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Altruistic behavior in Chinese children with hearing impairment: Associations with power cognition and word comprehension

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ABSTRACT

Altruistic behavior is a crucial manifestation in the socialization process of preschool children with hearing impairment, yet research on this topic among Chinese children remains limited. This study investigated the effects of power cognition and word comprehension on altruistic behavior in preschool-aged children with hearing impairment. A sample of 64 children, including both hearing-impaired and typically developing children, completed altruistic behavior tasks, power cognition tasks, word comprehension tasks, and the Raven's Combined Test. The results revealed that: (1) Children with hearing impairment exhibited significantly lower levels of altruistic behavior compared to typically developing children; (2) Both power cognition and word comprehension were positively correlated with altruistic behavior in children with hearing impairment; (3) Word comprehension mediated the relationship between power cognition and altruistic behavior in children with hearing impairment.

1. Introduction

Altruistic behavior refers to voluntary actions that incur personal costs to benefit others without expectation of reward (Eisenberg & Shell, 1986; Lozada et al., 2014). This behavior manifests throughout the lifespan, from daily interactions to emergency situations, and serves as a critical indicator of children's socialization (Valsala & Menon, 2023). The determinants of altruistic behavior have been extensively studied across disciplines including social psychology, ethics, and economics. Notably, the Dictator Game paradigm from behavioral economics provides a simple yet effective method for systematically investigating children's altruistic behavior (Benenson et al., 2007; Yu et al., 2024; Zhu et al., 2008). In this paradigm, participants receive windfall gains (or rewards) and unilaterally decide how much to allocate to a passive recipient, who must accept the proposed allocation without negotiation (Engel, 2011).

For children with hearing impairment, altruistic behavior is particularly crucial for fostering social responsibility and advancing social equity (Cooper et al., 2013). However, research within the domain of special education remains limited, particularly in the Chinese context, where the developmental characteristics and influencing mechanisms of altruistic behavior in children with hearing impairments are still poorly understood. Existing studies have yet to establish a consensus on whether altruistic behavior differs between hearing-impaired and typically developing children.

1.1. Do children with hearing impairment exhibit developmental lag in altruistic behavior?

Numerous studies have demonstrated that altruistic behavior emerges early in child development, with toddlers aged 1–2 years exhibiting spontaneous helping, sharing, and comforting behaviors without external rewards (Hepach et al., 2012; Song et al., 2020). However, the development of altruistic behavior in children does not follow a linear trajectory. Research indicates that while the forms of altruistic behavior become more diverse and complex after age 3, they do not necessarily progress with age (Paulus, 2018; Rose et al., 2024).

Studies on the altruistic behavior of children with hearing impairments are limited, particularly in the context of Chinese populations, and the existing findings remain inconsistent. For instance, research on toddlers aged 29–32 months with moderate hearing loss found that, despite delays in language development, these children exhibited emotional empathy levels comparable to their typically developing peers (Dirks et al., 2017). Similarly, studies on hearing-impaired

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primary school children aged 7–9 reported higher levels of sharing behavior than their hearing peers (Wang, 2021), while no significant differences were found in the prosocial tendencies of hearing-impaired adolescents compared with typically developing adolescents (Wang et al., 2018). In contrast, other studies concluded that the sharing behaviors of hearing-impaired adolescents aged 12–16 were equivalent to those of typically developing children aged 6–11 (Hao & Wu, 2019). A meta-analysis further highlighted that parent-reported prosocial behaviors in children with hearing impairment were significantly lower (Stevenson et al., 2015).

1.2. The relationship between power cognition and altruistic behavior

Power cognition refers to an individual's perception, understanding, and judgment of power relations based on others' resource control and behavioral regulation capabilities (Guinote, 2017; Gülgöz & Gelman, 2017). Social life is permeated with power dynamics, as power constitutes a fundamental concept in the social sciences (Cheng et al., 2018). Particularly in children's socialization, well-developed power cognition may enhance social adaptability and facilitate the internalization of social norms (Schmidt & Tomasello, 2012).

However, the mental representation of power and status may have evolved in humans as a response to environmental complexities. Similar to other species, preverbal human infants establish dominance hierarchies through zero-sum conflicts, where certain individuals consistently supplant others (Thomsen, 2020). Both naturalistic behavioral observations and experimental studies indicate that infants as young as 6–10 months old can detect social status and authority through physical and situational cues (Pun et al., 2016; Strayer & Trudel, 1984; Thomsen et al., 2011). This suggests that power cognition may not be an advanced ability as traditionally assumed, but rather a foundational capacity emerging early in development.

In contrast, altruistic behavior (toward non-kin) develops relatively later. While 18-month-olds demonstrate flexible helping behaviors—such as inferring others' goals and taking context-appropriate actions—humans' heightened cooperation and altruism compared to primates coexist with persistent hierarchical structures across cultures (Thomsen, 2020; Warneken & Tomasello, 2006). Thus, the relationship between power cognition and altruistic behavior warrants in-depth investigation. A seminal study found that preschool children's prosocial behavior is influenced by both chronic and situational status positions (Guinote et al., 2015). The authors posit that the link between social hierarchy and altruism emerges prior to the acquisition of literacy, complex moral reasoning, or formal value system.

Notably, evolutionary biological perspectives further elucidate this relationship. Research suggests that asymmetries in power and dominance play a crucial role in the evolution of altruistic behavior. High-power individuals may motivate cooperation by controlling resources or opportunities, while low-power individuals may exhibit altruistic behaviors to gain social recognition or elevate their status (Phillips, 2018). Studies on hearing-impaired middle school students further underscore the importance of social power cognition. Findings reveal that beliefs in a just world not only directly influence altruistic behavior but also exert indirect effects through gratitude and life satisfaction (Guo et al., 2020). Additionally, beliefs in a just world were found to moderate the relationship between justice-related scenarios and helping behavior (Wu, 2018).

1.3. The relationships of power cognition with language ability and nonverbal reasoning

As posited earlier, the capacity to recognize and adaptively respond to status cues may have emerged through evolutionary pressures, implying domain-specific cognitive adaptations (Guinote et al., 2015). Within this framework, language—as a specialized cognitive mechanism—likely evolved via natural selection as an extension of such socio-cognitive scaffolding (Hauser et al., 2002). The influence of language on power cognition seems to be evident. However, does power cognition also have an effect on language ability?

Chiao et al. (2009) identified a semantic distance effect in both numerical and social status comparisons, revealing heightened neural activation in the bilateral intraparietal sulci (IPS) during semantically proximal versus distal comparisons. This suggests that power perception engages cognitive mechanisms potentially foundational to language development. Similarly, Cui et al. (2022) demonstrated that neural processing of Japanese honorific agreement is modulated by the speaker's social status, confirming power cognition's direct impact on linguistic processing.

Embodied cognition research further elucidates these connections. Schubert et al. (2011) established that cognitive associations between power and spatial cues (e.g., elevation, size) drive the emergence of metaphorical language reflecting these conceptual mappings. Their work substantiates how power cognition scaffolds language development through perceptual symbols and cultural practices linking power with vertical spatial dimensions. Specifically, spatial metaphors such as "up" (e.g., "rising to power") and "down" (e.g., "falling from grace") are grounded in these embodied associations.

In addition to its potential ties to language, power cognition may also intersect with nonverbal reasoning, which involves recognizing patterns and analyzing relationships without relying on linguistic skills. Evolutionary pressures to navigate social hierarchies likely favored cognitive adaptations that process relational cues non-linguistically, pointing to a connection between power cognition and nonverbal reasoning (Cosmides & Tooby, 2013). For example, children often assess power in social conflicts by focusing on resource control rather than physical strength alone, a process that hinges on nonverbal relational reasoning and suggests power cognition's role in shaping such abilities (Pietraszewski & Shaw, 2015). Neural evidence further supports this link, as the processing social hierarchies engages the fronto-parietal network—a region tied to nonverbal reasoning tasks—indicating that power cognition might enhance these cognitive capacities (Zink et al., 2008). This suggests that power cognition might influence nonverbal reasoning, just as it may affect language ability, offering two potential pathways for further theoretical exploration.

1.4. The relationships of altruistic behavior with language ability and nonverbal reasoning

Language ability plays a pivotal role in the quality of life, social interactions, and mental health of children with hearing impairment (Fellinger et al., 2009; Hintermair, 2015), and is equally critical for the development of altruistic behavior. Empirical evidence demonstrates positive correlations between lexical knowledge, reading skills, and altruistic behavior (Cassidy et al., 2003). Language ability may mediate the relationship between theory of mind and altruistic behavior (Imuta et al., 2016), and may also indirectly influence prosocial actions through emotional comprehension (Ensor & Hughes, 2005). A longitudinal cohort study revealed that expressive language ability at age 3 predicts prosocial behavior at age 5, suggesting that advanced language skills facilitate positive social engagement. The authors further advocate for modeling distinct associations between prosocial behavior and specific linguistic processes, including expressive language, receptive language, and pragmatics (Girard et al., 2017).

Of particular relevance, studies on sharing behavior in children with hearing impairment indicate that children aged 6–11 with hearing impairment exhibit significant delays in both word comprehension and sharing behavior compared to their typically developing peers of the same age. In contrast, children aged 12–16 with hearing impairment demonstrate performance levels in these domains comparable to typically developing children aged 6–11 (Hao & Wu, 2019). These findings highlight that, relative to other linguistic competencies (e.g., syntactic or phonological abilities), word comprehension may hold unique significance for altruistic behavior in children with hearing impairment.

Research highlights the central role of language ability—especially word comprehension—in fostering altruistic tendencies among children with hearing impairment. Yet, beyond this group, altruistic behavior also appears linked to nonverbal reasoning, which involves abstract pattern recognition independent of language. Early prosocial actions, like helping someone in distress, often depend on a child's ability to interpret complex situational cues, suggesting a tie to nonverbal reasoning (Warneken & Tomasello, 2009). Studies show, for instance, that young children assist others by inferring unspoken needs from context, a skill that points to nonverbal reasoning as a driver of altruistic tendencies (Dunfield & Kuhlmeier, 2013). Additionally, evidence connecting general intelligence to prosociality reveals that abstract reasoning boosts altruistic actions, likely by aiding decisions that benefit others (Han et al., 2012). Evidence from these studies suggests that nonverbal reasoning might influence altruistic behavior by enhancing children's ability to discern others' needs and intentions, much as language ability appears to do separately, inviting further exploration of these links.

2. Methods

2.1. Participants

Based on statistical methods and sample sizes reported in prior studies (Deng et al., 2023; L. Rose et al., 2024; Song et al., 2021), we conducted an a priori power analysis using G*Power 3.1. With a medium effect size ($f^2 = 0.15$), significance level ($\alpha = 0.05$), and statistical power ($1\text{-}\beta = 0.8$), the analysis indicated a minimum requirement of 68 participants. Although initial recruitment aimed for a larger sample, logistical constraints related to testing frequency and duration limited final enrollment to 64 participants during the two-month recruitment period. To address potential statistical power limitations, Bayesian hypothesis testing was incorporated to validate analytical robustness (see "2.4 Data analysis").

The 64 participants were recruited from a rehabilitation center and its affiliated kindergarten in Gansu Province, China. The hearing impairment group comprised 32 children aged 3.5–6.3 years ($M = 4.92 \pm 0.70$) with an average aided threshold of 35.88 ± 7.81 dB HL across five frequencies (250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz) in the better ear. The control group included 32 age-matched typically developing children ($t = 0.697$, $p = .489 > 0.05$; $BF_{10} = 0.314 < 1$, *error %* = 0.011).

To control for socioeconomic status—a factor influencing altruistic behavior and power cognition (Benenson et al., 2007; Hashim, 2021)—all participants were from urban middle-income families with annual household incomes ranging from 100,000 to 500,000 RMB (National Bureau of Statistics of China, 2019).

The study received approval from the university's ethical committee, and written consent was obtained from all participants' caregivers and teachers.

2.2. Measurement tools

2.2.1. Altruistic behavior test

The altruistic behavior test was designed based on the Dictator Game paradigm, as outlined in previous research by Dong et al. (2016) and Schug et al. (2016). Participants allocated cartoon cards between themselves and two recipients: the experimenter and a hypothetical peer. The procedure was implemented as follows:(1) Four boxes of cartoon cards were displayed, and participants selected their preferred set. (2) Upon opening the chosen box, the experimenter stated: "There are 3 cards here, belonging to you and me/the other child. You decide how to distribute them. How many will you give to me/them, and how many will you keep?"(3) Scoring followed a prosocial hierarchy based on self-other allocation ratios:3–0 (self-other): 1 point, 2–1: 2 points, 1–2: 3 points, 0–3: 4 points. Total scores were calculated across two allocation trials (experimenter and hypothetical peer), yielding a maximum of 8 points.

2.2.2. Power cognition test

The power cognition test was developed with reference to Gülgöz and Gelman (2017), measuring two dimensions: control over resources and control over behaviors. The test consisted of four illustrated scenarios presented as comic strips. After participants were shown and read the materials, they were asked, "Who is in charge? [Name of first character] or [name of second character]?" and subsequently questioned, "How do you know?" Participants were allowed to indicate their choice by naming or pointing to the character. Correct identifications scored 1 point, as did Power-related rationale (e.g., "A decides because they have more candies"). The total possible score was 8.

2.2.3. Word comprehension test

Word comprehension was assessed using a subtest from the Mandarin Clinical Evaluation of Language Fundamentals (MCELF) (Liu, 2021). The test consisted of 35 items, including common nouns, verbs, and adjectives, administered via auditory word-to-picture matching. The test demonstrated strong reliability and validity, with Cronbach's $\alpha = 0.90$ and a correlation of 0.82 with the PPVT-R (Wu et al., 2020). Raw scores were used for analysis.

2.2.4. Raven's combined test

The Combined Raven's Test (CRT) (Li et al., 1988) is a merged version of the Colored and Standard Progressive Matrices, revised and developed by Chinese psychologists. The CRT consists of six sections (A, AB, B, C, D, and E), each containing 12 items, for a total of 72 items. Raw scores were used for analysis.

2.3. Procedures

Power cognition, Raven's reasoning, and word comprehension tasks were administered via Lenovo tablets (12.7-in. screen, 144 Hz refresh rate), while altruistic behavior and unexpected content tasks were conducted using physical objects. Each test was conducted over two sessions within a month, with each session lasting approximately 30 min. To control for order effects, a Latin square design was implemented, dividing participants into eight groups, with different test sequences assigned to each group. For instance, the test sequence for the first group (Participants 1–4) followed the order ABCD, whereas the second group (Participants 5–8) followed ACDB.

2.4. Data analysis

Data were analyzed using SPSS 27.0 for independent samples *t*-tests and correlation analyses. Mediation effects and Bootstrap tests were performed using PROCESS 4.2 for SPSS (Hayes, 2018). Furthermore, Bayesian statistical analyses were conducted using JASP (Wagenmakers et al., 2018) to enhance the robustness of parameter estimation, incorporating MCMC tests to examine mediation effects. In contrast to Frequentist approaches relying on null hypothesis significance testing (NHST) (Fornacon-Wood et al., 2022), Bayesian methods consider unknown parameters as random variables instead of fixed constants, focusing on updating beliefs about parameters through prior information and observed data (Zhang et al., 2019). In recent years, Bayesian methods have gained widespread application in psychological research, particularly for their robust performance in regression or mediation analyses with sample sizes below 50 (Fang & Zhang, 2012; Stamey et al., 2011; van de Schoot et al., 2021; Yuan & MacKinnon, 2009). The primary Bayesian metric employed in this study was the Bayes Factor (BF). BF_{10} reflects the strength of evidence supporting H_1 over H_0, while $BF_{inclusion}$ measures the evidence for including a specific variable in the model compared to excluding it. A Bayes Factor (BF) of 1 indicates equal support for H_1 and H_0, whereas a BF >1 favors *H1*, with higher values signifying stronger evidence in its favor (Hu et al., 2018; Wagenmakers et al., 2018). For instance, $BF_{10} = 10$ suggests the alternative hypothesis is 10 times more likely than the null hypothesis under the given data (Wu et al., 2018).

3. Results

3.1. Descriptive statistics, independent samples t-tests, and correlation analyses

As shown in Table 1, children with hearing impairment exhibited significantly lower scores in altruistic behavior ($t = -4.731$, $p < .01$), power cognition ($t = -7.998$, $p < .01$), and word comprehension ($t = -8.080$, $p < .01$) compared to typically developing peers, while demonstrating superior performance in Raven's reasoning ($t = 2.598$, $p < .05$). Bayesian analyses further validated these patterns: The Bayes factor for age differences ($BF_{10} = 0.314$) provided anecdotal evidence supporting the null hypothesis of no group difference, whereas the Raven's reasoning analysis ($BF_{10} = 4.119$) yielded moderate evidence for the alternative hypothesis. Critically, extreme evidence emerged for group disparities in altruistic behavior, power cognition, and word comprehension, with BF_{10} values exceeding 100, decisively favoring the typically developing group.

Pearson correlation analyses were conducted to examine the relationships among altruistic behavior, power cognition, word comprehension, and Raven's reasoning, with Bayesian factors calculated to validate the results. For children with hearing impairment (Table 2), altruistic behavior showed significant positive correlations with word comprehension ($r = 0.620$, $p < .01$, $BF_{10} = 208.208$, *95 % CI* = [0.324, 0.784]) and power cognition ($r = 0.520$, $p < .01$, $BF_{10} = 18.882$, *95 % CI* = [0.194, 0.720]). Additionally, word comprehension was positively associated with power cognition ($r = 0.518$, $p < .01$, $BF_{10} = 18.035$, *95 % CI* = [0.191, 0.718]).

In contrast, typically developing children exhibited broader associations (Table 3), with altruistic behavior positively correlated with word comprehension, Raven's reasoning, and power cognition. These findings suggest distinct mechanisms underlying altruistic behavior in children with hearing impairment compared to their typically developing peers.

3.2. Mediation analysis

To further examine the mechanisms underlying the influence of power cognition on altruistic behavior, a mediation analysis was conducted using Model 4 in PROCESS for SPSS (Hayes, 2017), with power cognition as the independent variable, word comprehension as the mediator, and altruistic behavior as the dependent variable for children with hearing impairment. Bayesian inclusion factors ($BF_{inclusion}$) for regression coefficients were calculated in JASP.

As shown in Fig. 1, Table 4, and Table 5, power cognition significantly positively predicted altruistic behavior in children with hearing impairment ($B = 0.433$, $t = 3.336$, $p < .01$; $BF_{inclusion} = 57.232$, *95 % CI* = [0.137, 0.707]). Power cognition also significantly predicted word comprehension ($B = 2.367$, $t = 3.315$, $p < .01$; $BF_{inclusion} = 54.326$, *95 % CI* = [0.948, 3.957]). However, when both power cognition and word comprehension were included in the regression model, the direct effect of power cognition on altruistic behavior became nonsignificant after controlling for word comprehension ($B = 0.227$, $t = 1.672$, $p = .105$; $BF_{inclusion} = 3.264$, *95 % CI* = [−0.051, 0.504]).

Both Bootstrap (5000 resamples) and MCMC tests confirmed the significance of the total and indirect effects (95 % CIs excluding zero), while the direct effect was nonsignificant (95 % CI including zero). These results robustly support the mediating role of word comprehension in the relationship between power cognition and altruistic behavior in children with hearing impairment.

A parallel mediation analysis was conducted for typically developing children, with Bayesian inclusion factors calculated for regression coefficients. Results indicated that Raven's reasoning significantly mediated the relationship between power cognition and altruistic behavior (see Fig. 2, Table 6, and Table 7).

4. Discussion

4.1. Significantly delayed altruistic behavior in children with hearing impairment

The current study demonstrates that preschool children with hearing impairment exhibit delayed development of altruistic behavior compared to their typically developing peers. This finding aligns with prior work by Hao and Wu (2019) and Stevenson et al. (2015), indicating that young children with hearing impairment face challenges in demonstrating altruistic behaviors, regardless of whether the recipient is a concrete stranger (e.g., the experimenter) or a hypothetical peer.

From a normative perspective, the mean altruistic behavior score of children with hearing impairment ($M = 3.72 \pm 1.42$) fell below the theoretical midpoint of the measurement scale, whereas their typically developing counterparts scored above this benchmark ($M = 5.41 \pm 1.43$). These results suggest that preschool children with hearing impairment have not yet fully overcome egocentric tendencies and may experience heightened difficulties in peer interactions and social adaptation.

4.2. Word comprehension as a mediating mechanism between power cognition and altruistic behavior in children with hearing impairment

This study revealed a significant positive correlation between power cognition and altruistic behavior in preschool children with hearing impairment. Although power cognition did not directly predict altruistic behavior (direct effect = 0.227, *95 % CI* = [−0.051, 0.504]), it exerted an indirect effect through word comprehension (indirect effect = 0.207, *95 % CI* = [0.068, 0.436]). These findings suggest that word comprehension serves as a critical mediator linking power cognition to altruistic behavior in this population. While experimental studies on preschool children with hearing impairment remain scarce, related research

Table 1
Descriptive statistics and independent samples t-test results.

	Hearing Impairment Group ($n = 32$)	Typically Developing Group ($n = 32$)	t	BF_{10}	*error %*
Age (years)	4.92 ± 0.70	4.78 ± 0.87	0.697	0.314	0.011
Word comprehension	20.06 ± 7.79	31.63 ± 2.21	−8.080**	2.237e+8	5.229e-14
Raven's reasoning	20.69 ± 7.33	16.66 ± 4.82	2.598*	4.119	0.008
Power cognition	2.00 ± 1.70	5.72 ± 2.00	−7.998**	1.640e+8	7.834e-14
Altruistic behavior	3.72 ± 1.42	5.41 ± 1.43	−4.731**	1312.073	4.932e-9

• Raw scores were used for all test measures.
• Values are presented as $M \pm SD$.
• p values: * < 0.05, ** < 0.01 (two-tailed).
• BF_{10} indicates the Bayes Factor supporting the alternative hypothesis (H_1) over the null hypothesis (H_0).
• *Error %* represents the percentage error in Bayesian estimation.

Table 2
Correlation matrix of variables in the hearing impairment group.

	Word comprehension	Raven's reasoning	Power cognition	Altruistic behavior
Word comprehension	1			
Raven's reasoning	−0.097	1		
Power cognition	0.518**	0.232	1	
Altruistic behavior	0.620**	0.050	0.520**	1

• Raw scores were used for all test measures.
• *p* values: * < 0.05, ** < 0.01 (two-tailed).

Table 3
Correlation matrix of variables in the typically developing group.

	Word comprehension	Raven's reasoning	Power cognition	Altruistic behavior
Word comprehension	1			
Raven's reasoning	0.481**	1		
Power cognition	0.296	0.614**	1	
Altruistic behavior	0.385*	0.800**	0.513**	1

• Raw scores were used for all test measures.
• *p* values: * < 0.05, **< 0.01 (two-tailed).

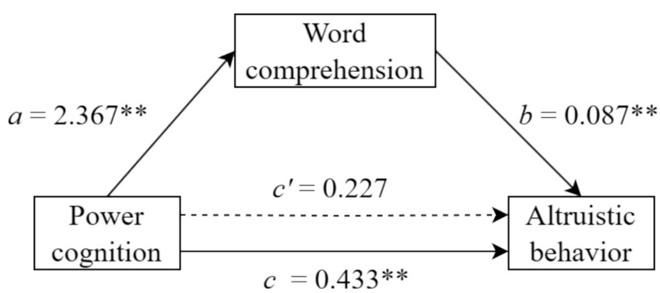

Fig. 1. Mediation analyses with unstandardized regression coefficients in the hearing impairment group (*p* values: ** < 0.01).

partially supports this mechanism. For instance, Liao and Li (2023) found a positive correlation between social authority cognition and altruistic behavior in school-aged children ($r = 0.112$), and Lin (2015) demonstrated that elementary students' authority cognition significantly influenced sharing behavior.

The relationship between power cognition and altruistic behavior can be understood from an evolutionary perspective. As a fundamental cognitive ability shaped by evolutionary pressures, power cognition enables individuals to decode hierarchical structures and adjust their behavior accordingly to optimize group cooperation (Blader & Chen, 2014). This ability does not operate in isolation but is closely intertwined with social norms, as altruistic behavior can be seen as an adaptive response that aligns hierarchical cognition with normative compliance (Tomasello, 2014). The capacity to recognize social hierarchy is not unique to humans but is widespread among social species. In

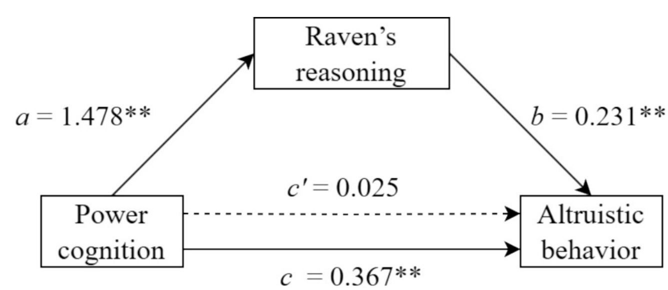

Fig. 2. Mediation analyses with unstandardized regression coefficients in the typically developing group (*p* values: ** < 0.01).

Table 4
Regression analysis of the mediation model for word comprehension between power cognition and altruistic behavior in the hearing impairment group ($n = 32$).

Regression equation		Model fit indicators		Significance of regression coefficients		Bayesian test of regression coefficients	
Outcome variable	Predictor variable	R^2	*F*	*B*	*t*	$BF_{inclusion}$	*95%CI*
Altruistic behavior	Power cognition	0.271	11.126**	0.433	3.336**	57.232	[0.137, 0.707]
Word comprehension	Power cognition	0.268	10.992**	2.367	3.315**	54.326	[0.948, 3.957]
Altruistic behavior	Power cognition	0.439	11.339**	0.227	1.672	3.264	[−0.051, 0.504]
	Word comprehension			0.087	2.949**	61.972	[0.027, 0.148]

• R^2: Coefficient of determination; *B*: Unstandardized regression coefficient; $BF_{inclusion}$: Evidence strength for including the predictor in the model.
• *p* values: * < 0.05, ** < 0.01 (two-tailed).

Table 5
Mediation effect test of word comprehension between power cognition and altruistic behavior in the hearing impairment group ($n = 32$).

Effect	Bootstrap test		MCMC test		
	Effect value	*95%CI*	Posterior probability	*95%CI*	*R-hat*
Total effect	0.433	[0.168,0.699]	0.433 ± 0.138	[0.160,0.699]	1.001
Direct effect	0.227	[−0.051,0.504]	0.227 ± 0.138	[−0.048,0.503]	1.000
Mediated effect	0.207	[0.068,0.436]	0.207 ± 0.098	[0.042,0.431]	1.000

R-hat is used to evaluate the convergence of MCMC chains. An *R-hat* value close to 1 indicates good convergence, suggesting that the MCMC sampling results are reliable.

Table 6
Regression analysis of the mediation model for Raven's reasoning between power cognition and altruistic behavior in the typically developing group ($n = 32$).

Regression equation		Model fit indicators		Significance of regression coefficients		Bayesian test of regression coefficients	
Outcome variable	Predictor variable	R^2	F	B	t	$BF_{inclusion}$	*95%CI*
Altruistic behavior	Power cognition	0.263	10.697**	0.367	3.271**	48.374	[0.092, 0.656]
Raven's reasoning	Power cognition	0.377	18.136**	1.478	4.259**	709.951	[0.724, 2.105]
Altruistic behavior	Power cognition	0.641	25.839**	0.025	0.247	0.761	[−0.127, 0.190]
	Raven's reasoning			0.231	5.520**	160,064	[0.166, 0.313]

• R^2: Coefficient of determination; B: Unstandardized regression coefficient; $BF_{inclusion}$: Evidence strength for including the predictor in the model.
• p values: * < 0.05, ** < 0.01 (two-tailed).

Table 7
Mediation effect test of Raven's reasoning between power cognition and altruistic behavior in the typically developing group ($n = 32$).

Effect	Bootstrap test		MCMC test		
	Effect value	*95%CI*	Posterior probability	*95%CI*	*R-hat*
Total effect	0.367	[0.138,0.596]	0.347 ± 0.116	[0.135,0.594]	1.000
Direct effect	0.025	[−0.182,0.231]	0.023 ± 0.106	[−0.185,0.235]	1.001
Mediation effect	0.342	[0.148,0.541]	0.344 ± 0.103	[0.161,0.572]	1.001

R-hat is used to evaluate the convergence of MCMC chains. An *R-hat* value close to 1 indicates good convergence, suggesting that the MCMC sampling results are reliable.

macaques, specific brain regions—including the amygdala, raphe nucleus and reticular formation, posterior hypothalamus, posterior putamen, caudate tail, and dorsal septum—are significantly correlated with social status, indicating their role in processing hierarchical structures (Noonan et al., 2014). Similarly, baboons rely on vocalizations and postural cues to discern and respond to social hierarchies, adjusting their behavior accordingly based on different individuals' calls (Wittig et al., 2007). Human infants, even at the age of 10 months, can infer social dominance relationships from nonverbal cues such as differences in body size (Thomsen et al., 2011). These findings suggest that power cognition may have an evolutionarily conserved basis, inherited and refined throughout human development while also persisting in other species in various forms.

The mediation of word comprehension in this process can be attributed to its role in symbolic representation and social communication. As a symbolic system, language enables individuals to translate abstract social hierarchies into concrete behavioral norms. Through symbolic mediation, power-related cues become encoded into language structures, influencing decision-making processes. For instance, group-specific symbols, such as badges or uniforms, reinforce social identity and foster in-group loyalty, motivating individuals to engage in altruistic behavior for the benefit of their social group (Swann et al., 2014; Tajfel, 1979). Additionally, moral labels such as "role model" or "traitor" shape reputation-based altruism by regulating behavioral expectations through neural reward and punishment mechanisms (Fehr & Camerer, 2007). Furthermore, social role scripts embedded in language and other symbolic representations can activate embodied cognition, leading individuals to internalize normative obligations and sustain altruistic behavior as a role-driven commitment (Adam & Galinsky, 2012; Batson, 2011).

For children with hearing impairment, compensatory neural plasticity plays a crucial role in shaping their cognitive adaptations, particularly in the domain of visual language processing. Cross-modal neuroimaging studies have shown that individuals with hearing impairment exhibit significant neural reorganization, particularly in the enhancement of visual and tactile processing, which allows them to compensate for the absence of auditory input (Merabet & Pascual-Leone, 2010). These children often demonstrate enhanced visual attention, heightened sensitivity to emotional expressions, and superior performance in peripheral visual tasks, along with an increased reliance on tactile perception. Due to their reliance on visual rather than auditory channels for communication, power cognition in children with hearing impairment is more dependent on the fine-grained processing of visual linguistic symbols. For instance, sign language grammar employs spatial representations to encode hierarchical relationships, such as the height of hand positions symbolizing power levels, while variations in facial expressions serve as intensity markers to convey authority (Emmorey, 2015). Given this unique cognitive modality, word comprehension may function as a critical mediating mechanism that transforms power-related visual symbols into behavioral decision-making processes.

4.3. Distinct mechanisms linking power cognition to altruistic behavior in children with hearing impairment

This study found that the mechanisms through which power cognition influences altruistic behavior differ between preschool children with hearing impairment and their typically developing peers. For children with hearing impairment, word comprehension mediated the relationship between power cognition and altruistic behavior, with an effect size of 0.207, accounting for 47.81 % of the total effect. In contrast, for typically developing children, Raven's reasoning ability served as the primary mediator, with an effect size of 0.342, explaining 93.19 % of the total effect. This discrepancy in mediation mechanisms can largely be attributed to the constraints imposed by auditory deprivation in children with hearing impairment.

The absence of auditory input necessitates the development of alternative cognitive resources, including sign language, as compensatory mechanisms for language processing (Bavelier et al., 2006). As a result, this compensatory adaptation may position word comprehension as a critical cognitive bridge facilitating the transformation of power cognition into altruistic behavior. Through linguistic symbols, children with hearing impairment can precisely decode role expectations embedded within power structures, thereby activating mechanisms of social norm compliance. In contrast, typically developing children, with intact audiovisual integration, are better equipped to abstract multimodal social information (Dionne-Dostie et al., 2015), leading to an advantage in nonverbal social reasoning. Consequently, their power cognition is more reliant on abstract relational modeling, as assessed by Raven's reasoning ability, which allows them to map dynamic power structures and engage in embodied decision-making.

Furthermore, differences in educational and social environments may contribute to these distinct mechanisms. Children with hearing impairment typically undergo intensive language rehabilitation training, which strengthens semantic network connections. Although their spoken language abilities may remain delayed, their use of multiple linguistic systems, including sign language, facilitates cross-modal activation in the auditory cortex and enhances connectivity between language-related and non-language-related brain regions (Kral & Eggermont, 2007). This neural adaptation may give rise to a functional spillover effect, whereby word comprehension extends its influence beyond linguistic processing to shape social cognition. For children with hearing impairment, language—particularly sign language—is not merely a communicative tool but also a cultural symbol shared within the Deaf community (Hall et al., 2019). It can thus be inferred that, during their socialization process, word comprehension plays a pivotal role in transforming evolutionarily conserved power cognition into prosocial behavior. In contrast, abstract reasoning training in typical educational environments may facilitate the transfer of analytical skills to social domains, privileging non-linguistic cognitive systems in mediating altruism.

5. Summary and limitations

This study employed a psychometric approach to investigate the mechanisms by which power cognition influences altruistic behavior in preschool children with hearing impairment. The findings indicate that power cognition does not directly influence altruistic behavior but instead operates through word comprehension as an indirect pathway. A plausible explanation lies in the evolutionary and neurocognitive interplay: while power cognition represents an innate, evolutionarily conserved ability, altruistic behavior constitutes an acquired adaptive output that translates hierarchical cognition into normative compliance. However, auditory deprivation in children with hearing impairment enhances neuroplasticity and behavioral adaptability, redirecting their power cognition toward refined linguistic symbol processing (including sign language). Consequently, word comprehension emerges as the critical mediator converting symbolic power representations into altruistic decision-making.

Despite these novel findings, several limitations must be acknowledged. This study's theoretical premise—treating power cognition as an independent variable influencing both altruistic behavior and word comprehension—is grounded in an evolutionary psychology perspective but remains exploratory. Further empirical evidence from psychological research is required to substantiate this framework. Additionally, the study was conducted with a sample of Chinese children, without cross-cultural comparisons, making the potential impact of sociocultural factors on these mechanisms uncertain. Lastly, the assessment tools employed in this study may not fully capture the natural dynamics of power cognition. Future research should implement experimental interventions in real-life settings to investigate how power cognition training shapes altruistic behavior in children with hearing impairment, thereby enhancing the ecological validity of these findings.

CRediT authorship contribution statement

Weibin Hu: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Xueru Zhang:** Writing – review & editing, Supervision. **Jiancheng Shao:** Investigation. **Yuanfen Wang:** Investigation.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the development of this manuscript, the authors utilized ChatGPT and DeepSeek to aid in translation and language refinement. Following the use of these tools, the authors carefully reviewed and revised the content as necessary, assuming full responsibility for the final published version.

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Declaration of competing interest

The authors declare that this research was conducted without any commercial or financial relationships that could be perceived as a potential conflict of interest.

Data availability

The data supporting the findings of this study involve sensitive information about children and are therefore not publicly available to protect the privacy and confidentiality of the participants. However, de-identified data can be made available from the corresponding author upon reasonable request and with approval from the relevant ethics committee.

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