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Humans can identify cats' affective states from subtle facial expressions

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Abstract

Although cats' popularity as pets rivals that of dogs, cats are little studied, and people's abilities to read this apparently 'inscrutable' species have attracted negligible research. To determine whether people can identify feline emotions from cats' faces, participants (n = 6,329) each viewed 20 video clips of cats in carefully operationalised positively (n =10) or negatively valenced states (n = 10) (cross-factored with low and high activity levels). Obvious cues (eg open mouths or fully retracted ears) were eliminated. Participants' average scores were low (11.85/20 correct), but overall above chance; furthermore, 13% of participants were individually significantly successful at identifying the valence of cats' states (scoring ≥ 15/20 correct). Women were more successful at this task than men, and younger participants more successful than older, as were participants with professional feline (eg veterinary) experience. In contrast, personal contact with cats (eg pet-owning) had little effect. Cats in positive states were most likely to be correctly identified, particularly if active rather than inactive. People can thus infer cats' affective states from subtle aspects of their facial expressions (although most find this challenging); and some individuals are very good at doing so. Understanding where such abilities come from, and precisely how cats' expressions change with affective state, could potentially help pet owners, animal care staff and veterinarians optimise feline care and welfare.

Keywords: *affective states, animal care, animal welfare, cats, emotional states, facial expressions*

Introduction

Cats are popular pets, and even more common than dogs in many countries (European Pet Food Industry Organisation 2016; American Pet Products Association 2018). Despite this, people's bonds with cats are sometimes rated weaker than their bonds with dogs (Martens *et al* 2016; Arahori *et al* 2017). Furthermore, compared to dogs, cat behaviour, welfare and cognition has attracted far less research (Walker *et al* 2014; Sheve & Udell 2015; Udell & Shreve 2017). For instance, at least 16 studies have investigated humans' abilities to identify dogs' affective or motivational states (see Table S1: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Their findings include that videos of dogs in positive states are typically identified correctly, while those of dogs in fearful or anxious states are not (unless raters have professional canine expertise) (Wan *et al* 2012; Demirbas *et al* 2016); that people perform better than chance when asked to match recorded growls with context (eg food-guarding versus play) or states like 'aggressiveness' (Taylor *et al* 2009; Faragó *et al* 2017); and that images of the faces of dogs in affectively diverse contexts are generally correctly identified as indicating positive, negative or neutral states (Schirmer *et al* 2013; Kujala *et al* 2017). However, beyond the dramatic, widely recognised signals of cats under threat (the fully retracted ears, hissing open mouths and piloerection so well-described by Darwin [1998] and Leyhausen [1979]), how well humans can read cats, in contrast, has been little researched, attracting just four peer-reviewed studies to date. Three investigated vocalisations, showing that people have limited abilities to correctly match recorded 'meows' to the contexts or states of unfamiliar cats (though some raters are successful, especially for familiar cats) (Nicastro & Owren 2003; Belin *et al* 2008; Ellis *et al* 2015; Table S1 [https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material]). The fourth focused on facial expressions (Holden *et al* 2014): Veterinarians and veterinary nurses asked to distinguish between still images of the faces of painful and pain-free cats were often incorrect. However, significantly high success rates were observed for some images and, also, again, for some individual raters. Furthermore, careful quantitative measurements of specific anatomical landmarks revealed that pain did indeed induce consistent, if small, changes in cats' muzzle shapes and ear positions (Holden *et al* 2014).

Evidence thus indicates that at least some humans can detect subtle changes in painful cats' faces, but whether such abilities translate across a wider spectrum of emotions has yet to be determined. Three factors made this question worth addressing. First, cats have a reputation for being 'inscrutable' (Bradshaw 2013), making it important to study subtle signals (as likely in facial expressions) that could otherwise be missed. Second, practically, a cat's face may sometimes be its most visible body part (for example, if in a box or carrier, or restrained by being wrapped). Third, the homology and cross-species 'readability' of facial expressions is of great fundamental interest. Humans are neurologically adapted for rapid, sophisticated facial processing (eg McKone *et al* 2007; Vuilleumier & Pourtois 2007), making us skilled at detecting the transient, subtle facial expressions generated by even minor changes in emotion in other people (Ekman 1992); and, furthermore, some facial expressions are homologous across mammals, including humans (eg 'pain faces' [Chambers & Mogil 2015]; 'disgust' faces to aversive tastes [Berridge 2000; Hanson *et al* 2016]; eye-widening when alarmed [Core *et al* 2009; Lee *et al* 2014]; and open-mouthed 'play faces' [Aldis 1975]). We therefore aimed to assess the extent to which humans can identify negative affective states, beyond pain and overt responses to threat, from cats' facial expressions. We also sought to determine whether such abilities extend to positive states. As well as testing these hypotheses, we also aimed to identify how various rater characteristics, such as gender and experience with cats, influence raters' abilities to identify feline affective states: such factors often prove important in similar research on dogs (Wan *et al* 2012; Schirmer *et al* 2013; Flint *et al* 2018), and the few cat studies to date already suggest large individual differences between people (Nicastro & Owren 2003; Holden *et al* 2014).

To do this, we designed methodologies based on what we saw as best practice in the published literature. First, we obtained facial expressions from a large number of diverse individual adult cats, to avoid 'stimulus pseudoreplication' (Kroodsma *et al* 2001) (for an example, see Bloom & Friedman 2013) and to enhance the generality of any findings (cf eg Taylor *et al* 2009). To do this, we capitalised on the vast number of cat videos posted on YouTube (Marshall 2014) (for a similar approach, see Dermibas *et al* 2016). Second, inspired by the success with which other companion animal researchers have recruited participants online (eg Wan *et al* 2012; Ahola *et al* 2017; Jacobs *et al* 2017), we used a web-based survey to collect ratings. Third, we avoided a modular or discrete emotions approach as potentially anthropomorphic (for a similar argument, see Scheumann *et al* 2014). Instead, we used the 'valence-arousal' view of emotions (Russell 2003) which categorises affective states more simply as whether experienced as pleasant (thence preferred) or unpleasant (thence aversive), while also emphasising that such states vary in the degrees of associated activation, activity or physiological arousal. Fourth, we agreed with other authors (eg Pongrácz *et al* 2011; Schirmer *et al* 2013) that selecting stimulus animals with known affective states is crucial, if challenging; and that it is important to avoid the subjectivity, circularity or non-replicability that could occur if selection either relied on experts' judgments of stimulus animals' affective states (see Table S1; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), or had little or no stated rationale (cf eg Schirmer *et al* 2013; Bennett *et al* 2017; Kujala *et al* 2017). We therefore drew up clear objective selection criteria, based as far as possible on scientific research on the causes and functions of emotions. This involved carefully operationalising the identification of feline affective states, largely based on subjects showing approach behaviour consistent with reward/positive reinforcement (cf Rolls 2007; Schirmer *et al* 2013) or avoidance behaviour consistent with punishment/negative reinforcement (Rolls 2007) (for details, see *Materials and methods*). Fifth, and finally, to avoid clues, distractors or confounds in our video clips, we masked or blurred all potential contextual cues (cf eg Langford *et al* 2010); avoided using cats showing obvious displays of affect (ie ears fully back and/or mouths open [Leyhausen 1979; Darwin 1998]); and also assessed cat activity levels, counter-balancing these across valence classes (partly as a proxy for the 'arousal' component of affect [Russell 2003], but also to ensure that activity or arousal was not confounded with valence).

Materials and methods

Video selection

Videos posted on YouTube (providing not 'viral', widely known ones), of patients recorded and submitted to us by veterinarians, and of pets recorded and submitted by ourselves/colleagues were considered. Those fitting our criteria were reviewed until 40 were obtained spanning two broad affective categories: positive (n = 20), and negative (n = 20). Of these 40 videos, 75% (30/40, spanning both valences) originated from YouTube; 7.5% (3/40) were submitted by veterinarians (all of inactive cats in negative states); and 17.5% (7/40) were submitted by ourselves/colleagues (of pets in positive states). For the surveys, we thus used the first 40 videos that met our inclusion criteria (provided in more detail below); these are listed in Table S4 (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

Criteria for identifying negative affect

Cats were classed as experiencing negative affective states if:

• Clearly showing signs of avoidance, via observable retreat behaviour (eg withdrawing from an object, person or conspecific; fleeing to a hiding spot), via observable or reported attempts to do so despite being unable (eg struggling when restrained), or inferred from owner commentaries that implied retreat/avoidance/withdrawal (eg 'he's hiding under the bed');

• Clearly prevented from achieving a goal (eg approach attempts were blocked by an obstacle), such that the apparent aim of the behaviour (eg accessing the outdoors) was thwarted, in a manner consistent with frustration (Rolls 2007);

• Displaying well-validated signs of negative affect: growling (Kessler & Turner 1997; Rodan *et al* 2011; Mathews *et al* 2014), hissing (Rodan *et al* 2011; Mathews *et al* 2014), or startle (Gourkow *et al* 2014);

• Judged from clinical context, by a veterinarian, as experiencing either pain (eg after invasive surgery, and not

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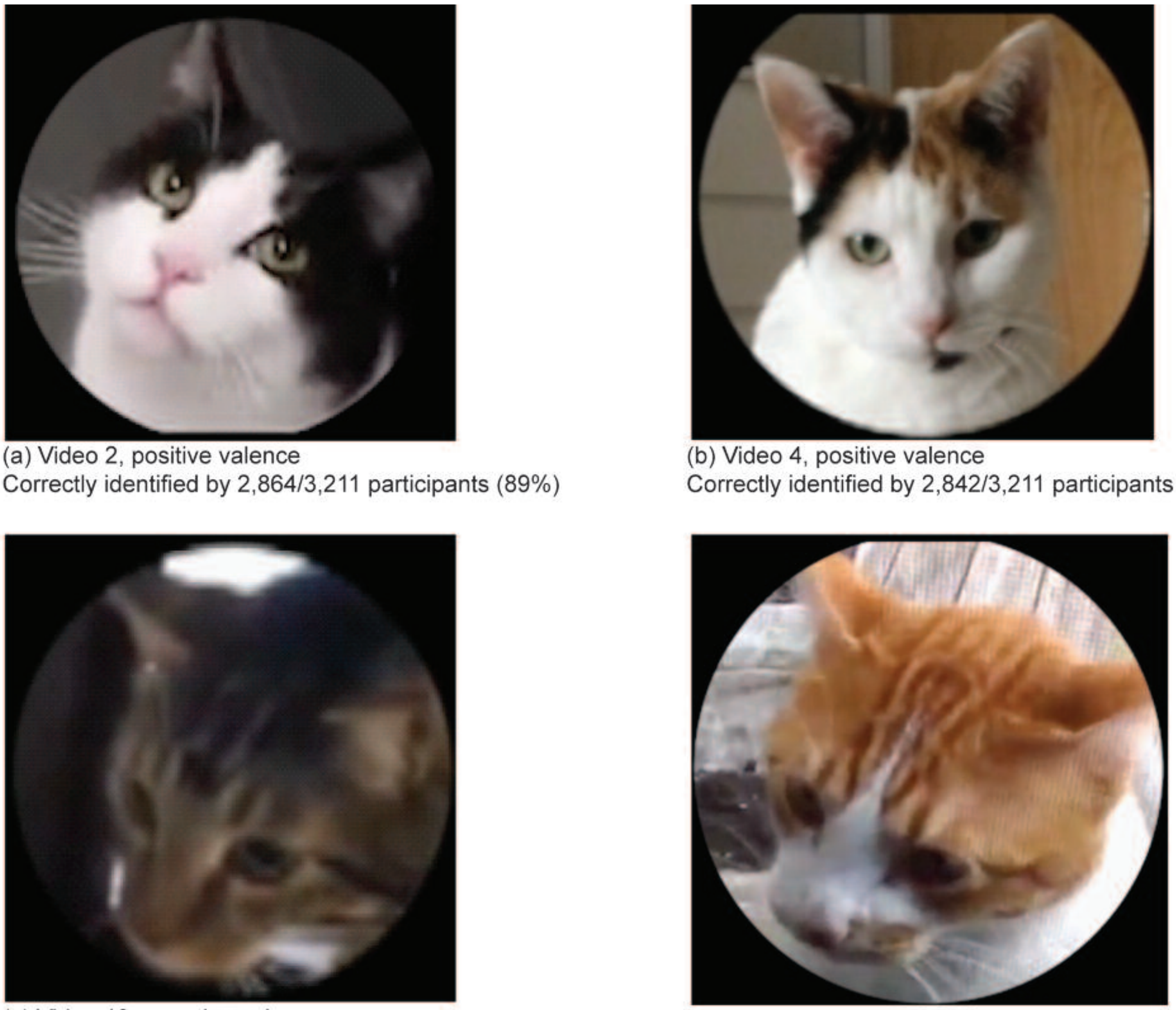
Figure 1



(a) Video 2, positive valence
Correctly identified by 2,864/3,211 participants (89%)

(b) Video 4, positive valence
Correctly identified by 2,842/3,211 participants (89%)

(c) Video 13, negative valence
Correctly identified by 2,775/3,211 participants (86%)

(d) Video 11, negative valence
Correctly identified by 2,619/3,211 participants (82%)

Still images of facial expressions from the (a, b) highest scoring positive and (c, d) negative cat valence videos.

given analgesics), or malaise/nausea (eg immediately prior to vomiting, a state also known to condition taste aversion in cats [Rabin & Hunt 1992]).

Videos of cats which were malnourished, severely injured, very hungry or thirsty, or exposed to extreme heat or cold were excluded as often containing other visual cues too extensive to mask (eg matted or dirty fur, visible injury, bandages).

Criteria for identifying positive affect

Cats were classed as being in positive affective states if clearly approaching or having approached an object, conspecific, or human (either observed, or inferred from owner reports implying seeking/approach behaviour [eg 'she's climbed into her favourite spot'], or in the absence of other evidence, if the cat had their tail up, as used in positive greetings [Cameron-Beaumont 1997]), as long as:

• The cat did not subsequently retreat and/or show any other signs of fear (see above; for example, as could occur when cats were exploring novel objects);

• A desired object was not withheld for more than 5 s, to avoid potential frustration (see above);

• The approach was not agonistic, or cats had not approached each other for mating, due to the affectively ambiguous nature of feline mating (males often bite females' necks [Hart & Hart 2014], and have penile spines which can rake the vagina upon withdrawal [Aronson & Cooper 1967]; females often end encounters by jumping away [Aronson & Cooper 1967]).

Cats given catnip were also excluded, as the mood-altering effects of catnip are not well understood.

Activity levels

Equal numbers of active and inactive cats were sought for each valence group (eg the 20 videos of cats in positive states comprised ten active cats and ten inactive). Activity was defined as clear movement (ie running, walking, jumping, playing, rolling, swatting, or scratching); inactivity as the cat being clearly unmoving (whether prone, sitting, or lying), as long as awake with eyes open. When videos included both active and inactive states, a clip was categorised according to the predominant activity level (> 50%) immediately preceding the edited section.

Other exclusion criteria

The quality of each potential video was assessed, and any with pixelated or blurred cats' facial features excluded. Videos were also excluded if they did not show the cat's head from an angle between a front view to 90 degrees lateral. We also excluded kittens, and cats with phenotypes making facial changes difficult to see (eg brachycephaly as in Persians; breeds with folded ears; any with long hair obscuring the face; and any with black/very dark facial colouring unless both eyes and mouth were clearly visible). Finally, no individual was included more than once, such that the final 40 videos represented 40 different cats.

Video editing

Videos meeting these criteria were edited to produce short clips (< 4 s) using Adobe Premiere Pro CS6 (Adobe, San Jose, USA). Clips were chosen using objective rules to avoid 'cherry picking', based on the timing of affectively significant events and the first clear facial shot: thus the first clear shot during the period of withdrawal or approach, up to 5 s after the eliciting stimulus; when prevented from achieving a goal for at least 5 s; or immediately prior to vomiting. For videos without clear preceding events, the first clear shot of the face was selected. Videos were clipped to exclude instances of the mouth being open (eg in mid-hiss, mid-meow, or mid-yawn) or obvious ear retractions. Clips were then edited using 'track and hide' masking and audio muting in Adobe Premiere Pro CS6 to remove contextual cues (cf eg Langford *et al* 2010). All 40 clips were selected and edited by either JC or LCD, and a random subsample of these was reviewed by GM and LN to confirm that they met all criteria.

The resulting 40 videos of 40 cats all involved close-ups of the head/face (for examples, see Figure 1). Final clip lengths varied, depending on the period the cat remained in view and met criteria (mean 2.22 s; range 0.63–3.37 s), but did not differ between the eight valence-activity groups across survey versions ($F_{7,32} = 0.48$; $P = 0.84$).

Participant recruitment and questionnaire

The survey was created and hosted online by Qualtrics. Its use was approved by the University of Guelph's Research Ethics Board (REB #16-12-226). All interactions with human subjects complied with this and informed consent was always obtained prior to participation. To be eligible to participate, individuals had to be at least 18 years of age with normal or 'corrected to normal' vision (eg wearing spectacles). Advertisements were posted on Facebook and the authors' personal blogs and sent through the University of Guelph Campbell Centre for the Study of Animal Welfare's email listserv. Participants were also encouraged to share the survey link with others to lead to snowball sampling (Biernacki & Waldorf 1981). Participants were randomly and evenly assigned to one of the two survey versions, each containing 20 video clips (differing by version), displayed in random orders. For each, participants were asked whether the cat was feeling positive or negative and also provided with a 'prefer not to answer' option. Participants were then asked demographic questions and questions about cat experience (eg whether they currently or have ever lived with a cat) (see Supplementary Methods: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material for the full list of questions). Participants also completed the Lexington Attachment to Pets Scale (LAPS) (Johnson *et al* 1992), to assess the strength of their bond with their cats.

Statistical analysis

Prior to analysis, we excluded responses from participants self-declared as under 18 years old, or without normal/corrected to normal vision, along with any not fully completing the survey. Binomial tests were used to examine whether overall performance differed from chance; to identify cut-off sum scores for above (≥ 15/20, binomial; $P = 0.02$) or below chance (≤ 5/20, binomial; $P = 0.02$); and to compare the proportions of participants with above or below chance scores to expected proportions. For all models, the cut-off for statistical significance was $P > 0.05$.

Main model: Factors predicting correct identification of a cat's affective state

A mixed effects logistic regression model was constructed, with correct or not correct (encompassing both incorrect and 'prefer not to answer' responses) as the outcome, participant as a repeated measures random effect, and survey version as a fixed effect (to avoid a multi-nested model and permit model convergence). Additional potential inputs, along with survey data, included the day a participant took the survey and how long completion took them.

All potential inputs were screened in univariable models, and those with $P \leq 0.20$ retained. These were included in a main effects model generated through manual stepwise selection; during this process, variables were retained if $P \leq 0.05$ and they significantly improved model fit (assessed through likelihood ratio tests) (Dohoo *et al* 2003). All biologically plausible two-way interactions were tested for statistical significance (Dohoo *et al* 2003). Contrast statements were constructed for each significant interaction between categorical variables, to evaluate effects at each level. For the final mixed effects model, normality of the variance of the best linear unbiased predictors (BLUPS) was evaluated, along with the homogeneity of the variance of BLUPS, and residual outliers (by evaluating a normal quantile plot, a plot of predicted outcome vs BLUPS, and a visual assessment of Pearson residuals) (Dohoo *et al* 2003). *Post hoc* analyses (contrasts) further investigated professional experience effects, with participants being categorised according to the nature of such experience (ie via veterinary medicine, animal shelter work, etc).

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Sub-model 1: Participant characteristics predictive of individually significantly high scores

To explore which characteristics predicted notably high success, we constructed a mixed effects logistic regression model using similar methods as described above (but without 'participant' as a repeated measures factor), and the outcome being 'high scorers' (sum score ≥ 15/20) compared to all other participants (sum score ≤ 14/20). All demographic variables were tested as potential predictors, and the model built using the process described above. *Post hoc* analyses (contrasts) again investigated whether the professional experience effects varied with the nature of that experience.

Sub-model 2: Other video characteristics predicting the correct identification of cat states

Although not a planned objective of our study, we opportunistically explored whether any other characteristics of the 40 videos predicted greater chances of correct assessment, namely video length, predominant face colour around the eyes (light/dark), predominant face colour around the mouth (light/dark), and modular affective state (Ekman & Cordaro 2011) (subcategories of valence reflecting specific situations in line with discrete emotions, ie retreating or attempting to retreat as if scared; prevention from reaching a goal [frustration]; pain and/or illness; approaching an object, human or location; playing). To investigate this, a generalised linear model was constructed with the percentage of participants that were correct, arcsine square-root-transformed, as the outcome. Due to overlap between modular affective state categories (eg playing perfectly overlapped with the positive active category), cat activity and valence were then re-evaluated as predictor variables in a model with modular affective state removed.

Results

Participant demographics

The survey was kept open for ten days, during which 11,040 individuals participated. Responses from those under 18 years old (n = 77), without normal vision (or corrected to normal via corrective lenses) (n = 273), or who did not answer every question or answered all with 'prefer not to answer' (n = 4,361) were removed, leaving responses from 6,329 for analysis. Most were female (n = 4,659; 74%), and 18–44 years old (n = 5,027; 79%), 42% (n = 2,636) being in the 25–34 age-band. Participants resided in 85 countries, 33 of which yielding more than ten participants. Canada was best represented (n = 2,301; 36%), followed by the USA (n = 1,904; 30%), and Russia (n = 562; 9%). Most participants were well-educated: 45% (n = 2,845) had a college degree and 34% (n = 2,159) had a post-graduate degree.

In terms of cat-related experience, most participants had lived with a cat as adults (n = 5,859; 93%), and for a mean duration of 12 years (range: 1–79 years). Many were also currently living with at least one cat (n = 5,035; 80%). Lexington Attachment to Pets Scale (LAPS) scores spanned the full range, from 0/69 to 69/69, averaging 44. Most participants (n = 5,083; 80%) reported having not read or heard of previous cat facial expression research. Most (n = 4,721; 75%) also reported not having employment or volunteer experience that could improve their knowledge of feline behaviour. Those *with* such experience comprised veterinarians (n = 208; 3%), veterinary technicians (n = 618; 10%), staff members at animal shelters (n = 248; 4%), volunteers at animal shelters (n = 613; 10%), cat sitters (n = 424; 7%), and cat trainers (n = 75; 1%), along with people who had worked with cats in another capacity (n = 311; 5%), some participants having experience working in two or more positions (see Table S2 for full breakdown of demographic characteristics; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

Descriptive statistics

Overall, participants scored significantly above chance for correctly identifying the cats' valence across the set of 20 videos per survey (binomial test; $P < 0.001$), but the average performance was low: participants' scores for correctly identifying valence ranged from 1 to 19 out of 20, and averaged 11.85 (59%). When scores were categorised as whether significantly different from chance for each participant (namely ≥ 15/20 or ≤ 5/20; binomial test; $P = 0.021$), 13% of participants (n = 797) achieved scores significantly above chance, whereas only 0.33% (n = 21) performed significantly below chance: a difference that was itself significant (binomial test; $P < 0.001$). Turning to the full set of 40 videos, the percentage of participants correctly identifying valence for each video varied greatly, ranged from 17 to 89%, with a mean of 59% correct. Nine out of 40 videos were scored correctly by more than 80% of participants (see Figure 1 for some still images and Table S4 [https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material] for the percentage of participants that correctly identified the valence of each video).

Main model: Factors predicting the correct identification of the valence of cats' states

Years living with a cat, education, country, and time to complete the survey were removed at the univariable model stage (all $P > 0.20$), while having lived with a cat, current number of cats, and having heard of past research were removed for lack of significance (all $P > 0.05$) during stepwise model building. Variables that *did*, in contrast, significantly predict correct identification of valence in the final model, were: survey version, participant gender, age, professional experience, LAPS sum score, and day the survey was completed (see Table 1 for odds ratios, 95% confidence intervals and *P*-values). Interactions between cat valence and activity, and cat valence and LAPS sum score were also significant and included in the final model (see Table 1 and Figures 2 and 3).

Women thus emerged as more likely to correctly identify cat valence than men, as were participants with professional cat experience (eg veterinary staff and shelter volunteers) compared to those without any such experience. *Post hoc* analysis suggested that those with experience working in

Table 1 Multi-variable mixed effect logistic regression model for correctly identifying the valence of feline affective state in a short video clip, with participant ID as a random effect and survey version as a fixed effect. Arrows indicate the direction of predictor variables' significant effects.

Variable	Description	Odds ratio		95% CI	P-value
Cat valence*	Negative	Referent			
	Positive	1.21	↑	1.14–1.29	< 0.001
Activity level in video*	Low	Referent			
	High	0.96		0.93–0.99	0.017
Participant gender	Male	Referent			
	Female	1.04	↑	1.01–1.07	0.007
	Other	1.01		0.91–1.13	0.851
Participant age	18–24 years old	Referent			
	25–34 years old	0.99		0.96–1.02	0.604
	35–44 years old	0.96	↓	0.93–1.00	0.049
	45–54 years old	0.93	↓	0.89–0.98	0.002
	55–64 years old	0.92	↓	0.87–0.97	0.002
	65–74 years old	0.86	↓	0.79–0.93	< 0.001
	75–84 years old	0.82		0.66–1.02	0.075
	85 years old or higher	0.93		0.62–1.40	0.736
Professional experience	No	Referent			
	Yes	1.07	↑	1.04–1.10	< 0.001
LAPS sum score*		1.00		0.99–1.00	0.085
Day completed survey		0.99	↓	0.98–0.99	< 0.001
Valence × Activity	Negative* Low vs Negative* High	0.96	↓	0.93–0.99	0.017
	Positive* Low vs Positive* High	1.32	↑	1.28–1.37	< 0.001
	Negative* Low vs Positive* Low	1.22	↑	1.14–1.30	< 0.001
	Negative* High vs Positive* High	1.67	↑	1.57–1.78	< 0.001
Valence × LAPS sum score		1.01		1.00–1.01	< 0.001
Survey vision**	Version 1	Referent			
	Version 2	0.74	↓	0.72–0.76	< 0.001

* These variables are part of a significant interaction term and so their odds ratios cannot be interpreted independently; see Figures 2 and 3 for details.
** For *post hoc* investigations of the implications and possible causes of this survey version effect, please see Supplementary Methods and Results (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

veterinary medicine showed the best abilities (OR = 1.06, 95% CI = 1.03–1.08; $P < 0.001$): veterinary technicians and veterinarians both had a higher odds of being correct (technicians: OR = 1.11, 95% CI = 1.06–1.15; $P < 0.001$; veterinarians: OR = 1.11, 95% CI = 1.03–1.19; $P = 0.006$), compared to those without such experience. As for the effect of gender and professional veterinary experience together, female veterinary technicians were more likely to be correct than men without experience (OR = 1.10, 95% CI = 1.02–1.19; $P = 0.011$), and women without experience (OR = 1.07, 95% CI = 1.01–1.12; $P = 0.014$); there were no significant differences between all other groups (all $P > 0.05$). As participants aged, they also had decreasing odds of correctly identifying cat valence compared to the youngest age-group (18–24 years). Participants who took the test soon after the survey was launched also performed slightly but significantly better than those taking it towards the end of the ten-day access period.

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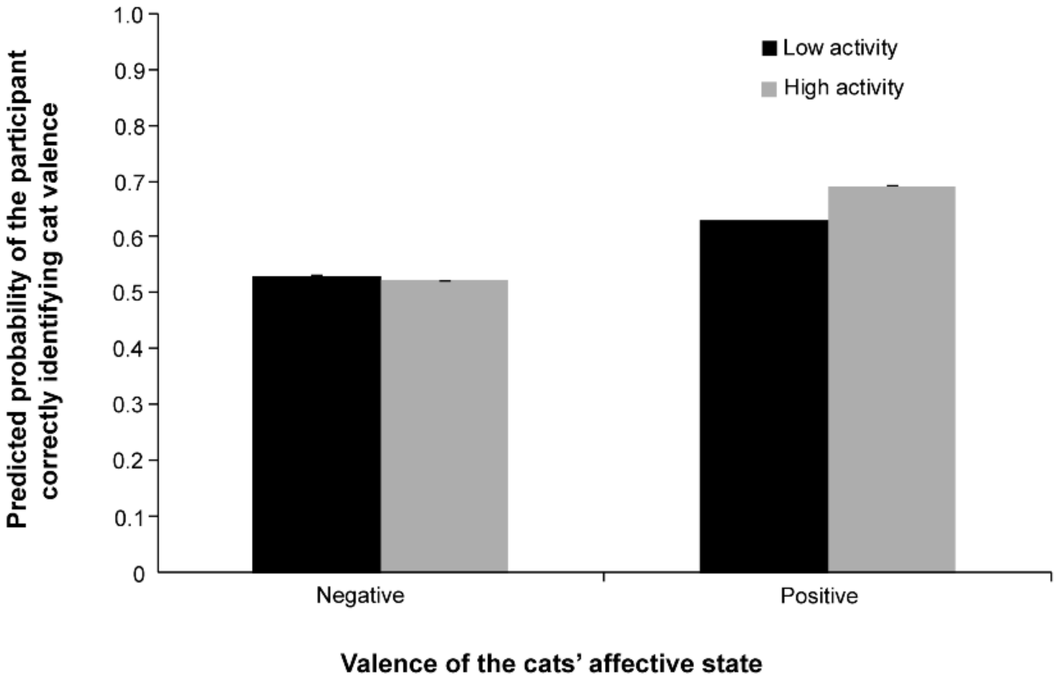
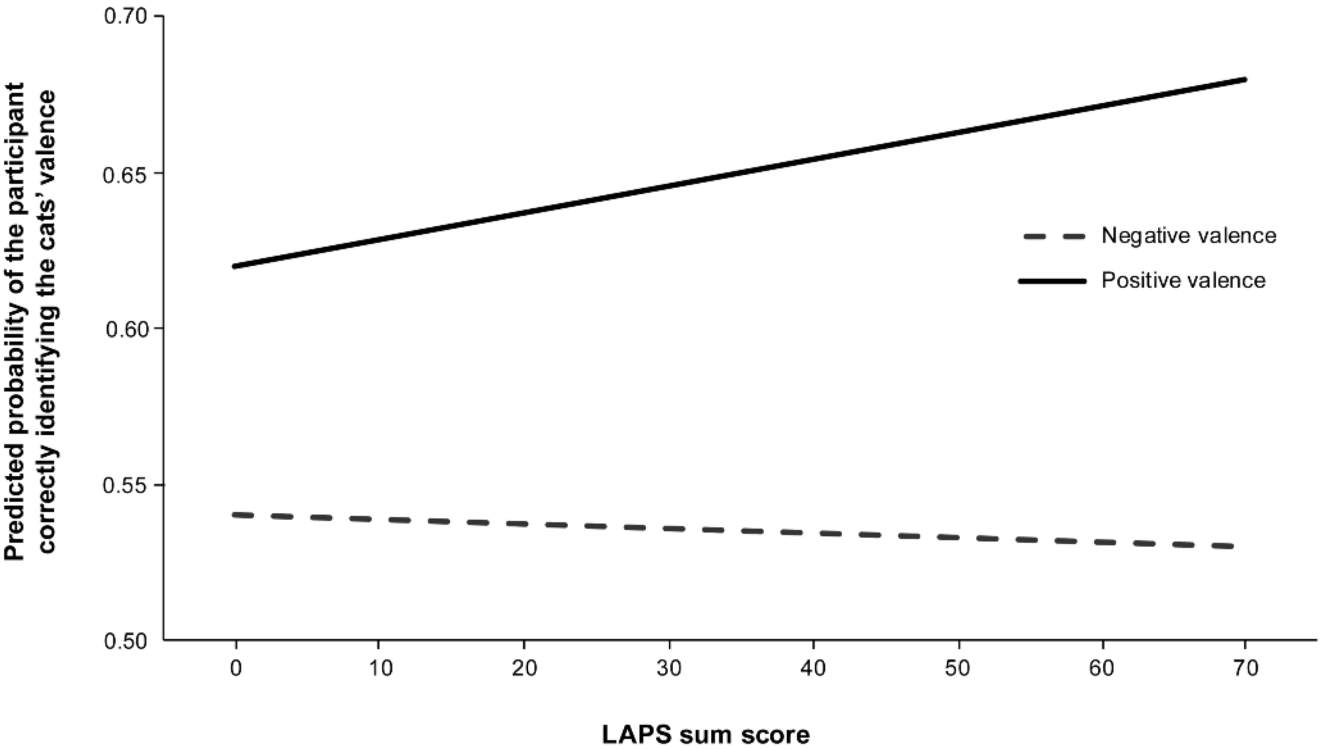
Figure 2



The effect of cats' activity levels on the predicted probability (± 95% CI) that a participant correctly identified the valence of their facial expressions, for cats in both negative and positive states.

Figure 3



The effect of Lexington Attachment to Pets Scale (LAPS) sum scores, in interaction with cats being in positive versus negative affective states, on the predicted probability that a participant correctly identified the valence of their facial expressions.

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Table 2 Multi-variable mixed effect logistic regression model for participant variables predicting individually significantly high scores (≥ 15/20) when identifying the valence of cat affective state (compared to those scoring 14 or lower). Arrows indicate the direction of significant effects.

Variable	Description	Odds ratio		95% CI	*P*-value
Participant gender	Male	Referent			
	Female	1.61	↑	1.31–1.98	< 0.001
	Other	1.29		0.62–2.71	0.498
Participant age	18–24 years old	Referent			
	25–34 years old	0.99		0.80–1.23	0.958
	35–44 years old	0.93		0.72–1.19	0.543
	45–54 years old	0.64	↓	0.47–0.87	0.005
	55–64 years old	0.67	↓	0.43–0.99	0.047
	65–74 years old	0.93		0.52–1.66	0.796
	75–84 years old	0.35		0.04–2.68	0.309
	85 years old or higher*	–		–	–
Professional experience	No	Referent			
	Yes	1.41	↑	1.18–1.67	< 0.001
Day completed survey		0.95	↓	0.91–0.98	0.003

* No variation in outcome variable due to insufficient sample size.

Turning to video characteristics, when a clip was of a cat in a negative state, high activity decreased the odds of valence being correctly identified. Conversely, videos of cats in positive states were more likely to be correctly identified if the cat was active. This interaction between cat valence and activity level is represented in Figure 2. Amongst both low *and* high activity videos, however, videos of cats in positive states were more likely to be correctly identified than were cats in negative states. There was also an interaction between cat affective valence and the participant's cat attachment score: an increased LAPS sum score increased the likelihood of being correct for cats in positive states, but decreased (albeit to a lesser extent) the likelihood of being correct for cats in negative states (see Figure 3).

Finally, participants randomly assigned the second version of the survey had lower odds of correctly identifying valence, compared to those assigned the first version. Since this effect was unexpected and relatively large, it was explored further to assess its impact (see Supplementary Methods; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). These *post hoc* analyses revealed that the survey version had interactive effects with gender and professional experience; and that these two variables only had significant effects in Survey Version 1 (see Supplementary Results; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

Sub-model 1: Participant characteristics predictive of individually significantly high scores

Factors predicting individually significantly high scores (≥ 15/20 correct) were similar to those detected by the main model, save that personal feelings for cats (LAPS sum scores) proved even less important here. Thus, during model building, all variables related to personal experience with cats (ie having lived with a cat, current number of cats, years living with a cat, and LAPS sum score), as well as education, country, having heard of past research, and time to complete the survey were all removed for lack of statistical significance (all $P > 0.05$). Participant characteristics that *did* predict significantly high scores in the final version of Sub-model 1 are listed in Table 2. Women and participants with professional experience were thus again more likely to be high scorers than men and those without experience; while middle-aged individuals (45–64 years of age) and those participating later during the survey access period were again less likely to be high scorers. Such effects held across both versions of the survey (see Supplementary Results; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

Post hoc analysis also suggested that amongst the different types of professional experience, again working in a veterinary environment was the best predictor of success (OR = 1.25, 95% CI = 1.08–1.44; $P = 0.002$); specifically,

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compared to individuals with no experience working in veterinary medicine, the odds of being a significantly high scorer were 1.48 times higher for those with experience working as a veterinary technician (95% CI = 1.17–1.89; $P = 0.001$). Similarly, those with experience working as veterinarians were 1.74 times more likely to be high scorers (95% CI = 1.16–2.62; $P = 0.008$).

Sub-model 2: Exploring whether other video characteristics predicted participants' scores

In all univariable models, as well as in the full model with all potential predictor variables included, no other video characteristics significantly predicted the proportion of participants correctly identifying valence (all $P > 0.10$) (see Table S3; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

Discussion

One immediate, incidental finding from this study was confirmation that cats and the internet are a powerful combination (cf Myrick 2015): YouTube proved a rich source of videos of cats in very diverse states, while our online survey attracted over 6,000 participants in just ten days. Turning to our research aims, we found that participants presented with short videos of the faces of cats in states of positive or negative affect were collectively able to correctly identify the valence of these states significantly above chance. Furthermore, within this sample, about 13% of participants achieved individual scores that were significantly above chance. Thus, even without contextual cues or obvious signals like fully retracted ears and open mouths, people could 'read' the affective states of cats from their faces. However, despite this, our results were also consistent with cats' reputations for inscrutability: the overall average score was low, and the individual scores of most participants were below chance. There was thus enormous variation in how well people performed: variation which reflected participant gender and age, whether they had professional feline experience, the activity levels of the cat in the video, and (surprisingly), which of the two survey versions was taken.

Women were thus more likely than men to correctly identify cats' affective states. This is the first demonstration of such an effect for cats, but is consistent with previous research demonstrating that women have greater abilities to decode non-verbal displays of emotion in both humans (Babchuk *et al* 1985; Thayer & Johnsen 2000) and dogs (again from facial expressions: Schirmer *et al* 2013). The 'primary caretaker hypothesis' (Babchuk *et al* 1985) explains this in terms of natural selection favouring caretakers who can readily detect changes in indicators of both negative (eg distress) and positive (eg satiety) states in their infants, with this ability perhaps generalising to other scenarios. Female cat owners are also more attached to their pets than are male cat owners (Martens *et al* 2016), but we doubt that attachment explains their better cat-reading abilities. For one, the gender effect was significant even after controlling for attachment; and, furthermore, attachment had only rather subtle, complex effects on performance. For any given video, as attachment to cats increased, participants became better at correctly identifying positively valenced states, but *poorer* at correctly identifying negative states. This finding now needs replicating, but if confirmed it could reflect that highly attached owners choose to focus on their cats in positive emotional states (eg while playing): after all, dog owners with high attachment scores report more indicators of positive affect in their animals, a finding suggested to reflect increased attention to positive canine affective states (Buckland *et al* 2014). Alternatively, highly bonded owners may provide their cats with lives that induce more positive affect (eg more toys), giving them greater exposure to positively valenced facial expressions; or, instead, owners of cats which often retreat from interaction may have both more practice interpreting their cats' negative facial expressions and weaker bonds with their animals.

Whatever explains this unexpected attachment effect, one general principle was clear: personal experience with cats was not important. Thus, abilities to read cat faces were not improved by having ever lived with a cat, the number of years spent living with cats, nor by their current number of owned cats. At first sight surprising, this does resemble previous findings for cat vocalisations: in one study, personal involvement with cats did not help people correctly identify the valence of bouts of recorded meows, though it did with single meows (Nicastro & Owren 2003); while in the other, cat owners could only reliably interpret the context of their *own* cat's meows, but not those of unknown cats (Ellis *et al* 2015). Likewise, several studies find that dog ownership does not improve peoples' abilities to interpret canine emotions: thus, it did not improve abilities to describe canine behaviour (in videos of dog-dog interactions) (Tami & Gallagher 2009), nor to recognise affect from still images of dog faces (Schirmer *et al* 2013); with one study even finding that dog ownership can *reduce* abilities to identify canine fear and anxiety (Demirbas *et al* 2016). Instead, as has been found for other species (eg macaques [Maréchal *et al* 2017] and dogs [Wan *et al* 2012]), professional experience proved valuable. More specifically, participants with veterinary experience seemed to have the most superior abilities. Veterinarians and veterinary technicians may be self-selected 'animal people', intrinsically empathic and attuned to animal emotions, and/or they may receive more formal training in recognising subtle behavioural changes indicating affective states (eg for pain management). They also probably learn 'on the job', since they can deal with dozens of cats a month, and must monitor them carefully, partly to avoid being bitten or scratched, and partly to assess their health and wellness.

Finally, compared to participants in the youngest age group (18–24 years old), middle-aged individuals were less likely to correctly identify the valence of cats' states. This is in contrast to previous research which found no effect of age on abilities to interpret cat vocalisations (Nicastro & Owren 2003) or dog behaviour (Tami & Gallagher 2009). One possible explanation is that the enjoyment of online cat media declines with age (Myrick 2015). Young individuals might therefore be more likely to seek out online cat videos, giving them more experience watching recorded cat behaviour onscreen, in turn increasing their abilities to interpret cat faces in this study.

Whether abilities to correctly interpret cats' facial expressions can indeed be learned with experience, and/or improved via training, should be a topic for future research: important given our participants' low average scores. One approach would be to train observers using many repeated exemplars of cats in positive and negative states, the valences of which are then revealed to help participants learn. Another would be to use objective methods to quantify what is changing empirically in the faces of cats in different states, to then generate detailed descriptions of anatomically based facial movements (Borod *et al* 1997; Bennett *et al* 2017) which, in turn, could be used to coach human observers. For example, Holden *et al* (2014) used anatomical landmark techniques to objectively identify numerical distance changes in the faces of cats in pain, and then used this to develop training tools. Such research could reveal the extent to which people's abilities to read cats' facial expressions can be enhanced through experience and training, as well as identifying the precise changes that occur in the faces of cats in different states.

Turning to the 'readability' of the cat videos themselves, the individual clips ranged enormously in how frequently they were correctly scored, from 89 down to just 17%. With our sample of just 40 stimuli, we could not pinpoint the attributes that were instrumental here: neither specific affective state (eg fear versus sickness, or contentment versus playfulness), nor cat face colour, nor video length, significantly predicted how easily valence could be judged. However, we did find that some of the variation reflected an unexpected effect of survey version. Because, inadvertently, one author (JC) had primarily selected videos in Version 1, with a different author (LCD) primarily selecting videos in Version 2, this effect in turn seemed to reflect the different search terms used to find videos, and perhaps also the computer used for searching (see Supplemental Results; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), with author, JC, somehow finding more 'readable' cats videos. One final factor contributing to how often a video was correctly scored was cat activity level: positive states were more likely to be correctly identified in cats which were active (as if playful or excited expressions were particularly easy to read), while negative states were more likely to be correctly identified in cats which were inactive (though effects here were small, with an odds ratio of 0.96). This topic is thus clearly one needing further study.

Future research should therefore now investigate the objective changes that cats display in their faces during different affective states (using the empirical techniques outlined above), as well as the factors that might make an individual cat's face more or less readable. Such research should use more exemplars (for greater power), and/or better controlled, customised videos than those we used here. Furthermore, as well as the variables we tested, it should investigate additional likely influential factors, including the side of the face visible (since in many species, emotional facial expressions are asymmetrical, being more marked on the left especially for negative affect, eg Hauser 1993; Borod *et al* 1997; Hook-Costigan & Rogers 1998; Fernández-Carriba *et al* 2002; Nagasawa *et al* 2013); the angle of view (ie straight vs profile); breed or coat colour (especially as orange cats are often said to be 'friendly'; white cats 'calm' and 'shy'; and tri-coloured cats like tortoiseshells, 'intolerant' [Delgado *et al* 2012]); and, finally, the relationship between the cat and the viewer. Thus, the effects of the familiarity of the cat to the rater should be investigated (to see if, as for vocalisations [Ellis *et al* 2015], people are better at reading their own cats than strange cats); as should the closeness of the bond of the rater to the subject (since many people report feeling close to their cats, and attribute to them a range of affective states: Voith 1985; Martens *et al* 2016; Arahori *et al* 2017); and, finally, whether or not filmed in the presence of a human, especially the owner, since 'audience effects' (Kraut & Johnson 1979; Bavelas *et al* 1986; Jones & Raag 1989) are now known to influence dogs' facial expressions (dogs being more expressive when humans are facing them [Kaminski *et al* 2017]).

Together, our findings reveal that affective states can be correctly inferred from cats' subtle facial expressions (without obvious cues such as mouth-opening and ear-retraction), and that cats have human-detectable facial expressions across a much wider range of affective states, positive as well as negative, than has been previously shown (Holden *et al* 2014). However, our findings also show that most people find this hard (at least using our short video clips). Participant age, sex and gender affected their abilities, with implications for effective cat care: our results indicate that young women with veterinary experience will typically be better than others at detecting when cats are experiencing negative states (such as illness) or are instead relaxed and 'happy'. Our findings could have further practical implications too, for cat welfare assessment (especially when the animal is showing no other sign of emotion, or its body is hidden), since facial expressions are useful tools for identifying affective states in other species (Descovich *et al* 2017). If cat facial expressions likewise prove useful for assessing well-being, this would be very valuable: understanding feline facial expressions could help veterinary clinic and animal workers to provide optimal feline care, and cat owners to better comprehend the emotional lives of their animals (in turn, strengthening the human-cat bond). Investigating precisely what these expressions are would also allow some new, fascinating fundamental questions to be addressed, including whether different types of negative and positive affect elicit different expressions; whether cats' facial expressions are lateralised, as in other species; and whether cats are more expressive in the company of familiar humans.

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