Melody Matters: An Acoustic Study of Domestic Cat Meows in Six Contexts and Four Mental States

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Abstract
This study investigates domestic cat meows in different contexts and mental states. Measures of fundamental frequency (f0) and duration as well as f0 contours of 780 meows from 40 cats were analysed. We found significant effects of recording context and of mental state on f0 and duration. Moreover, positive (e.g. affiliative) contexts and mental states tended to have rising f0 contours while meows produced in negative (e.g. stressed) contexts and mental states had predominantly falling f0 contours. Our results suggest that cats use biological codes and paralinguistic information to signal mental state.

Introduction
Acoustic cues to paralinguistic information like a human speaker's physical and emotional state can be found in fundamental frequency (f0), intensity and duration (see e.g. Gangamohan, Kadiri, & Yegnanarayana, 2016). Some of these cues are related to so called biological codes, which can be observed in humans as well as nonhuman species. An example is that according to the 'frequency code' high f0 indicates smallness, submission, friendliness, and uncertainty, while low f0 signals largeness, dominance, aggressiveness, and certainty (Morton, 1977; Ohala, 1983; Gussenhoven, 2016). Animals are able to experience and express emotions (Bekoff, 2007, p. 42; Briefer, 2012), and as a consequence, it is reasonable to expect that their physical and mental state influences their vocalisations to include paralinguistic information found in f0 and duration.

Domestic cats (*Felis catus*) are – next to dogs (*Canis lupus familiaris*) – the most common companion animals in the world. Over 600 million cats are said to live with humans worldwide (Saito, Shinozuka, Ito, & Hasegawa, 2019). Cats have developed an extensive, variable and complex vocal repertoire, probably best explained by their social organisation, their nocturnal activity and the long period of association between mother and young (Bradshaw, Casey, & Brown, 2012). Moreover, as a consequence of their interaction with human beings, cats have learned to vary and nuance their voices ever since they were domesticated, approximately 9500 years ago (Vigne, Guilaine, Debue, Haye, & Gérard, 2004).

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Cat–human communication is considered to be understudied (Saito et al., 2019). The findings of only a few studies on the topic suggest that the acoustics of cat vocalisations vary depending on the context, and the cats' emotional state. Brown, Buchwald, Johnson, & Mikolich (1978) compared sounds from kittens and adult cats in isolation, food deprivation, pain, threat, acute threat and kitten deprivation and found differences in duration, initial and peak f0. Nicastro (2004) found acoustic differences (duration and mean and max f0, first and second formant, and spectral tilt) between meows produced by domestic cats and African wild cats (*F. silvestris lybica*) in food-related, agonistic, affiliative, obstacle and distressing contexts. Yeon et al. (2011) analysed domestic cat vocalisations (growls, hisses and meows) produced by domestic and feral cats in one affiliative and four agonistic contexts and found differences in duration, mean fundamental and peak frequency. Schötz and van de Weijer (2014), finally, compared f0 of domestic cat meows in food- and vet-related contexts and found a predominance of rising contours in food-related contexts, and of falling contours in vet-related contexts, as well as larger f0 standard deviation in food-related meows.

In the present study we compare duration and f0 in meow vocalisations by domestic cats in six different contexts and four mental states. We hypothesised that cats use biological codes to convey paralinguistic-like information like emotion and intention depending on the context in which the cat was recorded and on their mental state.

Materials and Methods

The collected material consisted of audio and video recordings of 58 cats interacting in everyday contexts with humans (mainly their owners, but occasionally with one of the experimenters). The recordings were made using a GoPro Hero 4 Session video camera and a Roland R-09HR WAVE/MP3 recorder with Sony ECM-AW4 Bluetooth wireless microphones attached to collars worn by the cats. In addition, whenever a cat did not accept to wear the collar or when owners recorded and sent us videos recorded by them privately, other equipment (e.g. cell phones) was occasionally also used. Care was always taken to place or hold the microphone as close to the cats' mouths as possible without disturbing their natural behaviour. Audio files (unless recorded using the Roland R-09HR) were extracted from the video files as 44.1 kHz, 16 bit WAV files.

The material used in this study was recorded in one of the following six contexts: while waiting at a door (or a window) (*door*), while approaching a befriended human or cat (*greeting*), while soliciting or receiving food (*food*), while soliciting or during play (*play*), while being lifted (*lifting*) or while being in a cat carrier (*transport box*). Of these, the first five were relatively positive contexts while the last one generally was relatively negative for the cats. The mental state of the cats was classified as *attention seeking, content, discontent* or *stressed* based primarily on visual cues of the body, head and tail posture and movements (see e.g. Bradshaw & Cameron-Beaumont, 2000, pp. 73–74). Finally, each vocalisation was classified as either a *meow, trill, growl, hiss, howl, snarl, purr* or *chirp* (or a combination of two types), as described in Schötz (2018, pp. 254–257). Naturally, not all cats produced vocalisations in all contexts or mental states.

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The type of vocalisation, recording context and mental state were all annotated with the speech analysis tool Praat (Boersma & Weenink, 2019) by the first author. A randomly selected sample of the files was independently annotated by the second author to estimate agreement in the type of vocalisations that the cats produced. Results showed varying degrees of agreement between the two labellers with kappa values ranging from 0.43 to 0.97 with an average of 0.70.

The most common human-directed vocalisation in our recording collection was the meow, defined as a voiced sound generally produced with an opening-closing mouth and containing a combination of two or more vowel sounds (e.g. [eo] or [iau]) with an occasional initial [m] or [w] (after Schötz, 2018). A total of 780 meows produced by 40 cats (22 females and 18 males, aged 1–12;6 years) were selected for acoustic analysis in this study. For all tokens, measures of f0 (maximum, minimum, mean and standard deviation (sd)) as well as duration were obtained. Additionally, F0 contours were generated using Praat Pitch Objects and manually corrected when necessary. To facilitate between-cat comparison, the contours were normalised by setting the minimum f0 for every meow to 0 semitones (st). Mean contours were obtained for each context and mental state by averaging f0 measured at 100 evenly distributed points in each meow. Differences between meows produced in different contexts and mental states were compared through visual inspection of the mean f0 contours as described below. Figure 1 shows an example of individual f0 contours and the corresponding mean f0 contour for the context *play*.

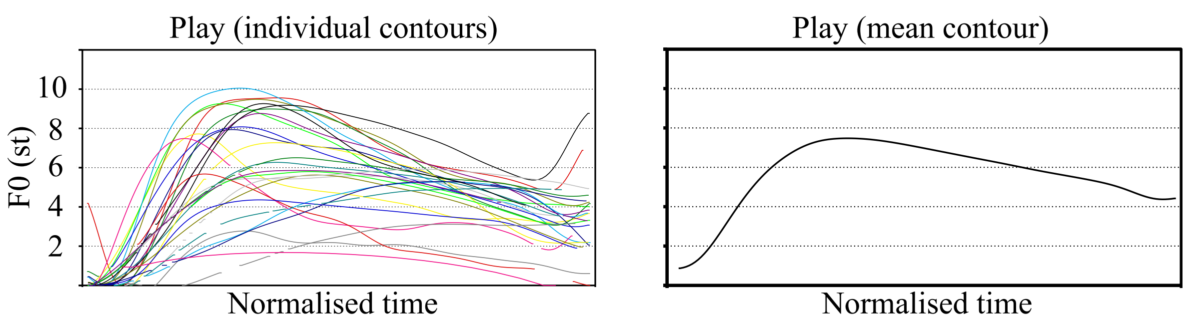

Figure 1.: Individual and average f0 contours for the context *play*.

Results

Duration and f0

Table 1 shows mean acoustic values in the different contexts and mental states. Differences between contexts and mental states were analysed for f0 mean, f0 sd, and duration (f0 minimum and maximum were not analysed as they highly correlated with f0 mean, and f0 range was not analysed as it highly correlated with f0 sd). The analysis was done in two steps. First, we performed mixed effects regression analyses to obtain an overall typical value for each cat across all contexts. Subsequently, these estimated values were subtracted from the values for each meow resulting in a positive number for a meow produced with a relatively high parameter value and a negative number for a meow with a relatively low parameter value. The resulting values were analysed using mixed effects regression with context and mental state as fixed effects and random intercepts for the different cats.

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Table 1: Acoustic measurements (mean values).

Context	*n*	*duration (ms)*	*f0 (Hz) min*	*max*	*mean*	*range*	*sd*
door	75	754	601	712	661	111	30
food	341	728	501	641	581	140	38
greeting	61	670	395	542	484	148	44
lifting	20	724	575	720	654	145	39
play	27	561	318	444	393	124	36
transport box	165	932	484	617	546	133	33
Mental state							
attention	487	719	478	618	559	140	40
content	52	545	414	551	495	137	40
discontent	150	843	493	609	554	117	29
stressed	78	912	520	671	579	151	39

For contexts, we found that meows produced in *food* contexts were characterized by relatively high mean f0 (EST = 13.914, SE = 4.863, t = 2.861, p = 0.006) and short duration (EST = –31.94, SE = 13.27, t = –2.407, p = 0.023). On the contrary, meows produced by cats in a *transport box* were characterized by low mean f0 (EST = –26.988, SE = 6.846, t = –3.942, p = 0.000) and long duration (EST = 71.84, SE = 19.11, t = 3.759, p = 0.001). Meows produced in *door* contexts were relatively high in mean f0 (EST = 20.105, SE = 9.833, t = 2.045, p = 0.044), and meows produced in *play* contexts were characterized by low f0 variability (EST = –9.248, SE = 4.134, t = –2.237, p = 0.026). The remaining effects were all not significant.

For mental states, meows produced by *stressed* cats showed low average f0 (EST = –29.329, SE = 8.080, t = –3.630, p = 0.000), and long durations (EST = 99.727, SE = 27.307, t = 3.652, p = 0.000). Finally, meows produced by *discontent* cats were (marginally) significantly lower in f0 variability (EST = –3.475, SE = 1.777, t = –1.956, p = 0.051). All remaining effects were not significant.

F0 contours

Figure 2 shows mean f0 contours for the six contexts and the four mental states. The f0 contours for the meows in the positive (affiliative) contexts *door, greeting, food*, *play* and *lifting* all display rising patterns — the clearest can be seen in *greeting* — sometimes combined with a later fall. In contrast, the average contour produced by cats in a *transport box* is falling. Similarly, the f0 contours for the positive mental states *attention* and *content* are rising, while those produced by cats who were *discontent* or *stressed* display falling patterns

Discussion and future studies

The results from this study suggest that cat vocalisations are influenced by the context in which they were recorded or the mental state of the cat. We found effects on average f0, f0 variation, duration and on the melody (f0 contours). Roughly summarized, we observed that meows produced in positive contexts (by cats with a positive mental state) were high in pitch, short in duration and had a rising melody, while those produced in negative contexts (by cats with a negative mental state) were low in pitch, long in duration and had a falling melody. It should be noted that some contexts contained meows by very few cats, e.g. *play* (2 cats) and *lifting* (4 cats). In future studies a larger number of cats will be analysed in each context and mental state.

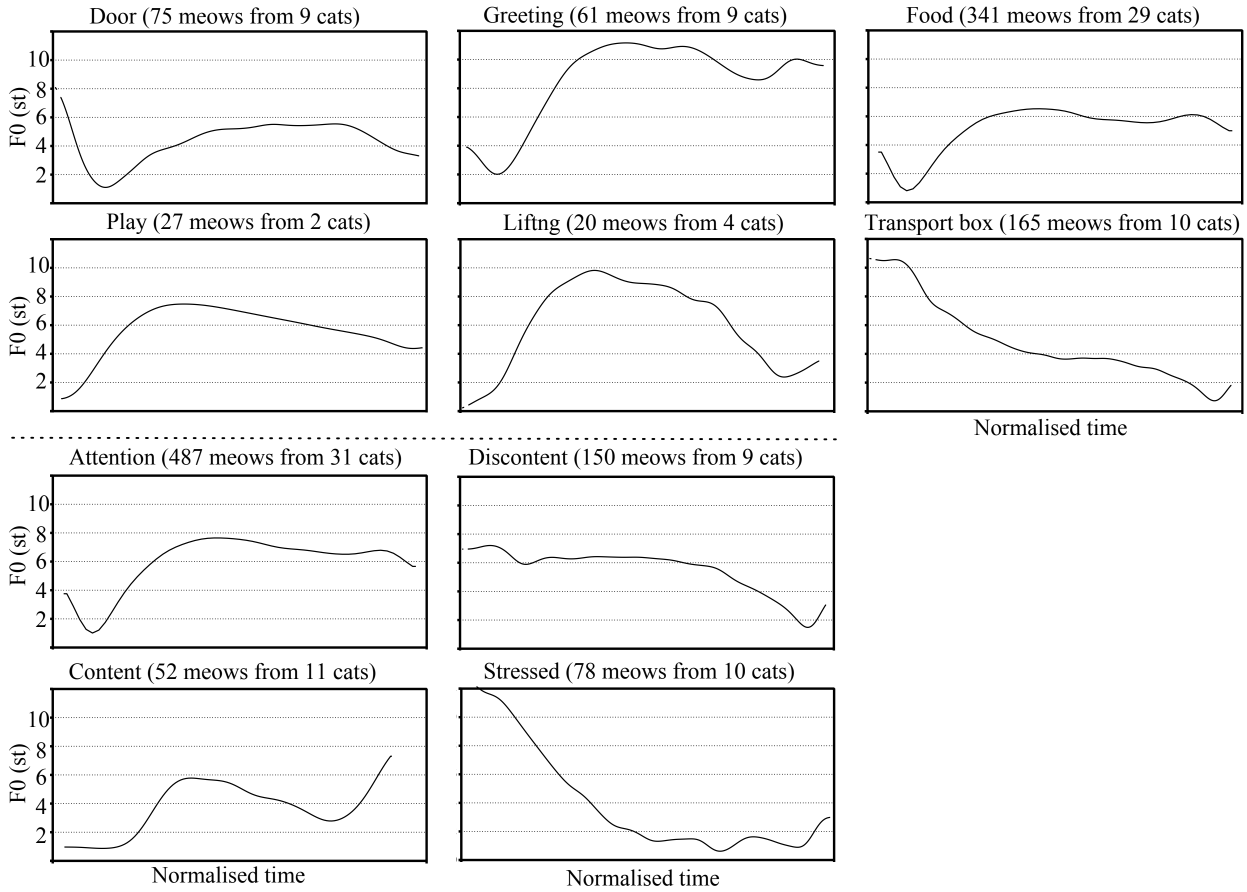

Figure 2. Mean f0 contours of meows from six contexts and four mental states (st: semitones).

A possible explanation of our findings is that cats use biological codes like the frequency code to vary the meaning of their vocalisations. Whether this is innate or a learned behaviour used mainly with humans is still unclear. We will investigate this in a future study by comparing human–directed and cat–directed vocalisations.

In order to understand the exact mechanism behind the paralinguistic variation in acoustic characteristics of meows we will need to explore the data further and include measures of intensity and voice quality. Other factors that potentially influence the acoustics of cat vocalisations need to be taken into consideration. Possible candidates are sex, age, weight, breed and level of emotional arousal. Environmental factors, such as the number of cats in a household, may also play a role.

Whether or not variation in f0 and duration can be used to assess the mental or emotional well-being of cats remains to be tested. Rising patterns, in that case, are likely to indicate contentment, while falling patterns signal stress or discontentment. Additionally, meows were far from the only type of vocalisation in our collection, which also included trills, growls, hisses, howls, snarls, purrs or chirps, and also combinations of two vocalisation types. Our next step in trying to chart the vocal system of the cat will be to subject these other vocalisation types to similar acoustic analyses to see whether we find effects of context and mental state there as well.

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