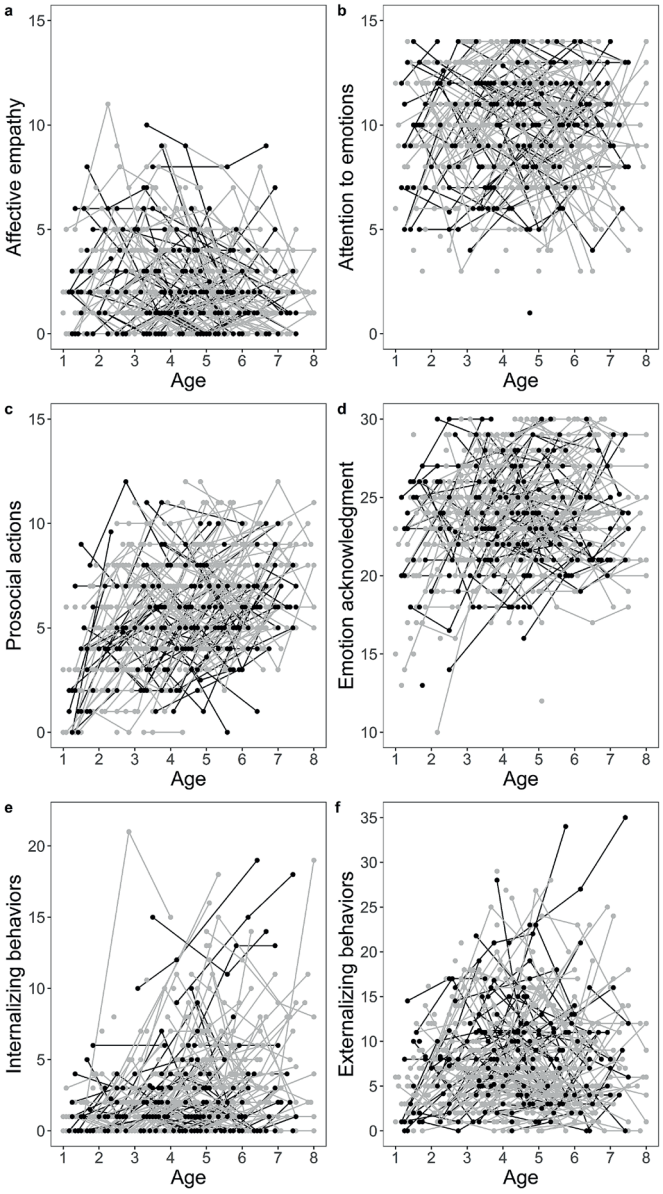

Figure S5.2.1. Longitudinal graphic representation of age at the four time points of **1a.** affective empathy; **1b.** attention to others' emotions; **1c.** prosocial actions; **1d.** emotion acknowledgment; **1e.** internalizing behaviors; **1f.** externalizing behaviors. Each participant is presented by an individual line and each time point is presented by a point. Children with a cochlear implant are displayed in black, and typically-hearing children in grey.

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CURRICULUM VITAE

Yung-Ting Tsou was born in 1988 on the 24th of April in Keelung, Taiwan. In 2006, she graduated from the Affiliated Senior High School of National Taiwan Normal University. She later obtained her bachelor degree in Foreign Languages and Literatures at National Taiwan University in 2011, and won the Presidential Award in 2009. In 2012, she received her master degree in Linguistics at Leiden University. After graduation, she worked as a research assistant at the Department of Otorhinolaryngology – Head and Neck Surgery at Chang-Gung Memorial Hospital, Linkou, Taiwan, and studied language and social development in children with cochlear implants. In 2016, Yung-Ting started her PhD project at the Institute of Psychology of Leiden University, under the supervision of Prof. dr. Carolien Rieffe, Prof. dr. ir. Johan H. M. Frijns, Dr. Boya Li, and Dr. Mariska E. Kret. Her research focused on the processing of emotions in social contexts in children who are deaf or hard-of-hearing, using eye-tracking and pupillometry technologies. After her PhD, Yung-Ting will work as a postdoctoral researcher in the "Breaking the cycle" research project with Prof. dr. Carolien Rieffe and Dr. Els Blijd-Hoogewys (INTER-PSY), also at Leiden University. She will work on the development and implementation of an intervention scheme for creating a more inclusive environment at schoolyards.

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