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The Relative Influence of Fundamental Frequency (*F*0) on Perception of Dominance

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1 Introduction

Voices are fundamental parts of our daily living, and this is true for the majority of the human beings: they are omnipresent in the social environment we live in (Belin et al., 2004; Belin, 2006), accompanying us from the womb to the very last moments of our lives. They are our first tool when we want to communicate with each other, providing us through language a very unique way of expressing ourselves and our intentions, which distinguishes our species from any others. At the same time, when we use our voices to convey our thoughts and ideas, there is often someone that listens and therefore perceives our intentions, giving them an interpretation. Indeed, voices are also able to allow listeners to make use of the message they carry, and thus to extract information that can also orientate social behaviour. Accordingly, they carry "a wealth of socially relevant information" (Frühholz et al., 2019) that can be both verbal and non-verbal, such as emotional states or personality. (Frühholz et al., 2019). The ability of the human beings to perceive this particular information not only concerns the sound of voices, but it is also strictly affected by many cues that each person carries when we look at someone and then we form our first impressions. This has a high evolutionary relevance: evidences suggest that voices and other cues like faces are in fact likely shaped by the influence of evolutionary forces, particularly one over all: sexual selection. That happens especially if we think about the wide differences that lie between male and female voices and traits: they are indeed highly dimorphic and this anatomical and acoustic sexual dimorphism has a significant role in the context of sexual selection, affecting men and women perceptions of attractiveness and dominance and therefore influencing mating behaviours (Puts et al., 2012).

1.1 Sexual selection theory

Charles Darwin was the first to notice that animals have evolved weird structures that may have nothing to do with survival, and therefore could go against his theory of Natural Selection (Darwin, 1871). One of the most iconic examples is the peacock's brilliant plumage, which particularly obsessed Darwin. The eyespots on the peacock's tail seem in fact to be a cost for the animal, instead of an advantage, exposing him even more to predation. But if so, why has this trait evolved? Darwin interrogated himself, and eventually proposed his second evolutionary theory: the theory of Sexual Selection (Darwin, 1871). According to this novel assumption, adaptations evolve "as a consequence of successful mating" (Buss, 2019). In this particular case, the peacock's flamboyant tail has evolved because it is a quality desired by the female that will tend to choose it when it is time to mate. This is what Darwin calls "intersexual selection", one of the two mechanisms by which sexual selection works. The other one is called "intrasexual selection" and it refers to the competition between males from the same species when the mating behaviour occurs: the loser typically has no access to the female and fails mating, whereas the victor's qualities will be passed on to his offspring. If mating really works like that, presumably evolution has arisen as a consequence of the intrasexual competition (Buss, 2019). As a result of this fight, males have typically developed qualities that define their strength and physical dominance, and therefore makes it more likely for them to win a physical fight and to be chosen by females. Again, having a brighter tail in a peacock will tell females that that particular male is strong enough to risk being exposed to predators, thus he has a good *fitness,* described by Darwin as the "physical capacity to do the tasks necessary to ensure one's survival and capacity for reproduction" (Prum, 2017). These argumentations were extremely

revolutionary, as the animals were not anymore defined as "merely subject to the extrinsic forces that create Natural Selection" but rather could play a "distinct and vital role in their *own* evolution through their sexual and social choices" (Prum, 2017).

According to these findings, both intrasexual and intersexual competition have thus been fundamental in shaping different mating behaviours during evolution. At the same time, this may have had a role in determining systematic difference in form between the two sexes of the same species, also referred as sexual dimorphism.

1.2 Evolution of sexual dimorphism

Sexual dimorphism refers to the striking physical differences occurring between males and females of the same species. In the animal kingdom these differences are clearly visible, for example in the different colorations between sexes and ornamentations, but also in behaviours such as territorialism or parental behaviour (Berns, 2013). Sexual selection (Darwin, 1871) has probably driven the evolution of these sexual differences between males and females: indeed, being more attractive to the other sex (intersexual dimorphism) and being dominant defeating the other males (intrasexual dimorphism) enhanced the probability of reproductive success (Berns, 2013). This is accurate referring to the animals and their evolution, but it was not so clear if mate choice and intrasexual competition have also played a role in shaping sexually dimorphic traits in humans: indeed, sexual dimorphism in our species may be not so far from this idea.

Although human males and females may be not so divergent in their appearance compared to some animal species, men and women are placed in the 90th percentile for

visual sexual dimorphism (Dixson et al., 2005; Puts et al., 2012). This is due to the existing differences between their body shape, where men are bigger in size and have different muscles and hair distribution as well as a different skeletal structure, which particularly include a more prominent and larger mandible (Enlow et al., 1996; Puts, 2013). According to the differences in the mean body size, men and women have also evolved different vocal characteristics: lager vocal folds in men have resulted in lower and more profound voices, with a Fundamental Frequency ($F0$, typically defined as the closest acoustic parameter to perceived voice pitch) of about 5 standard deviations below women (Puts et al., 2016).

The cause of all these differences between sexes are mainly biological. At proximate level, sex differences both in physical shape and voices are the consequence of being exposed to sex hormones, particularly testosterone. This sex steroid is responsible for developing secondary sex characteristics in male, like facial hair growth and longer vocal folds in males (Puts, 2012; Puts et al., 2016). Meanwhile, women's oestrogen levels cause the development of feminine traits such as wider hips, and also defining a generally higher vocal pitch and timbre. But why have these sexual differences evolved? This is particularly relevant in order to understand human sexual and social behaviours, since these traits could predict mate preferences and mating strategies, affecting perceptions of attractiveness and dominance when interacting to a person (Puts, 2012).

Sexual selection is the primary adaptive cause of sex differences (Puts et al., 2006) and it seems to be particularly important in shaping men's traits. On the one hand, female mate choice may have influenced the evolution of men's sexual secondary traits, as

women appear to prefer (in terms of attractiveness rating) more masculine characteristics, such as more masculine faces and lower voice pitches (Puts, 2012); on the other hand, male contest competition may have also had an evolutionary role in evolving sex differences, as masculine faces and voices seem to be rated as more dominant both by female and low-dominance men (Puts, 2012). Moreover, particularly dominant males may have had an advantage in physical fight against other males, and thus have had more chances of being chosen as sexual partners, as the sexual selection has taught us. Thus, both female choice and intra-sexual competition may have shaped sexually dimorphic traits. Across studies, dominance signaling seems to have a larger role in this: in fact, facial and vocal masculinity are considered a threat display which influences the perception of dominance, rather than a sexual ornament that affects the perception of attractiveness (Puts, 2012).

Regarding on sexual selection's influence on women's trait, male mate choice has had a remarkable role in shaping women's feminine traits. In particular, some studies on voice and face perception (Fraccaro et al., 2010; Fraccaro et al., 2011; Fraccaro et al., 2013) have revealed that men tend to rate feminine faces (Figure 1) as more attractive, particularly when interested in long-term relationships (Fraccaro et al., 2010).

Figure 1 Examples of feminized (left) and masculinazed (right) versions of a female face. These face stimuli have been used in several studies (e.g., Fraccaro et al., 2010; Jones et al., 2007; Welling et al., 2007, 2008).

Whereas referring to voice perception and male's preferences, men seem to have the tendency to prefer higher-pitched voices when choosing women, particularly for short-term commitments (Fraccaro et al., 2010). Furthermore, these researches suggested that more feminine and healthy faces may reflect a long-term reproductive value, whereas a higher voice pitch may be an index of current fertility and low dominance, and that this may explain men's preferences for highly dimorphic traits in women. (Kleisner et al., 2021). Sexual dimorphism is thus significant when occurring to mate choice (Fraccaro et al., 2010), even if the cause underlying the correlation between men's preferences for feminine faces and voices does not appear to be so clear. In fact, this preference does not seem to be linked to age or attractiveness-related variation in attractiveness

judgments, suggesting that neither self-rated attractiveness nor age explain the correlation (Fraccaro et al., 2010).

All of these sexually dimorphic features, which mark clear differences between human males and females, may have hence evolved with the aim to communicate evolutionary salient qualities to the other members of the same species, such as to a potential mate or competitor. For instance, a more sexually dimorphic feminine face, usually connoted by big eyes and chubby cheeks (Geldart et al., 1999), considered to reflect baby schema (Alley, 1981; Hildebrandt & Fitzgerald, 1979), tends to be judged as more attractive, both in male and female targets. Ethologist Konrad Lorenz (Lorenz, 1943) conceptualised this baby schema (*Kindchenschema*) as a set of infantile traits (like bigger heads, eyes and lips) that has evolved with the evolutionary function of enhancing the probability to survive in offspring (Glocker et al., 2009), eliciting a more caretaking behaviour towards infants. This schema, applied to human adult faces, may have evolved for the same reason, as many studies suggest that infant-like adult faces evoke a positive affective response in human (Glocker et al., 2009) and they tend to elicit more helping behaviours (Keating et al., 2003). In other words, these peculiar face characteristics may have evolved with the function of cueing social approach. Indeed, female faces with a higher level of this baby schema seem to elicit more caretaking behaviour, as well as be rated as more pleasant and attract more attention than adult faces, regardless of the participants' gender (Brosch et al., 2007). Interestingly, a face rated as more attractive is also notoriously correlated with more symmetrical and average features (Keating et al., 2003), and these may be signals of a higher level of fitness and health (such as parasite resistance) (Swaddle et al., 1995), generally required characteristics of a potential partner in evolutionary terms. All of these physical signals

that communicate evolutionary salient information can go under an evolutionary remarkable concept known as “signaling theory”.

1.3 Signaling theory

Humans, like many other species, have learnt through millions of years to take advantage of different ways of communicating information without using language, particularly aiming to increase their mating opportunities. This ability has been regulated by evolutionary forces, sexual selection above all.

In biology, the ability of an animal to communicate evolutionary salient information through peculiar behaviours and structural characteristics can be explained by introducing the “signaling theory” concept. Signaling significant information to a conspecific or even to a predator has evolved and maintained in many species as it has represented an evolutionary advantage for the “signaller”, who influencing through specific signs the behaviour of the signal’s “receiver”, took benefit from it. Within the same animal species, this kind of communication can be used to signal the presence of good genes and desirable qualities to a prospective partner, increasing mating opportunities for the signaller. At the same time, signaling can be displayed across different species: for instance, pointing out to a predator the presence of qualities such as physical stamina, which may depict the signaller as a hard prey to catch. Signaling can thus benefit both the signaller and the receiver, or even just the signaller. In this regard, we can distinguish signals in “cues” and actual “signals”. When referring to “cues”, these are generally behaviours or physical traits that only benefit the signaller, such as signaling poisonousness through colours even if the animal is not really

dangerous, which occurs in the Batesian mimicry. When a trait benefits both the signaller and the receiver in biology, this is called instead a “signal” (Bradbury et al., 1998).

Signaling is a more common way of communication than we expect. In particular, animals and humans use it especially as a means to attract mates by indicating their fitness. When communicating good genes and qualities through signaling, those signals usually cannot be faked and that is why they are called “honest”. A paradigmatic example in this regard is a behaviour known as “stotting”, played out by gazelles and some other ungulates when faced with predators. By their ability of majestically leaping into the air, they display their strength and healthiness, sending a clear signal to their hunter: they are not worth chasing, since this would require too much energy for the predator who usually prefers waiting on sick and older prey, easier to hunt. This particular behaviour is impossible to fake and thus has to be trusted by the hunter. The same principle goes for the peacocks and their extravagant plumage, which is not beneficial for their survival against predators, instead for communicating worthiness to a potential mate. It is important to point out that both the stotting behaviour and the brilliant feathers do not come without any costs: as these characteristics make the animals more visible, they have to be able to defend themselves in order to survive. This is why these two signals are considered genuine signs of good fitness.

To sum up: signaling is the act of transmitting costly information, so they are believable. This does not only apply to animals: signaling is in fact an extremely powerful means for humans as well. Every day we signal information about ourselves and we pick up the same from the people surrounding us, most of the time without even

being aware of it. And we do it constantly. We do it through the way we dress and speak, through our posture and our manners. Indeed, signaling is multimodal (Aung et al., 2020). Accordingly, people have developed the ability to perceive multiple cues and signals, and this is an evolutionary advantage, likely evolved to improve our detection of salient signals through the integration of different sensory information (Bro-Jørgensen, 2010).

In an ecological context, this ability of detecting and combining multiple cues, including physical characteristics as well as behaviours and acoustic variables (Aung et al., 2020), really influence the way people form their first impressions on other individuals, most of the time without being aware of it. The literature on this topic has been particularly focused on the importance of visual cues when interacting with people, with a particular regard for faces. As an example, studies (Dixon et al., 2021) have revealed that human males with a higher *width-to-height ratio* (fWHR, a perceived wider jaw) may signal a more aggressive personality and thus tend to be rated as more dominant. Facial dominance may so have the function to cue "aggressiveness, resource holding potential, and physical formidability" (Re et al., 2014). Indeed, researchers have demonstrated that men with wider faces are associated with more aggressive behaviours, and this can be due to an increased testosterone exposure during puberty (Haselhuhn et al., 2015), as the same is not true for women. Interestingly, women perceive more dominant faces as more attractive, but only for short-term relationships (Haselhuhn et al., 2015). Valentine and colleagues (Valentine et al., 2014) hypothesised that this may happen because a higher fWHR is also linked with traits like aggression, which is undesirable for long-term relationships. Thus, these results suggest that fWHR may be a physical marker of dominance, which signaling the presence of a higher level

of testosterone could make wider-faced men appear attractive and desirable by women, but only in a speed-dating context (Valentine et al., 2014).

Apart from the impact of visual cues and other peoples' physical appearance on social evaluations (Stern et al., 2021), most recently researchers are focusing on how acoustical cues influences socially relevant impressions (Stern et al., 2021), with special regard for voice pitch, considered as the most perceptual salient (Puts et al., 2019) voice parameters, especially since it has an impact on the perception of characteristics related to social power (Puts et al., 2019). However, before going into more details, we need to give an overview on what a voice is, how it is structured and how it can influence our judgments about others, with a particular focus on its role in the sexual selection framework.

1.4 Acoustical features of voice

Every sound comes generally with two sides: the production and the perception of it (Frühholz et al., 2019). As "voice perception is grounded in voice production" (Latinus et al., 2011), to perceive vocal sounds, as it happens for the great vastness of sounds that we are everyday exposed to, we need to analyse the sound source which produces them. In this regard, the majority of mammals, humans included, have evolved a very sophisticated anatomical structure which has allowed them to produce vocalisations as well as voice sounds: the organic vocal tract. This structure has a key role, since it exists in the first place to support vital functions, like breathing and swallowing, and then it peculiarly adapted during evolution in order to produce vocalisations and allow humans to develop a unique way of communicating: the human language. Therefore, in order to

develop the ability to speak, the human vocal tract has evolved a very sophisticated and integrated process of sound articulation, which has differentiated us from all the other species.

Specifically, from an anatomical point of view (Figure 1), the human vocal system includes “a power source (lungs, trachea), a sound source (larynx, vocal folds), and a sound modifier or filter system (pharynx, oral cavity, nasal cavity)” (Frühholz et al., 2019). Vocal sounds are generally derived from the interaction between the sound source (the vocal folds located in the larynx) and a filter (the vocal tract located above the larynx) (Latinus et al., 2011).

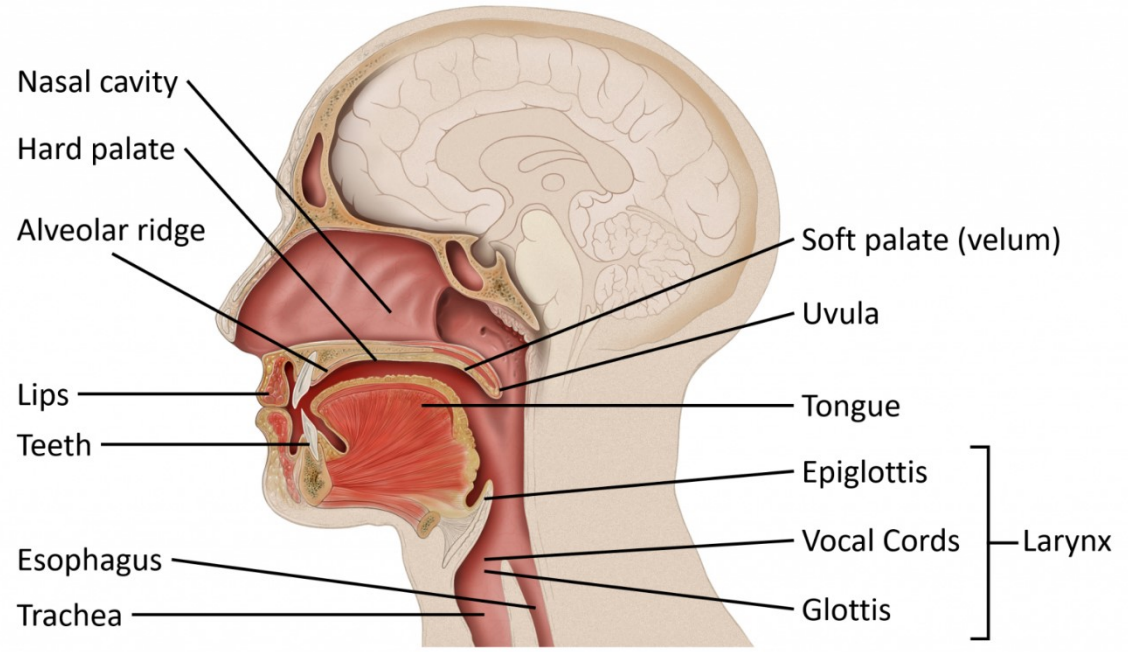

Figure 2 Parts of the human vocal tract (Mouth Anatomy by Patrick J. Lynch, medical illustrator).

To go into more detail, the voice as we know it results from the dialogue between three components, which are responsible for the production of the "spoken words": voiced sound, resonance and articulation. The first one is produced by a vibration occurring in the vocal folds; resonance is the amplification of the voiced sound which is modified exactly by the "resonators" (the throat, the mouth cavity and the nasal passages); and the last one, articulation, is the process of expressing detectable words through specific movements arranged by the vocal tract "articulators" (tongue, teeth, soft palate, lips).

Voiced sounds, which are the most common detectable human sounds (Latinus et al., 2011), are typically produced during a phase called phonation, when a vibration in the vocal folds produced by aerodynamic phenomena arises. More specifically, this happens when the column of air gained through breathing moves from the lungs towards the vocal cords, thanks to the coordinated action of the diaphragm, abdominal muscles and rib cage. These sounds are then amplified and modified by the vocal tract resonators, and result as recognizable words after going through the articulation process. The vibration of vocal folds occurring during phonation is also relevant because it is responsible for one of the most perceptually salient acoustic parameters, which is precisely modulated by the increasing and decreasing in the frequency of the vibrations: the fundamental frequency (*F*0), judged as *voice pitch* (Aung et al., 2020, Schild et al. 2020; Titze, 1994). Depending on their length, vocal folds can vibrate at different *F*0 and be perceived and rated as different voice pitches. Typically, longer vocal folds produce a lower fundamental frequency and characterise human males, which are typically bigger in size. This is probably related to the effect of testosterone in male puberty, which causes a 60% longer vocal folds in men rather than women. (Aung et al., 2020). Indeed, despite the wide range of values *F*0 can reach, its average rate varies

especially according to the size of the individual producing the voice sounds (and so to the length of vocal folds).

Another relevant vocal parameter involved in the production of voiced sounds is commonly known as *timbre* (Ghazanfar et al., 2008), and it is what gives sounds and voices a particular "colour" and personality, making them recognizable and unique. It can be described as the perceptual correlate of the vocal tract resonances (Ghazanfar et al., 2008), also defined formants, which vary according to the vocal tract length (Ghazanfar et al., 2008) and are modulated by the acoustic filter above the larynx (Frühholz et al., 2019). Since formants especially depend on vocal tract size, as it happens for *F*0, their value also varies according to the body size of the speakers, and consequently on their age and sex. For example, when pronouncing the same vowel, it has been found that men have lower formant frequencies compared to female speakers and children (Frühholz et al., 2019). Thus, we typically relate to voice features like formant frequencies and fundamental frequency when we distinguish male from female voices. (Pernet et al., 2012; Frühholz et al., 2019). To conclude, these two acoustical features are interesting not only because they are highly dimorphic, but also because their wide range variations can carry linguistic and prosodic information, as well as socially relevant cues. These latter in particular can contribute to the wide range of inferences we make when meeting new people (Stern et al., 2021), for instance allowing us to distinguish voice sounds and integrate acoustic information with other perceptual cues, helping us shaping our "perceived personality impression" on others. In this regard, many recent studies suggest that *F*0 is the most perceptually salient voice's acoustic property (Puts et al., 2020; Titze, 2000) able to convey social information (McAleer et al., 2018; Pisanski et al., 2018; Frühholz et al., 2019). Its role in this

context needs to be clarified, first of all explaining the crucial relationship between the voice and the evolutionary force that has contributed to shape its multiple nuances: sexual selection.

1.5 Role of voice in sexual selection

Voice pitch, being highly dimorphic, has likely being shaped by sexual selection, not only in humans but also in most animal species. Recently, many studies have focused particularly on the lower fundamental frequency (*F*0) which characterises men and on how it is subtly connected to social power, influencing the perception of dominance of the speaker. A lower fundamental frequency in men can in fact influence the perception of the male speaker, making him look "larger, older, more masculine and more physically and socially dominant" to the interlocutor (Puts et al., 2020). Since in humans a "large sound source" (Puts et al., 2020) tends to be associated with a lower voice pitch (Hughes, 2021), humans could have learnt to lower their vocal frequencies to be more threatening and appear bigger in size, and to do the opposite when signaling subordination or affiliation (Hughes, 2021). Thus, as we know from the sexual selection theory, low-frequency vocalizations could have had in time a role at conveying information of social superiority to other males, frightening them and by being perceived as more dominant; or they could also have been used to attract to women, increasing the female mate choice and then their mating chance.

But is a lower voice pitch in men an honest signal of formidability and social power? A lower fundamental frequency can actually provide information about physical power and strength (Puts, 2020), as it is typically linked to male sex maturation and increasing

levels of testosterone, which usually reflect aggressive behaviours as well as physical dominance. But there is also evidence of men adjusting their voice pitch in relation to their interlocutor, often without awareness, lowering their fundamental frequency when asserting power and modulating a "fake signal" of dominance through it (Puts, 2020). As an example, a greater perception of men's formidability communicated through more persistent vocalisations can sometimes falsely predict the fighting prowess of the speaker and not his actual fighting success (Hughes, 2021). Hence, the evidence on the honesty of this cue is not always confirmed. Despite this, some authors (Puts et al., 2020) contend that low male voice pitch is likely to be at least a partly honest signal, since deceptive signaling is a requirement for an evolutionarily stable signaling system (Puts et al., 2020). Indeed, "low male voice pitch, if entirely dishonest, would not have been maintained as a salient signal over evolutionary time" (Puts et al., 2020).

The dynamic of voice modulation can also be observed in women. Indeed, some evidence suggests that they tend to lower their voice pitch across social contexts when wanting to be perceived as more dominant. This effect seems to be weaker and we also have a relatively paucity of evidence in this regard (Hughes et al., 2021). Women voice pitch modulation seems also to have changed over time. In particular, women's voices seem to have lowered across time. Indeed, a cross-cultural study run in Australia compared the recordings made in 1945 and 1993 of women speaking, revealing that women in 1993 had significantly deeper voices than women of the same age recorded in 1945. (Pemberton et al., 1998). In particular, the fundamental frequency of these women had dropped by 23 Hz over five decades: from an average of 229 Hz to 206 Hz, a significant audible difference (Pemberton et al., 1998). The factors underpinning this effect were discussed, but the researchers speculated this deepening in voice may have

reflected the rise of women to more socially relevant and prominent roles, leading them to make use of a deeper tone to project their dominance at work (Pemberton et al., 1998).

This ability to regulate voice pitch cannot only be used to appear more socially dominant: at the same time, it can be exploited by the speaker to be perceived as a more attractive individual and thus to increase the courtship success (Hughes et al., 2021), which is a fundamental aspect of sexual selection. For a male, being perceived bigger in size and socially dominant through a lower formant frequency is an evolutionary advantage when it comes to intrasexual competition, which usually leads to mating success. In this regard, some recent evidences (Rosenfield et al., 2019) showed that in a small-scale population of Bolivian forager-horticulturists, the Tsimané, men with lower formant frequency had a higher number of offspring, providing a further confirm to the hypothesis of sexual selection being responsible for shaping voice. But for a woman, the evolutionary goal is typically to be seen as more attractive and desirable to a male potential partner and this seems to be achieved by raising their voice pitch. Regarding this, one study in particular investigated the relation between visual and vocal attractiveness in women as judged by men (Collins et al., 2001): 34 women were recorded speaking four vowels and then measured their peak frequency, the first five harmonic frequencies, the first five formant frequencies and formant dispersion (Collins et al., 2001). These women were also photographed (head shot) and several body measures were taken as well as their ages. A sample of males had to judge the women's age and to rate their attractiveness by only listening to the recordings; in a second time they had to assess the women's attractiveness by looking at their pictures. Women with

a higher voice pitch were assessed as being more attractive and belonged to younger women (Collins et al., 2001).

This association between voice and biological sex is strictly connected to the idea of masculinity and femininity (Hughes, 2021). In an evolutionary perspective, the voice is thus modulated according to mating behaviours. Since human males have a relatively "lower minimum obligatory investment" in offspring (Hughes, 2021) compared to the human females, sexual selection may have had a bigger role among our male ancestors in shaping traits (such as a lower voice pitch) that can favour mating opportunities and increase the chance of being chosen by a female. In a recent study (Hughes et al., 2014) these different peculiarities regarding voice modulation between the two sexes have emerged more clearly: indeed, when asking male and female subjects to convey through their voice information that might portray confidence or sexiness, males were only able to do the first one and the opposite occurred for the women participants (Hughes et al., 2014). This may be since confidence is a trait often linked to social power, money and all those characteristics which are usually taken into account by a female when choosing a male partner; instead, men tend to focus their mate preferences on younger and more attractive women, usually connotated by a higher formant frequency, which are typically linked to greater fertility. Moreover, when asking to sound more masculine or feminine, both sexes tend to respectively lower and raise their voice pitch (Cartei et al., 2012). In contrast, when asking to sound more attractive (Hughes, 2014), interestingly women tend to lower their voice pitch even more than men. Despite this, the effect has not been confirmed by other studies (Fraccaro et al., 2013) in which the baseline voice pitch was rated more attractive than the manipulated one. Accordingly, many recent

studies agreed on the effectiveness of voice modulation in the mating context. Nevertheless, there are still many contrasting sceneries that need to be investigated.

Apart from sexual selection and its evolutionary purposes, modulation of vocal cues serves many other different functions in nonverbal communication. For instance, it can elicit social stereotyping that may influence the way a listener perceives the speaker (Leongómez et al., 2021). Indeed, voice modulation is a significant predictor of social outcomes, and this can affect the perception and the behaviour of the listeners (Leongómez et al., 2021). As an example, during a conversation we may be able to grasp some voice's nuances that may influence how we perceive the interlocutor and thus change the way we see him/her, and this may also affect our social decisions in his/her regard (i.e. people usually vote as a leader someone who can be trusted and is socially dominant: trustworthiness in political context has in fact been correlated with lower voice pitch) (Leongómez et al., 2021).

In conclusion, the production and perception of human voice modulation and its relationship with social context is very important to understand, since it can help us define how voices may influence people's interpersonal and social outcomes (Leongómez et al., 2021).

1.6 Voice pitch and social perception

As already mentioned, fundamental frequency and vocal tract resonances can convey a wide set of perceptually salient information that can help us "point out" the voice of the speakers in many different ways (Ghazanfar et al., 2008): by their gender, their

approximative age and even by associating an identity to the voice we are exposed to; all of it potentially without the need to look at the person in question, nor knowing anything about the speech content or the language of the speaker (Latinus et al., 2011). Moreover, we could also infer the speakers' mood and affectivity, as well as more subtle information such as the perceived attractiveness, trustworthiness and dominance of an individual (Latinus et al., 2011). All of it is possible since we have evolved sophisticated cognitive faculties to extract this relevant information. Consider the following example: we hear someone talking on a train, and we cannot have access to any visual information, so we are not looking at his/her face. Nevertheless, we can extract a whole bunch of information on this individual only by hearing his voice sound: first, we can identify the gender of the speaker through the combination of voice pitch and formant frequencies (Frühholz et al., 2019; Pernet et al., 2012;); the age (Zaske et al., 2013); the weight and size; thus, we can infer many stable characteristics of the speaker (Frühholz et al., 2019). Furthermore, we could also extract information about the emotional state of the speaker (Frühholz et al., 2019; Schirmer et al., 2006), and even more subtle socially relevant cues that can help us to form an impression on the speaker's personality, like his/her physical dominance and attractiveness.

Many studies in the last decade have actively demonstrated that we can extract a wealth of salient information from voices (Latinus et al., 2011). In particular, we will clarify the role of voice pitch in this context, as it is a very remarkable index when referring to social perception: indeed, *F*0 influences various aspects along social dimensions that can be particularly relevant when interacting to people (Frühholz et al., 2019), concurring to form a fairly detailed picture of our socially relevant impressions (Latinus et al., 2011), especially when visual cues are absent.

Many judgments we make based on human voices' sound are somehow associated with important life outcomes (Stern et al., 2021): indeed, studies have previously reported that voice characteristics, particularly *F*0, can predict social behaviours such as courtship and reproductive success (Apicella et al., 2007; Leongómez et al., 2014; Stern et al., 2021), and could even influence personality judgments (Stern et al., 2021). The rate of vocal fold vibrations, judged as voice pitch, has a fundamental role in this regard, as low pitches tended to be perceived as more dominant both in men and women. Indeed, a lower voice pitch typically correlates with the perception of a more masculine and socially dominant speaker (Puts et al., 2020). Regarding this, a study has even revealed that people tend to prefer voting for politicians with lower-pitched voices, typically associating them with more dominant personalities, more physical prowess and integrity as compared to the high-pitched candidates (Tigue et al., 2012). Moreover, another study (Leaderbrand et al., 2008) in particular revealed that a lower *F*0 may even influence the perception of attractiveness, and that men with a lower voice pitch and timbre (formant frequencies) were indeed perceived as more attractive, both when rated by men and women (Collins et al., 2000; Feinberg et al., 2011; Hodges-Simon et al., 2010; Jünger et al., 2018; Puts 2005; 2006; Stern et al., 2021). Interestingly, the opposite happened for women: higher voice-pitched women were judged as more attractive, but in a significant way only when rated by men (Fraccaro et al., 2011; Leaderbrand et al., 2008). This may be since women with higher *F*0 tended to be younger and generally more fit (Leaderbrand et al., 2008). Moreover, speaking with a higher voice may be a powerful tool for women, as it may help to reduce the amount of "mating effort" in order to attract and retain potential mates (Fraccaro et al., 2011).

Having a higher voice pitch is not only linked with attractiveness, but also correlates positively both in men and women with rated neuroticism: as a matter of fact, these people are also perceived less agreeable and more neurotic (Apple et al., 1979; Scherer et al., 1978).

Other relevant researches have suggested that also judgments about trustworthiness can vary according to the speakers' voice pitch (Schild et al., 2019). The social dimension of trustworthiness is particularly important in order to initiate and maintain interpersonal relationships with other people (O'Connor et al., 2011; Ewin et al., 2015; Schild et al., 2020). Above aspects such as facial impressions (Oosterhof et al., 2009; Schild et al., 2020) and receptive behaviours (Levin et al., 2006; Schild et al., 2020), the voice is considered to be another crucial factor when forming social impressions that can influence our tendency to trust other people (Schild et al., 2020). In particular, a recent study (Schild et al., 2020) indicated that, when referring to mating-related trustworthiness, *F*0 is a valid cue to judge men's trustworthiness, whereas it is not so reliable as a general cue to judge men's general trustworthiness. Participants in this study seem to be more likely to trust a speaker with lower *F*0 in an economical context, whereas women subjects judged men with lower *F*0 less trustworthy in committed relationships (Schild et al., 2020). As certain women seem to be able to judge "sexual infidelity" from a man's voice at zero acquaintance (Schild et al., 2020), this may be seen as an evolutive advantage, benefiting women that want to choose a trustworthy partner for initiating a committed relationship (Schild et al., 2020). In line with this finding, another recent study (Schild et al., 2021) has reported that males with lower *F*0 were actually more likely to report a past history of sexual unfaithfulness, providing

first evidence that voice pitch could be considered as a valid cue in the context of sexual infedelity (Schild et al., 2021).

Judgments about a male speaker's trustworthiness can thus vary across different domains. However, these solid results have not been too much investigated on women yet, which leaves it open whether these results are also transferable to female speakers.

A different voice pitch can hence have an impact on person perception, and it is remarkable to point out that this can happen both in a naturalistic environment, where individuals are exposed to more perceptual features other than voice; but can also occur in experimental contexts where the voice is presented as an isolated cue. Thus, the voice is an important variable to consider when we interact with people. Indeed, altering acoustic parameters when speaking, especially the voice pitch, can suggest specific qualities of the speaker, and then influence social perception (Hughes et al., 2021).

According to these recent findings, with the present study we will focus on the relationship between voice pitch modulation and the social domain of dominance, in particular physical dominance, to see how they correlate with each other in a relatively high ecological context in which the participants hear and watch (multimodal signaling) female speakers talking for 10 seconds.

2 The Relative Influence of Fundamental Frequency (*F*0) on Perception of Dominance

Past research has shown that vocal pitch modulation (fundamental frequency, *F*0) can have a relevant influence on the perception of characteristics related to many social domains. A lower voice pitch, in particular, has been associated with the perception of more socially dominant features, such as physical strength and leadership abilities. However, most of the previous studies have been focused especially on the relationship between men's voice modulation and dominance, and very few data are available when referring to women. Moreover, the majority of these studies solely considered the influence of the voice on person perception, without integrating any other salient perceptual cues (i.e. visual information) which are normally present during a conversation in everyday life, and because of this they provided little ecological validity.

Here, we investigated the role of one of the most perceptually salient vocal parameters, *F*0, and how it affects the dominance perception of female speakers in a relatively high ecological context.

Participants had to judge the perceived physical dominance of different female speakers seen talking in 10 seconds videos. Our hypothesis was that women speaking with a lower F0 would have been perceived and rated as more physically dominant. In order to verify this, we have manipulated voice pitches of each speakers providing a lower and higher *F*0's version as well as the standard version. Analyses showed a significant difference particularly between the low and high voice pitch versions. These results suggest that lower *F*0 is a valid cue to the perceived dominance of female speakers.

2.1 Hypothesis

With the present investigation we hypothesised that manipulations of the female speakers' fundamental frequency (*F*0, judged as voice pitch) may lead to significant changes in dominance ratings, such that speakers with lower *F*0 may receive higher dominance scores. Even though we expected this effect in male speakers, according to the previous research on this topic, the same was not so obvious for female speakers, since we have a paucity of evidence in this regard.

2.2 Objectives of the present study

This study is attempting to demonstrate that voice pitch generally influences perceptions of dominance regardless of the presence of other perceptually salient cues (such as physical aspect, gender, age and spoken language) in a context where participants are exposed to 10 seconds videos and have to rate the perceived physical dominance of each speaker.

3 Methods

This study has been pre-registered online at the Open Science Framework (OSF; https://osf.io/an52f/) before any data were collected. The raw data, analysis script, administered questionnaires, and the instruction material are also provided in the OSF.

3.1 Participants

A total of 90 participants (n= 59 men; n= 31 women; aged 18 to 53) were recruited through the online platform Prolific (https://www.prolific.co/), a website that makes it easy to outsource studies to individuals from all over the world that can perform tasks virtually. We recruited prolific workers with prolific scores > 98 and at least 50 previously completed studies. Informed consent was obtained from all subjects. All participants were at least 18 years old and received an amount of £ 1.75. Subjects with hearing and visual impairments, more precisely deafness and blindness, have been excluded. We collected demographic information from all participants.

Due to our study design, we had to determine two sample sizes: one for the number of videos (i.e., stimuli) and one for the number of raters. For the video, we used G*Power (Erdfelder, Faul, & Buchner, 1996) to conduct a power analysis. Our goal was to obtain .80 power to detect a medium effect size of d =.35 (for a one-tailed matched pair t-test; alpha = 0.03). This resulted in a final sample size of 65 videos which we oversampled slightly. For the raters: we recruited 90 participants, because averages of ratings of dominance stabilise with 31 raters (Hehman et al., 2018). Since there are 3 versions of each video, we needed three times as many raters, i. e. 93 raters, which we slightly oversampled. In a sensitivity power analysis using G*Power96 this sample had

sufficient power (>0.80) to detect an effect size of d = .35, assuming one-tailed alpha = 0.03.

3.2 Materials

We have collected 65 videos in which a female speaker is shown talking. The videos were collected using Vimeo (https://vimeo.com/creativecommons/cc0), an American video hosting, sharing and services free online platform. In particular, we selected videos with Creative Commons (CC0) licence, which is an opensource software licence and universal tool, since it is not adapted to the laws of any particular legal jurisdictions. The content and language of the videos vary.

We created three versions of each video: the original version, one version of the video with increased *F*0 (+ 0.5 equivalent rectangular bandwidths or ERBs, a psychoacoustic measure which approximates bandwidths of the filters in human hearing), and one version with decreased *F*0 (- 0.5 ERBs). In all videos, audios were normalised to 70 dB. The *F*0 was manipulated using *Praat* (dutch for "talk"), which is a free computer software designed by Paul Boersma and David Weenink (University of Amsterdam) able to analyse and reconstruct acoustic speech signals. The software can be downloaded from the following website: http://www.fon.hum.uva.nl/praat/. For each manipulation, we used the script provided by David R. Feinberg (see https://osf.io/q7w43/). Since we know voice pitch is a highly dimorphic parameter, when manipulating male voice pitch it is usually used the default script values provided by Feinberg, with a positive minimum F0 of 60 Hz and a positive maximum of 300 Hz

pitch range; whereas for the female voice pitch manipulation we used a 100-500 Hz pitch range. Each video had a duration of 10 seconds.

3.3 Procedure

Participants recruited by Prolific attended the study remotely using their own personal computer. We collected demographic information from all participants. This includes age and gender.

During the experiment participants have been randomly assigned to one of the three versions of each video. Randomization has been ensured using the survey framework formr (https://formr.org). Each participant watched and rated a total amount of 65 videos.

To assess the perception of dominance of each speaker, after every 10 seconds video participants were asked to rate the perceived physical dominance of the speaker on a 7-point Likert-scale, from 1 “not dominant at all” to 7 “very dominant”. In particular, they had to answer the following question: “On a scale from 1 to 7, how likely would the speaker win a physical fight against an average woman?” (see Schild et al., 2020)

In each condition, the dominance ratings of each video group (higher, original, and lower *F*0s) have been averaged.

4 Results

All analyses were computed with the statistical software R (R Core Team 2016). We excluded n = 1 participant from the analyses as this person gave the same rating in > 75% of the time. We also wanted to exclude participants that took < 12 minute to end the study, n = 13 participants did not meet the requirement. Eventually, the analyses were based on N = 90 (N_{male} = 59; N_{female} = 31).

We calculated the means for F0 low (*M* = 3.63), F0 medium (*M* = 3.59), F0 high (*M* = 3.44) which correspond to the average dominance ratings. We then compared the three conditions F0 low, F0 medium and F0 high using three paired t-tests (alpha = .03). Results (Figure 3) show F0 low was linked to a greater perception of dominance as there is a statistically significant difference between F0 low and F0 high conditions ($t(64) = 4.6$, $p < .03$, $d = .55$). The results are in line with our hypothesis.

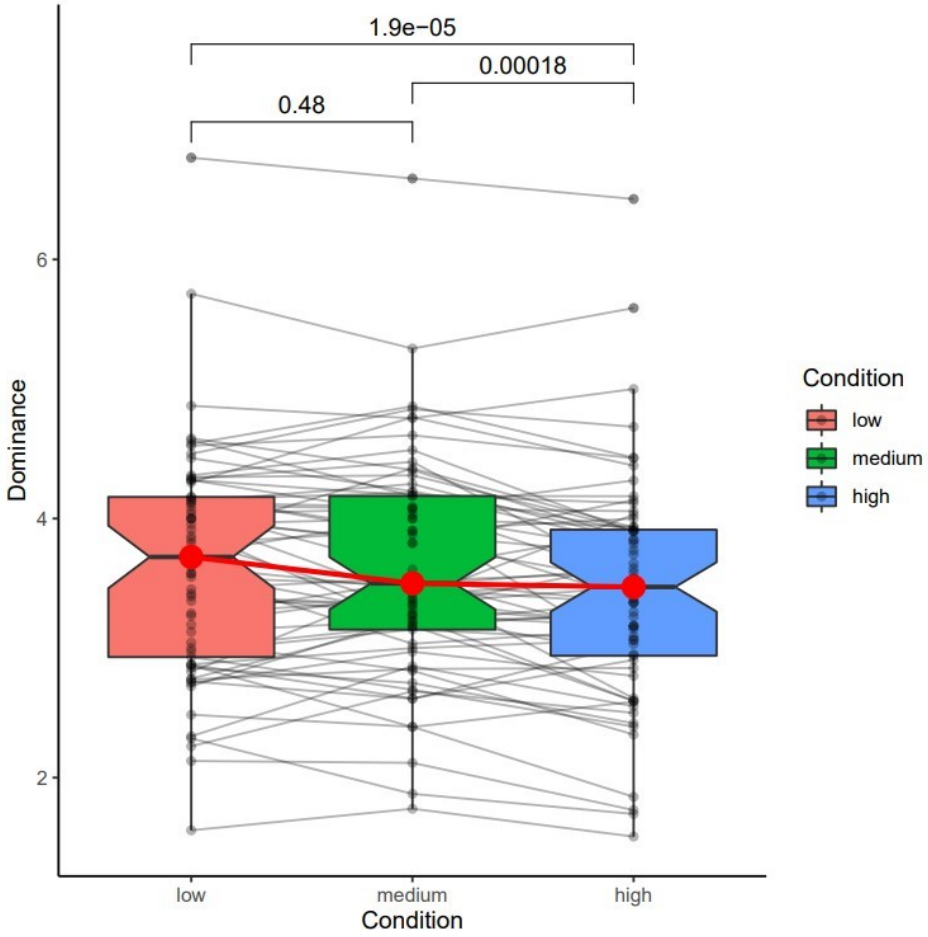

Figure 3 This plot shows the three p values between each condition. As we can notice, there is a statistically significant difference (t(64) = 4.6, $p < .03$) between the low and the high condition, as the dominance ratings were higher for the low voice pitch versions of videos.

5 Discussion

The aim of the present study was to investigate the relationship between voice pitch modulation and person perception analysing the role of one of the most perceptually salient vocal parameters, voice pitch (fundamental frequency, *F*0), and how it can affect the perception of dominance of women speakers based on first impressions. Indeed, according to past research, vocal pitch modulation influences the perception of characteristics related to many social domains. A lower voice pitch has been associated with the perception of more socially dominant features (Puts et al., 2012; Puts et al., 2020), such as physical strength and leadership abilities, and this effect has been particularly investigated for men speakers. The reason why men with a more profound voice have been rated as more dominant find a clear explanation in hormone regulation, since men are characterised by higher levels of testosterone, the principal cause of determining longer vocal folds responsible for a lower voice pitch (Puts, 2012; Puts et al., 2016). As we cannot state the same for women and as their voice pitch is remarkably less profound than men's, the relationship between a deeper voice sound and the perception of dominance in women speakers was not so clear, and has not been much investigated yet. In particular, it was not clear if the presence of other perceptually salient information, such as visual features of the person, may co-variate with the perception of dominance, such that the voice pitch manipulation may be underpowered by the look of the speaker.

In this study we hypothesised that a lower fundamental frequency, judged as voice pitch, had an influence on the perception of dominance of women of different age, languages and physical aspects that were rated while seeing them in 10 seconds videos.

In order to test our hypothesis, we conducted a study in which we created three different versions of the voice pitch of women speakers: one higher, one standard and one lower. In particular, we manipulated voice pitches through a software called Praat (https://www.fon.hum.uva.nl/praat/). Therefore, we wanted to verify if a lower fundamental frequency may have been considered a valid signal for the perception of dominance of women when other perceptual cues were present, considering that past research (Tigue et al., 2012; Puts, 2020; Hughes et al., 2021; Puts et al., 2012) in line with sexual selection theory has found correlation between lower *F*0 and stronger dominant features, such as physical strength and more dominant personalities, but finding significant results almost merely for men.

Our results are in line with previous findings indicating that fundamental frequency actually influences the perception of dominance (Puts, 2020). In particular, female speakers shown talking in 10 seconds videos that were characterised by a lower manipulated version of *F*0 were perceived as more dominant than the ones speaking in standard or higher manipulated versions of the voice pitch. Indeed, the participants of the present study rated them as more likely to win in a physical fight (measure of physical dominance). Consistent with previous studies, our findings suggested then a significant difference between the low and high voice pitch versions (Cohen's d = .55), supporting the idea that lower *F*0 is a valid cue to the perceived dominance of female speakers.

6 Limitations

Our investigation has some potential limitations that need to be discussed. First of all, despite the fact we found a significant difference between the higher and lower version of voice pitch ratings (where the lower version of *F*0 has been rated as more dominant for each speaker), this effect may have been influenced by the fact our manipulations were also relatively strong. Second, we only had a sample size of 90 participants which belonged to European countries. This may make our data less generalizable. In terms of number of participants, for the main research question the study is well powered. However, we have some limitations regarding whether this effect of *F*0 may be stronger or weaker for some speakers: indeed, it could be the case, especially changing the perception of average women. For instance, if someone looks extremely strong and dominant, then the effect of voice pitch may not change much. Also, if a person looks very "weak", then the voice pitch may not change the effect much either. But if someone looks like a "normal" person, then it might have a stronger effect on person perception. Accordingly, we cannot really say if the effect is the same for old speakers, which are the ones that may probably be perceived as weaker. As another limitation to our study, we cannot tell if there are any specific differences between each raters' perceptions. As we had only average perceptions, as an example we could not predict if the perception of voice pitch for men participants may be different than women's perception. Moreover, we only had 65 videos, so we could not really tell if the effect is specific to a sub-group. It could be that for some women the change in voice pitch makes a huge difference and for some it does not. To put this into context, if we think about a person like Mike Tyson, an American former professional boxer, he was especially known for having a particularly high-pitched voice. However, if we look at

him, we would not try to fight him for sure. Thus, for him the voice pitch would not make a huge difference in the overall dominance perception. However, for the average person we could have a larger effect. In this study we could not test this, as we did not code for speakers' characteristics such as particularly sporty or muscular women.

7 Conclusions

Our findings supported our initial hypothesis, so that a lower voice pitch is associated with a more dominant perception in women. These results can have some practical implications: indeed, this research shows that by manipulating voice pitch you can change perceptions of video recordings. To give an example of that, this may be used in the advertisement's market: by manipulating voice pitch, particularly lowering it, you could make an advertisement appear more dominant. Moreover, adjusting voice pitch is a particularly easy and effective thing to do, without the need of any particular editing skill, so it is something that can be broadly used to influence perception in specific directions.

As future implications for this study, we suggest to consider how a lower voice pitch may influence the perception of other significant variables such as attractiveness and trustworthiness, particularly to verify if the voice modulation has an effect when other perceptually salient information is present in videos. Moreover, coding for information such as the age of the speaker or the language may have a role in changing the perception of dominance, attractiveness and trustworthiness and future studies should set out to further extend these suggestions.

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Breve riassunto dell'elaborato

In letteratura, le ricerche finora condotte hanno dimostrato che la modulazione del tono di voce o "picco" (frequenza fondamentale, *F*0) può influenzare la percezione di svariati domini sociali. Un tono di voce più basso, in particolare, è stato associato alla percezione di caratteristiche socialmente dominanti come maggiore forza fisica e abilità di leadership. Tuttavia, la maggior parte di questi studi si è concentrata soprattutto sulla relazione tra la modulazione del picco di voce maschile e la percezione di dominanza, mentre sono disponibili pochissimi dati in riferimento alla modulazione del picco di voce femminile e di come questo possa influenzare la percezione sociale. Tali studi hanno inoltre tendenzialmente fornito una scarsa validità ecologica, considerando quasi esclusivamente la modulazione del picco di voce come *cue* isolato, senza integrare la presenza di ulteriori segnali percettivamente salienti (es. percezione visiva) solitamente presenti durante una conversazione ecologica.

Nel presente studio abbiamo indagato il ruolo di *F*0, uno dei parametri vocali più percettivamente salienti, e di come questo possa influenzare la percezione di dominanza in soggetti femminili presentati in un contesto ecologico relativamente elevato. In particolare, i partecipanti hanno valutato la dominanza fisica di 65 donne di età, lingua e genere differenti, presentate in video della durata di 10 secondi. Per ciascun video abbiamo manipolato sperimentalmente i picchi di voce, creando una versione F0 più bassa e una più alta (*range* 100-500 Hz) rispetto alla versione standard. Ciascun soggetto sperimentale è stato esposto a una delle tre versioni (F0 basso, F0 standard/ medio, F0 alto) di ciascun video in maniera randomizzata. Le analisi hanno evidenziato una differenza significativa nella percezione di dominanza, in particolare tra le versioni

del picco di voce più basso e più alto (d di Cohen = .55). Pertanto, questi risultati suggeriscono che un *F*0 più basso è un segnale significativo per la dominanza sociale in soggetti femminili nonostante la presenza di altri segnali percettivamente salienti, come ad esempio l'aspetto fisico.

Come implicazioni per la ricerca futura, suggeriamo di indagare come questo effetto possa variare in funzione di altri fattori come l'età, la lingua parlata e l'attrattività percepita.