GENDERED SCIENCE COMMUNICATION: THE ROLE OF SPEAKER GENDER & PITCH IN PERCEIVED CREDIBILITY AND PERSUASION OF CLIMATE SCIENCE

BY

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ABSTRACT

Science communication is necessarily concerned with not only education, but also persuasion: strong persuasive messages have the power to shape scientific beliefs and influence policy support, especially for highly politicized topics such as climate change. Following the political psychology subfield of persuasion studies, this study explored how the persuasion process may be shaped by attributes irrelevant to the scientific information conveyed. Specifically, this study examined how the American public respond to the same climate change message voiced by speakers with varying voice pitch and gender. Based on a survey experiment (N=645), this study found that both male and female speakers, regardless of their voice pitch, were similarly effective in changing participants' climate beliefs. Moreover, all speakers were rated similarly by participants in terms of subjective expertise, benevolence, and integrity. The results of this study are inconsistent with prior studies which found a general preference for male voices and lower-pitched voices. This is especially surprising, given that science is a male-dominated field in which women are historically underrepresented and discriminated against. The results suggest that perhaps climate science content creators should focus on developing the most persuasive arguments, rather than overemphasizing the role of the presenter.

TABLE OF CONTENTS

INTRODUCTION

As misinformation on issues such as climate change and COVID-19 grow rampant in popular media, communication scholars have become increasingly interested in the possibility of educating the public on scientific information through science communication. However, communicating science is a complex task, since the same information is often perceived and interpreted differently by different individuals, communities, and partisans (National Academies of Sciences, Engineering, and Medicine, 2017). Given that conflicting political interests and values interfere with science-related decision making, it is important that science communication is engaged in not just education but also persuasion. Powerful persuasive messages are known to not only inform people of scientific facts, but also influence support for policy actions (Priest, 2019). Therefore, the study of science communication necessarily involves the study of persuasion.

The study of persuasion is a multi-disciplinary field, one that sits at the intersection of linguistics, cognitive psychology, and political science. Among these various disciplines of persuasion studies, the political psychology approach, one that's commonly taken by communication scholars, focuses on the mental processing of persuasive devices and their influence on decision-making, social and political behaviors, and voting outcomes (Stone et al., 2014). Many studies in this field explored how the content of a message can shape persuasive effects. For example, in the context of science communication, researchers have tested whether presenting certain types of climate change evidence will be more effective in persuading climate skeptics. Alternatively, studies have also looked at persuasion through what's called the peripheral route: as opposed to the content of what is conveyed, the peripheral route is concerned with the context under which it's conveyed (Petty & Cacioppo, 1986). The peripheral route

involves both parties of communication: the speaker, or the communicator of the persuasive message, and the listener, hereby referred to as the receiver. Attributes of the speaker such as vocal tone and physical appearances, as well as attributes of the receive such as mood and personality, can all play a role in the persuasion process. One of these notable attributes is voice pitch: researchers consistently found that speakers with lower voice pitch are associated with more positive perceptions and greater voter preference (Klofstad, 2016; Tsantani et al., 2016). Another important attribute of the speaker is gender. For example, studies found that female speakers are perceived as less credible than their male counterparts when featured as voiceovers for political or commercial advertisements (Strach et al., 2015; Zoghaib, 2019). Furthermore, the gender of the receiver also affects their attitude towards speakers of different genders (Rodero et al., 2013).

The role of gender is especially important in science communication, given the gendered nature of science as a field of study. Due to barriers to entry and biased evaluation, women are historically underrepresented in scientific fields, which has fueled the science-is-male stereotype (Knobloch-Westerwick et al., 2013; Moss-Racusin et al., 2012). Consequently, people may be biased against female scientists and female science communicators, which has considerable implications for their ability to persuade. Nonetheless, there are very few studies that have examined speaker gender and persuasion collectively in science communication, and to my knowledge there is no study that draws on experimental evidence to demonstrate the field's gender bias. Furthermore, though studies have addressed the aggregate effect of speaker's voice pitch and gender on perception, there exists a gap in the literature to address the fundamental difference between pitch and gender: one as a purely acoustic feature, while the other as a social identity. In other words, it is unclear whether gender—let alone how it determines the quality of

voice (such as pitch) to an extent—affects the persuasion process and the receiver's perception of the subject matter conveyed.

The purpose of this study is to address this important question by inspecting the roles of speaker gender and pitch in persuasion in the context of science communication. Specifically, it examined how Democrats and Republicans respond when listening to the voiceover of an educational excerpt summarizing why climate change is human-caused. In an online survey experiment (N=645), participants were randomly assigned to listen to female vs. male speakers whose pitch were also manipulated (low vs. high). Through this experiment, this study aims to uncover: 1) whether speaker gender and pitch affect the persuasion process and if such an effect is consistent with previous studies and 2) if there is such an effect, whether this effect varies by attributes of the receiver.

LITERATURE REVIEW

A. The Study of Persuasion

In order to theorize the role of persuasion in science communication, it is first important to acknowledge the two general approaches that scholars have taken to study persuasion: the linguistics approach and the political psychology approach. The linguistics approach focuses on analyzing textual content and the use of linguistic structures as persuasion devices. For example, the rhetorical tradition of persuasion studies involves looking at how word choice, sentence form, and passage construction combine to enhance the persuasion effect (Fahnestock, c2011). Under the linguistics approach, literary devices were also well analyzed for their persuasive power: rhymes and alliterations could be used to enhance memory; rhetorical questions may stimulate greater depth of cognitive processing, while metaphors positions something in connection to something else to strengthen its benefits (Pogacar et al., 2018).

The alternative approach to studying persuasion, one that this study will pursue, is the political psychology approach. This approach is less concerned with the form of persuasion devices (the language itself), and places more emphasis on how the mental processing of those devices affects decision making, attitudes and values, social and political behaviors, as well as voting outcomes. (Stone et al., 2014) . The history of the study of political persuasion dates back to the 1920s, when scholars pondered on the effect of propaganda that served World War I (Perloff, 2012). This type of research gained much traction and academic respectability starting with Hovland, Janis, and Kelley's work on communication and attitudes: the authors laid out the framework for observing "the ways in which words and symbols influence people" using controlled experiments (Hovland et al., 1953, p. 1). They outlined a method in which an audience is selected to be exposed to specially constructed messages, followed by a measurement of change in opinions or attitudes through a questionnaire. This very same approach is still used by numerous persuasion studies that followed, including this study. Hovland and his colleagues also highlighted the notion that there is an interaction between the receiver and communicator of a persuasive message such that the persuasion effect is a factor of "attitudes toward the communicator and the cues which elicit them" (Hovland et al., 1953). This highlights how researchers should take into account of both sides of communication, the receiver and the communicator, to obtain a full picture of how persuasion took place.

As the field of study developed, it became increasingly multifaceted, encompassing not only political communication but also marketing, science communication, and more. In science communication specifically, researchers are often interested in whether framing the same scientific information differently influences the persuasion effect and how the information is received (Luong et al., 2019). One of the topics of interest in this field that gained traction

recently is climate change. Climate change is known as the major environmental challenge that the society is facing, with potentially catastrophic impact on humanity. Despite the clear evidence supporting an anthropogenic global warming, policy actions are long overdue partly due to the politically motivated polarization of climate opinions in the United States. In 2016, the partisan divide in climate beliefs was so evident that only 23% of Republicans surveyed believed in anthropogenic global warming, compared to 69% of Democrats, representing a 46% gap (Funk & Kennedy, 2020). Since society's ability to address this impending environmental crisis is contingent on a public consensus on its existence and cause, there has been strong scholarly interest in applying persuasive strategies to communicating the science behind climate change. For example, studies have explored constructing the type of message that most effectively communicates the existence and human-caused nature of climate change (Bolsen et al., 2019). Given its unique political challenges and its relevance to the study of persuasion, climate change is an ideal topic for this study.

Moreover, the political psychology approach of studying persuasion also involves multiple media of communication, including speech. Speech is especially important in this sector because many types of political communication, including campaign speeches and political advertising, involve a voice component. The human voice contains unique persuasive cues and nuances that cannot possibly be captured by a transcription of the very same content; the same content can also have different persuasive effects if voiced by different speakers, which will be demonstrated in the following sections. Studying speech has also become increasingly important in recent years due to a shift in consumer behavior: online media consumption among young people has far outpaced traditional media consumption, and short-form videos, which involve a vocal component, have dominated the online platforms (Deloitte, 2016). As a result, there was a

shift from traditional media to new media such as YouTube to engage the public with science, and researchers started to pay more attention to behaviors on those platforms (AbiGhannam, 2016). Since the human voice has become a crucial component of persuasion, this study also adopted a speech element: specifically, it relied on the human voice to create persuasive messages and used them as stimuli, as explained in the Methodology section.

In summary, this study took the political psychology approach to study the cues in speech that elicit a change in attitude towards climate change. Using an experiment where participants were randomly exposed to constructed audio messages about climate change, I identify persuasion effects through measuring receivers' perceptions of the speaker and their change in climate beliefs.

B. Gender and Persuasion

Petty and Cacioppo's (1986) elaboration likelihood model states that there are two separate routes through which the persuasion processes operate: the central route, which involves the receiver's careful and thoughtful consideration of the content of the information presented, and the peripheral route, which deals with the context in which the information is presented, "without necessitating scrutiny of the […] issue-relevant information presented" (Petty & Cacioppo, 1986, p.3). Studies that focused on the central route typically manipulated the content of persuasion, by presenting participants with various forms of content with the same persuasion goal. For examples, Kim and Liu (2022) examined whether presenting causal evidence (e.g., "climate change is caused by a rising level of carbon dioxide which is a product of…") or scientific consensus (e.g., "97% scientists agree that climate change is happening") is more effective in persuading participants that climate change is human-caused.

On the other hand, the peripheral route involves simple cues that do not require a high level of mental processing and could be a subconscious biological or emotional response. Mood of the receiver, objects in the surrounding, and vocal tone of the communicator can all affect the persuasion process through the peripheral route. For example, Reif et al. (2020) manipulated the environment in which scientific information is presented (e.g. TV interviews vs. YouTube videos), as well as the communicator's age and gender. Similarly, this study focuses on the peripheral route in the sense that it is not the content of persuasion that is manipulated, but the gender of the speaker.

Gender is one of the most salient attributes of the peripheral route, for both the speaker and the receiver of a message. The following sections discuss speaker gender and receiver gender's respective effects on peripheral persuasion.

Speaker Gender as A Peripheral Cue in Persuasion

Studies have found an effect of speaker gender on the persuasion process. For example, Strach et al. (2015) analyzed a sample of 4348 ads sponsored by political candidates and political parties that aired during 2010 and 2012 U.S. House and U.S. Senate elections, and grouped them by the gender of the announcers. In addition, the researchers collected surveys that asked for participant's ratings of ads' credibility, and obtained an aggregate credibility score for every individual ad included in the sample (Strach et al., 2015). It was found that female announcers were perceived as less credible overall compared to their male counterparts, which may explain why ad makers disproportionately chose male (62.7% of ads sampled) over female (27.7%) announcers to voice their political ads. However, male announcers are not *always* perceived to be more credible: the researchers found an interaction between the gender of announcers and the "gender" of an issue. Stratch et al. operationalized the femininity or masculinity of a political

issue using survey data from Pew that asked men and women what they think the most important societal issues are. Issues such as education, healthcare, and social security were identified as important by most female respondents, hence considered feminine, while issues such as national defense, energy, and finance were identified as important by most male respondents, hence considered masculine. Issues that were highly rated by both genders were coded as non-gendered. It was found that when broken down by subject, women were perceived as more credible if the issue discussed in the ad is feminine or non-gendered.

The finding that listeners favor ads in which the gender of the voice and the subject matter are consistent was confirmed in Searles et al's (2020) experiment, although they had different measurements for the "gender" of political issues. In Searles et al's experiment, a female announcer and a male announcer each voiced two ad scripts, one presenting a masculine issue (e.g. "securing our national defense through a strong military.") and one presenting a feminine issue (e.g. "supporting families by providing access [to] affordable childcare"). An issue was defined as masculine or feminine if men or women are thought to be more competent in the area. After watching the ad, participants assessed the candidate on a 1-to-7 scale on several attributes including favourability, credibility, whether it grabs attention, and the amount of content learned. The results were consistent with Strach et al.'s in that the interaction between speaker gender and gender of issue helps explain favorability: masculine issues had higher favorability when voiced by males, while feminine issues had higher favorability when voiced by females. Moreover, when the gender of the voice and the issue conflicted, the male voice outperformed the female voice. While having a male speaker voice a feminine issue (favorability score 4.96) was only slightly less favorable than having a female voice a feminine issue (4.97), having a female voice a masculine issue was much less favorable (4.84) than having a male

voice a masculine issue (4.99). Overall, having a female voice a masculine issue was found to be particularly ineffective.

Another study that found an overall preference for the male voice was Zoghaib's experiment in which participants indicated their preferences for 16 versions of the same ad (Zoghaib, 2019). To create the ads, a male and a female voice actor were recruited; acoustic aspects of their voice such as pitch (defined as the fundamental frequency of a voice), brightness (defined as the concentration of frequencies above or below 1500Hz), and roughness (defined as the irregular vocal fold vibrations) were manipulated to make 16 versions out of the original two recordings. After hearing each ad, participants' (N=597) attitude toward the speaker, perception of speaker's social traits and acoustic traits of their voice were measured. It was found that speaker gender partly shapes participant's attitude in the sense that participants associated male speakers with more positive attitudes. Acoustic qualities of the voice also had an effect on the perceived competence of the speaker: high (vs. low) voice pitched, rough (vs. smooth), and bright (vs. dull) pitched voices were found to have negative effects on participant's attitudes toward the speaker. Pitch, one of the most "perceptually salient elements of the voice" as described by Zoghaib, will be discussed in length a following section.

In summary, speaker gender has a significant effect on persuasion processes in the following way: female speakers are perceived as less credible than their male counterparts when featured as voice-overs for political advertising. Moreover, there is an interaction between the gender of the speaker and the content of persuasion, as masculine political issues had higher favourability when voiced by males than when voiced by females. Therefore, it is crucial to investigate the effect of speaker gender when observing the persuasive power of science communication messages.

Receiver Gender as A Peripheral Cue in Persuasion

In addition to the speaker's gender, the receiver's gender also plays a role in the peripheral route of persuasion. Some studies found that both males and females prefer the voices of the opposite gender. For example, Rodero et al.'s (2013) study in which participants listened to ads voiced by females and males found that both male and female receivers tend to perceive the voice of the opposite gender as more effective. In this study, participants rated the effectiveness of an ad on multiple dimensions (e.g. "persuasiveness", "agreeableness", "authority", "correctness"). It was found that females rated the male voice as more effective than the female voice, and to a greater extent than male's favourability for female voice (Rodero et al., 2013). The researchers theorized that this is perhaps related to the degree of sexual attraction between males and females, especially because the sample used in the study is at an age when they start to seek a partner (aged 21-23). The study did not look into whether the same effect is found with non-heterosexual individuals, as they were not recruited into the study at scale. It should be noted that the absence of participants who identify as non-binary genders is common in prior studies, and will continue to be a weakness of this study due to difficulties with recruiting such participants. Future studies should acknowledge this limitation and fill in the gap.

Another study that investigated receiver gender was Strach et al.'s (2015), which drew on U.S. House and U.S. Senate elections ads and survey data with credibility ratings for each ad. They found that female receivers perceived female announcers to be more credible than male announcers, which may be why ads aired during programs with a higher proportion of female audience were more likely to be voiced by females. Though the finding that female receivers prefer female announcers seems to contradict Rodero et al.'s finding that both genders prefer the voice of the opposite gender, the difference may simply be due to the different contexts of the

two studies: while the Strach study looked at political ads, Rodero's study focused on product advertising; there may be a fundamental difference between how the two types of ads are perceived. Moreover, Strach et al.'s study linked survey data to real ads that were aired, while Rodero et al. conducted an experiment, which is arguably more reliable.

In conclusion, though the listener's gender likely affects their perceived persuasiveness of the speaker, it is unclear what direction it goes, and whether it varies based on the content of persuasion. This is what this study will attempt to fill in with a larger sample size than Rodero et al.'s (N=372).

C. Gender in Science

Since this study sets out to examine gender's persuasion effects when conveying scientific information, it is important to acknowledge whether the field of science has inherent biases that may affect how gender roles are perceived. Indeed, science is known to be a field dominated by the male gender; its masculine nature has important implications for both the effectiveness of female scientists and female science communicators.

Bias Against Female Scientists

Historically, an overwhelming majority of scientists were male, and the occupation is strongly associated with men: in 1966, only 7% of undergraduate women pursued their bachelor's degrees in STEM (Science, Technology, Engineering, Math), compared to 26% of men (National Science Foundation, 2011). The science-is-male stereotype has permeated the field for so long that Lloyd (c1984.) remarked: "the intellectual virtues involved in being a good Baconian scientist are articulated in terms of the right male attitude to the feminine: chastity, respect and restraint. The good scientist is a gallant suitor" (p. 17). Although women's presence in science has increased drastically over the years, the change has been uneven and constrained

to non-math-intensive fields: in 2011, half of all MD degrees and 52% of PhDs in life sciences, 57% of PhDs in social sciences, and 71% of PhDs in psychology were awarded to women. However, women were still a clear minority in math-intensive fields such as physics and engineering (Ceci & Williams, 2011).

The underrepresentation of women in math-intensive fields is a function of both the barriers to entry that women face and biased evaluation of women as scientists. For example, in a randomized double-blind experiment in which university faculty members were invited to rate profiles of applicants for a laboratory manager position, male applicants were rated as more competent and hireable than an identical female applicant (Moss-Racusin et al., 2012). Women also have trouble receiving fair evaluation of their work: hypothetical publications from male scholars are perceived as having greater scientific quality compared to female scholars, holding the content of the publication constant (Knobloch-Westerwick et al., 2013). Yet another study that reviewed 23,000 papers submitted to journals found that papers with female first authors have slightly lower peer-review scores and are more likely to be rejected (Fox & Paine, 2019). Ultimately, the biases against women fall into a vicious cycle that drives women away from science. As a result, not only are women disadvantaged under stereotypes that link the female gender to a lower level of competence in science, the fact that math-intensive domains are stereotyped as masculine also makes women unwilling to pursue careers in these domains (Cheryan, 2012).

Bias Against Female Science Communicators

It is also important to make a distinction between scientists and science communicators. Scientists are people who study the subject of science, while science communicators are people who communicate that information to the public. The latter is what we focus on when studying

science communication. While scientists can be science communicators, science communicators are not necessarily scientists. With the rise of social media and YouTube, the public is exposed to a diverse group of communicators who frequently differ from the stereotypical image of scientists as White males (Reif et al., 2020).

Despite this diversity, some studies found that the bias against female scientists has extended to female science communicators. For example, science-related channels hosted by females on YouTube are significantly more likely to receive hostile or negative comments than their male counterparts (Amarasekara & Grant, 2019), suggesting that people are often more critical of female communicators who engage in the scientific subjects. This finding is consistent with the role congruity theory, which hypothesizes that bias against female communicators originates in the differences between the female gender role and the common expectations toward individuals who are knowledgeable about science (Eagly & Karau, 2002). According to this theory, female science communicators will be perceived as less competent and perhaps less persuasive because their gender role is incongruent with the perceived role of a science communicator's.

In contrast, one study did find the opposite effect of gender: in Reif et al.'s (2020) experiment in which participants were exposed to randomly assigned video stimulus about physics, videos that featured a female STEM expert as opposed to a male expert were found to have slightly higher perceived expertise (Reif et al., 2020). However, this conflicting finding may be due to some of the limitations of this study. For one, to simulate realistic media exposure, this study used real materials that vary in their specific topics addressed and the expertise of the presenters themselves, which makes it hard to isolate the effect of gender. Moreover, the sample used in the study was a group of highly educated, young individuals who may be more acceptive

of diversity. Therefore, future studies (including this study) should use a more representative sample with better controlled stimuli to test whether the results can be replicated.

In conclusion, as science is perceived to be a male-dominant subject, female's gender role is thought to be incongruent with the expected roles of an expert of science. As a result, female scientists tend to be perceived as less competent and less credible than their male counterparts. Taking this a step further, it is possible that female science communicators will also be perceived as less competent and less persuasive when conveying scientific information such as those relevant to climate change.

D. Gender and Pitch

As previously mentioned, the study will be examining the persuasive effectiveness of the same message delivered by different speakers However, the choice of observing the effect of gender from speech introduces specific complications. This is because speaker's gender, a social construct, can only be inferred from a combination of acoustic characteristics which includes timbre (what allows us to distinguish vowels from consonant), and pitch (what allows us to recognize intonation) (Allen et al., 2017; Meister et al., 2020; Pernet & Belin, 2012). This makes it hard to separate the effect of gender from timbre and pitch because any effect of gender could be said to be the aggregate effect of the acoustic qualities associated with the gender.

Although both pitch and timbre are associated with gender, this study will focus solely on pitch, since it is easier to operationalize and would require a smaller sample size: a study that looks at timbre could require up to 16 conditions, since the acoustic properties associated with timbre are much more complex and variable (Zoghaib, 2019). Though this is a limitation of this study, it should not undermine the study's validity since studies have demonstrated that voice gender categorization can be accomplished using pitch only (Pernet & Belin, 2012).

Pitch is determined by "the number of vibrations per second made by the vocal folds to produce a vocalization", termed fundamental frequency (Tusing & Dillard, 2000, p. 150). Fundamental frequency is measured in Hertz (Hz), and the lower the Hz the lower the pitch. Researchers have consistently found that speakers with lower Hz values are perceived to be more masculine, dominant, trustworthy, strong, mature, and lead to more positive attitudes and greater voter preferences (Anderson & Klofstad, 2012; Klofstad, 2016; Tsantani et al., 2016; Zoghaib, 2017, 2019). One study that demonstrated the preference for lower pitched voice is Anderson and Klofstad's (2012) experiment on participant's perception of candidates running for a leadership position. 10 female speakers and 10 male speakers were recruited for the experiment, and each speaker recorded the same phrase "I urge you to vote for me this November". The fundamental frequency of each recording was manipulated so that they are converted into lower and higher pitched versions then grouped into pairs, in which a pair consisted of a lower pitched and a higher pitched recording of the same speaker. Participants (N=71) listened to pairs of recordings; after each pair, they were asked to vote for one of the two speakers. In one condition, participants were told that the speakers are running for school board, while in the other condition they were told that speakers are running for the president of the Parent Teacher Organization (PTO), a position typically held by women. The study found that participants of both genders generally preferred male and female leaders with lower pitched voices, regardless of the position they are running for (i.e. school board vs. PTO president). However, female respondents did not seem to discriminate low vs. high pitched voices when the speakers were male, though the opposite was not found for male respondents.

Klofstad (2016) replicated the finding that people prefer political candidates who have a lower voice pitch in a later study that combined experimental data with voting turnouts

(Klofstad, 2016). Both experiments had the same procedures of having participants choose the candidate (in this case hypothetical candidates for the Cooperative Congressional Election) they would vote for from pairs of high and low-pitched voices, and found that both male and female participants preferred to vote for candidates with lower pitched voices, regardless of candidate's gender. However, this preference is stronger when participants are older, have higher levels of education, and are more politically engaged. Klofstad also analyzed data from 2012 U.S. House Elections, where he took the top two candidates with the largest vote share in each 2012 House Elections and measured their voice pitch. Consistent with the experiment, he found that the mean pitch of the winning candidates was lower than the mean pitch of their opponent's, regardless of the gender of the candidates. In conclusion, voters seem to be biased in favour of speakers with lower-pitched voices, which could potentially contribute to the underrepresentation of women in leadership positions and in government, since voice pitch is on average twice as high in women than in men (Titze, 1994).

There are also several studies that examined the interaction between speaker gender and pitch. Specifically, a couple of studies found that there is a stronger preference for lower pitched voice when the speaker is female (Klofstad, 2016; Tsantani et al., 2016). However, it is unclear whether such interaction varies by the context of the message. Furthermore, a thorough search of the relevant literature did not yield any relevant study in the field of science communication. This is precisely the gap that this study will fill.

E. Conclusion and Hypotheses

So far, the review of literature has followed the political psychology tradition of studying the central and peripheral routes of persuasion. It noted that both the gender of the speaker and the gender of the receiver are elements of the peripheral route: although a number studies found a

general favourability toward male speakers and a subject-dependent preference for both male and female speakers, the interaction between speaker gender and receiver gender remains unclear. It also discussed the gendered nature of science as a field of study, and questioned whether the biases against women in science would extend to women as science communicators. Lastly, it highlighted the implications of using pitch as a proxy for gender, and called into question the role of pitch and gender in the persuasiveness of scientific information.

To explore these questions, a survey experiment was conducted online. Participants listened to one of four different recordings of the same article about the causes of climate change. The recordings varied in two dimensions: speaker gender (female/male) and pitch (high/low). Results would suggest whether the low- or high-pitched voice is more persuasive, and whether the male speaker or the female speakers is more persuasive. Participant's climate change opinions were measured pre- and post- listening to the recordings; they were also asked to rate the credibility of the speakers that they heard from on several dimensions.

Based on the literature review, several hypotheses were constructed. First, since some studies found male speakers are perceived as more credible than female speakers (Strach et al., 2015; Zoghaib, 2019), in addition to a greater congruency between the typical gender roles of male and the roles of individuals engaged in science, I predict that:

> *H1: The male speaker will be perceived as more credible than the female speaker, regardless of pitch.*

In addition, since a number of studies found that speakers with lower pitched voice are associated with more positive perceptions (Anderson & Klofstad, 2012; Klofstad, 2016; Tsantani et al., 2016; Zoghaib, 2017, 2019), I predict that:

> *H2: The speakers with a lower-pitched voice will be perceived as more credible, regardless of speaker gender.*

However, due to scarce literature and conflicting findings in some areas, there remain questions that are difficult to set up hypotheses for. For one, the majority of studies reviewed measured perceived credibility, typically by asking participants to rate the speaker's credibility after exposure to the message. However, perceived credibility does not necessarily entail actual persuasion, or the actual change in beliefs or opinions induced by the messages, which is something that this study aims to measure experimentally. There are studies that demonstrated how the mere exposure to scientific information is able to change attitudes toward the subject matter: for example, exposure to sexual media content is known to affect adolescent sexual behavior (Bleakley et al., 2011), while increasing participants' perceptions of the scientific consensus on climate change was associated with an increase in the belief in an anthropogenic climate change (van der Linden et al., 2015). However, these studies are not particularly relevant to this study, since they dealt with receiver's perceptions of the subject matter conveyed, rather than perceptions of the speaker themselves. It remains unclear whether receiver's perceptions of pitch and gender of a speaker could be linked to changes in their attitudes and ultimately behavior. Coping with the failure to identify relevant prior research, this study posed the following research questions:

> *Q1: Would speakers with a lower-pitched voice lead to a greater positive change in receivers' climate change beliefs?*
>
> *Q2: Would male speakers, as opposed to female speakers, lead to a greater positive change in receivers' climate change beliefs?*

Finally, though receivers' gender and partisanship will likely have an effect on their perceptions of the speakers, with conflicting findings from previous studies it is hard to predict which way the effect will go. Therefore, this study will explore the questions:

Q3: Is there interactions between receivers' gender and how they respond to the speakers?

Q4: Is there interactions between receivers' political affiliation and how they respond to the speakers?

This study will follow the standard procedures of modifying voices and constructing persuasive messages, but it is innovative in several ways: first, it is among the first studies to experimentally measure the effect of gender and pitch on perceptions of speech in the context of science communication. Moreover, it follows a between-subjects experiment design, unlike the within-subjects design adopted by many previous studies (e.g. Anderson & Klofstad, 2012; Rodero et al., 2013; Tsantani et al., 2016; Zoghaib, 2017, 2017). This design limits exposure to one stimulus—in this case, each participant will only listen to one version of the recordings—so that learning and transfer between stimuli will be avoided to the best extent. Finally, this study not only asks participants for their perceived trustworthiness and competence of the speakers, but also directly measures the difference in their climate change opinions as an effect of speaker gender. Details on how exactly the change in opinion will be measured and its implications for observing persuasion effects will be discussed in the methodology section.

METHODOLOGY

A. Study design

To explore the effect of speaker gender and voice pitch on scientific messaging, a randomized controlled online experiment was conducted over Qualtrics. In the experiment, participants in the treatment groups were exposed to a message that explains how climate change is linked to human activities such as fossil fuel burning. Participants in the control groups were

exposed to a message irrelevant to climate change. The gender and pitch of the speaker were manipulated in different conditions. Participant's climate beliefs, support for climate policies, and perceived credibility of speaker were measured. Data was then analyzed using regression and ANOVA; the effect of outcome variables as well as heterogeneous effect of priors including participant's partisanship and gender were examined using multiple regression.

B. Sample

330 Republicans and 330 Democrats were recruited on Prolific (N=660), each paid $1.10. Although Republicans are typically the population of interest for climate change opinion studies due to their higher levels of skepticism in human-caused climate change, this study is mostly concerned with the extent to which the messages' effectiveness vary by speaker gender, as opposed to the extent to which the messages work. Moreover, Democrats were included so that any heterogeneous effect by participant's partisanship could be observed. Data was collected in February 2022, in the span of two days. After collection, 15 participants were excluded due to auditory problems or failure to answer the attention check questions properly, leaving a final sample size of 645.

C. Stimuli

Treatment Messages

Participants were exposed to recordings of different speakers reading the same scientific message explaining why scientists concluded that climate change is human-caused. This message was modified from a New York Times article titled "The Science of Climate Change Explained: Facts, Evidence and Proof" (Rosen, 2021). It outlined how the carbon structure in greenhouse gases represents strong evidence that global warming is caused by human activities such as burning fossil fuels, and explained why many other natural factors can be ruled out. A

transcription of the full message is attached in the appendix (Appendix A). A previous study that used the same message found that it substantially reduced Republican's misbeliefs in climate change (Kim & Liu, 2022)

To create the recordings, a male and a female voice actor were hired on Fiverr, an online marketplace for freelance voice actors. To ensure the quality of the recordings and realistically simulate what participants are used to hearing on radios and other media platforms, both voice actors are professionals who have been employed by major broadcasting networks and leading marketers. The voice actors were be asked to record in the following manner: first, they recorded in a soundproof room using a professional microphone. Second, the male voice actor recorded first, after which his recording was sent to the female voice actor. The female voice actor then replicated the intonation, pauses, and timing of the male voice actor's recording to the best extent possible. Third, the recordings were examined aurally and visually using the acoustic software Adobe Audition to ensure that the two recordings are in sync; any discrepancies in pauses and timing were manually adjusted. All these efforts were made to isolate speaker gender and pitch from other acoustic variables to the best extent possible. Then, the recordings were modified in Adobe Audition so that the volume was constant throughout, and any background non-speech noise was removed. In the end, the recordings are each two-minutes long.

Then the two raw audio recordings were modified in Praat to create 4 versions: the formant frequency of the male voice (Mean F0=126 Hz) was leveled up (+20 Hz; Mean F0=145 Hz) to create a high-pitched version, and leveled down (-20 Hz; F0=113 HZ) to create a low-pitched version. Similarly, the female voice (Mean F0=209 Hz) was leveled up (+20 Hz; Mean F0=229 Hz) and down (-20 Hz; Mean F0=189 Hz) to create high- and low-pitched versions. In the end, four versions were created out of the original two recordings: low-pitched male voice,

high-pitched male voice, low-pitched female voice, high-pitched female voice. Using the same recording for both the low and high-pitched versions controls for any confounding variables so that the only variable is pitch. The pitches of all four versions were within the human average pitch band, which ranges from 85 to 155 Hz for male voices and 165 to 255 Hz for female voices. At the end of the experiment, participants were asked to identify the pitch and gender of the speaker that they just heard from ("I heard from a: a) low pitched, female speaker; b) high pitched, female speaker, etc.") to confirm that the manipulation is successful.

Control Messages

Participants assigned to the control condition were exposed to messages recorded the same way as the treatment messages, except they were about a relatively non-politicized subject (in this case the movie *Squid Game*, see Appendix B) instead of climate change. The messages were recorded by the same voice actors, were approximately the same length (2 minutes), and were modified using the same process outlined. Two control messages were created from this process, one from the male speaker and one from the female speaker. The presentation of the two control messages were randomized so that half of the participants heard the male speaker, while the other half heard the female speaker.

D. Measures

Belief in anthropogenic climate change and support for climate policies were the primary outcome variables that indicate participants' opinions on climate change after exposure to the climate change message. *Belief in anthropogenic climate chan*ge refers to the belief that climate change is caused by human activities as opposed to natural changes. This variable was measured before and after the treatment, but the pre-treatment values were measured using one item, whereas the post-treatment values was be measured using a battery of five. Its pre-treatment

value was measured on a 7-point scale based on questions about belief in whether natural factors or human activities caused climate change and rescaled to 0-1 where 1 indicates a strong belief that climate change is caused by human activities. Those indicating "not sure" were coded as .5. Its post-treatment value was measured based on three indicators (in addition to the same pre-treatment questions, there are separate questions asking "how much" participants think "burning of fossil fuels" or "natural patterns in the Earth's environment" is contributing to climate change, and "how much…do you trust scientists" there is for each scenario.) that are on a 4-point scale. Each indicator was rescaled to 0-1, where 1 indicates a strong belief that climate change is caused by human activities. The average was taken from the three indicators to generate the post treatment *belief in anthropogenic climate chan*ge (Cronbach's alpha = 0.88).

Support for climate policies refers to support for various government actions for combating climate change. It was measured based on two indicators ("Do you think the federal government should be doing more about rising temperature", measured on a 5-point scale; "Should dealing with climate change be a top priority for the president and Congress?", measured on a 4-point scale). Each indicator was rescaled to 0-1 and then averaged (Cronbach's alpha =0.92).

In addition to the primary outcome variables that measured opinions, this study also measured the *perceived credibility* of the voices. It relied on the METI scale developed by Hendricks et al.(2015) designed to measure epistemic trustworthiness, which is defined as "all judgments laypeople make when deciding whether to place epistemic trust in an expert in order to solve a scientific informational problem that is beyond their understanding." (Hendriks et al., 2015; Reif et al., 2020). It is important to measure trustworthiness because trust in speaker is closely linked to the persuasiveness of a message: for example, the Accuracy-Motivated

Bayesian Model of Persuasion suggests that citizens vary in which information source they find trustworthy, which also determines how they perceive scientific information (Bayes et al., 2020). Following this model, Republicans could dismiss information about climate change because they tend to have low trust in scientists to begin with. Therefore, it is plausible that Republicans will be able to update their climate beliefs if they are persuaded that the source of climate science is trustworthy. Since science communicators may have a considerable influence on public's trust in science and scientists (Reif et al., 2020), this study examined how participants perceive the trustworthiness of science communicators of different genders.

According to the METI scale, there are three dimensions in epistemic trustworthiness: expertise, integrity, and benevolence (Hendricks, et al, 2015). For each of the dimensions, a number of indicators were measured using a 1-7 scale: expertise was be measured using 6 indicators, integrity was measured using 4 indicators and benevolence was measured using 4 indicators. The individual indicators are described in Table 1. Each indicator was rescaled to 0-1, where 1 indicated an extremely positive attitude (e.g. "competent", or "professional). Then, the average of all the indicators in each of the three dimensions was taken to obtain an overall score for expertise, integrity, and benevolence (Cronbach's alpha=0.92, 0.93, 0.92, respectively). Linear regressions were performed on these dimensions.

Finally, relevant demographic information was collected. Variables of interest included gender and partisanship.

Table 1. METI: Dimensions of Epistemic Trustworthiness and Their Respective Attributes (Hendricks et al., 2015).

Dimensions	**Measurement**
Expertise	Competent-Incompetence
	Intelligent-Unintelligent
	Educated-Poorly Educated
	Professional-Unprofessional
	Experienced-Inexperienced
	Qualified-Unqualified
Integrity	Fair-Unfair
	Just-Unjust
	Honest-Dishonest
	Sincere-Insincere
Benevolence	Moral-Immoral
	Ethical-Unethical
	Responsible-Irresponsible
	Considerate-Inconsiderate

E. Study Procedures

The experiment was a 10-minute survey conducted over Qualtrics. First, participants were asked about their prior belief on climate change, and trust in scientist, followed by a demographic questionnaire. Then, to prepare for the audio stimuli, listening instructions were be provided in the survey: 1) Quiet environment: participants were asked to do the survey in a quiet environment with a working sound device. To ensure that they will be able to play the audio recordings, participants could only access the survey from a computer or a tablet. 2) Healthy participants: participants were asked if they have any auditory problems, and those who do would not be able to proceed answering the rest of the survey 3) Volume and level of listening:

prior to the treatment message, participants would hear a ring tone, and be advised to adjust the volume of their device to a clear and loud level. Then they heard another message that is completely irrelevant to the stimuli ("colorless green ideas sleep furiously"), after which they were asked to recall what they just heard ("What is the color of the ideas that sleep furiously?"). This ensures that participants were able to hear the audio recording clearly and comprehend the content correctly. These procedures control for varying listening levels between participants to an extent, though there could still be certain biases.

Participants were then randomly assigned to one of the four experimental conditions or the two control conditions (a total of 6 conditions). Block randomization on pre-treatment belief in human-caused climate change (7-point) was conducted: participants were categorized into 7 blocks, and then randomly assigned to the 6 conditions within each block, ensuring that the conditions are balanced on prior belief. After exposure to the stimuli, participants were asked about their post-treatment beliefs on climate change and opinions on climate policies. Then they were asked about their impression of the speaker using the METI metrics on 1-7 Likert scales. Lastly, they were asked to identify the pitch and gender of the speaker. This is not an outcome variable, but a manipulation check confirming that participants are able to perceive the target variables. Please refer to Appendix D for the full survey.

F. Statistical Analysis

After data collection, linear regressions were performed over the belief in anthropogenic climate change and support for climate policies variables. The regression models for belief in climate change and support for climate policies include pre-treatment covariates for statistical precision. Heterogeneous effects by priors, specifically participant's partisanship and gender,

were also examined. Additionally, ANOVA was conducted to assess whether perceived trustworthiness variables varied by conditions.

RESULTS

A. Randomization and Manipulation Checks

The final sample consists of 645 participants, with 50.1% females and 49.4% Democrats. Participants were evenly assigned into the six experimental conditions. Each condition had roughly the same distribution of age, gender, and partisanship. See Table 2 for a breakdown of participant demographics by experimental conditions. After examining the efficacy of gender and pitch manipulations, it was found that over 98% (640 out of 645) participants correctly identified the speaker gender, though 5 participants in the female conditions incorrectly identified the speaker as male. The accuracy of identifying speaker pitch ("Is this a high- or low-pitched speaker") was considerably lower than that of speaker gender, but this is expected given the difficulty with identifying the relative frequency of pitch when each participant only listened from one of the speakers. Even so, participants in the low pitch conditions attributed the voice to a low-pitched voice significantly more ($p<0.001$) than to a high-pitched voice, vice versa. These measures demonstrated the efficacy of the manipulations.

Table 2: Demographics by Experimental Condition (N=645)

Experimental condition	Control (Male)	Control (Female)	High-Pitch (Male)	Low-Pitch (Male)	High-Pitch (Female)	Low-Pitch (Female)
n	110	109	106	105	108	106
Democrats (%)	55	49	44	46	50	46
Republicans (%)	45	51	56	54	50	54
Female (%)	55	50	50	44	55	46
Age (mean)	38	40	39	40	38	40

Note: Median education for all participants was "2-year or 4-year college degree"

B. Effect on Climate Change Opinions

Belief in Anthropogenic Climate Change

Figure 1: Raw Means for Belief in Anthropogenic Climate Change by Conditions

Belief in anthropogenic climate change was the primary outcome variable in the study. First, as shown in Figure 1, participants in the four treatment conditions expressed firmer belief

in anthropogenic climate change than those in the two control conditions (pooled)[1], regardless of speaker pitch and gender. Compared to the control condition, the treatments have positively changed participant's belief by an average of 9.8 percentage points across the four conditions ($p<0.001$) (Model 1); when adjusted for baseline variables including pre-treatment belief in climate change, pre-treatment trust in climate scientists, and partisanship, the average effect size increased to 10.2 percentage points ($p<0.001$) (Model 2). Adding the baseline variables improved the fit of the model from an adjusted R-squared of 0.038 to 0.742. A summary of the precise regression estimates can be found in Table 3, in which Model 1 shows the effect of treatment messages on climate belief across four conditions, and Model 2 shows the same effect when adjusted for pre-treatment variables.

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Table 3: Regression Estimates of Belief in Climate Change by Treatment Conditions

	Climate Belief	
	Model 1	**Model 2**
High Male	0.105***	0.114***
	(0.026)	(0.014)
Low Male	0.101***	0.094***
	(0.026)	(0.014)
High Female	0.096***	0.102***
	(0.026)	(0.014)
Low Female	0.090***	0.098***
	(0.026)	(0.014)
Baseline Belief		0.412***
		(0.022)
Baseline Trust		0.192***
		(0.022)
dem		0.005
		(0.012)
Constant	0.605***	0.171***
	(0.015)	(0.014)
N	638	618
Adjusted R2	0.038	0.742

***p < .001; **p < .01; *p < .05

[1] There was no difference between the two control conditions ($p>0.9$), so they were pooled for precision.

I then turned to examine the difference between the four treatment conditions. First, I looked into Q1, which questioned whether a low-pitched (as opposed to high-pitched) voice will lead to a greater positive change in receivers' climate beliefs. Compared to the control condition, the average effect of the high-pitched conditions across genders was 10.8 percentage point, while the average effect of the low-pitched conditions was 9.6 percentage point, as reported in Table 4. This means that the effect size of the high-pitched conditions was on average larger than that of low-pitched conditions by 1.2 percent. However, this difference was not statistically noticeable ($p>0.05$), even when adjusted for pre-treatment variables, as summarized by Table 5, where the high-pitched conditions serve as the baseline. In sum, contrary to prior studies, there was an absence of meaningful difference between the effects of high versus low-pitched voices.

Table 4: Regression Estimates of Belief in Climate Change by High- vs. Low-pitched Conditions, Adjusted for Pre-treatment Variables with Control Condition as the Baseline

	Climate Belief
High Pitch	0.108***
	(0.011)
Low Pitch	0.096***
	(0.011)
Baseline Belief	0.413***
	(0.022)
Baseline Trust	0.191***
	(0.022)
dem	0.004
	(0.012)
Constant	0.171***
	(0.014)
Adj. R-squared	0.743

***p < .001; **p < .01; *p < .05

Table 5: Regression Estimates of Belief in Climate Change by High- vs. Low-pitched Conditions, Adjusted for Pre-treatment Variables with High-Pitched Condition as the Baseline

	Climate Belief
Control	-0.108***
	(0.011)
Low Pitch	-0.012
	(0.011)
Baseline Belief	0.413***
	(0.022)
Baseline Trust	0.191***
	(0.022)
dem	0.004
	(0.012)
Constant	0.279***
	(0.014)
Adj. R-squared	0.743

***p < .001; **p < .01; *p < .05

Similarly, a comparison of the male and female conditions (Q2) revealed that the two are not statistically distinguishable from one another. On average, belief in anthropogenic climate

change was 10.4 percent higher in the male conditions, and 10.0 percent higher in the female conditions than the control condition ($p<0.001$ for both), as shown in Table 6. However, there was no statistically significant difference between the male and female conditions ($p>0.05$), as shown in Table 7. A regression model that compared the four treatment conditions (high male, low male, high female, low female) individually also revealed that no one condition was meaningfully more or less effective than the other three treatment conditions, despite all being significantly different from the control condition. In sum, the results show no evidence that the persuasive effect of the climate change message varied by speaker gender; likewise, there was no evidence that this effect varied by the voice pitch of the speakers.

Table 6: Regression Estimates of Belief in Climate Change by Male vs. Female Speaker Conditions, Adjusted for Pre-treatment Variables with Control Condition as the baseline

	Climate Belief
Male	0.104***
	(0.011)
Female	0.100***
	(0.011)
Baseline Belief	0.413***
	(0.022)
Baseline Trust	0.190***
	(0.022)
dem	0.004
	(0.012)
Constant	0.171***
	(0.014)
Adj. R-squared	0.742

***p < .001; **p < .01; *p < .05

Table 7: Regression Estimates of Belief in Climate Change by Male vs. Female Speaker Conditions, Adjusted for Pre-treatment Variables with Male Condition as the Baseline

	Climate Belief
Male	-0.104***
	(0.011)
Female	-0.004
	(0.011)
Baseline Belief	0.413***
	(0.022)
Baseline Trust	0.190***
	(0.022)
dem	0.004
	(0.012)
Constant	0.275***
	(0.014)
Adj. R-squared	0.742

***p < .001; **p < .01; *p < .05

Support for Climate Policies

Considering the downstream effect of treatments on policy preference, support for climate policies was also measured, once pre-treatment as a covariate and once post-treatment as

an outcome variable. However, unlike belief in anthropogenic climate change, the treatment's effect on support for climate policies is less compelling. Though the coefficients of the regression model appear to suggest that the treatment has positively affected support for climate policies, this effect was only significant in the low-pitched male and high-pitched female conditions (by 3.9 and 4.3 percentage points respectively, $p<0.05$ for both). Additional analyses revealed that despite being significantly different from the control condition, the low-pitched male and high-pitched female conditions were not significantly different from the other two treatment conditions ($p>0.05$). Table 8 reports the precise coefficient estimates of the treatment effect on climate policy support, while Table 9 presents the raw means of post-treatment climate policy support by conditions. In conclusion, this study failed to find a clear answer as for whether this climate change message significantly raised support for climate policies, and whether the effect differ by speaker gender or pitch.

Table 8: Regression Estimates of Support for Climate Policies by Treatment Conditions, Adjusted for Pre-treatment Variables

	Climate Belief
High Male	0.031
	(0.019)
Low Male	0.039*
	(0.020)
High Female	0.043*
	(0.019)
Low Female	0.011
	(0.019)
Baseline Belief	0.387***
	(0.031)
Baseline Trust	0.365***
	(0.032)
dem	0.066***
	(0.017)
Constant	0.156***
	(0.019)
Adj. R-squared	0.707

***p < .001; **p < .01; *p < .05

Table 9: Mean Climate Policy Support and Standard Deviation by Conditions

	Mean	Standard Deviation
Control	0.731	0.298
High Male	0.738	0.308
Low Male	0.782	0.313
High Female	0.764	0.266
Low Female	0.724	0.307

C. Perceived Credibility

The third measure that this study employs is participants' self-reported rating of the speaker's expertise, integrity, and benevolence, which combines to form the perceived credibility of a speaker according to the METI scale (Hendriks et al., 2015). To eliminate the possibility that the content of the messages could impedes the speaker's perceived credibility, the two control conditions, which contained information irrelevant to climate change, were excluded from this analysis.

The overall mean score as well as the mean scores for each condition were computed for each of the three METI dimensions. It was found that across conditions, the speakers were rated as higher in expertise than in integrity or benevolence, which is expected since the message was highly scientific and educational. On the other hand, the mean scores for each condition seem to suggest some variability in perceived credibility based on gender and pitch: for example, the mean scores for the low-pitched female condition were the lowest across all dimensions (0.81, 0.74, and 0.75 respectively), while the high-pitched female condition received relatively high ratings in all three categories (0.85, 0.79, and 0.79 respectively). The group means and overall means are reported in Table 10. Nonetheless, ANOVA revealed that the group means are not significantly different from one another in expertise (F value=1.475, $p>0.05$), integrity (F value=1.028, $p>0.05$), or benevolence (F value=0.871, $p>0.05$). In other words, the perceived credibility of the treatment conditions was not statistically different from one another. In conclusion, the results failed to reject the null hypotheses for H1 and H2, since no gender or pitch was perceived to be more credible than the other.

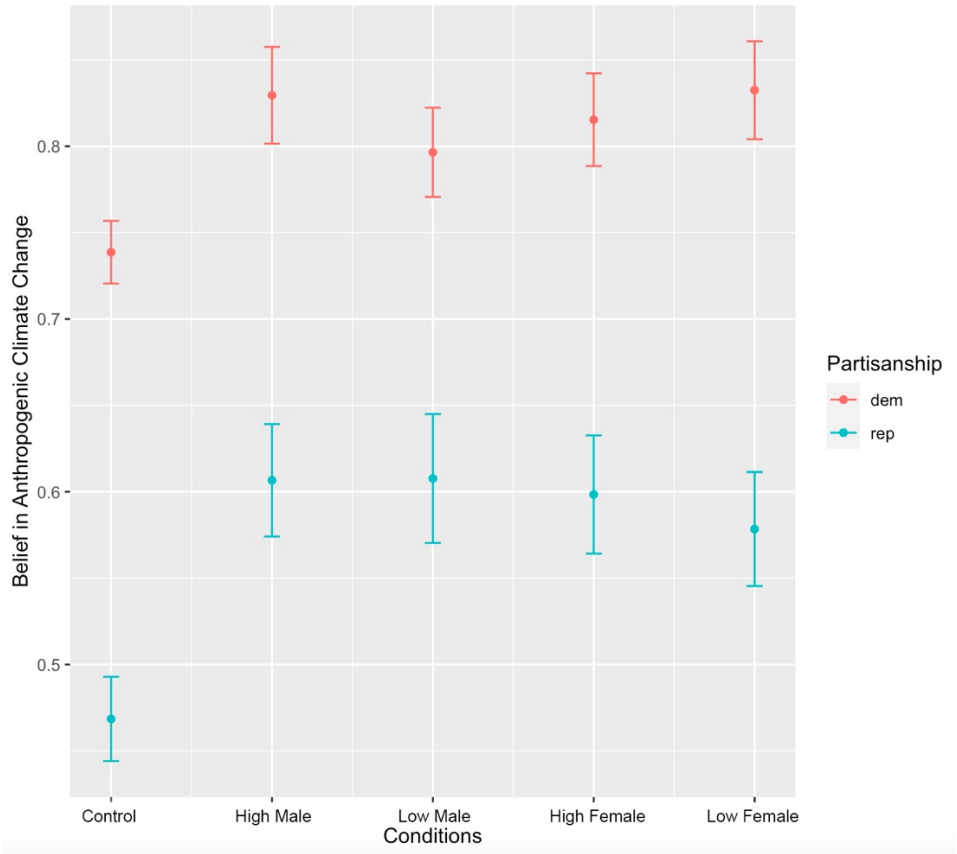
Table 10: Mean Scores for Expertise, Integrity, and Benevolence by Groups

	Expertise		Integrity		Benevolence	
	M	SD	M	SD	M	SD
High Male	0.83	0.17	0.77	0.18	0.78	0.20
Low Male	0.85	0.17	0.78	0.21	0.77	0.24
High Female	0.85	0.17	0.79	0.20	0.79	0.21
Low female	0.81	0.18	0.74	0.22	0.75	0.23
Mean	0.84	-	0.77	-	0.77	-
F Values	1.475		1.028		0.871	

D. Heterogeneous Effects

Lastly, to answer Q3 and Q4, heterogeneous effects by priors were also investigated.

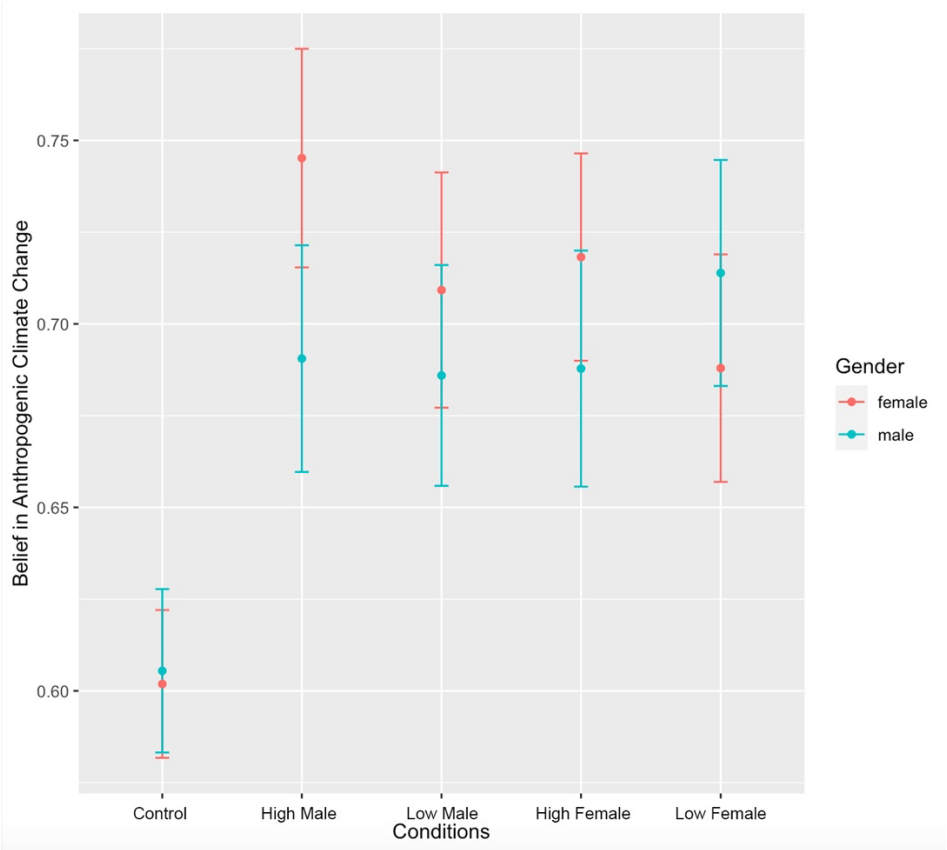
Figure 2: Predicted Values of Climate Belief by Conditions and Partisanship



Partisanship. As shown in Figure 2, the treatment effects on climate belief were statistically significant regardless of partisanship of the receivers; in other words, both

Democrats and Republicans expressed firmer belief in anthropogenic climate change in the treatment conditions than the control conditions. The coefficients also suggest an interaction in which the treatment effects were slightly greater for Republicans than Democrats; however, this difference was only significant in the low-pitched male ($p<0.01$) and high-pitched female ($p<0.05$) conditions. No interaction was found between receiver partisanship and support for climate policy. The full regression model of this interaction can be found in Appendix C.

Figure 3: Predicted Values of Climate Belief by Conditions and Receiver Gender



Receiver gender. As shown in Figure 3, the treatment effects on climate belief were statistically significant for both male and female receivers. The coefficients suggest that the effect was more salient among female participant, though statistically this only holds true for the high-pitched male condition ($p<0.05$). In other words, it is possible that the high-pitched male

voice was especially effective for female receivers. Much like partisanship, there was no interaction between receiver gender and treatment conditions for climate policy support ($p>0.05$ for all conditions). It should also be noted that no interaction was found between perceived credibility and receiver gender. The full regression model of this interaction can be found in Appendix C. In conclusion, the short answer for Q3 and Q4 is that it is likely that receiver's gender and partisanship moderated the treatment effects on receivers' climate beliefs, but the relationship is likely not a linear one.

In summary, neither of the two hypothesis was supported: the male speaker was not perceived as more credible than the female speaker, nor was the lower-pitched speaker perceived as more credible than the higher-pitched speaker. In fact, they were rated so similarly by the participants that any difference in perceived credibility would be statistically indistinguishable. Furthermore, there was barely any difference between the persuasive effectiveness (Q1, Q2) of male vs. female, and high- vs. low-pitched speakers—all were similarly effective on changing the receivers' belief on anthropogenic climate change. Though this effect is much weaker for shaping receivers' policy support, the difference is not attributable to gender or pitch. Lastly, receivers' partisanship and gender seem to have played a role in their reaction to the messages. Specifically, the low-pitched male and high-pitched female speakers may have been particularly effective for Republican receivers, while the high-pitched male condition may have been particularly effective for female receivers. However, these interactions were not substantial, and require further testing.

DISCUSSION

This study has examined the role of speaker gender and voice pitch in persuasion when communicating scientific information. Based on a review of relevant literature, it was

hypothesized that science communicators with a lower voice pitch, or science communicators that are male would be perceived as more credible when educating the public on climate change. Since a persuasion effect is said to be partially formed by receivers' attitudes toward the communicator (Hovland et al., 1953), it was also reasonable to suspect that the male, lower-pitched science communicators would be more persuasive, leading to a greater positive change in receivers' climate beliefs. However, contrary to these predictions, this study failed to find any effect of speaker gender and voice pitch on the persuasion process or the speakers' perceived credibility. All science communicators, despite their gender and pitch, were equally effective in increasing receivers' belief in anthropogenic climate change. They also had highly similar levels of perceived credibility. This study provided no evidence that speaker gender and pitch played a substantial role in the persuasiveness of scientific communication. Furthermore, though the role of speaker gender and pitch appears to vary by receiver's gender and partisanship, the relationship remains unclear and non-substantial, and requires further investigation to test its reliability.

The results of this study stand in stark contrast to prior studies which found that the male voice is associated with more positive attitudes and higher perceived credibility (e.g. Zoghaib, 2019; Searles et al, 2020; Strach et al., 2015). They are also inconsistent with studies that found a preference for lower-pitched voices (e.g. Anderson & Klofstad, 2012; Klofstad, 2016; Tsantani et al., 2016; Zoghaib, 2017, 2019). This is especially surprising, given that science is a male-dominated field in which women are historically underrepresented and discriminated against. Despite past findings suggesting that the bias against female scientists may have been extended to female science communicators in a way that undermines their perceived credibility

(Amarasekara & Grant, 2019), the current findings suggest that to the extent that such bias exists, it will be substantially small.

What could have contributed to the conflicting findings from past studies and the current study? First, as noted in the literature review, most past studies pertaining to speech and political-psychological persuasion focused on voter preference and product marketing, and there is very limited research on science communication. This study is among the first to analyze the persuasive role of speaker gender and pitch in science communication using experimental data. Therefore, it is possible that attributes of the speaker are less likely to induce a change in science-related beliefs, compared to voter preference or product marketing. One could argue that science communication relies on factual information, which encourages the receivers to focus on the persuasiveness of the arguments themselves rather than attributes of the speaker. On the other hand, the appeal of product marketing is much more subjective, while the nature of voting draws receivers' attention to the candidates themselves. In sum, the peripheral route of persuasion may have a weaker effect on scientific content than any other types of information. If this is true, science content creators should place a greater emphasis on generating content using persuasive arguments, rather than hiring science communicators who will *sound* potentially more "persuasive" than others. It also suggests that any discrimination against female voice actors would be groundless and irrational, at least when choosing a voice for scientific content.

Another factor that might have contributed to the difference between the present study and past studies is the length of the stimuli. Experiments that involve manipulation of speaker's vocal attributes often use messages that are relatively short: for example, in Anderson and Klofstad's study (2012) about participants' perceptions of candidates running for a leadership position, participants heard only a single sentence ("I urge you to vote for me this November").

Similarly, the Tsantani study (2016) which demonstrated a general preference for low-pitched voices used a single word ("hello") as the stimuli. By adopting a short message, these studies were able to amplify the effect of the peripheral cues in persuasion, for example speaker gender and pitch, irrespective of the content of persuasion. However, the same approach is not feasible in this study since evidence for anthropogenic climate change cannot be presented in a single sentence, especially when considering the strength of such arguments. It is possible that having a long message (2 minutes) encouraged receivers to focus on the content of the messages as opposed to peripheral cues, which is a limitation of this study. Future studies should look into shortening this message while keeping it informative and persuasive.

On a similar note, it is also possible that the gender cues are not salient enough in this study, since participants could only infer gender from voice. Other studies that examined the credibility of science communicators (e.g. Reif et al, 2020; Amarasekara & Grant, 2019) had a video component in which participants could see what the speakers look like. Such supplementary visual information arguably made the gender cue much more salient than the audio recordings used in this study, though they also introduce other confounding variables such as speaker's facial features, age, body movements and gestures. The present study did not involve a visual component because it would make it difficult to parse out the effect of vocal attributes. However, future studies should look into comparing different media of communication—for example text, audio, and video—to see whether speaker gender and pitch interact with the persuasion effect differently. Furthermore, it is possible that without a visual component, people treated the voice as merely a narrator, rather the author owning the content of the message. Future studies could look into whether visual manipulation can enhance the attribution of authorship and hence highlight the effect of gender.

Finally, in contrast to the present study, most prior studies have followed a within-subjects experimental design (e.g. (Anderson & Klofstad, 2012; Jones et al., 2010; Klofstad, 2016; Tsantani et al., 2016; Zoghaib, 2017, 2019). For example, in Zoghaib's study (2019) about the effect of gender and vocal characteristics on consumer responses to product marketing, each participant heard 16 versions of the same ad that varied by speaker gender, pitch, brightness, and roughness, and evaluated them by comparing them against one another. Similarly, in Jones et al.'s 2010 study, each participant listened to 6 pairs of recordings and were asked to evaluate each one's dominance and attractiveness. Exposing the same participant to multiple different stimuli could have made the difference between them more salient: for example, having the low- and high-pitched voices side by side may have made the lower-pitched voice sound lower and the higher-pitched voice sound higher to the participant. Through this process, the difference between treatment conditions is presumably amplified, and the effect of peripheral cues of persuasion could be better demonstrated. In contrast, the present study adopted a between-subject design, to mirror the real-life experience of listening and attending to aural information: after all, individuals rarely hear the same information repeated to them by different speakers multiple times in a short time frame. As such, the different experimental designs may have led to different results. Further research should look into conducting both within-subject and between-subject experiments using the same stimuli, and see whether they result in different effect sizes.

There are other limitations to this study that should be acknowledged. First, the sample is not a random sample representative of the population, but is instead a convenience sample drawn from Prolific. Crowdsourced online samples are known for data quality concerns, as well as for having "professional participants" whose familiarity with survey experiments makes their responses potentially biased (Hillygus et al., 2014). In addition, the sample size (N=645) is

relatively small, which further undermined the generalizability of this study. The choice of allowing participants to take the survey on their own devices also introduce confounding variables that may have resulted in different listening levels between participants. To account for these issues, future studies could replicate the experiment with a larger, more representative sample, and in a more controlled setting when feasible. Future studies can also seek to replicate the study in a more natural setting using more casual speakers (as opposed to professional voice actors), since the experimental setting of this study may have encouraged participants to focus on the content of the message or the central route of persuasion. Moreover, like most prior studies in the field, the concept of gender used in this study is a binary one, which systematically left out certain populations. Future studies could integrate speakers and receivers of non-binary genders, which could enrich our understanding of the effect of gender as a social construct.

That said, this study has successfully demonstrated the persuasive power of climate change communication, in spite of varying characteristics of the science communicators. Though to say that speaker gender and pitch have no effect on the persuasion process of science communication would be an overstatement, the findings of this study indicate that it is highly unlikely that speaker gender and pitch are the major factors that determine the persuasiveness of scientific messages; to the extent that any effect exists, it will be extremely small and overpowered by the persuasiveness of the content itself. The findings seem to support an optimistic view of the world in which bias against women in science does not impair their perceived competence as science communicators: both male and female speakers effectively persuaded their audience, resulting in higher levels of belief in anthropogenic climate change.

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APPENDICES

Appendix A: Transcription of the Scientific Message Presented to Participants

Climate scientists have concluded that average global temperature today is warmer than pre-industrial times and that human activity is the main factor. Why are human activities responsible? It's in part basic physics: the level of carbon dioxide (or CO2), a greenhouse gas that blocks heat from getting out of the planet, has been rising steadily. But how would we know that the rise in CO2 is caused by human activities?

The answer lies in the chemistry of the carbon in CO2. Carbon comes in 2 common forms: the non-radioactive Carbon-12 and the radioactive Carbon-14. Being radioactive simply means that Carbon-14 would break down and eventually disappear over time. Therefore, if we dig up ancient plant and animal remains, we would find that they contain Carbon-12, but no Carbon-14. So CO2 released from burning fossil fuels, which are made of ancient materials, would only contain Carbon-12. From this, scientists reasoned that a rise of Carbon-12 but not Carbon-14 is directly related to fossil fuel burning -- and that's exactly what we're seeing.

In addition, scientists ruled out many natural factors that could have affected the climate. For example, movements of crust and mantle, variation in the Earth's orbit, and the energy of the Sun were once proposed to cause climate change. However, it would take millions of years for these processes to be big enough to affect the climate. As such, the rapid warming that we are seeing must be due to a different cause—human activities. But why should we care? Because climate change will ravage human society and the economy. If current warming continues, global G.D.P. per capita will decrease between 7% and 23% by the end of the century — an economic blow equivalent to multiple COVID pandemics every year.
(291 words)

Appendix B: Transcription of the Message in the Control Condition

Win or die trying. Netflix's "Squid Game" hooked fans in with its high-stakes twist on classic Korean children's games from the moment it dropped on the streaming site in September.

Beginning in episode one, 456 players fight for their lives — and a cash reward that increased into the billions — after accepting an ominous invitation to play a series of children's games. Each round is monitored by masked guards wearing pink suits as the Front Man oversees it all. The nine-episode series quickly takes a dark turn when the contestants realize that every challenge brings the possibility of injury or death. The question of which players can be trusted and which ones will do anything to survive is something viewers must ask themselves week after week.

According to the movie's creator, the deadly challenges also serve as commentary on the world over the last decade. "I wanted to write a story that was an allegory or fable about modern capitalist society, something that depicts an extreme competition, somewhat like the extreme competition of life. But I wanted it to use the kind of characters we've all met in real life," he told Variety last month. "The games portrayed are extremely simple and easy to understand. That allows viewers to focus on the characters, rather than being distracted by trying to interpret the rules."

In its first four weeks of release, "Squid Game" pulled in 1.65 billion hours of viewing, surpassing "Bridgerton" as the most-watched Netflix original series in history. With major nominations at the Golden Globes, SAG Awards and Critics Choice Awards, "Squid Game" is positioning itself as a major Emmy contender later this year.
(274 words)

Appendix C: Additional Regression Tables

Table 11: Regression Estimates of Support for Climate Policies and Partisanship by Treatment Conditions. Model 1 Un-adjusted for Pre-treatment Variables; Model 2 Adjusted for Pre-treatment Variables

	Policy Support	
	Model 1	**Model 2**
High Male	0.031	0.036
	(0.019)	(0.026)
Low Male	0.039*	0.030
	(0.020)	(0.028)
High Female	0.043*	0.067*
	(0.019)	(0.027)
Low Female	0.011	0.028
	(0.019)	(0.026)
Baseline Belief	0.387***	0.418***
	(0.031)	(0.036)
Baseline Trust	0.365***	0.411***
	(0.032)	(0.037)
Democrats	0.066***	0.450***
	(0.017)	(0.064)
High Male:Democrats		-0.003
		(0.038)
Low Male:Democrats		0.024
		(0.038)
High Female:Democrats		-0.043
		(0.038)
Low Female:Democrats		-0.021
		(0.038)
Base Belief:Democrats		-0.218**
		(0.070)
Base Trust:Democrats		-0.229***
		(0.069)
Constant	0.156***	0.109***
	(0.019)	(0.022)
Adj. R-squared	0.707	0.723

***p < .001; **p < .01; *p < .05

Table 12: Regression Estimates of Support for Climate Policies and Gender by Treatment Conditions

	Policy Support
High Male	-0.039
	(0.029)
Low Male	-0.007
	(0.033)
High Female	0.010
	(0.032)
Low Female	0.001
	(0.033)
Baseline Belief	0.369***
	(0.044)
Baseline Trust	0.439***
	(0.046)
Female	0.049*
	(0.024)
High Male:Female	0.128**
	(0.045)
Low Male:Female	-0.0002
	(0.039)
High Female:Female	-0.009
	(0.045)
Low Female:Female	-0.012
	(0.045)
Base Belief:Female	-0.053
	(0.045)
Base Trust:Female	0.023
	(0.063)
basetrust:female	-0.153*
	(0.064)
dem:female	0.035
	(0.034)
Constant	0.137***
	(0.031)
Adj. R-squared	0.713

***p < .001; **p < .01; *p < .05

Appendix D: Full Survey

Start of Block: Default Block

q1
We invite you to participate in a research study being conducted by investigators from The University of Pennsylvania. The purpose of the study is to understand people's opinions about the current issues.

If you agree to participate, we would like you to answer questions about current issues. We would also ask you to listen to a short **audio recording**, so please make sure that you are in a **quiet environment** with a working sound device to do the survey on. It will take approximately 5-6 minutes. (You will receive $1.10 via Prolific.)

We will not collect your name, ID, or any identifying information about you. We will store the data collected from you and may publish it in the case that the study get published, but again it would be impossible to link you to your responses to the survey. Taking part in this research study is completely voluntary. If you do not wish to participate in this study, simply close the tab.

If you have questions about the rights of research subjects, please contact the Institutional Review Board at University of Pennsylvania Institutional Review Board 3600 Civic Center Blvd, 9th Floor, Philadelphia, PA 19104 or call (215) 898-2614. We encourage you to ask questions.

If you have any questions about the research study itself, please contact: Sophia Liu (sl9403@sas.upenn.edu).
Thank you very much for your consideration of this research study.

- ○ I agree
- ○ I do not agree

End of Block: Default Block

Start of Block: Does not consent

Display This Question:

If q1 = I do not agree

q2 As you do not wish to participate in this study, simply close the tab.

End of Block: Does not consent

Start of Block: Auditory check

Q56 As aforementioned, this study involves a listening component. Are you in a quiet space with a device that has a working sound system?

- No
- Yes

Q57 Do you have any auditory problems?

- No
- Yes

End of Block: Auditory check

Start of Block: Block 24

Display This Question:

If Q56 = No

Q58 This study asks that you are in a quiet environment with a working sound device. If you are not, please come back later when you are in a quiet environment with a working device to participate in the study.

End of Block: Block 24

Start of Block: baseline 1

q7 You may have heard about the idea that the world's temperature may have been going up slowly over the past 100 years. Do you think a rise in the world's temperatures would be caused by human activity, or by natural causes?

- Mostly by human activity
- About equally by human activity and natural causes
- Mostly by natural causes

Display This Question:
If q7 = Mostly by human activity

q8 Is your belief that human activity is responsible for climate change...

- ○ Very Weak
- ○ Weak
- ○ Neutral
- ○ Strong
- ○ Very Strong

Display This Question:
If q7 = Mostly by natural causes

q9 Is your belief that natural causes are responsible for climate change...

- ○ Very Weak
- ○ Weak
- ○ Neutral
- ○ Strong
- ○ Very Strong

Display This Question:
If q7 = About equally by human activity and natural causes

q10 Which is closer to your view?

- ○ Human activities are at least somewhat more responsible for climate change
- ○ Natural causes are at least somewhat more responsible for climate change
- ○ Human activities and natural causes are equally responsible
- ○ Not sure

Page Break

End of Block: baseline 1

Start of Block: baseline 2

q11 How much, if at all, do you trust climate scientists to give full and accurate information about global climate change?

- Not at all
- A little
- Some
- A lot

End of Block: baseline 2

Start of Block: Demographics

q12 What is your gender?

- Male
- Female

q13 How old are you?

_____

q14 What is the highest level of education you have completed?

- ○ Less than high school
- ○ High school / GED
- ○ Some college
- ○ 2-year college degree
- ○ 4-year college degree
- ○ Masters degree
- ○ Doctoral degree
- ○ Professional degree (JD, MD)

End of Block: Demographics

Start of Block: Adjust volume

Q96 In the following section, you will listen to some audio recordings.

First, we would like to run some audio tests to make sure that your device is working and that you can clearly hear the audio. Please play the following audio clip, and adjust the volume of your device so that it is at a comfortable level. You should be able to clearly hear the ringtone.

End of Block: Adjust volume

Start of Block: Audio test female

Q97 Now please listen to another recording. Please pay close attention to the content of the recording and be ready to answer recall questions later in the survey.

End of Block: Audio test female

Start of Block: Audio test male

Q98 Now please listen to another recording. Please pay close attention to the content of the recording and be ready to answer recall questions later in the survey.

End of Block: Audio test male

Start of Block: Audio test recall question

Q62 What is the color of the ideas that sleep furiously

- Red
- Green
- Yellow

End of Block: Audio test recall question

Start of Block: High Pitch Male

Q63 Now you are going to listen to another recording about a current event. Please pay close attention while listening to it. You will be asked to recall its contents later in this survey.

End of Block: High Pitch Male

Start of Block: Low pitch male

Q64 Now you are going to listen to another recording about a current event. Please pay close attention while listening to it. You will be asked to recall its contents later in this survey.

End of Block: Low pitch male

Start of Block: High pitch female

Q65 Now you are going to listen to another recording about a current event. Please pay close attention while listening to it. You will be asked to recall its contents later in this survey.

End of Block: High pitch female

Start of Block: Low pitch female

Q66 Now you are going to listen to another recording about a current event. Please pay close attention while listening to it. You will be asked to recall its contents later in this survey.

End of Block: Low pitch female

Start of Block: Control female

Q645 Now you are going to listen to another recording about a current event. Please pay close attention while listening to it. You will be asked to recall its contents later in this survey.

End of Block: Control female

Start of Block: Control Male

Q646 Now you are going to listen to another recording about a current event. Please pay close attention while listening to it. You will be asked to recall its contents later in this survey.

End of Block: Control Male

Start of Block: Check

q46 Which of the following is consistent with what you just heard?

- ○ 93% of scientists are in favor of animal research
- ○ One of the factors of climate change is CO2 released from burning fossil fuels.
- ○ Climate change is mainly caused by natural factors, not human activities
- ○ Squid Game is a major Emmy contender later this year.

End of Block: Check

Start of Block: Chance to listen again

Q90 You failed to answer the previous question correctly. Would you like to listen to the recording again?

- ○ Yes
- ○ No

End of Block: Chance to listen again

Start of Block: Check 2

Q648 Which of the following is consistent with what you just heard?

- ○ If current global warming continues, global G.D.P. per capita will decrease between 7% and 23%in the centry
- ○ Climate change is caused by movements of the Earth
- ○ Climate change is not a scientific consensus
- ○ Scientists have rejected the claim that carbon dioxide causes climate change

End of Block: Check 2

Start of Block: check 3 (for everyone)

Q99 Please describe what you just heard in a few words (a couple of words is fine).

_____

End of Block: check 3 (for everyone)

Start of Block: post-treat1

q31 You may have heard about the idea that the world's temperature may have been going up slowly over the past 100 years. Do you think a rise in the world's temperatures would be caused by human activity, or by natural causes?

- Mostly by human activity
- About equally by human activity and natural causes
- Mostly by natural causes

Display This Question:

If q31 = Mostly by human activity

q32 Is your belief that human activity is responsible for climate change...

- Very weak
- Somewhat weak
- Neither weak nor strong
- Somewhat strong
- Very strong

Display This Question:

If q31 = Mostly by natural causes

q33 Is your belief that natural causes are responsible for climate change...

- Very weak
- Somewhat weak
- Neither weak nor strong
- Somewhat strong
- Strong

Display This Question:

If q31 = About equally by human activity and natural causes

q34 Which is closer to your view?

- Human activities are at least somewhat more responsible for climate change
- Natural causes are at least somewhat more responsible for climate change
- Human activities and natural causes are equally responsible
- Not sure

End of Block: post-treat1

Start of Block: post-treat 2

q35 How much do you agree or disagree with the following statements?

q36 How much do you think human activity, such as the burning of fossil fuels, contributes to global climate change?

- ○ Not at all
- ○ Not too much
- ○ Some
- ○ A great deal

q37 How much do you think natural patterns in the Earth's environment contribute to global climate change?

- ○ Not at all
- ○ Not too much
- ○ Some
- ○ A great deal

End of Block: post-treat 2

Start of Block: post treat 3

q38 How much evidence is there to support the idea that human activity, such as the burning of fossil fuels, contributes to global climate change?

- ○ Not at all
- ○ Not too much
- ○ Some
- ○ A great deal

q39 How much evidence is there to support the idea that natural patterns in the Earth's environment contributes to global climate change?

- ○ Not at all
- ○ Not too much
- ○ Some
- ○ A great deal

Page Break

X→

q40 How much, if at all, you trust climate scientists to give full and accurate information about global climate change?

- Not at all
- Not too much
- Some
- A lot

End of Block: post treat 3

Start of Block: post treat 4: policy

q42 Do you think the federal government should be doing more about rising temperatures?

- Should be doing much less
- Should be doing a little less
- Is currently doing the right amount
- Should be doing a little more
- Should be doing much more

q45 Thinking about priorities for President Biden and Congress this year, should dealing with global climate change be...

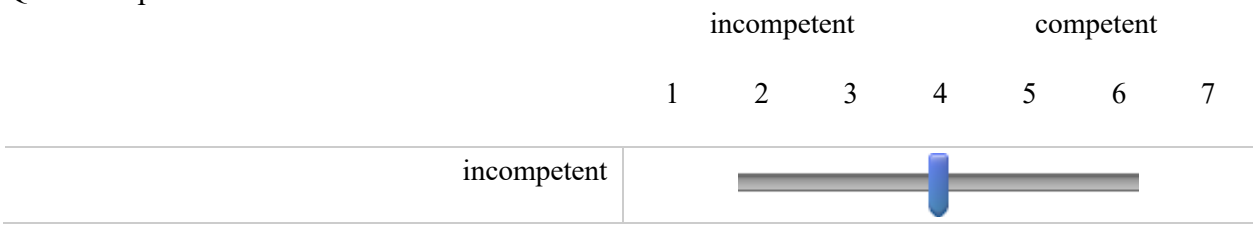
- Nothing should be done about it
- Not too important
- Important but lower priority
- A top priority

End of Block: post treat 4: policy

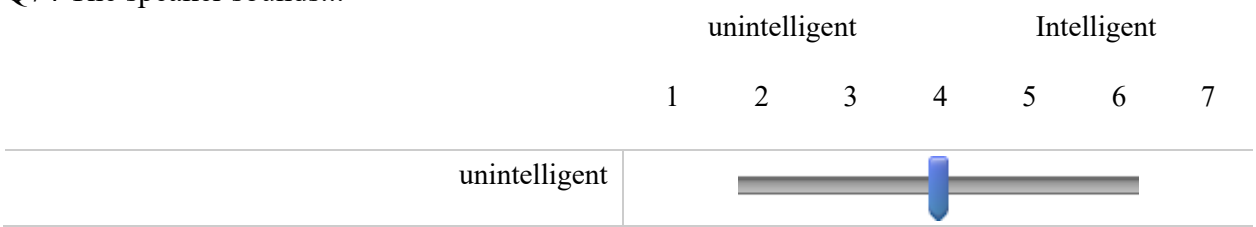
Start of Block: METI

Q67 Now please take a moment to think of the speaker who you just heard from. You will be asked to rate your impression of the speaker using a series of metrics.

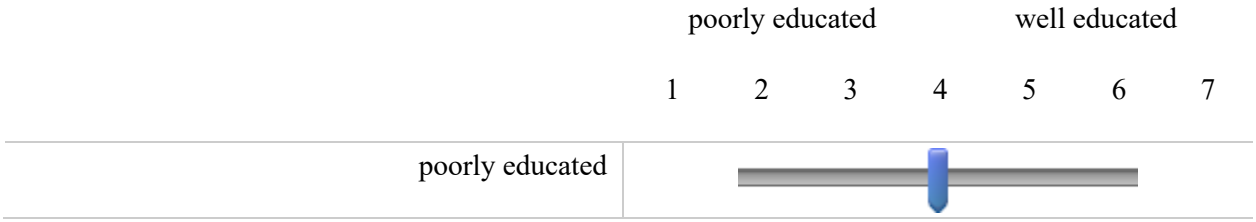
Q72 The speaker sounds...



Q74 The speaker sounds...

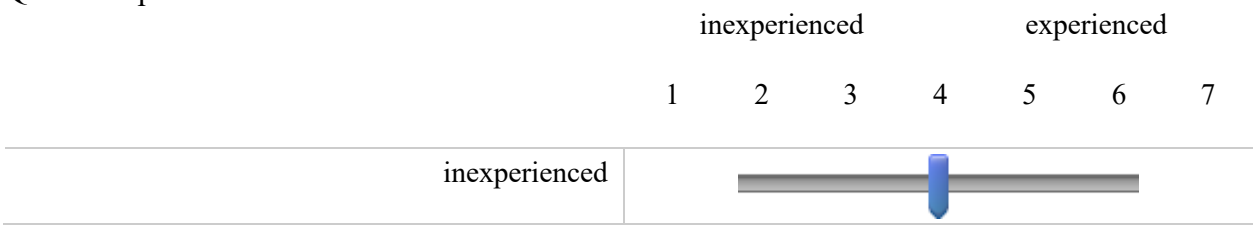


Q75 The speaker sounds...

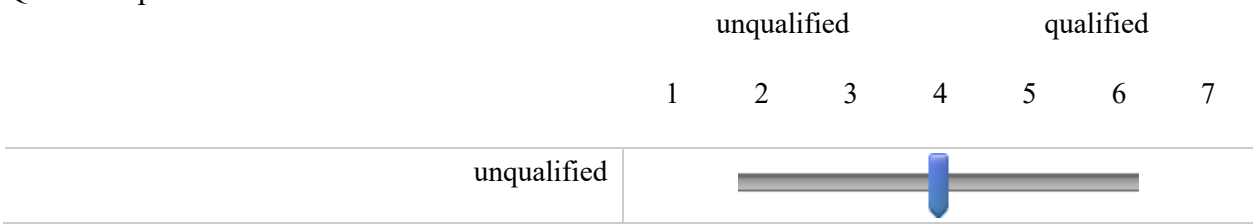


Q76 The speaker sounds...

Q77 The speaker sounds...

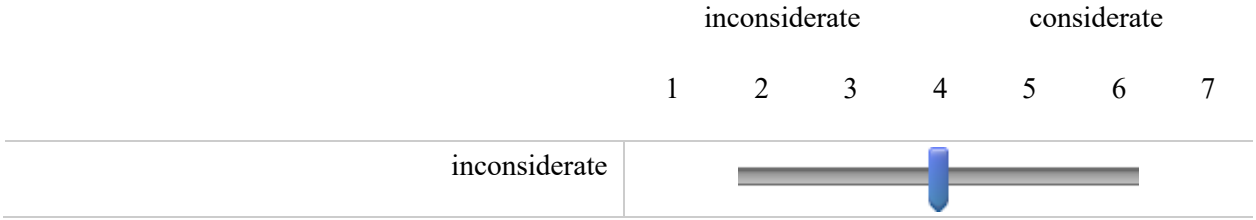


Q79 The speaker sounds...

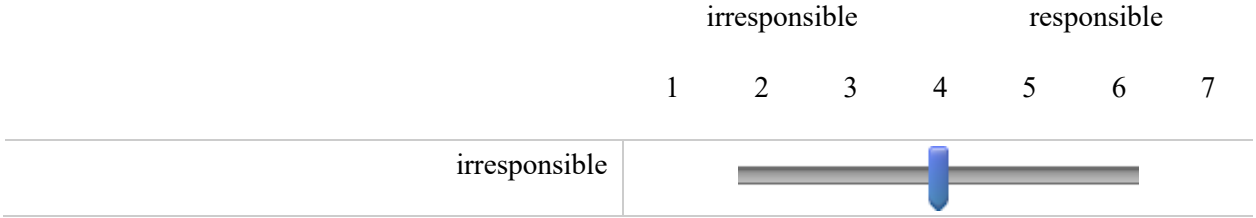


Page Break

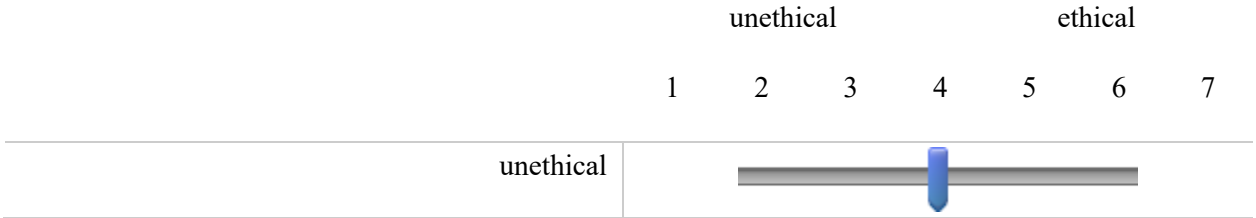
Q80 The speaker sounds...



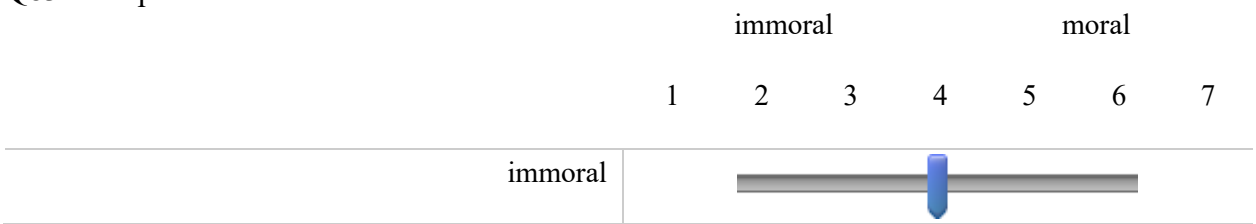
Q81 The speaker sounds...



Q82 The speaker sounds...

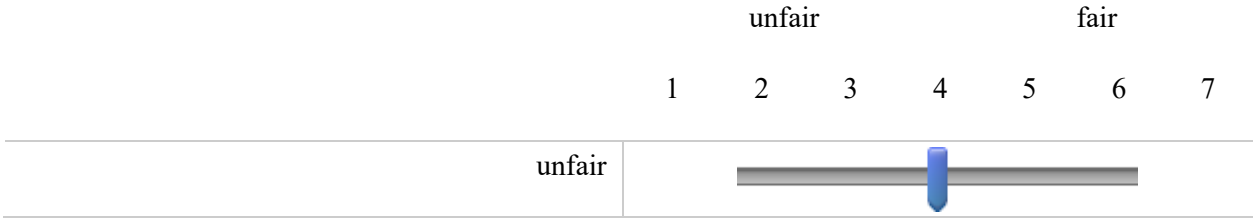


Q83 The speaker sounds...

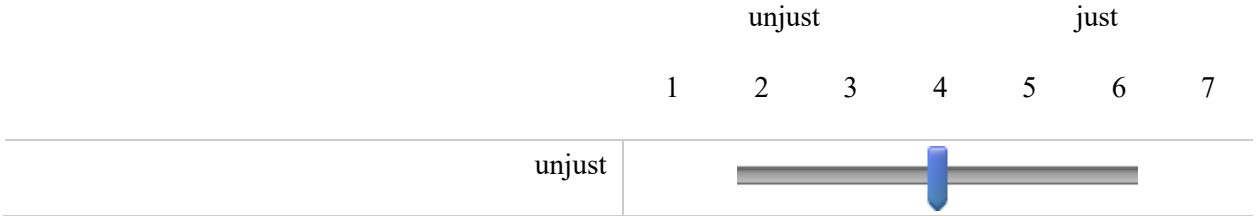


Page Break

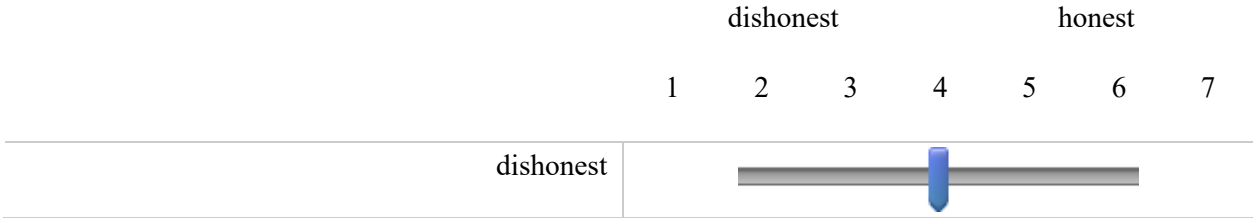
Q84 The speaker sounds...



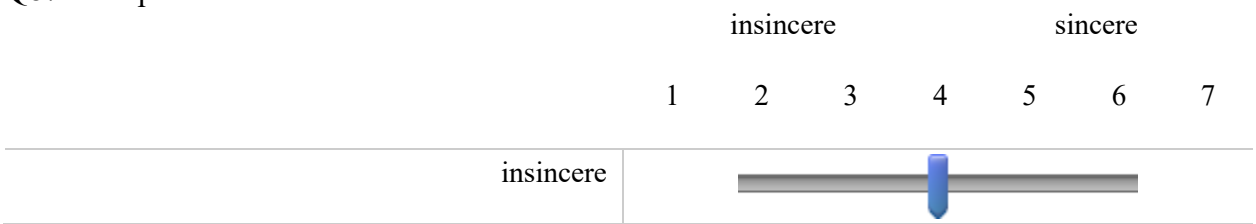
Q85 The speaker sounds...



Q86 The speaker sounds...



Q87 The speaker sounds...



Page Break

Q71 How would you best describe the speaker?
I heard from a

- ○ Low-pitched, female speaker
- ○ High-pitched, female speaker
- ○ Low-pitched, male speaker
- ○ High-pitched, male speaker

End of Block: METI

Start of Block: Thank you block

Q93 Thank you very much for taking the time to complete the survey; your contribution to this study is much appreciated.

You will be redirected to the Prolific completion page by a url once you proceed to the next page.

Again, If you have questions about the rights of research subjects, please contact the Institutional Review Board at University of Pennsylvania Institutional Review Board 3800 Spruce St. First Floor, Suite 151 Philadelphia, PA 19104, or call (215) 898-2614. We encourage you to ask questions. If you have any questions about the research study itself, please contact: Sophia Liu (sl9403@sas.upenn.edu).

End of Block: Thank you block
