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Acoustic Cues Of Physical Formidability In Cage Fighters

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ACOUSTIC CUES OF PHYSICAL FORMIDABILITY IN CAGE FIGHTERS

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CHAPTER 1

INTRODUCTION

Since the time of Darwin's *The Decent of Man* (1871), intra-male competition has been recognized as a powerful driver of sexual selection, shaping both mind and morphology (Miller, 1998; Zechner et al., 2001). Darwin described men as "rivals of other men". Indeed, males will compete over whatever resource is valued by females (Buss, 1988); among group living primates, social status itself is a valued resource (e.g., Maestripieri, 2008) and this is reflected as an emotional drive (Huberman, Loch, & Önculer, 2004). The likely reason for such rivalry lies in the importance of obtaining dominance over others, the phylogenetically deepest and most basic form being physical in nature.

Physical dominance is a ubiquitous feature of social life (see Cummins, 2000; Fernald, 2014). Even among highly egalitarian societies, physical dominance continues to be of importance (Chagnon, 1979), especially in evolutionarily relevant domains in which resources can be monopolized (e.g., mate acquisition and retention) (Emlen & Oring, 1977). Physical dominance continues to be important despite the existence of social forces (e.g., rule of law) arrayed against it and the availability of alternative routes towards dominance (e.g., prestige). Take for example the finding that taller men (height being a relevant component of physical dominance; Sell et al., 2009) are likely to have higher starting salaries (Loh, 1993). Indeed, among humans, social dominance is broadly correlated with the same fitness outcomes as physical dominance is among other species, leading some researchers to conclude that the two are functionally identical (Ellis, 1995). Regardless, among many cultures, physical dominance is an important determinant of social status (Daly & Wilson, 1988), which until recently was strongly correlated with reproductive success (Barrett, 2010).

Given the historical importance of physical dominance for reproductive success, men are expected to have evolved to compete vigorously for dominance (Geary, 1998). Across the animal kingdom, this form of competition—known as intrasexual competition—has produced elaborate secondary sexual characteristics deployed to achieve dominance (Emlen, 2008). Interestingly, these secondary sex characteristics not only serve as sex and maturity badges, but also show a high degree of within sex variation, making them well suited to convey status or formidability information because they allow differentiation among individuals along the formidability dimension (Emlen, 2008).

Conveying a Foregone Conclusion: The Role of the Human Voice

Dominance is not only determined through all-out combat. In point-of-fact, dominance is rarely established through direct conflict (Maynard-Smith & Parker, 1976; Parker, 1974). Only when both parties are highly motivated to achieve it and are close in physical formidability—a key determinant of physical dominance—do animals resort to combat (Hammerstein & Parker, 1982). Thus animals attempt to convey physical formidability and motivation so as to prevail and yet avoid a fight by intimidating the opponent. Given the cost inherent in combat, evolution has also shaped the psychology of signal receivers to assess and appropriately respond to honest signals of physical formidability (Guilford & Stamp Dawkins, 1991). Indeed, this adaptation appears to be online in humans within the first year of life (Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011).

Although physical formidability can be assessed through visual inspection, often in domains that are highly relevant for fitness (e.g., mate selection, dominance, kin recognition, predator avoidance), evolution favors the development of redundant signals. This multimodal redundancy increases the speed and fidelity of information transfer and increases discriminability (Rowe, 1999). One redundant means by which physical formidability may be conveyed in humans, and the focus of this paper, is through auditory signals (Evans, Neave, Wakelin, 2006; Puts, Apicella, & Cárdenas, 2012; Puts, Gaulin, & Verdolini, 2006; Puts, Hodges, Cárdenas, & Gaulin, 2007; Sell et al., 2010).

Similar to animal weaponry, the sexually dimorphic features of the human voice show a high degree of variability both between and within the sexes. Furthermore, within the frequency range of men's voices (centered around 100 Hz), between-male variability in pitch falls well within detection limits (i.e., just-noticeable-difference, JND) by about a factor of five[1] (Ladefoged, 1996).

Such findings are consistent with the comparative evidence. Across taxa, sexually dimorphic auditory signals are used in conjunction with visual signals to signal threat potential and to establish patterns of dominance and deference between animals (Clutton-Brock & Albon, 1979; Davies & Halliday, 1978; Hardouin et al., 2007; Kitchen, Seyfarth, Fischer, & Cheney, 2003; Ladich, 1998; Mager, Walcott, & Piper, 2007). Morton (1977) has likened this vocal dynamic to piloerection.

Recently, much research has focused on vocal pitch and timbre as potential dominance signals among men. Both are highly sexually dimorphic (Puts, Apicella, & Cárdenas, 2012) and these sex differences emerge at puberty, a time when males first start entering the mating market (de Bruyn, Cillessen, & Weisfeld, 2012), hence a time in which dominance contests become increasingly relevant. Although these sex differences can emerge through female choice—indeed, women rate masculine voices as more attractive (Collins, 2000; Daniel & McCabe, 1992)—the evidence is more consistent with a dominance competition account (Puts, Gaulin, & Verdolini, 2006; Sell et al., 2010). For instance, manipulating the voice alters attractiveness and dominance ratings but the effect size for the latter is larger suggesting that dominance is a more salient factor (Puts, Gaulin, & Verdolini, 2006).

Specifically, the fundamental frequency (hereafter simply referred to as pitch)—which is the primary determinant of perceived pitch—is half as high in men as it is in women (Titze, 2000). In a large sample of US participants and in a second sample of hunter-gatherers, Puts, Apicella, and Cárdenas (2012) report large sex differences in pitch (Cohen's d = 5.7 and 4.4 for US and Hadza samples respectively). Similarly, formant dispersion (hereafter simply referred to as timbre)—which is perceived as timbre or resonance and is also a component of perceived pitch—

[1] This was calculated using the variability data from Puts, Apicella, and Cándenas, 2012.

is about 12-10% lower among men than among women (percentages calculated from Puts, Apicella, & Cárdenas, 2012). Puts and colleagues (2012) reported a large sex difference in this metric as well (Cohen's *d* = 3.3 and 2.3 for US and Hadza samples respectively). To put these differences in perspective consider that height and upper body strength, which are both sexually dimorphic, only correspond to Cohen's *d's* of 2 and 3 respectively (McGraw & Wong, 1992; Lassek & Gaulin, 2009, respectively).

Pitch is determined by the length, tension, and thickness of the vocal folds (Titze, 2000) while timbre is largely a property of vocal tract length (Fitch & Hauser, 1995). As the vocal folds lengthen and thicken, pitch decreases. Likewise, as the vocal tract length increases, the spacing between formants decreases producing a more resonating, or sonorous, voice. The development of these structures are partially determined by androgens as well as human growth hormone (King, Ashby, & Nelson, 2001) and departs from isometric growth in males but not females during puberty due to the vocal folds and vocal tract growth outpacing overall body growth (Fitch & Giedd, 1999; Lee, Potamianos, & Narayana, 1999).

Given that these acoustic properties demonstrate large sex differences and are partially produced by sex hormones, researchers have been interested in testing whether these acoustic properties function as signaling mechanisms. Pitch and timbre have been found to be associated with a host of factors important for physical formidability. For instance, Evan, Neave, and Wakelin (2006) found that pitch was negatively correlated with shoulder-to-hip ratio, as well as shoulder circumference, chest circumference, and weight. Similarly, they found that weight and height were associated with timbre as were several other sexually dimorphic body shape metrics (e.g., neck thickness). Puts, Apicella, and Cárdenas (2012) report a similar pattern of findings between sexually dimorphic acoustic parameters and indicators of physical formidability, including a negative relationship between pitch and testosterone, among both a Western and hunter-gatherer sample. Additionally, they report a positive association between monotonicity (the degree to which pitch varies which is also sexually dimorphic) and self-reported physical aggression, such that men whose voices varied less in pitch reported more physical aggression.

Going beyond these correlational findings, Puts, Gaulin, and Verdolini (2006) found that manipulating pitch influenced subjects' ratings of physical and social dominance (the effect on the former being greater than on the latter). Specifically, when pitch was decreased, perceptions of dominance increased. Interestingly, they also found that men who believed themselves to be more physically formidable than a rival lowered their voice when addressing the rival, whereas if men believed themselves to be less physically formidable they raised their voice (in pitch). These data provide evidence that dominance relations might be partially communicated through voice pitch. This is consistent with the physiology of the vocal folds and the emotional dynamics that occur during dominance competition (Mazur, 2005). Replicating and expanding on these results, Puts, Hodges, Cárdenas, and Gaulin (2007) showed that independently manipulating pitch and timbre impacted dominance ratings. Again, physical dominance was more influenced than was social dominance. Furthermore, they found that timbre had a larger impact on dominance ratings than did pitch.

Finally, in a series of studies, Sell and colleagues (2010) found that rater judgments using the voice alone tracked upper body strength. Judges' ratings were more accurate when the targets were men, which indicates that the voice may be an important signaling mechanism in physical dominance competitions, particularly among men. Also, voice judgments of fighting ability tracked target's fighting history (recorded as the number of fights in the past four years) and self-reported physical aggression. However, and contrary to Puts, Apicella, and Cándenas (2012), pitch and timbre did not predict strength or weight, but timbre was related to height whereas pitch was not. Strangely however, pitch and timbre were used in judgments of strength, height, and weight. So we are left with the puzzle of how raters can use the voice to make accurate judgments of physical formidability and fighting propensity yet (at least some of) the cues purportedly used are not correlated with physical formidability. Rendall, Vokey, and Nemeth

(2007) suggest that people's putative misuse of pitch may stem from (i) generalizations between the contrast of children's and women's voices with adult men's voices, (ii) an overgeneralization of the concept that larger things make deeper sounds, and/or (iii) known common causes of both pitch and physical formidability (e.g., testosterone). An additional source of bias may come from generalizing pitch with emotional states. The tension on the vocal folds during states of high arousal (e.g., fear) raise pitch. Thus, people may generalize pitch differences across emotions to pitch variation in normal speech. However, another possibility exists. Since Sell and colleagues (2010) only consider the main effects of each, it is possible that they are used by judges in combination to assess physical formidability. That is, pitch and timbre may interact to predict physical formidability. Although this is possible, it does not explain the inconsistencies with the findings of Puts, Apicella, and Cárdenas (2012), who found main effects of each.

In conclusion, voice is accurately used as a cue for assessing physical strength (Sell et al., 2010; Apicella et al., 2012) and is used to convey relative strength (Puts et al. 2006). But is physical dominance purely dependent on physical strength? Given the evolutionary significance of dominance, accurately settling dominance disputes carries large fitness consequences.

Impugning Strength

Despite these findings, no research known to me has directly compared sexually dimorphic acoustic parameters with actual ability to win an all-out fight, a step that is crucial to demonstrate a signal's honesty. Indeed, although strength is integral to physical dominance, it does not form a one-to-one conceptual match. Other factors such as vigor, learning (e.g., a history of fighting), commitment, and confidence likely play a large role in physical contests. The present study was conducted to address this gap.

The Voice of a Fighter

Using a sample of mixed martial arts fighters from an elite fighting league (Ultimate Fighting Confederation, UFC©), pitch, timbre, and pitch variability were assessed as predictors for fighting ability. It was hypothesized that these variables would predict fighting ability. Specifically, these variables were predicted to be negatively correlated with fighting ability (i.e., a more male pattern was predicted to correspond to greater fighting ability). Additionally, interactions between these variables were used to predict fighting ability.

CHAPTER 2

METHOD

Subjects

Two-hundred and ninety-two fighters were included in this study. The fighters were chosen by selecting fighters that were listed on the UFC's website up until September 29, 2012. Following the convention of Zilioli et al. (2014), only experienced fighters—defined as having fought at least ten professional fights and one UFC fight—were included.

The fighters ranged in age from 21 to 42 years old (*M* = 30.02, *SD* = 3.95). Sixty-one percent of the fighters were from North America, 16% were Brazilian, 12% European, 6% Asian, and 5% were of a different origin. There is some evidence that where one habitually places one's voice varies cross-culturally (Grodol & Swann, 1983). As such, nationality was explored as a control variable.

The fighters' records were retrieved from Wikipedia while the voice samples were obtained from interviews found and downloaded from YouTube® between 2013 and 2014. Interviews for eight of the fighters could not be found, leaving a final sample of 284 fighters for whom interviews and fighting records were available.

Variables

Acoustics

All of the acoustic voice parameters were extracted from interviews using Praat (version 5.3.53), a freely available audio analysis software. A single random segment of continuous, conversational speech (*M duration* = 13.62 sec., *SD* = 3.86 sec.) was selected from each fighter's interview. I mention conversational speech in order to highlight the fact that these findings cannot be generalized beyond normal conversational speech; that is, they cannot be generalized across the emotional arousal spectrum.

Physical Formidability

The primary measure of formidability was the total number of fights in the UFC (tenure). Fighters that experience three consecutive losses are typically kicked out of the UFC (Horne, 2012), providing a 'quasi-Darwinian environment' (Zilioli et al., 2014). This metric was used in favor of percentage of wins since fighters are not matched randomly but rather matched on ability (i.e., the best fighters will often fight each other). Furthermore, wins and losses were positively correlated (r = .609, p < .001) even after controlling for years active as a fighter ($r_{partial}$ = .364, p < .001), thus wins do not provide a good metric for fighting ability.

Analytic Strategy

First, the bivariate relationships between the three vocal parameters, height, weight, and total number of UFC fights were examined using Pearson product moment correlations.

Next, partial correlations for each vocal parameter were examined separately to examine the association of each with total number of fights after controlling for years active as a fighter and height and weight.

Finally, two separate linear hierarchical regression analyses were conducted in order to examine the relative importance of each of the three vocal parameters regressed on total number of fights after controlling for years active as a fighter and height and weight. The second regression analysis included a third step in which the interaction term between pitch and timbre was included. Multicollinearity was examined using a tolerance cutoff of >.10 and a variance inflation factor < 10. In the case of multicollinearity, the predictor with the larger zero order predictor-criterion relationship was maintained while the collinear variable was removed from the model.

With a two-tailed alpha of .05, this sample size was substantially powered for large and medium effect sizes ($|r|$ = .50 and .30, power > .99) and inadequately powered for small effect sizes ($|r|$ = .10, power = .34).

CHAPTER 3

RESULTS

The bivariate relationships between the three vocal parameters, height and weight and total number of UFC fights are reported in Table 1. To correct for non-normality in the distribution of monotonicity (standard deviation of pitch) and pitch were logarithmically and inversely transformed respectively. None of the vocal parameters were related to height or weight (*p*s > .238). Among the vocal parameters, only pitch and monotonicity were significantly associated ($r = -.599$, $p < .001$). Note, this association appears negative but is in fact positive due to the inverse transformation applied to pitch.

Height, weight, pitch, monotonicity, timbre, and fighting ability (operationalized as total number of fights in the UFC) as well as the number of years active as a fighter (entered as a control variable[2]), were entered together into separate multiple regression analyses to predict pitch, monotonicity, timbre, and fighting ability (Table 2, Models, 1, 2, 3, 4). Fighting ability was the only significant predictor of pitch and monotonicity ($\beta = 0.265$, $P = .001$; $\beta = -0.346$, $P < .001$, respectively). None of the predictors were related to timbre (*p*'s > .289). Including ethnicity into these models did not significantly change any of these results.

Fighters who lasted longer in the UFC spoke in a lower pitch ($r = .135$, $p = .023$)[3]. This relationship held after controlling for years active as a fighter, height, and weight ($r = .191$, $p = .001$). Fighters with lower pitch won more fights ($r = .125$, $p = .036$) however, pitch was not associated with the percentage of fights won ($r = -.045$, $p = .455$). This lack of association probably stems from the fact that wins strongly correlated with losses ($r = .609$, $p < .001$).

Fighting ability was associated with monotonicity such that fighters whose pitch varied less had longer tenures in the UFC ($r = -.142$, $p = .016$). This relationship held after controlling for

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[2] Excluding this variable changed none of the conclusions.
[3] Note, because pitch was not normally distributed, the data was inversely transformed. Thus, a positive correlation represents a negative association.

years active as a fighter, height, and weight (*r* = -.250, *p* = .001). Once again, monotonicity was associated with the number of fights won (*r* = -.124, *p* = .037), but was not related to the percentage of fights won (*r* = .060, *p* = .310).

Timbre was not associated with fighting ability (*r* = .090, *p* = .131). This relationship was unchanged after controlling for years active as a fighter, height, and weight (*r* = .057, *p* = .339).

Having established that fighting ability is associated with pitch and monotonicity, I next examined the extent to which each explained unique variance in fighting ability. Fighting ability was regressed onto height, weight, pitch, monotonicity, timbre, and years active as a control. The overall model was significant ($F(6, 277) = 49.789$, $p < .001$). However, there was evidence that pitch and monotonicity were multicollinear (conditional index > 30 in conjunction with pitch and monotonicity variance proportions of .62 and .74 respectively). Rerunning the model after dropping pitch resulted in a significant overall model ($F(5, 278) = 59.589$, $p < .001$). The only significant predictor of fighting ability, apart from the control variable ($\beta = 0.708$, $p < .001$), was monotonicity ($\beta = -.182$, $t(278) = -4.356$, $p < .001$) (See Table 2, Model 5). A similar outcome was found when monotonicity was removed rather than pitch (pitch: $\beta = .141$, $t(278) = 3.319$, $p = .001$). Specifically, a decrease of one standard deviation in pitch (23.52 Hz) corresponded to a 6.26% increase in fighting ability (that is, having fought 1.36 more fights). Likewise, an increase in monotonicity (i.e., a decrease in pitch variation) of one standard deviation (7.94 Hz) corresponded to an 8.06% increase in fighting ability (that is, having fought 1.75 more fights).

Finally, to explore the potential moderating role of timbre on the relationship between pitch and monotonicity on fighting ability, two hierarchical regression analyses were run. A centered interaction term between pitch and timbre, was created and entered into step two of the model after entering height, weight, pitch, timbre,, and years active in step one. The interaction between pitch and timbre, was not significant ($\Delta R^2 = 0.000$, $p = .905$). Likewise, in the second interaction model examining the potential interaction between monotonicity and timbre, the interaction term was also non-significant ($\Delta R^2 = 0.000$, $p = .813$).

CHAPTER 4

DISCUSSION

Of the three vocal parameters, pitch and monotonicity were the only two to predict fighting ability and were highly correlated with one another. Timbre was not related to fighting ability. A straight forward interpretation of these findings is that pitch and monotonicity provide an honest signal of formidability independent of body size. Past research has indicated that timbre is a redundant signal of size, which among nonhuman animals is a strong determinant of dominance (see Wilson, 1975, table 13-2). In the current sample, the contribution of size to fighting ability is effectively removed due to the fighters being matched by weight-class; therefore it is unsurprising that timbre, a marker of size in past studies, was not significantly related to fighting ability. However, in the current sample, timbre was also unrelated to both height and weight, contrasting with some past human and animal findings (Evans, Neave, & Wakelin, 2006; Fitch & Hauser, 1995; Hodges-Simeon, Gurven, Puts, & Gaulin, 2014; Sell et al., 2010) but consistent with others (Puts, Apicella, & Cárdenas, 2012).

It is possible that timbre was poorly measured in the current sample as timbre is generally measured by having participants generate vowels rather than extracting timbre from a full speech utterance. However, Dabbs and Mallinger (1999) found that two measures of pitch, one generated by having participants state a series of numbers and another in which the participants generated a series of vowels, were highly correlated. The absence of fricatives in the vowels did not seem to greatly impact the association with normal speech. The same may be true of timbre.

More generally, these findings contribute to the idea that variation within a sexually dimorphic trait may not only serve as a sex and maturity indicator but also signal latent sexually dimorphic behavioral traits (Emlen, 2008). Indeed, having a more masculine vocal profile was associated with greater fighting abilities. Similarly, a recent study using the same dataset found that fighters with a more masculine facial width-to-height ratio, a sexually dimorphic trait in humans (Geniole, Denson, Dixson, Carré, & McCormick, 2015), were more successful in the UFC (Zilioli et al., 2014).

Although I did not find any significant interactions between pitch, monotonicity and timbre, a potential interaction may still exist between physical intensity of the voice and these variables. It may be difficult to speak in a lower register as one increases physical intensity; thus, observers may accurately use pitch when it is normed against the loudness of the speaker's voice. Unfortunately, I was unable to collect voice intensity data (dB) due to the use of unstandardized speaking distances (from the microphone) and the fact that these interviews were given in a normal decibel range, precluded my ability to test this hypothesis with the current data. Future work is required to address this possibility.

Indeed, a consideration of how far these results can be generalized is worth noting. Here, the vocal parameters that were extracted were under conditions of normal conversational speech (although the rank ordering is likely maintained across speaking conditions). Although these findings may not generalize beyond this condition, previous findings indicate that acoustic parameters correlate across content types, and changes in pitch and monotonicity have been found to relate to self-perceived dominance (Hodges-Simeon et al., 2010; Puts et al., 2006). A tentative conclusion from the present findings is that pitch and monotonicity under normal speech conditions can be used to accurately gauge fighting ability of professional combatants. It is an open question as to whether these vocal parameters can be used in a similar manner across the emotional arousal spectrum. Each arousal state might very well have its own vocal parameter profile and the acoustic components of each may differ in the degree to which they track physical threat.

These results are consistent with past research which has found that perceptions of whether a leader is competent is partially determined by having a more masculine vocal profile (Anderson & Klofstad, 2012; Klofstad, Anderson, & Peters, 2012; Tigue, Borak, O'Connor, Schandl, & Feinberg, 2012). Furthermore, these results suggest that people's use of these cues to gauge dominance is veridical (Hill et al., 2013; Hodges-Simeon, Gaulin, & Puts, 2010).

Limitations

There are several limitations to the current study. First, and most importantly, the results for the formant structure (timbre) may lack measurement validity and as a consequence may be best not interpreted, especially given the null finding here contrasted to past positive findings (Evan, Neave, & Wakelin, 2006; Puts, Apicella, & Cárdenas, 2012; Sell et al., 2010). Isolated vowel utterance is the usual method of obtaining recordings for formant measurement (e.g., Sell et al., 2010). This could not be done in the current sample.

Second, these results were obtained from men in the upper end of the distribution of fighting abilities (range restriction). However, this threat to validity likely would make it more difficult to finding a positive result, not less difficult as range restriction generally attenuates correlations. That I found significant associations despite this shortcoming argues for the strength of these relationships.

Next, the rate of anabolic steroid abuse could not be estimated and may have contributed both to fighting ability and vocal profiles. Indeed, in a case study of a 22-year-old hypogonadal professional male singer, hormone replacement therapy resulted in significant masculinizing changes to his vocal register (King, Ashby, & Nelson, 2001). Furthermore, circulating levels of testosterone are negatively associated with pitch and changes in pitch track diurnal changes in testosterone (Evans, Neave, Wakelin, & Hamilton, 2008). However, the organizing effects of testosterone and human growth hormone on the morphology of the vocal tract is likely nominal post puberty because once the epiphyseal growth plates have been closed (due to high levels of testosterone exposure during puberty) the growth of the cartilaginous framework of the larynx is complete (King, Ashby, & Nelson, 2001).

Lastly, the operationalization of fighting ability as tenure in the UFC may lack construct validity. However, although wins were strongly correlated with losses, the partial correlation between wins and tenure after controlling for years active was larger than the partial correlation between losses and tenure ($r_{partial}$ = .935, p < .001; $r_{partial}$ = .663, p < .001, wins and losses respectively). This suggests that tenure accurately captured the construct. Also, some nonrandom error is introduced by the fact that better fighters tend to fight each other making it more difficult to remain in the UFC than fighters of lower ability. Despite this source of error, I was able to find significant relationships between this measure of fighting ability and pitch and monotonicity.

Future Directions

These vocal cues appear to be another way in which relative formidability can be gauged. However, the accuracy of these cues has produced mixed results. For instance, Puts et al. (2007) found that both pitch and timbre influenced dominance attributions among men, whereas Sell et al. (2010) found that while both men and women could accurately gauge fighting ability from the voice alone, this relationship was not mediated by pitch or timbre. One possible way in which this question could be addressed with the current data would be to have raters listen to these recordings and make judgments of fighting ability. Should a relationship exist, the extent to which pitch and monotonicity mediate the relationship would provide further evidence for the signaling properties of these vocal parameters.

In conclusion, I was able to establish for the first time that men's pitch and monotonicity are associated with an actual measure of fighting ability. A wide variety of evidence suggests that sexually dimorphic acoustic parameters may signal physical formidability, but until now the critical link between vocal characteristics and fighting ability has been missing. Indeed, the current data illustrates the evolutionary impetus for why masculine voices are perceived as being more physically dominant; furthermore, this adds to the hypothesis that sexually dimorphic features of the male voice evolved more strongly under direct contest (i.e., intrasexual selection) rather than through mate choice (Hill et al., 2013; Puts, 2010). To the degree that it is feasible, future research will be needed to test the extent that these findings replicate beyond a sample of men from the extreme upper end of the distribution of fighting abilities to one across the normal range of abilities.

APPENDIX A

Table 1

Summary of intercorrelations, means, and standard deviations for study variables

	M	*SD*	1.	2.	3.	4.	5.
1. Height	179.11	8.60					
2. Weight	76.40	14.47	.765***				
3. Pitch	133.01	23.52	.070	.035			
4. Monotonicity	19.18	7.94	-.024	.033	-.599***		
5. Timbre	1078.67	49.59	-.007	.040	-.057	.049	
6. No. UFC Fights	21.72	9.64	.003	.047	.135*	-.142*	.090

Height is given in centimeters and weight in kilograms. Note, transformed data was used to compute correlations. $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

Table 2

Multiple regression predicting Pitch (F_0)

	Standardized beta coefficients (*t* statistic)	Zero-order correlations *r*	Partial correlations
Weight	-0.023 (-0.251)	0.035	-0.015
Height	0.099 (1.082)	0.070	0.065
Fighting Ability	0.265 (3.259*******)	0.135*****	0.191*******

$F(4, 279) = 3.076$*****; $R^2 = 0.042$. Note, the variable ‘years active as a fighter’ was included as a control variable. **p* < .05, ***p* < .01, ****p* < .001

Table 3

Multiple regression predicting Monotonicity (*F_0-SD*)

	Standardized beta coefficients (*t* statistic)	Zero-order correlations *r*	Partial correlations
Weight	0.085 (0.927)	0.033	0.055
Height	-0.106 (-1.178)	-0.024	-0.070
Fighting Ability	-0.346 (-4.310***)	-0.142*	-0.250***

$F(4, 279) = 5.327$***; $R^2 = 0.071$. Note, the variable 'years active as a fighter' was included as a control variable. *$p < .05$, **$p < .01$, ***$p < .001$

Table 4

Multiple regression predicting Timbre (*D_f*)

	Standardized beta coefficients (*t* statistic)	Zero-order correlations *r*	Partial correlations
Weight	0.100 (1.063)	0.040	0.064
Height	-0.085 (-0.915)	-0.007	-0.055
Fighting Ability	0.079 (0.957)	0.090	0.057

$F(4, 279) = 0.879$; $R^2 = 0.012$. Note, the variable ‘years active as a fighter’ was included as a control variable. *$p < .05$, **$p < .01$, ***$p < .001$

Table 5

Multiple regression predicting Formidability (*Total Fights*), excluding monotonicity

	Standardized beta coefficients (*t* statistic)	Zero-order correlations *r*	Partial correlations
Weight	-0.079 (-1.189)	0.047	-0.071
Height	0.011 (0.161)	0.007	0.010
Pitch	0.141 (3.319***)	0.135*	0.195***
Timbre	0.049 (1.155)	0.090	0.069

$F(6, 277) = 47.004$*******; $R^2 = 0.504$. Note, the variable ‘years active as a fighter’ was included as a control variable. *$p < .05$, **$p < .01$, ***$p < .001$

Table 6

Multiple regression predicting Formidability (*Total Fights*), excluding pitch

	Standardized beta coefficients (*t* statistic)	Zero-order correlations *r*	Partial correlations
Weight	-0.065 (-0.987)	0.047	-0.059
Height	0.005 (0.071)	0.007	0.004
Monotonicity	-0.182 (-4.356***)	-0.142*	-0.253***
Timbre	0.049 (1.161)	0.090	0.069

$F(5, 278) = 59.589$***; $R^2 = 0.517$. Note, the variable 'years active as a fighter' was included as a control variable. *$p < .05$, **$p < .01$, ***$p < .001$

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ABSTRACT

ACOUSTIC CUES OF PHYSICAL FORMIDABILITY IN CAGE FIGHTERS

by

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Across the animal kingdom, the sex that experiences the most reproductive variance tends to evolve sexually dimorphic traits—both behavioral and morphological—which aid in reproduction. Human evolution has been marked by greater male intrasexual selection and as a result, men display a variety of secondary sexual characteristics, putatively serving to enhance biological fitness. Among these, fundamental frequency, closely related to perception of pitch, among men is half that of women. Likewise, monotonicity, that is, variance in pitch across an utterance, is higher in men (i.e., women show greater variance in pitch) while formant dispersion, which gives the voice its timbre, is lower. The honesty of these vocal parameters as signaling mechanisms used in context of intrasexual competition has been investigated by a host of researchers; however no research to date has directly assessed the degree to which these parameters predict actual physical formidability, a key step in establishing the honesty of a signal. Here, I address this gap by testing whether these parameters are associated with fighting ability in a large sample of mixed martial arts fighters. Pitch, monotonicity, and timbre were extracted from interviews taken from 292 UFC® fighters and compared with the fighters' records. Pitch and monotonicity were associated with formidability such that a more

masculine profile was associated with higher formidability; timbre however was not associated with formidability. Taken together, these results indicate that pitch and monotonicity may be honest signals of physical formidability.

AUTOBIOGRAPHICAL STATEMENT

Stefan Goetz was born on July 4th, 1987 to Michael and Doris Goetz, the second child of four. He grew up first in Flint, MI before moving to the country at age nine. There he enjoyed his childhood exploring the surrounding woodlands and playing and working with his cousins on their family farms. Stefan graduated from Grand Valley University in 2011, where he studied psychology and German. He then worked as Justin Carré's lab coordinator for a year at Wayne State University before entering their psychology graduate program in 2012. There, he began his studies in Social Neuroendocrinology and Evolutionary Psychology. Stefan's primary research interests include Signaling Theory, Evolutionary Psychology, and Social Endocrinology. In his spare time, Stefan enjoys reading works of popular science, playing online video games, biking riding around Detroit, and watching science fiction and historical dramas.