Striatal and frontal signatures of social context and cost-benefit decision making in developmental stuttering

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Abstract

Background: Developmental stuttering is usually framed as a sensorimotor disorder, yet it manifests in communicative situations that engage motivational, self-referential, and regulatory processes.

Methods: In this case-control study, we combined a socio-economic decision task outside the scanner with a socially modulated speech task during fMRI to test how listener presence and self-referential speech shape neural activity in 34 adults who stutter and 32 controls.

Results: Both groups valued talking with another person about themselves more than talking with another person about someone else or talking to themselves. On the neural level, listener-directed (vs. private) speech and self-disclosure (vs. guessing the preferences of a famous other) elicited stronger responses in the ventral striatum and medial prefrontal cortex, extending social valuation effects previously reported in fluent speakers to adults who stutter. Within the stuttering group, individual differences revealed a systematic reweighting of socially modulated activation as a function of symptom burden: higher anticipation of stuttering and greater overall impact were associated with stronger engagement of motivational circuitry, greater recruitment of frontal evaluative-control regions, and reduced contextual differentiation within speech-language cortex.

Conclusion: Stuttering anticipation and lived experience gradually shift the balance between control, language, and motivational salience-processing systems, contributing to the disorder's marked heterogeneity and context sensitivity. These findings indicate system-level signatures of the interaction between social context and symptom severity, rather than isolated motor deficits, in developmental stuttering. More generally, they reveal how recurrent experiences shape brain activity through the interplay between language, motivational and control systems that governs human social interactions.

Introduction

Human speech is inherently social. Speaking to a listener carries motivational relevance (1) because it serves motivationally salient interpersonal goals such as affiliation (2,3), self-disclosure (4–6), and social evaluation (7,8). Listener presence fundamentally changes the incentives and consequences of speaking, as directed speech involves reputational and interpersonal stakes. By contrast, speech produced without a listener lacks these social consequences. Thus, social context modulates the value of speaking, and directed speech may recruit social-motivational control processes that shape speech production beyond lower-level sensorimotor mechanisms.

This social-context-dependent valuation of speaking is particularly relevant for developmental stuttering, a common speech disorder characterized by repetitions of sounds and syllables, prolongations, and blocks (9), and by pronounced sensitivity to social-evaluative context (10–12). Stuttering is highly situationally variable (13,14) and is markedly reduced during private speech (15,16) when utterances are not directed to a listener or embedded in a communicative goal. By contrast, adults who stutter (AWS) frequently report increased difficulty when speaking under conditions of audience presence or communicative pressure (17). On the neural level, perceived discomfort is associated with right amygdala activity during stuttering occurrence (18). Neuroimaging research has implicated alterations within cortico-basal ganglia-thalamo-cortical circuits involved in speech timing and motor control (19–21) yet it remains unclear how social context interacts with reward-related systems during speaking. Given the context sensitivity of stuttering, altered valuation of directed speech may represent a mechanism contributing to symptom expression (22,23).

A reward-related circuitry, including the nucleus accumbens and ventral striatum, supports the valuation of actions (24) and is reliably engaged by social rewards (25,26). Beyond responses to primary reward, ventral striatum is sensitive to being observed, receiving social feedback (27,28), and communicating self-relevant information (29,30). Consistent with a role in assigning motivational salience to social acts, both adults and children who stutter show altered grey-matter volume of the ventral striatum/nucleus accumbens, when compared to fluent speakers and typically developing peers (22,31,32). Interestingly, adults show increased right ventral striatum/nucleus accumbens morphology compared with fluent speakers, while children show reduced nucleus accumbens volume compared to their peers. This pattern points to an atypical developmental trajectory of striatal circuitry in stuttering. Rather than a uniform increase or decrease, it suggests that the motivational salience system for social communication is reorganized over time when language development is accompanied by a communication disorder such as stuttering. In this context, speech directed toward a listener is likely to recruit motivational circuits differently in people who stutter than in fluent speakers, with downstream effects on speech-motor and control systems in a listener-dependent manner.

Given that ventral striatum encodes the motivational salience of social communication and shows atypical development in stuttering, we aimed to test whether listener presence and self-referential content specifically modulate speech-related activity within this circuitry and its interaction with language and control networks. We investigated how social context modulates neural responses during speech, and whether this modulation differs between adults who do or do not stutter (AWS/AWNS). Participants completed a monetary decision task in which they either disclosed their own preferences or inferred the preferences of a well-known person, under share conditions (speech audible to the experimenter) or private conditions (speech inaudible) (29,30). This design enabled us to isolate the effect of directed speech (share) versus non-directed speech (private) while controlling for speech content. From a computational perspective, our paradigm requires participants to integrate social value, internal costs (e.g. effort, anticipated dysfluency), and monetary reward, engaging multiple valuation and control systems rather than a unitary 'speech' module. This follows proposals that ecologically valid paradigms combining several value dimensions are particularly informative for understanding neurodevelopmental and mental health-related differences in social behavior (33). We hypothesized that directed speech would increase activity in reward-related circuitry, particularly the nucleus accumbens, and that AWS would show altered social-context-dependent modulation relative to AWNS. To relate neural responses to subjective valuation, we additionally quantified the relative monetary value of speaking in these conditions in an independent behavioral examination (29).

Materials and methods

Participants

Thirty-four adults who stutter (AWS; 29 males, five females; aged 19-46 years; one left-hander) and 32 age- and sex-matched adults who do not stutter (AWNS; 28 males, four females; aged 21-46 years; one left-hander) took part in a larger project on persistent developmental stuttering. Handedness was assessed with the Edinburgh Inventory (34). AWS were recruited via advertisements and social media of the German Stuttering Association; AWNS were recruited from the Max Planck Institute for Human Cognitive and Brain Sciences volunteer database. Stuttering in AWS had been previously confirmed by a speech-language pathologist, and all self-identified as people who stutter. AWNS reported no personal or family history of stuttering or other speech or language disorders. All participants had normal or corrected-to-normal vision, met MRI safety criteria, and provided written informed consent. This study was approved by the University of Leipzig ethics committee [123/17-ek].

Stuttering severity of AWS was scored using the Stuttering Severity Instrument-4 (SSI-4) (35) and the German Version of the Overall Assessment of the Speaker's Experience of Stuttering (OASES) (36,37). SSI-4 outcomes ranged from very mild (n = 11), mild (n = 8), moderate (n = 6), severe (n = 2), to very severe (n = 7). OASES outcomes ranged from mild (n = 1), mild-to-moderate (n = 6), moderate (n =

16), moderate-to-severe (n = 7), severe (n = 2) to very severe (n = 1). Anticipation of stuttering was measured with the Premonitory Awareness in Stuttering Scale (PAiS) (38), a 12-item self-report questionnaire adapted from the Premonitory Urge for Tics Scale (39). Example items include: "Right before I stutter, I can sense that I am about to stutter," and "Right before I stutter, I feel tense." Trait and state anxiety were assessed with the German version of the State-Trait Anxiety Inventory (40), revealing modestly elevated but non-clinical anxiety levels in AWS relative to AWNS (Table 1).

Behavioral task: subjective value of speaking

The behavioral paradigm was adapted from Tamir and Mitchell (29) to quantify the subjective value of speaking under different social conditions (Figure 1A). On each trial, participants chose between answering a question aloud or waiting passively, with both options associated with small monetary outcomes. Four conditions were tested: *self share* (reporting one's own preference to a listener), *self private* (spoken but unheard), *other share* (reporting beliefs about a public figure's preferences to a listener), and *other private* (spoken but unheard). Angela Merkel served as the 'other' due to her high familiarity at the time of the study. Each trial was a two-alternative forced choice between speaking and waiting for 5 s; in waiting trials, participants viewed a fixation cross. When speaking was selected, participants read the question aloud and responded 'yes' or 'no'. Speech was recorded in all conditions but transmitted to the listener only in share trials. Each condition was presented 60 times (240 trials total), randomized across four runs (~45 min total). Questions probed everyday, non-controversial preferences.

To quantify the subjective value of speaking, we estimated for each participant and condition the monetary point at which speaking and waiting were chosen equally often (point of subjective equality, PSE). Negative PSEs indicate a willingness to incur a monetary cost to speak, whereas positive PSEs indicate that financial compensation was required. PSE values were entered into a repeated-measures ANOVA with Group (AWS, AWNS) as a between-subjects factor and Mode (share, private) and Person (self, other) as within-subjects factors. See the Supplement for full processing and analysis details.

Determination of stuttering in experimental recordings

Speech recordings were coded trial-wise for stuttering (present/absent) by a trained rater. Stuttering was defined as the occurrence of core symptoms (blocks, prolongations, and part-word repetitions, including dysrhythmic repetitions of monosyllabic words); other disfluencies (e.g. interjections, polysyllabic whole-word repetitions) were not classified as stuttering. For each AWS, we computed a stuttering response rate as the proportion of stuttered share trials and compared rates between private and listener-directed speech with paired Wilcoxon signed-rank tests. Inter-rater reliability, assessed on an

independently coded subset of trials, was high (Cohen's $\kappa = 0.81$). Stuttering rates did not change systematically across runs. See the Supplement for full pre-processing and analysis details.

fMRI task: social modulation of speech

The fMRI task was designed to test how social context modulates neural responses during speech, with a focus on nucleus accumbens. To maximize active trials, the waiting option used in the behavioral task was omitted. Participants completed the same four conditions (self/other × share/private) as in the behavioral paradigm and responded on every trial using a 5-point likelihood scale. During share trials, a study assistant outside the scanner listened to the spoken responses of the participants via headphones (Figure 2A). Each condition was presented multiple times in an event-related design across four runs (~45 min total), with item order and condition assignment randomized per participant; all questions were novel and did not overlap with the behavioral experiment. See the Supplement for full material and design details.

MRI data were acquired on a 3T Siemens Prisma scanner with whole-brain coverage ($2.5 \times 2.5 \times 2.5$ mm^3; TR = 2000 ms) using a dual-echo EPI sequence and a high-resolution T1-weighted anatomical scan. Functional data were pre-processed using customized and standard pipelines (echo combination, motion correction, spatial smoothing, high-pass filtering, and normalization to MNI space) and analyzed with general linear models. At the first level, we modelled the four conditions and estimated contrasts for Mode (share > private), Person (self > other), and their interaction. These contrasts were entered into higher-level random-effects analyses to test main effects and group differences (AWS vs AWNS). Whole-brain statistical inference used cluster-wise correction (cluster-forming threshold $Z > 3.1$, cluster-extent $p < 0.05$, family-wise error corrected). See the Supplement for full acquisition, preprocessing, and analysis details.

Correlation analyses with clinical measures

We examined whether individual differences in (i) anticipation of stuttering and (ii) overall stuttering impact were associated with social modulation of brain activity in AWS. To this end, we correlated PAiS and OASES scores with neural modulation by Mode (share > private) and by Person (self > other). PAiS and OASES were treated as conceptually distinct dimensions of stuttering experience, and age was included as a covariate. Voxel wise whole-brain analyses used cluster-wise correction (cluster-forming threshold $Z > 3.1$, cluster-extent $p < 0.05$, FWE-corrected). Because developmental stuttering is heterogeneous and robust group-level differences in the critical share > private contrast were absent, we focused on within-sample individual-difference associations, using a fixed-effects model with inference confined to this cohort.

Results

Effects of group and social context on the subjective value of speaking

Statistics of the PSE values indicated a significantly higher relative monetary value of speaking in AWS compared with AWNS (Figure 1C). A repeated-measures ANOVA revealed a main effect of Group ($F(1,57) = 5.1$, $p = .027$), with higher PSE values in AWS (mean = 1.47 cents, 95% CI [1.23, 1.70]) than in AWNS (mean = 0.83 cents, 95% CI [0.64, 1.03]). In addition, the ANOVA showed a Group × Mode × Person interaction ($F(1,57) = 4.1$, $p = 0.046$), as well as main effects of Mode ($F(1,57) = 9.1$, $p = 0.004$) and Person ($F(1,57) = 4.3$, $p = 0.042$). Across groups, participants were willing to sacrifice monetary reward to share information rather than keep it private (shared: mean = 1.36 cents, 95% CI [1.13, 1.60]; private: mean = 0.99 cents, 95% CI [0.78, 1.20]; Figure 1D), and for disclose information about themselves rather than judge the preferences of another person (self: mean = 1.23 cents, 95% CI [0.53, 1.46]: other: mean = 1.12 cents, 95% CI [0.90, 1.34]; Figure 1D).

To further characterize the three-way interaction, we conducted post hoc unpaired *t*-tests. These analyses suggested that AWS assigned higher value than AWNS to sharing information about themselves and to speaking about others in private; however, neither comparison survived correction for multiple testing. No group differences were observed for the remaining conditions (*other share* and *self private*; Table S1).

No effect of listener presence on stuttering rate

We next tested whether stuttering rate was modulated by listener presence. In the *share* conditions, participants were aware that the experimenter could hear their speech. Conversely, in the *private* conditions they knew that their utterances were not audible to the experimenter. Stuttering rates were highly similar across share and private conditions (Figure S1A) and showed a strong positive relationship, such that participants who stuttered more in the share condition also stuttered more in the private condition. Stuttering rates varied markedly across individuals, consistent with the broad range of symptom severity captured by the SSI-4 (Figure S1B). In AWS, Wilcoxon signed-rank tests indicated no significant differences in stuttering rate between the *self share* and *self private* conditions ($V = 308$, $p = 0.052$), nor between the *other share* and *other private* conditions ($V = 200$, $p = 0.153$). Descriptive stuttering rate data for both AWS and AWNS are provided in Table S2.

Effects of listener presence and self-relatedness on brain activity

Whole-brain analysis revealed significant effects of listener presence and self-relatedness of speech content. Speech produced in the presence of a listener (share > private) engaged widespread cortical and subcortical brain regions spanning medial and lateral prefrontal, premotor, posteromedial parietal, posterior cingulate, and temporo-parietal cortex, together with the caudate nucleus extending into the nucleus accumbens and cerebellar Crus I (Figure 2B; Table S3). Speech referring to the self rather than another person (self > other) recruited a distributed set of frontal and parietal association regions, including anterior cingulate, inferior frontal, and ventrolateral/orbitofrontal prefrontal cortex extending into the caudate nucleus, nucleus accumbens and thalamus, as well as precuneus and inferior parietal cortex, with additional involvement of lateral temporal and occipital regions, cerebellar Crus II, and hippocampus (Figure 2B; Table S3).

Listener-related modulation of brain activity by group

Listener-related modulation of brain activity (share > private) was observed in both groups and showed a largely overlapping spatial pattern. In AWNS and AWS, directed speech engaged medial prefrontal and premotor cortex, posterior cingulate and posteromedial parietal regions, as well as subcortical structures including the caudate nucleus, thalamus, and cerebellum. Additional frontal and temporal regions and extended activity of the nucleus accumbens were evident in the AWS map, whereas medial frontal and parietal components were more prominent in AWNS; however, the direct between-group comparison was not significant (Figure 3; Table S4).

Group differences in self-related speech responses

Self-related speech (self > other) engaged frontal and parietal association cortex in both groups, with prominent involvement of anterior cingulate and ventral frontal regions. In AWNS, self-related responses additionally extended into orbitofrontal and inferior frontal cortex, inferior temporal cortex, hippocampus, and brainstem regions encompassing the ventral tegmental area and dorsal raphe nucleus. In AWS, effects were more circumscribed, centered on anterior cingulate and frontal pole regions, with additional cerebellar involvement (Figure 4; Table S5).

Direct group comparison showed stronger self-related responses in AWNS than AWS in anterior cingulate cortex, whereas AWS showed greater responses than AWNS in medial inferior parietal cortex.

Correlates of stuttering anticipation in listener-related modulation

Within AWS, stuttering anticipation (PAiS) was associated with listener-related modulation of brain activity (share > private). Higher PAiS scores correlated positively with share-related responses in the

nucleus accumbens (Figure 5A; Table S6). In contrast, negative correlations were observed in left inferior frontal cortex, encompassing pars opercularis, triangularis, and orbitalis, as well as posterior superior temporal regions including ventral posterior superior temporal sulcus and adjacent temporal cortex (Figure 5B; Table S6).

Correlates with stuttering-related burden in listener-related modulation

Within AWS, greater stuttering-related burden (OASES) was positively associated with listener-related modulation of brain activity (share > private). Higher OASES scores correlated with increased responses in medial frontal and cingulate regions, including medial prefrontal cortex, anterior cingulate cortex, and medial superior frontal cortex, as well as inferior frontal and frontal opercular regions (Figure 6; Table S7).

Discussion

Speaking is a motor act embedded in socially motivated behavior that engages valuation and control systems. In a socio-economic decision task where participants chose between speaking and remaining silent, both listener presence and self-related speech carried clear subjective value for AWS and AWNS extending prior findings from fluent speakers (29) to AWS. Using fMRI, we further found that listener-directed and self-related speech engage reward- and evaluation-related brain regions, including ventral striatum and medial frontal cortex, in both groups. Although listener presence did not produce group differences, individual variability in neural modulation was systematically related to stuttering anticipation and overall impact, indicating that social context shapes brain activity in AWS along clinically relevant dimensions.

Behavioral effects of listener presence

Despite reports that AWS avoid challenging communicative situations, we did not observe systematic avoidance in this low-stakes setting: AWS did not forgo monetary reward to avoid speaking, and stuttering frequency did not differ reliably between shared and private trials. This suggest that, under these conditions, the subjective value of speaking and self-disclosure remains high in AWS and can be dissociated from overt avoidance behavior. It also implies that the neural effects we observed are unlikely to be driven simply by increased dysfluency under social exposure, but instead reflect changes in the motivational and regulatory state in which speech is produced.

Premonitory awareness, motivational valuation and speech-language hubs

Within AWS, listener-related modulation of the nucleus accumbens scaled with individual differences in stuttering anticipation: higher PAiS scores were associated with stronger differentiation between directed and private speech in this ventral striatal region. Given the established role of the nucleus accumbens in encoding motivational relevance and subjective value in socially meaningful contexts (41–47), this pattern suggest that socially directed speech acquires greater motivational salience as anticipatory load increases, rather than simply becoming more rewarding. In multi-system terms, anticipatory load appears to amplify automatic motivational signals in ventral striatum, consistent with how affective cues bias approach-avoid decisions via striatal circuitry (33).

Higher stuttering anticipation was also associated with reduced listener-related modulation in cortical speech-language regions, including inferior frontal and posterior temporal areas that support speech planning and perception (48–50), as well as the lateral orbitofrontal cortex (BA 47), implicated in controlled semantic processing and in integration of value and context into language and decision-making (51,52). These regions showed less differentiation between directed and private speech as anticipation increased, suggesting that increasing anticipatory load alters how socially directed speech is processed within cortical speech-language systems. One possibility is that, with higher anticipatory load, these regions are already strongly engaged during private speech, leaving less capacity for further modulation by listener presence. Alternatively, processing may shift away from fine-grained speech-language operations toward motivational-salience systems when social context is perceived as challenging.

Recent work indicates that the core language network, although not itself computing others' mental states (53,54), can be rapidly informed by feedback from theory-of-mind regions during naturalistic comprehension, with reliable functional coupling between these networks over time (55). Within broader prefrontal circuitry, lateral orbitofrontal and frontopolar regions have been linked to credit assignment and to counteracting biased value signals (33,56,57) complementing striatal mechanisms of value updating (58). In this context, concurrently reduced modulation in ventrolateral frontal regions, together with stronger listener-related responses in nucleus accumbens, is consistent with a shift in the relative engagement of ventral striatal motivational circuitry and cortical speech-language systems as stuttering anticipation increases.

Stuttering-related burden is associated with self-referential and regulatory regions

Listener-related increases in activity for share > private speech were observed in a medial prefrontal-cingulate network associated with social evaluation, self-referential processing, and context-dependent regulation (59–63) . Their greater engagement for directed relative to private speech suggests that speaking under observation places additional demands on evaluative and monitoring processes. Within AWS, higher OASES scores were associated with stronger listener-related modulation in medial

prefrontal and ventrolateral frontal regions, indicating that individuals who experience greater stuttering-related burden recruit this evaluative-regulatory circuitry more strongly under listener presence. OASES and PAiS were not correlated (Spearman $r(31) = 0.27$, $P = 0.13$, two-tailed), supporting the view that these neural associations track distinct aspects of the stuttering experience and phenotype. Within a multi-system framework (33), dorsal anterior cingulate cortex and medial prefrontal cortex may act as a hub, where learned negative consequences of speaking and current contextual cues jointly shape the value of speaking under observation.

The self > other contrast revealed group differences in regions implicated in self-referential and evaluative processing. Relative to AWS, AWNS showed greater engagement of the subcallosal cortex, often linked to affective valuation and self-related appraisal (64,65), whereas AWS exhibited stronger activity in the medial inferior parietal cortex, including angular gyrus, associated with perspective-taking and integration of self-related information within a broader social context (66,67). Although these differences require replication, the pattern suggests that self-related speech may rely on partially distinct self-referential circuits in AWS and AWNS, potentially reflecting differences in how self-relevant information is evaluated or contextualized during speaking. On current accounts, ventromedial prefrontal cortex/subcallosal regions encode cognitive 'maps' for self-relevant value, whereas parietal regions support perspective-taking and contextual integration (33). Within this view, self-related speech in AWS may depend relatively more on distributed perspective-taking networks and relatively less on ventromedial prefrontal-centered self-valuation schemas, possibly reflecting experience-dependent adaptations to chronic social evaluative contexts. Together with the OASES correlations, these group differences indicate that both the evaluation of self-related speech and its modulation by listener presence vary systematically with the perceived impact of stuttering.

Overall, our findings argue against a uniform neural deficit in developmental stuttering and instead support a shift in the balance between salience, control, and language processing systems that tracks anticipation and burden. This system-level perspective helps explain why stuttering is highly context-sensitive and heterogeneous and suggests that targeting motivational and evaluative processes, alongside speech motor mechanisms, may be important for understanding and treating the disorder.

Limitations

The paradigm isolates listener presence and self-relatedness but does not directly manipulate social evaluation or communicative consequences, and the reported associations are correlational rather than causal. More naturalistic interaction paradigms and longitudinal designs will be needed to clarify how motivational and regulatory systems interact with speech-motor processes over time (68). In addition, the sample size limits statistical power and the generalizability of the correlation findings, particularly given the marked heterogeneity of the stuttering phenotype. Nonetheless, the present results provide a

principled starting point and concrete effect-size estimates for future, larger-scale studies that aim to further map how social-motivational and speech-related neural systems interact in people who stutter.

Conclusion

Overall, our findings argue against a uniform neural deficit in developmental stuttering and instead point to a shift in the balance between salience, control, and speech and language processing systems that tracks anticipation and burden. This multi-system perspective may help account for the context sensitivity and heterogeneity of stuttering and underscores the contribution of social and emotional factors to the neural organization of speech processing. Our findings do not directly speak to treatment efficacy but suggest that clinical assessment may benefit from explicitly considering how social exposure and stuttering anticipation modulate activity in salience, control, and speech-language systems, alongside traditional measures of overt fluency. This may help explain why the same individual can show very different fluency profiles across situations and support approaches that focus on reducing social and emotional load in challenging contexts rather than targeting speech motor behavior in isolation.

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Data availability: The brain imaging data of the group averages in the standard space are available at: https://owncloud.gwdg.de/index.php/s/Jpd63stMeZZmBPW/download

Disclosures

The authors have nothing to disclose.

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Tables

Table 1 Demographic details of participants, clinical features of patients

	AWNS (n=32)	AWS (n=34)	Difference, (*P*)
Age in years, mean (SD)	32.1 (6.7)	31.2 (6.4)	0.57 (0.574) [b]
Sex, male (%)	28 (88)	29 (85)	0.83 (1) [c]
Handedness, *Mdn* LQ (IQR)	100 (12.1)	90 (21.5)	619.5 (0.300) [d]
School education, *Mdn* (IQR)	4 (0)	4 (1)	**679.0 (0.033)** [d]
Professional education, *Mdn* (IQR)	7 (2)	6 (3)	645.0 (0.176) [d]
Trait anxiety percentile rank, *Mdn* (IQR)	27 (40)	65 (49) [a]	**253.5 (< 0.001)** [d]
State anxiety percentile rank, *Mdn* (IQR)	16 (43)	51 (38) [a]	**318.0 (0.005)** [d]
SSI-4 overall score, *Mdn* (IQR)	0 (0)	22 (14.5)	**0 (< 0.001)** [d]
% stuttered syllables, *Mdn* (IQR)	0 (0.3)	5.5 (8.8)	**0 (< 0.001)** [d]
OASES total score, *Mdn* (IQR)	n/a	2.8 (0.8) [a]	n/a
PAiS, *Mdn* (IQR)	n/a	18 (7.8) [a]	n/a

LQ = laterality quotient; IQR = interquartile range; SSI = Stuttering Severity Index;(35) OASES = Overall Assessment of the Speaker´s Experience of Stuttering; (37,41) Premonitory awareness in stuttering;(38); school and professional education were coded as ordinal variables. Highest school qualification was classified as: (0) no qualification, (1) general education school-leaving certificate after grade 9, (2) general education school-leaving certificate after grade 10, (3) university of applied sciences entrance qualification, and (4) higher education entrance qualification. Highest professional qualification was classified as: (0) no qualification; (1) vocational training <1 year; (2) vocational training <2 years; (3) vocational training <3 years; (4) completed vocational qualification; (5) currently enrolled at a university or university of applied sciences; (6) bachelor's degree or master craftsman qualification; (7) master's degree or equivalent; and (8) doctoral degree or higher. an = 33; differences were tested with unpaired, two-tailed t-test (R command: t.test), cFisher's Exact Test (R command: fisher.test), and d Wilcoxon Signed-Rank Test (R command: wilcox.exact).

Figures

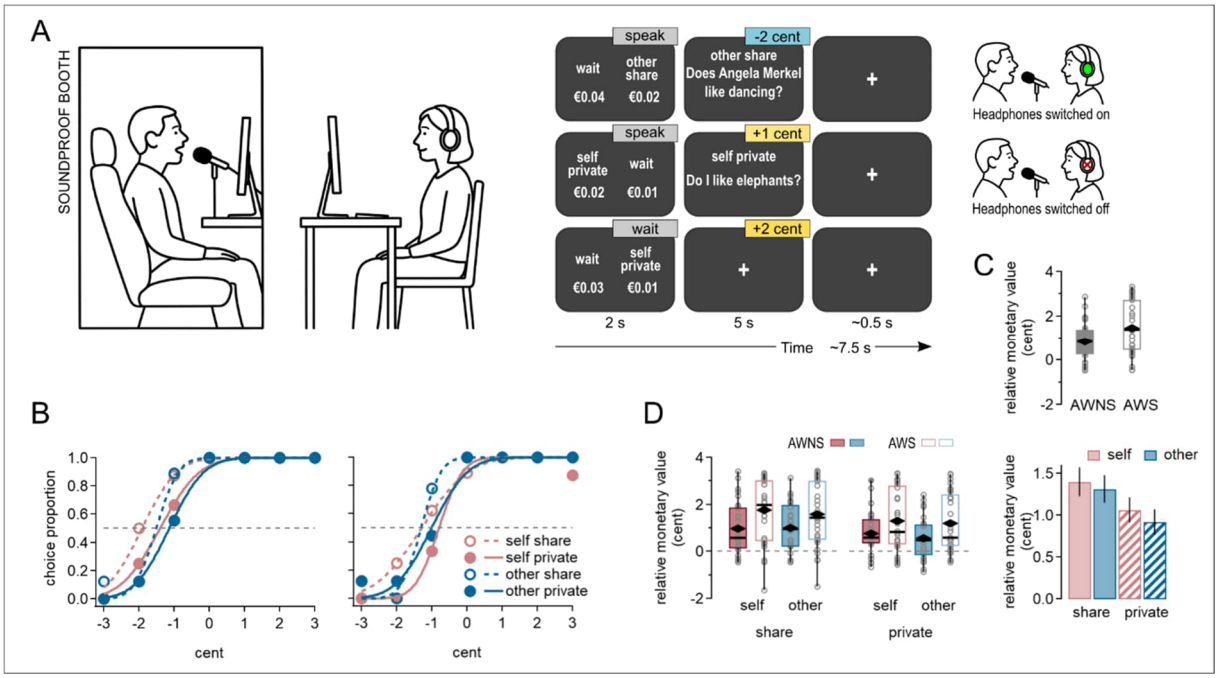

Figure 1 Task outside the MRI scanner and results. (A) Experimental setup. Participants were seated in a soundproof booth and viewed the stimuli on a screen. The investigator, located outside the booth, viewed the same stimuli and listened to participants' responses during share trials only. (B) Representative individual data showing PSEs from one AWNS (left) and one AWS (right). The AWNS example shows the most negative PSE in the self-share condition, indicating a willingness to forgo 2 cents to share self-related information. The AWS example shows negative PSEs for both self- and other-related conditions, indicating a willingness to forgo approximately 1.5 cents to speak. (C) Group-level PSEs by condition, shown separately for each group (left) and pooled (right). (D) PSEs pooled across all participants and conditions.

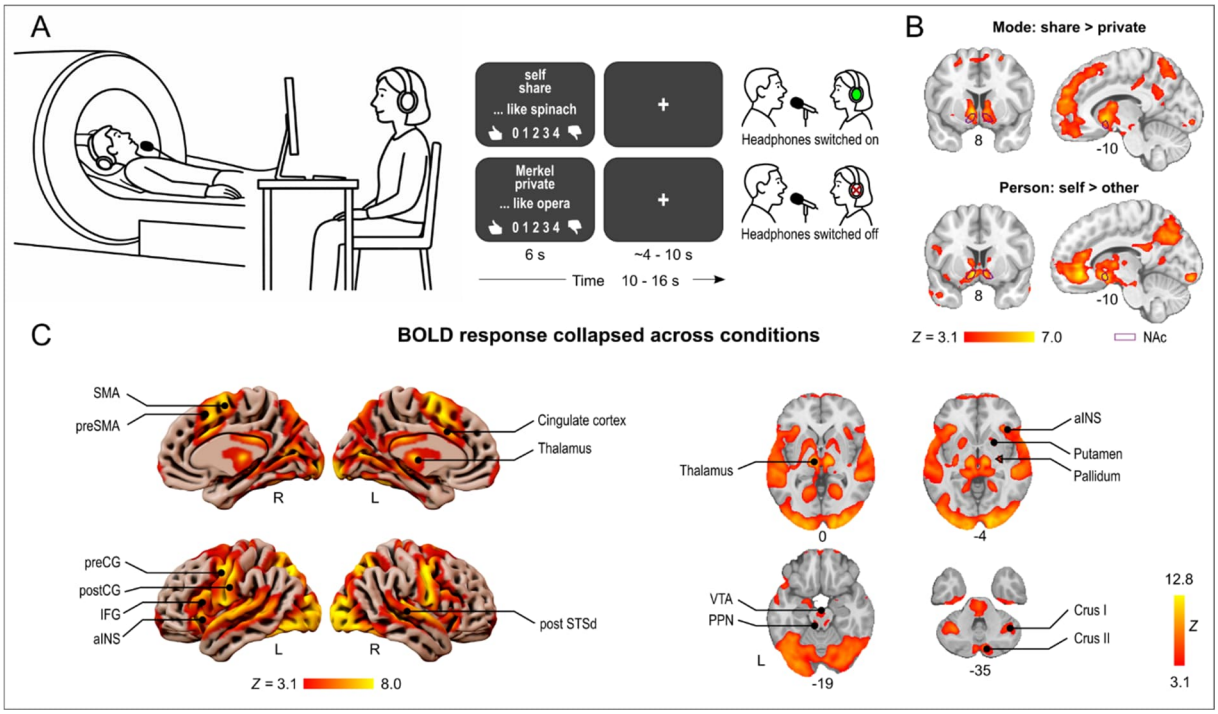

Figure 2 Task inside the MRI scanner and results pooled across groups. (A) Experimental setup. Participants lay in the MRI scanner and viewed the stimuli and responded to each trial. The investigator, located outside the scanner room, viewed the same stimuli and listened to participants' responses during share trials only. (B) Whole-brain analysis revealed a main effect of Mode, with greater nucleus accumbens (NAc) responses during share compared with private trials, and a main effect of Person, with greater NAc responses during self compared with other trials (results pooled across groups). (C) For visualization purposes, we performed a whole-brain analysis across all conditions to illustrate task-positive speech-related activity. Abbreviations: aINS, anterior insula; IFG, inferior frontal gyrus; NAc, Nucleus accumbens; PPN, pedunculopontine nucleus; postCG, postcentral gyrus; post STSd, dorsal posterior superior temporal gyrus; preCG, precentral gyrus; preSMA, presupplementary motor area; SMA, supplementary motor area; VTA, ventral tegmental area.

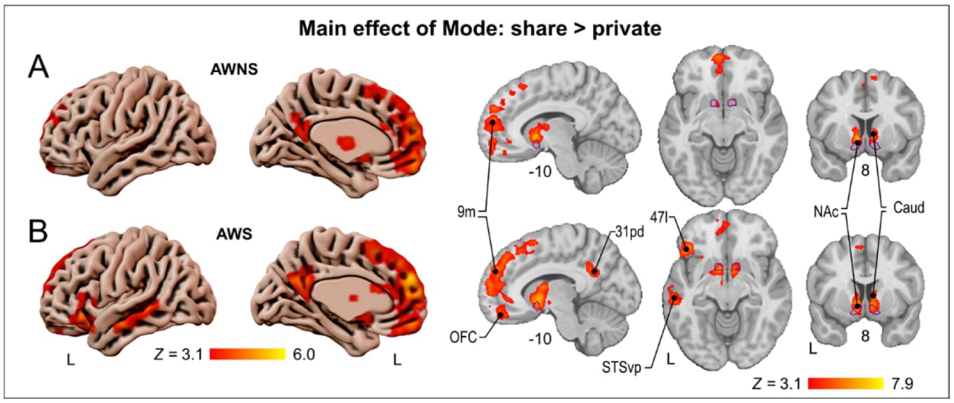

Figure 3 Listener presence. For the share > private contrast, both AWNS (A) and AWS (B) showed increased BOLD responses in the nucleus accumbens (NAc) and caudate nucleus (Caud), together with bilateral anterior cingulate cortex (area 9m) and thalamic activity. In AWS, additional effects were observed in the left inferior frontal gyrus, pars orbitalis (area 47l), the left ventral posterior superior temporal sulcus (STSvp) extending into middle temporal gyrus, and posterior cingulate cortex (area 31pd).

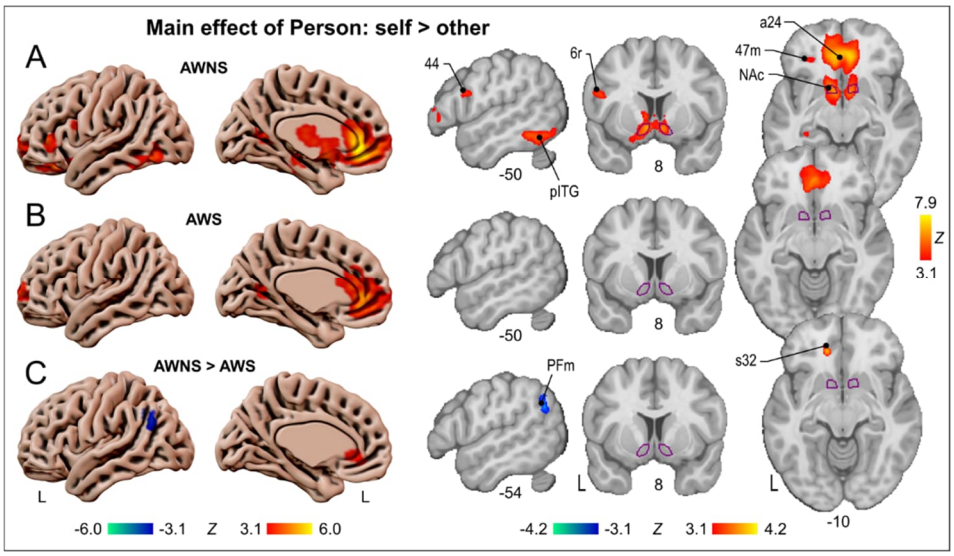

Figure 4 Self-related speech. For the self > other contrast, both AWNS (A) and AWS (B) showed increased BOLD responses in anterior cingulate cortex (a24) and frontal pole. In AWNS, effects extended into orbitofrontal cortex (47m) and nucleus accumbens (NAc), with additional clusters in inferior frontal gyrus (44), inferior frontal junction (6r), and posterior inferior temporal gyrus (pITG). Group differences (C) were observed in right subcallosal cortex (s32) and left medial inferior parietal cortex (PFm).

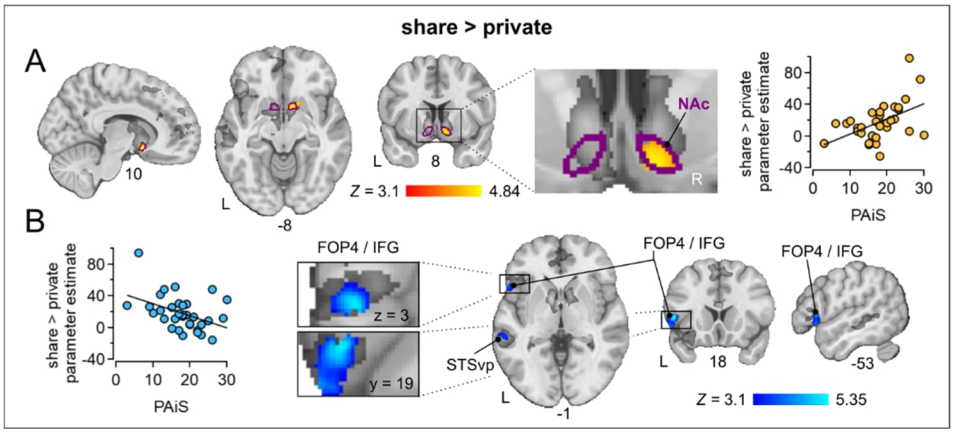

Figure 5 Correlates of stuttering anticipation. In AWS, within the cluster mask of the share > private contrast (dark grey overlay), higher PAiS scores were positively associated with listener-related modulation in the right nucleus accumbens (NAc) (A), and negatively associated with modulation in left frontal operculum (FOP4), inferior frontal gyrus pars orbitalis (IFG), and ventral posterior superior temporal sulcus (STSvp) (B).

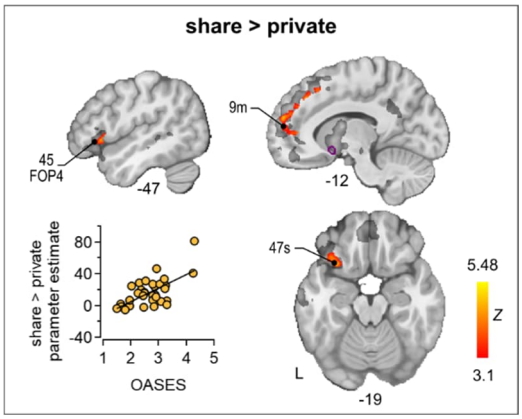

Figure 6 Correlates of overall stuttering experience. In AWS, within the cluster mask of the share > private contrast (dark grey overlay), higher OASES scores were positively associated with listener-related modulation in medial prefrontal and medial superior frontal cortex, anterior cingulate cortex (9m), and inferior frontal gyrus (pars orbitalis and triangularis) and frontal operculum (FOP4, 45).