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A novel use of choral speech significantly reduces stuttering in a simulated presentation setting: An exploratory study

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ABSTRACT

Choral speech, defined as speaking in unison with another voice, has long been recognised for improving speech fluency while maintaining speech naturalness for people who stutter (PWS). However, its practical application has been limited by the need for a live second voice. This exploratory study investigated whether choral speech could be used in a simulated presentation setting with two alternative voice sources: participants' own voice recording and computer-generated voice. The condition using participants' own recording built on findings that many PWS experience increased fluency when speaking alone; participants therefore recorded their voice on their own, which was later played back through headphones during their presentation. In the computer-generated voice condition, participants synchronised their speech with a text-to-speech (TTS) decoder after uploading the presentation text. Two additional conditions were included for comparison: a baseline reading with no intervention, and a non-speech auditory feedback using white noise. Results showed a substantial decrease in disfluent syllables, with the mean percentage dropping from 10 % at baseline to below 3 % in both choral speech conditions. One participant reduced stuttering from 49 % to 2 %, and shortened reading duration from approximately 19 to 4 min with the TTS decoder, while improving perceived speech naturalness. To the author's knowledge, these preliminary results are first to suggest that choral speech with a TTS decoder can significantly reduce stuttering in a simulated presentation setting. Further research should investigate its clinical potential to support real-life presentations and reduce public speaking avoidance.

1. Introduction

Public speaking is usually recognised as the most common fear in general population (Daly et al., 1989; Dwyer & Davidson, 2012), which can result in intense state anxiety during the pre-speech period (Sawyer & Behnke, 1999). The anxiety of negative social evaluation, especially in speech-related situations, is more pronounced in people who stutter (PWS); for instance, 46 % of adults who stutter experience social anxiety, compared with only 4 % of matched controls (Blumgart et al., 2010). Social anxiety deriving from stuttering may lead to a cycle of stress and avoidance of public speaking situations, which can limit opportunities in both social and professional contexts. The current study focuses on using the highly effective fluency enhancer, choral speech, to provide an option for PWS to reduce stuttering in a simulated presentation setting while preserving speech naturalness.

Abbreviations: PWS, people who stutter; TTS, text-to-speech; ChoralR, choral reading with participants' own voice recording; ChoralC, choral reading with computer-generated voice; ReadingWN, reading while hearing white noise.

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Despite decades of research, no universally effective fluency treatment for stuttering has emerged. Current therapeutic interventions generally focus on fluency shaping techniques through behavioural training. These techniques typically involve slowing speech, extending vocal gestures to smooth transitions and managing breath control to regulate airflow during speech (Ingham & Andrews, 1973; Webster, 1980; see a systematic review: Brignell et al., 2020). However, these approaches tend to disrupt the natural rhythm and tone of speech (Tasko et al., 2007), which can result in high relapse rates as many people return to their natural rhythm and tone. In recent years, there has been growing interest in non-invasive brain stimulation techniques as a means of enhancing neuroplasticity during fluent state of speech, with the aim of maintaining speech naturalness. Early research in this area is promising, but the protocols for such treatments remain in the experimental stage, and their long-term efficacy is not yet well understood (Busan et al., 2019, 2021; Chesters et al., 2018; Garnett et al., 2019; Moein et al., 2022).

On the other hand, temporary fluency enhancement can be achieved immediately through techniques that either provide external sensory feedback or allow the person who stutters to self-direct their speech without any communicative intent. In the former category, the fluency enhancement is temporary because the effects disappear once the sensory feedback ends. This is analogous to using corrective glasses to improve eyesight: the effect is present only while the glasses are worn. Delayed auditory feedback (DAF), which plays back the speaker's voice with a slight delay, and frequency-altered feedback (FAF), which modifies the frequency components of the voice, both have been shown to reduce stuttering to some extent (Stuart et al., 1996; Howell et al., 1983; Saltuklaroglu et al., 2009) though this reduction can come at the expense of distorting the natural rhythm and tone of speech, especially in the case of DAF. Metronome-paced speech, in which the speaker aligns their syllables or words with a steady rhythm, has been found to be effective at eliminating stuttering (Fransella & Beech, 1965; Howell & El-Yaniv, 1987) but can severely disrupt prosody.

In contrast, choral speech, where a person who stutters speaks in unison with another speaker, offers a more effective way of reducing stuttering (Meekings et al., 2025; Saltuklaroglu et al., 2009; Barber, 1939). One study demonstrated that choral speech substantially reduced stuttering, achieving fluency improvements of up to 98 %, whereas altered auditory feedback reduced stuttering by approximately 68 % compared with normal auditory feedback (Saltuklaroglu et al., 2009). This can be realised without the need for extensive training, and the effect is immediate (Kalinowski & Saltuklaroglu, 2003). However, the need for another speaker to assist as the synchronising voice presents a significant practical barrier to the widespread use of choral speech in real-life settings. To address this limitation, the current research examined whether choral speech can be adapted for use in a presentation context by replacing the live second speaker with a pre-recorded voice by the speaker or a text-to-speech (TTS) decoder.

The fluency enhancing mechanism of choral speech are not yet fully understood. One theory proposes that choral speech facilitates fluency by engaging mirror neurons (Kalinowski & Saltuklaroglu, 2003). A related but different perspective emphasises the motor command initiation circuit (Alm, 2004; Chang & Guenther, 2020; Civier et al., 2013). Both accounts acknowledge that choral speech may bypass disruptions in the internal motor initiation pathways. This is similar to mechanisms observed in movement disorders such as Parkinson's disease (Thaut et al., 2001). For example, people with Parkinson's disease, who have dopamine-depleted basal ganglia, demonstrate improved gait pattern when provided with external cues, such as visual cues for step initiation during walking (Bagley et al., 1991; Glickstein & Stein, 1991). However, stuttering may not be solely a motor command initiation issue; atypical sensorimotor integration in stuttering may interfere with the initiation circuit by affecting how an internal copy of the planned motor command is used to predict and monitor sensory feedback during speech (Civier et al., 2010; Max et al., 2004; Max & Daliri, 2019). Consequently, another prominent explanation is that choral speech corrects these auditory-motor mismatches (Daliri & Max, 2015, 2018; see review: Max & Daliri, 2019) by providing reliable external auditory input (Fox et al., 1996; Garnett et al., 2022; Toyomura et al., 2011), which temporarily bypasses the disrupted sensorimotor integration system and facilitates fluent speech.

Another way to dissipate stuttering is an intriguing phenomenon: PWS do not stutter when speaking to themselves alone (Jackson et al., 2021). In one study, Jackson et al. (2021) reported no instances of stuttering in over 10,000 syllables produced during private speech. It is worth noting that, in private speech, participants engaged in self-directed speech while performing a task alone, with no intention of communicating with others. In that sense, private speech is different from speaking alone if there is any communicative intention, such as recording voice that may be heard by others. In a survey of 1649 PWS, 66 % reported complete fluency when alone, with another 27 % noticing significant improvement, while just 2.6 % saw no change (Rasskazov & Rasskazova, 2007). These results suggest that stuttering is not only a speech-motor issue but is also modulated by psychological factors including the presence of an audience and mentalising on the audience's expectations, hesitancy of accurate and appropriate information transfer, negative self and social evaluation, and time pressure (Jackson et al., 2016; Eisenson & Horowitz, 1945; Quarrington, 1965; Sheehan et al., 1967; see Alm, 2014 for a review). Based on these findings, the present study investigated whether PWS could pre-record their speech fluently when alone and later use their own recording to perform choral speech during a simulated presentation task with an improved fluency.

Therefore, participants were first asked to record their voice while alone and later read the same text in unison with their pre-recorded voice through headphones, in a simulated presentation setting in the presence of a researcher and a camera. As an alternative, the study also tested a TTS decoder, where participants synchronised their speech with a computer-generated voice coming through headphones. Additionally, two control conditions were used: reading without altered auditory feedback and reading while hearing white noise, as masking noise has also been shown to reduce stuttering (Adams & Hutchinson, 1974). This exploratory study examined whether performing choral speech with a participant's own pre-recorded voice could significantly reduce stuttering during a simulated presentation. Further, it compared this approach with performing the same task using a computer-generated voice, which would be a practical solution for participants who would stutter when reading alone. The speech naturalness was also measured, with the prediction that performing choral speech with one's own voice would result in higher naturalness because people synchronise their voice with their own natural rhythm, including breathing, pauses, and pace. Much like public figures who read from pre-written texts, this method may offer ecological validity and presents a practical tool for delivering speeches fluently. Moreover, it would provide the flexibility for PWS to prepare and use their own speech, that aligns with real-world demands such as presentations, and teaching.

2. Method

2.1. Participants

The sample size was exploratory due to the absence of an available effect size. However, Saltuklaroglu et al. (2009) reported a significant reduction in stuttering (approximately 98 %) with a sample of 10 participants when they performed choral speech. Based on these findings, the inclusion of 14 PWS was considered sufficient to reach a comparable effect. Of these, 11 participants had received formal diagnoses from either a doctor or a speech therapist, while the remaining three self-reported their stuttering based on their own assessment.

Participants were recruited through advertisements on social media, word of mouth, email lists, posters, the University's website, and stuttering organisations such as the British Stammering Association (stamma.org) and the Oxford Stammering Meet-Up Group. Participants, aged between 18 and 35 years (mean age = 27), were all native English speakers with normal hearing and no language or speech impairments other than stuttering. Seven were female, and one identified as left-handed. Only one participant was undergoing therapy at the time of testing, although 12 reported prior therapeutic interventions. Ethical approval was granted by the University of Oxford Central University Research Ethics Committee (MS-IDREC-2023).

The mean total SSI-4 score across participants was 26.07, covering a range of 11–50 (see Table 1). Based on these scores, participants were categorised into four severity levels: 1 was classified as having very mild stuttering, 6 as mild, 4 as moderate, and 3 as very severe. Two participants, P13 and P14, who were classified as having very severe stuttering, did not complete the choral reading with recording of participant's own voice condition. This decision was made because their %ds in their voice recording when alone was 25.27 % and 23.77 %, respectively (see Table 2). These high disfluency rates indicated that synchronising with their own recorded voice would not have produced a reliable choral effect in order to benefit from the auditory feedback. Additionally, data is missing for the reading with white noise condition of P10 due to a technical problem.

The author analysed all the data related to stuttering rates and severity, and a second researcher independently analysed the data of the first 7 participants (50 % of the sample) of the SSI-4 data. Inter-rater reliability was assessed using intraclass correlation coefficient (ICC) which were interpreted based on established guidelines: < 0.50 as poor, 0.50–0.75 as moderate, 0.75–0.90 as good, and > 0.90 as excellent reliability (Koo & Li, 2016). The results demonstrated a high level of agreement between the two raters (ICC = 0.93, $P < 0.001$). The author then repeated the SSI-4 analysis of the first seven participants after at least one week to assess intra-rater reliability. A strong ICC was found for the intra-rater measurements (ICC = 0.93, $P < 0.001$) as well, indicating a robust consistency across repeated measurements.

2.2. Procedure

Before the experimental visit, participants were instructed to record their voice while reading a provided text (information about the text is detailed below). An example voice recording (using a different text, recorded by the author) was sent to them, and the participant recordings were later analysed as the Recording Alone (Rec. Alone) condition. Participants were not informed of the specific purpose of the recording. The instructions were sent via email and read as follows: "*We kindly ask you to make an audio recording of yourself reading the attached story (Antarctic) before your visit to the department. Please ensure that you are alone while making the recording, with no audience or anyone else who can hear you. You may re-record yourself as many times as needed until you are satisfied with the result. Please use a natural speaking rate that feels comfortable to you (an example recording is attached). You may email the recording to us prior to your visit, or bring it with you on a USB stick.*"

Table 1
SSI-4 scores based on four subcategories: reading, speaking, duration of the longest three stuttered utterances, and physical concomitants. The total score is derived from these subcategories and used to classify stuttering severity as very mild, mild, moderate, severe, or very severe. The data represent both the range and average scores across participants. Mean values are calculated for each category at the bottom. SSI: Stuttering Severity Index.

Participant	Reading	Speaking	Duration	Physical Concomitants	Total	Severity
P05	4	3	2	2	11	very mild
P06	6	3	8	2	19	mild
P08	4	2	10	3	19	mild
P09	7	2	8	2	19	mild
P10	7	3	6	4	20	mild
P11	7	2	8	4	21	mild
P04	6	5	3	10	24	mild
P01	5	5	10	5	25	moderate
P07	8	5	10	3	26	moderate
P12	7	8	8	3	26	moderate
P03	6	4	12	6	28	moderate
P02	9	8	12	9	38	very severe
P13	9	8	12	10	39	very severe
P14	9	8	19	14	50	very severe
mean	***6.71***	***4.64***	***9.14***	***5.54***	***26.07***	***moderate***

Table 2
Percentage of disfluent syllables and reading duration across four conditions. This table presents the percentage of disfluent syllables (%ds), reading durations (Rd. Dur: in minutes) and speech naturalness (Nat.) for each participant (Par.) across five conditions: Baseline reading, choral reading with recording of participant's own voice (ChoralR), choral reading with computer-generated voice (ChoralC), reading with white noise (ReadingWN), and recording voice while reading alone (Rec. Aln.). Participants' disfluency rates were measured as the percentage of stuttered syllables per total syllables and reading duration was measured from the beginning to the end of each trial. Speech naturalness was evaluated using a nine-point scale, with 1 indicating highly natural speech and 9 indicating highly unnatural speech. Missing data are indicated where applicable. Median values for each condition are provided at the bottom of the table.

Par.	Baseline reading			ChoralR			ChoralC			ReadingWN			Rec.Aln.
	%ds	Rd. Dur.	Nat.	%ds	Rd. Dur.	Nat.	%ds	Rd. Dur.	Nat.	%ds	Rd. Dur.	Nat.	%ds
P01	1.8	2.4	4.33	1.41	2.4	8	1.4	2.5	5.67	0.9	2.2	2	0.6
P02	7.76	3.5	7.33	1.1	3.3	4.67	0.5	3.3	3.33	5.8	3.3	6	5.5
P03	10.5	5.6	7.67	3.81	5.1	6.33	1.4	3.1	3.67	14.6	7.2	8.33	7.1
P04	1.37	3.2	3	1.7	3.5	4.33	0.3	4.1	3.67	1.2	2.9	4	7
P05	0.3	3.1	2	1.4	3.2	4.33	1.1	4.1	5.67	0.1	2.9	3.67	1.5
P06	1.67	2.9	3.33	0.9	3.2	3	0.8	4.1	5.33	0.5	3.9	2	0.1
P07	15.4	5.3	8.33	3.1	4.5	6.67	0.8	4.1	6.33	9.9	4.4	8	6.8
P08	0.15	2.3	3.33	1	3.5	5.67	0	2.3	1.67	0.9	2.4	2.33	0
P09	12.6	3.2	7	1.7	2.3	2.67	1.2	4.1	5.33	13.4	2.8	6.33	1.4
P10	6.4	3.2	7	6.2	3.1	6.33	2.4	3.5	6.67	NA	NA	NA	7.6
P11	1.1	2.4	2.33	1.7	2.4	4	0.9	4.1	5.67	0.5	2.5	2.67	2
P12	5.5	3.2	4.67	4.9	4.0	7	1.9	3.5	6.33	6.4	3.1	6	6.8
P13	30.3	8.5	8.67	NA	NA	NA	14	4.0	7	34.4	9.4	8.67	25.3
P14	48.7	19.5	9	NA	NA	NA	1.5	4.1	3.33	43.7	14.3	9	23.8
median	***5.93***	***3.22***	***6.5***	***1.67***	***3.27***	***5***	***1.15***	***4.04***	***5***	***5.78***	***3.08***	***5***	***6.16***

The experiment was designed as a single-session visit, lasting about one and a half hours. Upon their visit, speech samples were collected initially through reading and spontaneous question-answering tasks, with video footage used to measure baseline stuttering levels using the Stuttering Severity Instrument version 4 (SSI-4) (Riley, 2009). The study involved delivering presentations and concluded with a semi-structured interview. The interview data is explained in detail in the Qualitative Results (Section 3.2.).

Participants were asked to read a 655-syllable text with a readability level appropriate for a 15.5-year-old, which includes scientific terminology related to Antarctic research and glaciology. They delivered their speeches in a simulated presentation setting, standing in front of a camera and a researcher who acted as an observer. This setup was designed to evoke aspects of a public speaking context (e.g., being watched, recorded) while maintaining experimental control. Each participant was instructed as follows: "*Imagine you are a news presenter preparing to deliver the latest update from the British Antarctic Survey for the BBC-4 channel. You will read this passage four times, each time using a different approach*". Before the experiment starts, participants completed at least one training session with shorter texts (between 200 and 400 syllables), using both choral speech with a human voice recording and with the computer-generated voice separately. This helped participants become familiar with the experimental conditions, even though prior research showed that previous experience with choral speech has no significant impact on performance (O'Dell et al., 2010). Participants were instructed to synchronise their speech word-by-word with what they heard but were informed that minor deviations, such as missing or shadowing the recording, were acceptable. They were encouraged to follow the approach that felt most comfortable to them.

During the experiment, participants read the text under four conditions carried out in a 4 different randomised order across participants: (A) reading without altered auditory feedback (baseline reading), (B) choral reading with the participant's own voice recording (ChoralR), (C) choral reading with a computer-generated voice (ChoralC), and (D) reading with white noise (ReadingWN). Participants assigned to Order A performed the tasks in the sequence A, B, C, D, while those in Order B followed the sequence B, C, D, A, and so forth for the remaining orders. Between conditions, participants were given at least a 1-minute break to minimise fatigue.

A) **Reading with no altered auditory feedback (baseline reading)**

In this condition, participants read the text aloud as if presenting to an audience, while positioned in front of a camera and researcher, as was the case in all conditions. They wore headphones throughout in order to control for any effects related to wearing headphones, although no auditory feedback was provided.

B) **Choral reading with participant's own voice recording (ChoralR)**

Participants read the text while synchronising their speech with their own pre-recorded voice, that was recorded while alone and was delivered through headphones during the task. The volume of the recording was adjusted to a comfortable listening level using the researcher's judgment before the session began to help maintain consistency across participants.

C) **Choral reading with a computer-generated voice (ChoralC)**

Participants were asked to read the text in unison with a computer-generated voice created using the Microsoft Word's "Read Aloud" function. The pace of the computer-generated voice was set at a speed chosen by the participants, who were advised to select a slightly slower pace than their typical fluent speech, as the computer-generated voice was unfamiliar to them. Female participants listened to the same female voice, and male participants listened to the same male voice. The volume was standardised across participants using the same laptop, volume settings, and software.

D) **Reading with white noise condition (ReadingWN)**

Participants read the text while hearing white noise through their headphones. To avoid the Lombard effect (Lombard, 1911) where speakers unintentionally raise their voice in response to masking noise, participants were instructed to maintain a natural volume. The white noise was set at 60 decibels, based on previous findings where 50 decibels of white noise reduced stuttering by nearly half (Adams & Hutchinson, 1974; see a computational model: Civier et al., 2010).

2.3. Experimental setting

The recording of the session was conducted using both video and audio. A camera (Panasonic HC-V180) was placed at eye level in front of the participant, capturing the upper body and face to observe physical concomitants knowns as secondary behaviours of stuttering, such as involuntary eye blinking or head movements. Audio was recorded using a lapel microphone connected to this camera, while a secondary microphone (Samson C01UPRO) was connected to a laptop running Audacity software as an audio backup. Participants wore over-ear headphones (Sony MDR-ZX110NA) through which they listened to recordings or the computer-generated voice played via a Lenovo Windows laptop.

2.4. Statistical analysis

The percentage of disfluent syllables (%ds) was calculated for each of the four conditions by dividing the number of stuttered syllables by the total number of syllables produced in each trial, using the following formula: (Total number of disfluent syllables/Total number of syllables) $\times$ 100. The author manually analysed the disfluent syllables. Stuttering was defined as blocks, prolongations, part and whole word repetitions, however, whole word repetitions did not count as stuttering during SSI-4 analysis (Riley, 2009; see a similar methodological approach Chesters et al., 2018).

The distribution of %ds across experimental conditions was assessed for normality conducting the Shapiro-Wilk test. The primary results revealed non-normal distributions in all conditions ($p < 0.05$). Therefore, the Friedman test, a non-parametric alternative to repeated-measures ANOVA, was carried out to evaluate differences in %ds across the conditions. Eventually, pairwise comparisons were conducted using the Wilcoxon signed-rank test with Bonferroni correction to adjust for multiple comparisons.

To address a potential floor effect (e.g., participants with minimal stuttering having little room for improvement), an additional analysis was conducted on a subset of participants who showed more than 3 % disfluent syllables during the baseline reading condition. This subset included 8 Participants (2, 3, 7, 9, 10, 12, 13, and 14) (see Table 2). The same analyses described above were carried out for this subset to explore whether fluency improvement differed when excluding participants likely affected by a floor effect. Furthermore, after observing the data, a descriptive case-based analysis was reported to document the change in reading duration for the participant with the most severe stuttering (P14), whose reading duration was measured from the beginning to the end of each trial. To investigate the effects of Rec. Alone (see Table 2), a non-parametric Wilcoxon signed-rank test was used to determine whether this condition significantly reduced %ds compared with the baseline reading.

Speech naturalness was evaluated by three independent raters. Two raters held PhDs in Experimental Psychology, and the third was a PhD student in the same department. All raters were native English speakers except one, who had acquired English from early childhood and demonstrated C2-level proficiency which is the highest attainable level according to the International English Language Testing System (IELTS). All raters were blinded to the study's aims and the conditions under which the speech samples were collected. Immediately after listening to each sample, raters independently rated its naturalness based on how closely the speaker's speech aligned with the demographic norms of typical speakers (Martin & Haroldson, 1992; Riley, 2009). Ratings were provided on a nine-point Likert scale, where 1 indicated highly natural-sounding speech and 9 represented highly unnatural-sounding speech. A linear mixed-effects model was used to analyse the ratings, with condition as a fixed effect and, participant and rater as random effects. Inter-rater reliability was calculated across all conditions.

In cases where participants skipped certain syllables, these missing syllables were subtracted from the total read syllables, and the percentage of stuttered syllables was calculated based on the adjusted syllable count specifically for each participant. Additionally, the percentage of missing syllables was calculated for each condition.

3. Results

3.1. Quantitative results

A total of 9193 syllables were analysed in the baseline reading condition (14 participants: 5 missed syllables, 943 stuttered), 7832 in the ChoralR (12 participants: 52 missed, 187 stuttered), 9130 in the ChoralC (14 participants: 68 missed, 183 stuttered), and 8538 in the ReadingWN (13 participants: 3 missed, 868 stuttered). Descriptive statistics for %ds across conditions showed that in both ChoralR and ChoralC, the mean and median %ds fell below 3 %. For the baseline reading, the median (IQR) %ds were 5.93 (1.45–12.10); for ChoralR, 1.67 (1.29–3.25); for ChoralC, 1.15 (0.76–1.52); and for ReadingWN, 5.78 (0.91–13.39) (see Table 2, Fig. 1). The mean (*SD*) %ds were 10.25 (13.77), 2.39 (1.73), 2 (3.48), and 10.16 (13.86), respectively.

The distribution of the %ds across conditions was assessed using skewness and the Shapiro-Wilk test. Severe skewness was seen for ChoralC (3.13), while baseline reading, ChoralR, and ReadingWN showed moderate skewness (1.84, 1.16, and 1.51 respectively). The Shapiro-Wilk test confirmed non-normality for all conditions ($p < 0.05$). Consequently, non-parametric statistical methods were conducted.

A Friedman test revealed significant differences in the %ds across the four conditions (chi-squared = 9.76, df = 3, $W = 0.3$, $p = 0.02$). Pairwise comparisons of the %ds between conditions using the Wilcoxon signed-rank test showed statistical differences after Bonferroni correction. The %ds for the baseline reading were significantly higher than for ChoralC ($W = 101$, $p < 0.01$, $r = 0.89$), but not significantly different from ChoralR ($W = 58$, $p = 0.88$, $r = 0.42$) or ReadingWN ($W = 56$, $p = 1.00$, $r = 0.19$). Although ChoralR and ChoralC showed close median values, the test detected a significant difference ($W = 77$, $p < 0.001$, $r = 0.95$) due to the consistent direction of paired differences among participants, with ChoralR generally showing higher %ds than ChoralC. In contrast, ChoralR and ReadingWN did not differ significantly ($W = 21$, $p = 1.00$, $r = -0.30$), while the comparison between ChoralC and ReadingWN approached significance before correction ($W = 12$, $p < 0.02$, $r = -0.66$) but did not remain significant after statistical correction ($p = 0.10$). Overall, these results showed that ChoralC significantly reduces disfluency compared with the baseline reading and ChoralR condition.

3.1.1. Additional analyses on participants with > 3 % reading disfluency

Given that participants with minimal baseline disfluency had limited room for improvement, an additional analysis was carried out on participants with greater baseline disfluency (> 3 %) to evaluate whether ChoralC remained effective (Participants 2, 3, 7, 9, 10, 12, 13, and 14). For the baseline reading, the median (IQR) %ds were 11.57 (7.42–19.10); for ChoralR, 3.44 (2.02–4.62); for ChoralC, 1.46 (1.10–2.01); and for ReadingWN 13.39 (8.14–24.52). A Friedman test indicated a significant difference across conditions (chi-squared = 13.56, df = 3, $W = 0.90$, $p < 0.01$). Post hoc comparisons using Bonferroni-adjusted p-values showed a significant difference between the baseline reading and ChoralC ($p < 0.05$, $r = 0.94$), replicating the main analysis finding with higher effect size, despite the reduced sample size and statistical power. Comparisons between the baseline reading and ChoralR ($p = 0.21$, $r = 0.86$) and between

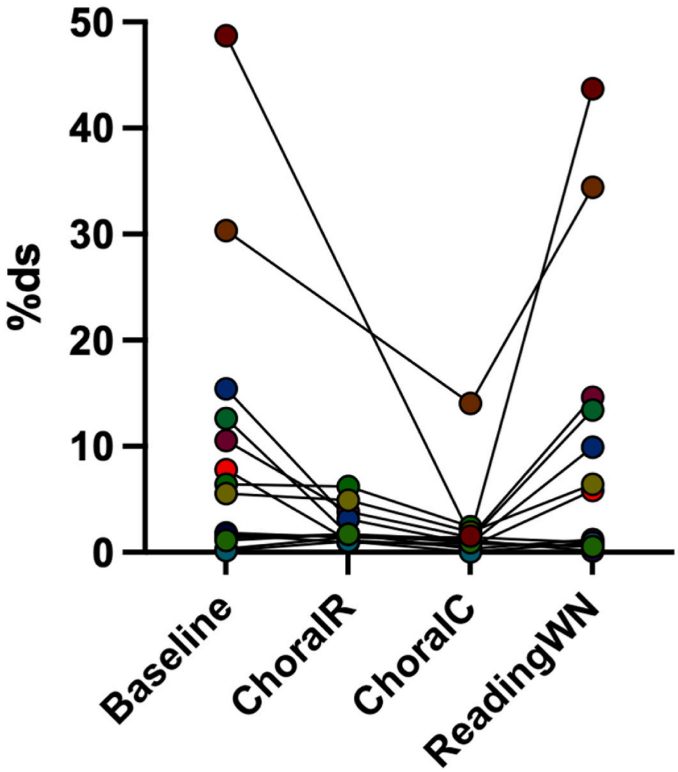

Fig. 1. Percentage of disfluent syllables by experimental condition. The graph illustrates the percentage of disfluent syllables (%ds) across four conditions: Baseline reading (Mdn = 5.93, IQR = 1.45–12.10); ChoralR (Mdn = 1.67, IQR = 1.29–3.25); ChoralC (Mdn = 1.15, IQR = 0.76–1.52); and for ReadingWN (Mdn = 5.78, IQR = 0.91–13.39). Each coloured dot represents an individual participant. Baseline: Normal reading condition without altered auditory feedback; ChoralR: Choral reading with participant's own voice recording; ChoralC: Choral reading with a computer-generated voice; ReadingWN: Reading with white noise condition.

ChoralR and ChoralC ($p = 0.19$, $r = 0.88$) were not statistically significant. It is important to note a descriptive case-based observation, in which P14 reduced their reading duration from 19.5 min in the baseline reading condition to 4.1 min in the ChoralC condition, representing a reduction of over 15 min, together with a decrease in disfluency from 48.7 % to 1.5 %.

3.1.2. Comparison between Rec. Alone and baseline reading

For Rec. Alone, the mean (SD) %ds was 6.83 (8.04) lower than the baseline reading mean of 10.25 (13.77). However, the median %ds of Rec. Alone was slightly higher at 6.16 (1.4–7.11) compared with the baseline reading median of 5.93 (1.44–12.09). Shapiro-Wilk tests indicated that both conditions deviated significantly from normality (Rec. Alone: $W = 0.74$, $p < 0.001$; baseline reading: $W = 0.73$, $p < 0.001$). A non-parametric Wilcoxon signed-rank test showed no significant difference between the two conditions ($W = 27$, $p = 0.12$, $r = -0.42$).

3.1.3. Speech naturalness ratings

For the speech naturalness test, the mean ratings, averaged across three independent raters for the conditions were as follows: reading ($M = 5.57$, $SD = 2.57$), ChoralR ($M = 5.03$, $SD = 1.65$), ChoralC ($M = 4.98$, $SD = 1.70$), and ReadingWN ($M = 5.31$, $SD = 2.71$), with median scores ranging from 5 to 6. The linear mixed-model analysis showed that there were no significant differences in ratings between ChoralC and ChoralR (Estimate = -0.39, p = 1.00), reading (Estimate = -0.60, $p = 0.60$), and ReadingWN (Estimate = -0.43, $p = 1.00$) conditions, based on Bonferroni-corrected pair-wise comparisons. Inter-rater reliability was good to excellent across conditions, with ICC(C,3) values of 0.96 for reading, 0.96 for ReadingWN, 0.89 for ChoralC, and 0.82 for ChoralR, all statistically significant ($p < 0.001$).

3.2. Qualitative results

When participants were asked whether they would consider using the methods tested in this study for presentations in real life, responses varied, reflecting a mix of interest and reservations. Participants' responses were categorised into three groups: 1) likely to use, 2) neutral/unsure, and 3) unlikely to use. Nine participants (P02–P07, P09, P13, P14), importantly all three participants with very severe stuttering, expressed a high likelihood of adopting these methods in real-life situations such as presentations or wedding speeches (Table 3). Most of these participants preferred either ChoralC or ChoralR, with some expressing a preference for both methods. Three participants (P01, P11, P12) were neutral or unsure, stating mixed feelings, due to discomfort with listening to their own voice or the challenge of synchronising speech with the computer-generated voice, which lacked natural breathing, prosody, and timing. Two of the participants preferred ReadingWN and one could prefer either ChoralC or ReadingWN. Finally, two participants with mild stuttering (P08, P10) reported they were unlikely to use any of the methods.

4. Discussion

To the author's knowledge, these are the first preliminary results showing the potential of choral speech as a fluency enhancer in a presentation setting, using self-recorded speech or a text-to-speech decoder without the need for a second human voice. The fluency improvements observed in the choral conditions are consistent with previous research using choral speech, where stuttering rates dropped significantly (Saltuklaroglu et al., 2009). In the present study, the mean (10 %) and median (5 %) baseline reading %ds were reduced to below 3 % for both choral conditions. Analysing only the eight participants with > 3 % baseline reading disfluency replicated the main TTS effect that the improvement persists despite reduced statistical power and is particularly robust for higher disfluent levels. Moreover, the analysis of speech naturalness showed no significant differences across conditions. The ability to reduce

Table 3
Participant responses to preferred methods and likelihood of use. This table summarises participants' stuttering severity, their preferred fluency-enhancing methods (ChoralC, ChoralR, ReadingWN, or none), and their likelihood of adopting the methods for real-life settings. Responses were categorised as "likely to use", "neutral/unsure", or "unlikely to use". Participants with more severe stuttering generally showed a higher likelihood of using the methods, with a preference for ChoralC (see Table 2 for details).

Participant	Severity	Preferred Methods	Response
P02	very severe	ChoralC	likely to use
P03	moderate	ChoralC/ChoralR	likely to use
P04	mild	ChoralC/ChoralR	likely to use
P05	very mild	ChoralR	likely to use
P06	mild	ChoralC	likely to use
P07	moderate	ChoralC	likely to use
P09	mild	ChoralR	likely to use
P13	very severe	ChoralC	likely to use
P14	very severe	ChoralC	likely to use
P01	mild	ReadingWN	neutral/unsure
P11	mild	ReadingWN	neutral/unsure
P12	moderate	ChoralC/ReadingWN	neutral/unsure
P08	mild	None	unlikely to use
P10	mild	None	unlikely to use

stuttering under severe conditions without breaking perceived speech naturalness is promising, as it points to the versatility of this approach for PWS seeking fluency improvements in structured presentations.

This finding was further supported by participants' self-reported preferences, as those with higher stuttering severity showed an interest in using the computer-generated choral speech method in future presentations. This is important because as people with severe stuttering have expressed a willingness to use this method in real-life settings, it could serve as a valuable tool for clinicians as well. By incorporating it into gradual exposure therapy, this method may help clients overcome public speaking avoidance and reduce speech-related anxiety over time.

As mentioned in the Results section, two participants (P13 and P14) were excluded from the choral reading with own voice recording condition due to their high stuttering levels. This decision was based on the observation that their severe disfluencies in their recording would prevent a reliable choral effect, thus compromising the validity of the results. Although this exclusion introduces a limitation related to missing not at random data, it was necessary to maintain the integrity of the analysis. Importantly, this approach also enhances the ecological validity of the study, as it reflects the practical limitations faced by people with severe stuttering who may not be able to use a self-recorded voice for choral speech.

4.1. Possible real-life implications

The current study suggests that the effect of choral speech using a computer-generated voice were most evident in participants with higher baseline disfluency. After excluding the six mildest baseline disfluency from the analysis, ChoralC lowered median disfluency from 11.6 % to 1.5 %, highlighting its robustness for severe stuttering. P14, who scored at a very severe stuttering level on the SSI-4, reduced their disfluency from 49 % to 2 % and shortened their reading duration from approximately 19 to 4 min under the ChoralC condition compared with the baseline reading condition. These findings suggest that ChoralC has the potential to serve as a powerful fluency enhancer for people with stronger stuttering severity (compare with other fluency enhancers: Saltuklaroglu et al., 2009). For example, in a possible real-life scenario, a person with severe stuttering could prepare their speech in advance for an upcoming presentation, input it into a TTS decoder application in their phone, and then deliver the presentation while synchronising their speech with a computer-generated voice through wireless earphones. This method could significantly enhance fluency, potentially reducing stuttering to near-absent level while maintaining a natural-sounding speech.

The ChoralR condition was less effective for people with severe stuttering, which can largely be attributed to the discontinuation of this condition for the two participants classified as having very severe stutter. Their high disfluency rates in the Rec. Alone condition (P13: 25 % disfluency; P14: 24 % disfluency) rendered the recordings inadequate for providing the necessary continuous auditory feedback to facilitate successful choral speech. As the primary aim of this study was to explore optimal presentation strategy for PWS, these results suggest that ChoralC may serve as a more suitable method for people with severe stuttering. However, it is important to consider a personalised approach when recommending methods, as some participants reported that the computer-generated voice in ChoralC lacked naturalness, especially in its omission of natural breathing pauses and prosody. This highlights the need for individualised solutions that balance fluency enhancement with comfort. Advances in artificial intelligence may soon allow TTS decoders to produce more human-like prosody (Kaur & Singh, 2023), including natural breathing rhythms and potentially matching the user's voice tone, thus improving the naturalness of computer-generated speech. Until such advancements are realised, ChoralC appears to be the most promising option for those with severe stuttering, while people with mild to moderate stuttering may benefit from a choice between ChoralC and ChoralR based on personal preference and speaking context.

These findings pave the way for further investigation of choral speech with TTS as a practical fluency aid in various real-life public speaking situations, such as presentations, teaching, or ceremonial speeches. Beyond the immediate benefits of fluency, it could be argued that this method can play an important role in reducing social anxiety associated with public speaking for PWS (Blumgart et al., 2010; Craig & Tran, 2014; Iverach et al., 2009; Iverach & Rapee, 2014). Achieving fluency in a high-pressure situation could serve as part of an exposure therapy, prevent avoidance, and potentially decreasing the social anxiety tied to public speaking. For example, a person who experiences anxiety about stuttering in front of an audience could use choral speech through wireless earphones, assisting them to deliver a fluent presentation and, over time, build confidence by more exposure. Even though this can be considered as a practical tool, much like using reading glasses, it is important to recognise that fluency alone in public speaking does not address the broader social and emotional aspects of stuttering all together. The anxiety of negative judgment, embarrassment, and social rejection in spontaneous speaking situations needs to be addressed separately (Craig & Tran, 2014; Iverach et al., 2009; Iverach & Rapee, 2014; Yaruss, 2010). Thus, in parallel with temporary fluency interventions, further research should investigate therapeutic approaches to eliminate stuttering in spontaneous conversations for those who want to work on their fluency while preserving speech naturalness and to mitigate the social anxiety associated with stuttering.

4.2. Within and between individual variabilities during recording-alone

Stuttering is not merely a motor related phenomenon. It has been long known that PWS tend to stutter to a lesser extent when alone compared with social situations requiring communicative intent (Andrews et al., 1982; Hahn, 1940; Jackson et al., 2021; Martin & Haroldson, 1988; von Krais Porter, 1939). Based on these findings, one of the hypotheses was that participants in the current study would experience improved fluency when recording their speech alone. Although the mean stuttering frequency showed a slight reduction (from 10 % to 7 %), a non-parametric test was conducted due to the non-normal distribution of the data, found no significant result difference between groups.

After being asked, some participants speculated that they might have been more fluent if they had not submitted their recordings to the researcher. These insights are compatible with earlier research suggesting that simply the awareness of being recorded and the idea of an audience (in the future) can maintain some levels of stuttering (Hahn, 1940). Jackson et al. (2021) further demonstrated that stuttering was eliminated during a self-directed speech task, where participants spoke privately without communicative intent and were unaware of being recorded. This reinforces the idea that the perception of being listened to or anticipation of they would be heard, can act as a trigger for stuttering (Alm, 2014). In this current study, this effect might have been present as well, as the act of recording likely triggered stuttering due to participants anticipating that their speech would eventually be judged, since they were instructed to send or bring their recordings to the researcher. This self-consciousness, "mentalising" the audience's expectations, and potential negative social evaluation seem to trigger stuttering, is in consistent with the idea that communicative intent and social judgement, whether real or imagined, may play a role in stuttering.

5. Limitations and future directions

One limitation of the study is that the Rec. Alone was analysed by using only audio recordings rather than video. This might have led to an underestimation of silent blocks, which could be harder to detect without visual cues of physical concomitants. Additionally, it could not be confirmed that participants were truly alone during Rec. Alone, which could have influenced participants' level of fluency.

Another limitation is the small sample size, consisting of 14 participants, including 7 with moderate to very severe stuttering, who, as the data suggest, may benefit more from this method. It is possible that a floor effect exists for people with mild stuttering, leaving little room for further enhancement of speech fluency through choral speech conditions. Future research can focus specifically on people with moderate to very severe stuttering to better understand for individual variability within this group, such as by using AI to replicate person's natural speech tone and rhythm. Additionally, practicing choral speech, particularly by becoming accustomed to using headphones and adjusting factors like speed and volume to suit individual preferences, may help people exert less effort and achieve greater fluency improvements over time.

It should be noted that the study used simulated presentation delivered in front of a researcher and camera rather than a live audience. Future research should evaluate this method in real public speaking contexts to provide evidence for its generalisability. Furthermore, the analyses of stuttering rates and severity were conducted by the author. While inter-rater and intra-rater reliability analyses demonstrated high consistency, the use of blinded raters would have further enhanced the robustness of the results by eliminating potential bias in scoring. In the exploratory analysis, the majority of participants, particularly those with very severe stuttering, reported a high likelihood of adopting this method in real-life situations. An element of potential compliance bias, as is possible in qualitative research, should be considered when interpreting this finding.

An unexpected finding was the lack of improvement in fluency during the white noise condition, where participants showed the same average stuttering frequency of 10 % disfluencies was seen in baseline. This may be attributed to the absence of noise-cancelling headphones and/or 60 decibels of white noise, which could have diminished the effectiveness of the white noise in facilitating fluency (Garber & Martin, 1974).

6. Conclusion

This exploratory study tested a novel application of choral speech as a potential tool for PWS to deliver structured presentations fluently. Results suggested that the choral speech method, especially when PWS spoke in unison with computer-generated voices, caused a significant reduction in stuttering, by bringing it to near-absent levels. An additional analysis focusing on a subset of participants with higher baseline disfluency replicated the main findings despite reduced statistical power, suggesting that the benefits of this method are particularly robust for people with higher baseline disfluency. This approach may offer a practical option for PWS to significantly reduce stuttering during structured presentations. Future advancements in AI could enhance the naturalness of computer-generated voices, making the choral speech experience more comfortable and aligned with the speaker's own prosody, stuttering patterns and rhythm. Furthermore, future research may explore the potential integration of this method into exposure therapy to support PWS in addressing avoidance and anxiety related to public speaking.

CRediT authorship contribution statement

Birtan Demirel: Writing – review & editing, Visualization, Software, Project administration, Investigation, Formal analysis, Conceptualization, Writing – original draft, Validation, Resources, Methodology, Funding acquisition, Data curation.

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Declaration of Competing Interest

The author declare that they have no competing interests.

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Birtan Demirel recently earned a PhD in Experimental Psychology from the University of Oxford and has begun working as a postdoctoral researcher at the same institution. His research includes neuroimaging (MRI, fMRI, MEG), non-invasive brain stimulation and virtual reality to investigate neural and psychological correlates of stuttering. During his PhD, he contributed to eight studies. He is the first author of a paper on language lateralisation in people who stutter, published in the *Brain Communications journal*, and has a pre-registered, first-author accepted paper in the *Neurobiology of Language* journal examining the efficacy of theta-gamma peak frequency stimulation in sensorimotor learning for speech production. He also worked as a tutor in neurophysiology at St Anne's College.