Speech with pauses sounds deceptive to listeners with and without hearing impairment

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Abstract

Purpose: Communication is as much persuasion as it is the transfer of information. This creates a tension between the interests of the speaker and those of the listener as dishonest speakers naturally attempt to hide deceptive speech, and listeners are faced with the challenge of sorting truths from lies. Hearing impaired listeners in particular may have differing levels of access to the acoustical cues that give away deceptive speech. A greater tendency towards speech pauses has been hypothesised to result from the cognitive demands of lying convincingly. Higher vocal pitch has also been hypothesised to mark the increased anxiety of a dishonest speaker.

Method: listeners with or without hearing impairments heard short utterances from natural conversations some of which had been digitally manipulated to contain either increased pausing or raised vocal pitch. Listeners were asked to guess whether each statement was a lie in a two alternative forced choice task. Participants were also asked explicitly which cues they believed had influenced their decisions.

Results: Statements were more likely to be perceived as a lie when they contained pauses, but not when vocal pitch was raised. This pattern held regardless of hearing ability. In contrast, both groups of listeners self-reported using vocal pitch cues to identify deceptive statements, though at lower rates than pauses.

Conclusions: Listeners may have only partial awareness of the cues that influence their impression of dishonesty. Hearing impaired listeners may place greater weight on acoustical cues according to the differing degrees of access provided by hearing aids.

Introduction

Non-verbal cues are an essential source of information that can clarify a speaker's attitudes and intentions. These cues give listeners indications of the meaning of the speaker's message, which are often non-literal and occasionally wholly untrue. Deception in particular presents a challenge to the listener, as the speaker attempts to hide their intentions rather than to communicate them. These can take the form of prosocial lies that spare the feelings of the listener or outright lies that are counterfactual (DePaulo et al., 2003; DePaulo & Bell, 1996). To the great fortune of the listener, even experienced liars may sometimes give themselves away with non-verbal and gestural tells that are difficult to control (Ekman et al., 1976). However, verbal tells may not be equally available to all listeners. For instance, though people with hearing impairments may regain partial hearing by the use of hearing aids, these devices are often optimised more for the intelligibility of the segmental contents of speech than for paralinguistic voice cues such as vocal expressions of emotion (Hopyan-Misakyan et al., 2009; Most & Aviner, 2009; Waaramaa et al., 2018).

Valid cues of deception are most likely to be found in features over which speakers have relatively poor voluntary control. Dishonest speakers are likely to suppress features which may give them away (Greene et al., 1985; Zuckerman et al., 1981). It is unlikely that any single cue reliably indexes lying as such simplicity would be too readily exploited by dishonest speakers. Indeed, the cues which most reliably give away deception may be idiosyncratic. However, two vocal cues – namely, the presence of pauses and increased vocal pitch – have emerged as candidates for broad markers of deception that may escape the speakers attempts to control them (DePaulo et al., 2003).

Lying is more cognitively demanding than telling the truth, and liars may therefore have greater cause to stop and think (Zuckerman et al., 1981). The need to monitor the plausibility of counterfactuals increases the cognitive load on the speaker, which may delay speech planning, leading to more and longer pauses in speech. Indeed, beyond the context of deception, greater cognitive load is associated with more pause-laden speech (Bóna & Bakti, 2020). There is some evidence to suggest that pauses are reliable indicators of deception (Chen et al., 2020; Zhang et al., 2022), however these findings are not always replicated, leading to effect sizes that are small on average (DePaulo et al., 2003; Sporer & Schwandt, 2006). This inconsistency may be attributable to differences in experimental design (Ekman et al., 1991). Pauses may be present when highly motivated speakers need to improvise deception but absent when they have time to prepare or are not invested in the outcome (DePaulo et al., 2003; Sporer & Schwandt, 2006). Regardless, listeners do utilise pauses in detecting deceptive speech (Loy et al., 2018) and become more effective lie detectors when they are trained to do so explicitly (deTurck, 1991).

Lying may also be anxiogenic (Ekman et al., 1976; Sondhi et al., 2017), causing increased physiological arousal which is marked in the voice by increased vocal pitch (Bachorowski & Owren, 1995; Giddens et al., 2013). The putative mechanism of action is that physiological arousal increases muscle tension, including within the muscles of the larynx (Ekman et al., 1991). Increased tension in the muscles of the larynx causes the vocal folds to vibrate at a higher frequency, which is perceived as higher vocal pitch (Kempster et al., 1988; Titze & Story, 2002). This association between stress and vocal pitch is illustrated by studies of communication in high-risk situations, such as aeronautical manoeuvres (Simonov et al., 1980). There is some evidence to suggest that stress induced vocal-pitch increases may also indicate deception, though less markedly (Chen et al., 2020; DePaulo et al., 2003; Scherer et al., 1985; Sporer & Schwandt, 2006; Streeter et al., 1979).

People with hearing impairments may have differing access to these acoustical cues to the extent that hearing aids relay some cues more reliably than others. For example, people with hearing impairment have greater difficulty decoding a speaker's emotional state than do their peers with normal hearing (Chatterjee et al., 2015; Most & Aviner, 2009; Yeshoda et al., 2020). However, there is some evidence to suggest that people with hearing impairments can detect dishonest speech, though they may misidentify aspects of the speaker's motivation that distinguish between selfish lies, white lies, and irony (González-Cuenca & Linero, 2020).

The present study sought to experimentally test the relative influence of pauses and vocal pitch on perceived deceptiveness by digitally manipulating samples of natural speech. This experiment was repeated in participants with or without hearing impairment in light of probable differences in the degree to which these acoustical cues are available to them. We hypothesise that if participants with hearing impairments have reduced access to acoustical cues to deception, their attributions of dishonesty will be more evenly distributed across conditions than the attributions of their hearing counterparts.

Methods

Participants

One hundred participants ages 18-40 years were recruited to take part in this study, 50 with normal hearing (28 female, 22 male) and 50 with self-reported hearing impairments (31 female, 19 male). Participants were recruited on the basis of having reported normal hearing or hearing impairment, respectively, upon registering with an online participant recruitment platform (www.prolific.co). While this recruitment strategy does not permit independent assessment of hearing status, it does ensure that self-identification was not influenced by study demands. Further information regarding the severity of hearing loss and assistive devices used were not collected as participants may not know the severity of their hearing loss.

All participants reported English as their first language spanning a diverse range of accents. The sample was 42% British, 38% American, 10% South African, 6% Canadian, and 1% each of Indian, Greek, Dutch, and Polish.

Participants were also screened for normal or corrected vision and Prolific approval rating above 90%. The approval rating is the percentage of studies which the participant has completed satisfactorily. Participants were paid for 15 minutes of participation at a rate of £7.50/hr.

Ethics

Informed consent was obtained from all participants and the research protocol had been approved by the University College London Ethics Committee (Approval ID Number: SHaPS-2019-CM-030).

Stimuli

Audio recordings were obtained from the London UCL Clear Speech in Interaction (LUCID) corpus (Baker & Hazan, 2011). The corpus was derived from recordings produced during a Diapix task in which pairs of participants played a 'spot the difference' game using a picture of a beach scene. For the purposes of the present study, audio clips were derived from four British English speakers (two male and two female). Twenty-five short clips were selected for each of the four speakers, providing a total of 100 unique audio clips. The clips each contained a clear and coherent short phrase with a self-contained meaning that were distinct across the set and lasting a single breath phrase of 4 to 6 seconds in duration. Stimuli were digitally edited to remove filled pauses (e.g., "ums") and silent pauses longer than 2 seconds where possible without disrupting the integrity of the speech sample. All stimuli were normalised to equal sound intensity levels using Praat software 6.1.38 (Boersma & Weenink, 2019).

All statements in the original speech corpus were spoken as truths, however the audio clips were altered to contain voice cues (silent pauses or higher vocal pitch) which have been hypothesised to increase the likelihood that a statement is perceived to be a lie. Three versions of each clip were created which had i) raised vocal pitch, ii) additional silent pauses, or iii) exposure to the same digital processing pipeline but otherwise unaltered.

Separate pitch and pause manipulations were introduced at approximately twice the estimated voice change observed in previous speech production studies to ensure that manipulations were strong but ecologically meaningful (Villar et al., 2013; Zhang et al., 2022). Hence, pitch shifted stimuli were transposed 3 semitones upwards using an in-house Praat script. Versions of the stimulus containing silent pauses were created by manually inserting 2-3 silent gaps of 500 ms at phrase boundaries or during naturally occurring pauses (see Figure 1). These stimuli were also processed with the pitch transposition script to produce a shift of 0 semitones (i.e., pitch unchanged) to ensure that all stimuli were exposed to the same pipeline. This procedure was repeated for 25 audio clips from each of four speakers (two female) to a total of 300 stimuli.

The individual audio clips may vary in the degree to which they are perceived as being dishonest based on the semantic contents of speech alone. Therefore, three alternative counterbalancing sets were created for the lie-perception task. Each recorded clip appeared once in each set, in the baseline, pause, or pitch conditions, respectively. This arrangement ensured that stimulus items appeared in each condition with similar frequency. Participants were randomly assigned to one of the three counterbalancing sets, and trials appeared in a random order for each participant.

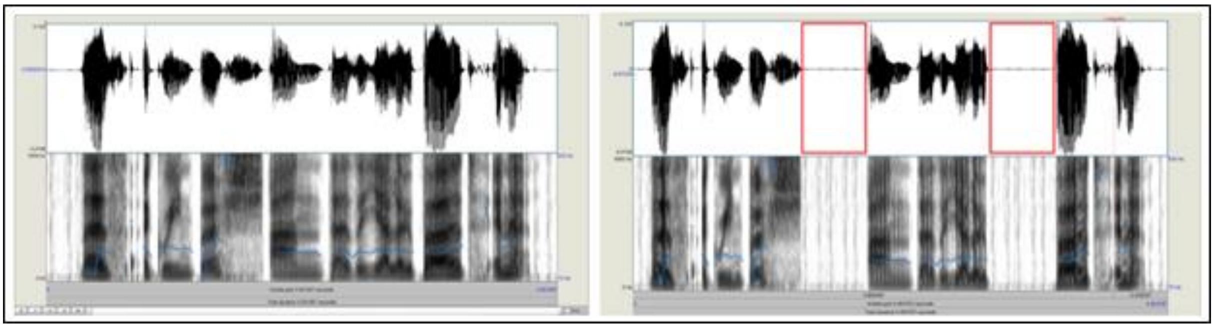

Figure 1. *Left: Waveform (upper) and spectrogram (lower) of an audio clip. Right: The same recording with two 500 ms silent pauses as indicated by the red boxes. The altered audio clip: 'There's a green bush (silent pause) and there's a (silent pause) yellow bird in it'.*

Lie-perception task

The experiment was created and hosted using Gorilla.sc, an online experiment builder (Anwyl-Irvine et al., 2020). Participants accessed the experiment through Prolific and ran the study online through their browsers. The participants were provided with instructions on how to enable their browser's auto-play functionality, and optional debugging instructions as needed. Participants were given explicit instructions to not wear headphones for this study as headphones may not be compatible with certain kinds of hearing aids. Participants were further instructed to complete the experiment in a quiet place, using a PC or laptop. The clips were to be played in free field and participants were given opportunities to adjust the volume of their device to a comfortable level.

In an initial familiarisation period, participants were exposed to 2 short clips of each of the four speakers to provide context for each speaker at baseline. Participants were then instructed: '*You will hear some statements describing a beach. Some statements are true and some are false. Your task is to listen to the following statements and decide whether they are true or a lie. You may hear occasional automated instructions, please follow them accordingly. These are to verify your participation'*. On each trial, participants were played a stimulus and asked to indicate whether 'this statement was a LIE' or 'this statement was TRUE'. Participants completed 99 trials divided evenly between the three conditions (control, pitch, pause).

Catch trials

Six catch trials were also included to verify that participants were attentive and actively engaging with the task. On these trials, participants were played a synthesised voice instructing them to 'please press lie' or 'please press true'. Participants who made more than 1 error on catch trials were excluded from further data analysis and replacement participants were recruited.

Free response box

At the end of the experiment, the participants were shown a free-response comment box and invited to indicate which cues they used to decide which statements were lies.

Analysis

The proportion of trials on which the stimulus was perceived to be a lie was tabulated for each participant and each condition. The proportion of lies were modelled using generalised Linear Mixed Models (gLMMs) in R (Bates et al., 2015; R Core Team, 2019). Models took the following form a binomial family distribution using a logit link:

eq (1) *Proportion_Lie ~ 1 + Hearing*Condition + (1 | Participant)*

The outcomes written in the free-text response box were manually coded by B.P. Word clouds were created from the raw text to permit interpretation free exploratory of these descriptions. Counts of words semantically related to pauses (e.g., pause, hesitation), pitch (e.g., tone), or the semantic contents of speech were tallied for explicit comparison.

Results

Quantitative measurement of implicit beliefs about deception cues

The median proportion of trials on which participants suspected a lie was 0.37 [CI = 0.35, 040]. Statements that contained pauses were more likely to be perceived as a lie compared to control statements (Z = 3.98, $p < .001$, estimate = 1.98, CI = [1.10, 3.43]). Estimates are log-odds describing the odds of responding that a statement was deceptive. The odds-ratio is therefore exp(1.98) = 7.2, indicating a seven-fold increase in the odds of reporting that a statement sounded deceptive when they contained pauses (see Figure 2).

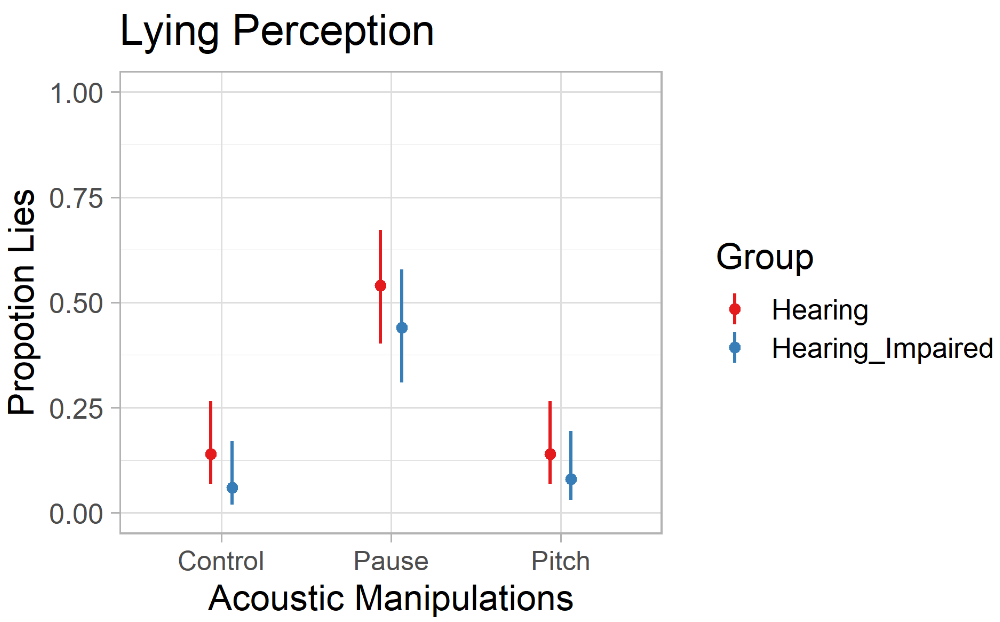

Figure 2: *The proportion of utterances that were perceived to be lies. Points indicate estimates from logistic regression with 95% confidence intervals.*

In contrast, increased vocal pitch had no effect on perceived deceptiveness (Z = 0, *p* = ~ *1*, estimate = 0.00002, CI = [-1.30, 1.29]). Participants with hearing impairments had a non-significant bias towards reporting that statements were true (Z = -1.29, *p* = *.194*, estimate = -0.093, CI = [-18.8, 0.45]). There was no interaction between hearing status and the acoustic manipulations. There was no detectable difference between the influences of pause cues (Z = 0.69, p = 0.517, estimate = 0.054, CI = [-1.10, 18.26])) or pitch cues (Z = 0.32, *p* = *.752*, estimate = 0.031, CI = [-1.89, 18.06]) between these group indicating that both groups were influenced similarly.

Qualitative measurement of explicit beliefs about deception cues

Ninety-six participants recorded free-text comments in response to a prompt asking for a self-assessment of the cues which they believed that they had used to identify deceptive statement (49 hearing participants and 47 hearing-impaired participants). From the normal hearing group, 26 (53.1%) wrote comments semantically related to pauses or similar (e.g., hesitancy), while only 16 (33%) wrote about using pitch cues (e.g., tone). Within the hearing-impaired participants, 32 (68%) wrote about pause cues and only 10 (21%) wrote about pitch differences in stimuli.

The rate at which participants mentioned words semantically related to pause or pitch by hearing or hearing-impaired listeners was modelled using a generalised linear model following a Binomial distribution. Statements related to the contents of speech were also included in the model as the most frequently mentioned category outside of the experimental manipulations (see Figure 3).

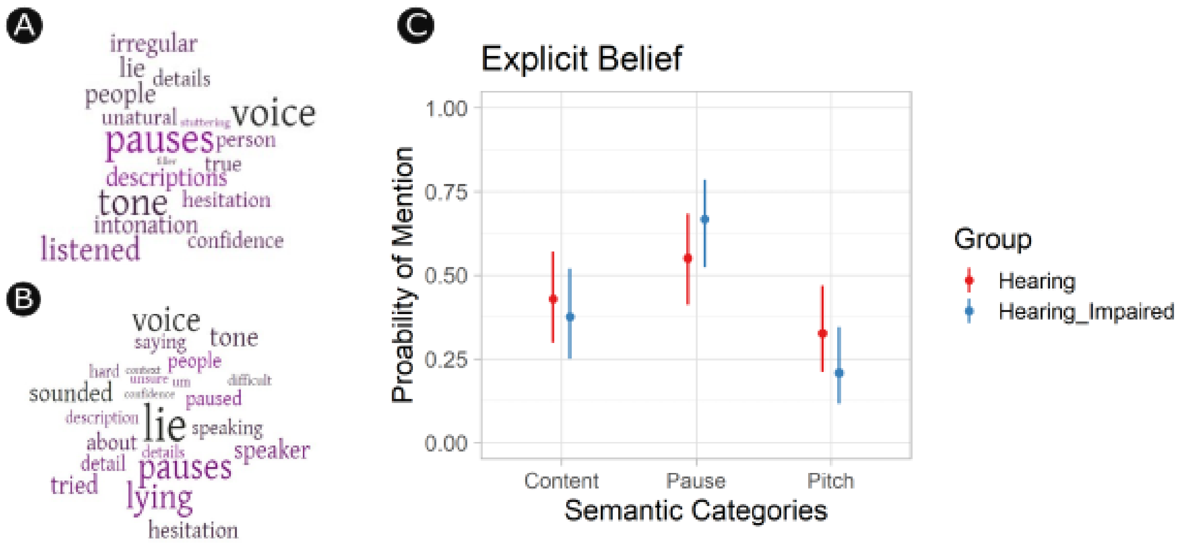

Figure 3: *A) Word clouds based on the frequency of mentions in free response on explicit beliefs about what makes speech sound like a lie in hearing and B) hearing-impaired listeners. Only 5 of 96 respondents commented that the stimuli were irregular or unnatural. C) The proportion of listeners who mentioned words semantically related to the contents of speech, pauses (e.g., hesitation, stammer), or pitch (e.g., tone). Points indicate estimates from logistic regression with 95% confidence intervals.*

Hearing-impaired listeners had insight into the cues that influenced their precepts of deception. Hearing-impaired listeners were less likely to mention the semantic contents of speech than pauses (Z-ratio = -2.8, $p = .015$, odd-ratio = 0.3), and more likely to mention pauses than vocal pitch (Z-ratio = 4.3, $p < .001$, odd-ratio = 7.6). While the findings from listeners with normal hearing were qualitatively similar, they were not statistically significant after Bonferonni correction for multiple comparisons (semantic content: Z-ratio = -1.2, $p = .68$, odds-ratio = 0.6, pauses: Z-ratio = 2.2, $p = .08$, odds-ratio = 1.1).

Other frequently mentioned cues to deception included the content of stimuli (41%), filler pauses (28%), confidence (12%), and intuition (12%). We also note that a minority of participants (6.25%) mentioned stuttering or stammering as an indicator of dishonesty, which may have implications for people whose speech naturally contains dysfluency.

Discussion

Listeners displayed a strong tendency to interpret pauses as indicative of a lie, which is consistent with cognitive load accounts of deception. In contrast, listeners displayed no tendency to interpret speech with increased vocal pitch as containing a lie. This pattern was replicated across participants with normal hearing and those with hearing impairments. Interestingly, there appears to be a partial mismatch between listeners' implicit beliefs about the cues that indicate a lie and their explicit judgements about potentially dishonest speech, with listeners overestimating the degree to which they made use of vocal pitch cues.

Listeners and speech scientists alike share a difficult challenge: speakers who are being deceptive may attempt to control cues that would otherwise reveal their dishonest intentions (Greene et al., 1985; Zuckerman et al., 1981). However not all cues that are present in the voice are equally amenable to control and listeners may attend selectively to cues that provide honest information about the intentions of the speaker. We observed that listeners make the most use of channels of communication in which the opportunities for deception are limited. This is line with findings from communicative systems across a broad range of species; listeners make the greatest use of signals that are biologically constraints to limit the opportunities for deception (Maynard Smith & Harper, 2003; Searcy & Nowicki, 2005).

The primacy of pauses

The problem of deception is made particularly acute by the faculty of language. Speech is generative which allows speakers to express an infinite range of meanings, only a small minority of which are true. Our observation that pauses are more strongly utilised by listeners as a cue to deception is consistent with previous findings, that pauses are indeed strongly indicative of deception (Chen et al., 2020; Levitan et al., 2018; Vrij, 2019; Zhang et al., 2022).

While it is possible that vocal pitch may yet provide some indication of deceptiveness (DePaulo et al., 2003; Sporer & Schwandt, 2006), it is also a channel of communication which informs a singularly extensive range of information. For example, the voice of an adult female has fundamental frequency approximately double that of an adult male, and the voices of children are higher still. Within the sexes there are consistent individual differences in voice pitch which may be due to biological factors (Pisanski et al., 2016). Within individual speakers, vocal pitch is also highly dynamic. At a slow timescale the voice may change along with hormonal cycles (Gunjawate et al., 2017; Pavela Banai, 2017). On a rapid timescale the voice is used to convey an impressive range of communicative effects. These include involuntary voice modulations such as the expression of genuine emotions (Bachorowski et al., 2001; Scheiner et al., 2006), bioacoustic correlates of the sound intensity of vocalisation (Titze, 1989), and declination across a breath phrase (de Looze et al., 2015; Pierrehumbert, 1979). Vocal pitch is also influenced by a number of voluntary factors including expressions of emotional states (Banse & Sherer, 1996; Belyk & Brown, 2014), linguistic prosody (Fonagy, 1978; Ladd & Morton, 1997), and in many languages the use of linguistic tone (Yip, 2002).

Notably, vocal pitch is controlled by a complex of muscles in the larynx (Titze et al., 1989; Titze & Story, 2002) over which humans have an unusually high degree of voluntary control (Belyk & Brown, 2017; Fischer & Hammerschmidt, 2019; Nieder & Mooney, 2019). Any influence that the anxiogenic properties of deception may have on the voice are liable to be masked by either the broad range of cues that are carried by the voice, or by the deliberate control of the deceiver. From the present data, it appears that listeners have at least an implicit understanding that vocal pitch cues may therefore be unreliable cues to deception. Interestingly, there is stronger evidence to suggest that listeners utilise pitch cues in gauging whether a speaker is trustworthy, i.e., less liable to engage in deception over the long term (Belin et al., 2017; Knowles & Little, 2016; Mahrholz et al., 2018; McAleer et al., 2014). How vocal indicators of the trait of trustworthiness and the state of lying may interact requires further investigation.

Implicit vs. explicit

While we observed that listeners were more strongly influenced by pauses than vocal pitch, there was little evidence that they had an explicit awareness of this distinction. Interestingly a modest self-knowledge of the preference for pauses was observed for the hearing-impaired listeners only.

We also note that a minority of listeners spontaneously reported stuttering (US English) or stammering (UK English) as a cue which may reveal deception. Stuttering is a speech disorder characterised by part word repetitions, prolongations, and pauses (Wingate, 1964). The unexpected semantic association between deception and stuttering was observed despite the absence of genuine stutters among the experimental stimuli. In addition to the physical realities of their speech people who stutter experience of communication can be exacerbated by stigma (Boyle, 2018; Boyle & Blood, 2015). Our findings suggests that this stigma may extend to how trustworthy they are perceived to be by some listeners.

Hearing aids

The tendency to rely on pauses over vocal pitch as a cue to deception was observed in both hearing and hearing-impaired participants. Notably, while the use of auditory cues was qualitatively similar in both groups, participants with hearing-impairments demonstrated a more accurate explicit understanding of the auditory cues that influenced their decisions. These broad similarities between the hearing and the hearing-impaired may be due to a tendency for hearing aids to be optimised for the temporal cues that drive speech intelligibility over spectral cues related to vocal pitch.

However, we note that these features may vary across devices, and we are not aware of systematic tests that have explicitly compared the fidelity of transmission of low-level acoustical features across makes and models of devices.

Previous research has demonstrated that people with hearing-impairments can readily identify non-literal statements, such as irony and lies, but nonetheless have difficulty parsing a speaker's underlying motivations (González-Cuenca & Linero, 2020). This may be due to emotional and attitudinal elements of prosody loading strongly onto spectral voice cues (Banse & Sherer, 1996; Belyk & Brown, 2014; Juslin & Laukka, 2003) to which they have reduced access.

The emotional state of a speaker provides a rich source of paralinguistic information, and indeed is the putative mechanism that has been proposed to drive pitch cues to deception. However, listeners with hearing impairments may have more difficulty recognizing emotions from vocal cues (Christensen et al., 2019), and instead rely on visual cues such as facial expressions and body language (Hopyan-Misakyan et al., 2009; Most & Aviner, 2009; Waaramaa et al., 2018). These visual cues provide a parallel and complementary informational channel that influences listeners judgements of deception (King et al., 2020), which may be relied upon to a increasing degrees with greater hearing-impairment (Picou et al., 2018) or in noisy environments (Chatterjee et al., 2015). These difficulties present during early childhood but may be mitigated by explicit training (Yeshoda et al., 2020). Similar cues drive emotional expression in music and are likewise not easily accessible to hearing aid users (Chasin & Russo, 2004). Hearing aid users may have difficulty recognizing emotions from the melodic line of musical scores relative to those with cochlear implants and may instead rely on variation in intensity and tempo to compensate for reduced access to the pitch cues that hold a melody (Kong et al., 2004; Whipple et al., 2015). This may be due to hearing aids in particular providing reduced access to spectral cues. Users of hearing aids report that music sounds less melodic, and this effect is most prominent with greater degrees of hearing impairment (Looi et al., 2019). Though difficulties in music listening may vary, a majority of hearing aid users report difficulty in listening to music while only a minority have discussed music listening with their audiologist (Greasley et al., 2020).

We observed broad similarity in percepts of deception between listeners with and without hearing impairment. While listeners with hearing impairments may make less use of paralinguistic vocal-pitch cues in general, listeners with normal hearing also did not interpret increased vocal pitch as indicative of a lie. Hence, this similarity may be due to a consensus among listeners that vocal pitch is an unreliable indicator of deception. The preference of hearing-aid users for temporal cues, such as pauses, may also lead them to provide greater weight to these more reliable cues to deceptive speech (Zhang et al., 2022). We note as well that this experiment contained auditory cues only, and that in live conversational contexts paralinguistic speech cues are supplemented by body language cues.

Limitations

All experiments were collected via online testing. Although participants were asked to complete the experiment in a quiet environment, this could not be independently verified. Hearing impaired participants were recruited on the basis of self-identification via their Prolific profiles. However, the study did not have access to more detailed information about the extent of hearing impairment or to the specifications of hearing aids used by individual participants. It is therefore not possible from the present data to evaluate whether findings are heterogenous across this group. Further studies are needed to evaluate the influence of these potentially mediating factors.

Vocal pitch manipulations consisted of global increases in vocal pitch in line with predictions from the arousal theory of deception. However, it remains possible that more complex changes in pitch contour not tested here may yet prove to be informative (Fish et al., 2017). Finally, no experimental stimulus contained a genuine lie, and as such stimulus manipulation itself may have reduced the naturalness of speech tokens. None-the-less, care was taken to preserve the naturalness of speech as much as possible by inserting pauses at phrase boundaries where naturally occurring pauses are most likely to occur. Despite these limitations, participants readily responded that a large proportion of statements were dishonest and did so systematically despite extensive counterbalancing. This design choice permitted the researchers to calibrate the degree of vocal pitch modulation and pause durations in proportion to estimates from previous experiments (Villar et al., 2013; Zhang et al., 2022). This method presents an inevitable trade-off between experimental control and ecological validity, which should be addressed by complementary research using more naturalistic but less well controlled stimuli.

Conclusions

Artificially introducing pauses into honest statements made listeners more likely to believe that the statements were dishonest. In contrast, artificially raising vocal pitch had no measurable effect on listeners. These findings are consistent with a cognitive load account of vocal markers of deception, and inconsistent with physiological arousal-based accounts. This pattern of findings was observed in equal measure in listeners with or without hearing impairments. Hearing-impairment may not have a detrimental effect on the ability to detect deceptive speech, which may be due to the high fidelity with which hearing aids transmit the temporal auditory cues that most strongly mark deceptive speech.

Data Availability

Data and analysis code are available in supplementary materials.

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Supplementary Materials

Patel_S1_RawData.csv: Anonymised but otherwise unprocessed data. Each row corresponds to one experimental trail, columns indicate the participant code, their hearing status, the name of the auditory stimulus, attributes of the stimulus such as experimental condition, and the participants response.

Patel_S2_ProportionData.csv: Processed data. Each row corresponds to one experimental condition for one participant. Columns indicate the participant code, their hearing group, experimental condition, and the proportion of responses that the participant indicated as a lie.

pate_S3_OpenCode.R: Reproducible code used to conduct analyses.