Social reinforcement, appeasement, and punishment:

The multiple functions of laughter

By

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Abstract

Laughter is ubiquitous, universal, and variable. This dissertation tests a new social functional account that explains the many physical forms laughter takes and the many social contexts in which it occurs. In contrast to previous perspectives that emphasize the internal state of the producer or the eliciting context, the current social functional account distinguishes laughter according to the behavioral intention it conveys and the subsequent behavioral response it elicits in the recipient. Laughter is a communicative signal that solves (at least) three basic social tasks that can occur across social contexts and relationships. The first proposed social function of laughter, both evolutionarily and developmentally, is to *reward* the behavior of others and reinforce the ongoing interaction. The second task accomplished by the production of modified laughter is the easing of social tension and signaling of *affiliation* and nonthreat. A third form of laughter non-confrontationally enforces social norms, negotiates status, and corrects undesirable behavior in others by conveying *dominance* or superiority.

We propose that people modify physical properties of their laughter in the service of the three social tasks, and that the acoustic modulations follow principles common to human and non-human vocal signaling. Three studies tested the validity of the social function account of laughter and investigated how the acoustic form of laughter is modulated in order to produce different social effects. Participants rated the extent to which laughs convey the social functions (Study 1), judged the similarity of laughs to validated smiles that accomplish the social tasks (Study 2), and produced natural laughter with a partner while watching and discussing videos that elicit responses relevant to the three social tasks (Study 3). We complemented traditional inferential statistics with machine learning algorithms trained to predict the social functions accomplished by instances of laughter.

In Study 1, perceivers' judgments of how rewarding, affiliative, and dominant laughter sounded were guided by distinct patterns of acoustic variables, which were in turn used by a machine learning model to accurately estimate the perceived social function of the laughs. This study suggested that perceivers infer nuanced social information from laughter based on its acoustic form. Study 2, which relied entirely on non-linguistic judgments about laughter-smile similarity, resulted in a laughter similarity embedding that retained the laughs' social functional category assignment from Study 1 participants' linguistic judgments. Study 2 therefore provided convergent evidence about the perceived social meaning of the laughter. Study 3 was the first study to test the social functional account of either smiles or laughter using naturally-occurring signals. Laughs generated by participant pairs across 3 functionally-relevant contexts differed on several acoustic variables, some of which converged with the perceiver-based data in Study 1. Throughout, we connect existing findings in the human and nonhuman vocalization literature to the current work's findings on the acoustic properties of reward, affiliation, and dominance laughter. In sum, this research accounts for some of the substantial variability in the physical form of laughter and, more generally, demonstrates the predictive power of a social functional approach to emotion expression.

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Introducing a social functional account of laughter

When people are together, they laugh. From about 4 months of age, laughter is ubiquitous in social interactions (Sroufe & Wunsch, 1972). It strengthens the bond between infants and caregivers, and elicits and encourages social interactions that support infant learning and survival (Nwokah, Hsu, Dobrowolska, & Fogel, 1994; Provine, 2004). As children develop, they laugh during social play and in response to humor and surprising events, always in the context of real or imagined social others (Nwokah et al., 1994). People continue to laugh, and seek out people who make them laugh, for the rest of their lives (Greengross, 2013; Mehu & Dunbar, 2008). In some analyses, laughter accounts for 10% of adults' vocalizations during natural conversation (Laskowski & Burger, 2007). Although laughter unsurprisingly occurs when people feel amusement in response to humor, more often than not it occurs in apparently non-humorous social contexts (Provine, 2004), accompanying diverse internal states such as embarrassment (Adelswärd, 1989; Lewis, 1997), anxiety (Zuk, Boszormenyi-Nagy, & Heiman, 1963), and feelings of derision (Bryant, Hezel, & Zillmann, 1979).

While most theoretical accounts focus on the emotional states and physiology that underpin laughter, such approaches fail to accommodate or explain the diverse elicitors and social consequences of this complex behavior. Here we complement and extend existing work on laughter by applying a social functional perspective, proposing that laughter can take different physical forms in the service of different social tasks (Martin, Rychlowska, Wood, & Niedenthal, 2017). Building on extant research on human and non-human vocalizations and laughter (Davila-Ross, Allcock, Thomas, & Bard, 2011; Owren & Bachorowski, 2003; Pisanski, Cartei, McGettigan, Raine, & Reby, 2016; Riters, 2012), we suggest that humans flexibly modulate the acoustic properties of laughter to elicit desired responses from others. In particular, we argue that laughter can serve as a social *reward* that reinforces the behavior of the recipient, as a social soother that conveys non-threat and *affiliation*, and as a social enforcer that asserts *dominance* or superiority (Wood et al., 2017). We reconcile the current framework with existing approaches that emphasize the internal state of the expresser by reframing spontaneous laughter in terms of its proposed social function, namely reward (Szameitat, Wildgruber, & Alter, 2013). The social functional framework, which has been applied to smiles (Rychlowska et al., 2017), generates testable predictions and offers a solution to the long-observed weak correspondence between nonverbal expressions and internal emotion states (de Gelder, 2017).

Laughter is an evolved signal of playfulness

Several lines of evidence suggest human laughter arose from an evolutionarily ancient social signal. Spontaneous human laughter originates from evolutionarily preserved subcortical systems (Jürgens, 2002; Wild, Rodden, Grodd, & Ruch, 2003). Human laughter shares many acoustic similarities with animal calls and, when the pitch and tempo of human laughter have been altered to map those of an animal vocalization, perceivers cannot tell them apart (Bryant & Aktipis, 2014). The spontaneous laughter of congenitally deaf individuals is acoustically similar to that of hearing individuals, suggesting an unlearned, innate component to the vocalization (Makagon, Funayama, & Owren, 2008). The phylogenetic and neural distinctiveness of speech and spontaneous laughter is made clear by the fact that bouts of spontaneous laughter are often difficult to inhibit (McGettigan & Scott, 2014). Across the heterogeneous acoustic forms of laughter—which can be voiced, unvoiced, or co-occur with speech—the common component is breath. The distinctive breathing pattern of forcible exhalations, caused by rapid contractions of the intercostal muscles and diaphragm, is the defining characteristic of laughter in humans, and, as we shall see, in non-humans animals (Filippelli et al., 2001).

Understanding the specific social tasks solved by human laughter requires first understanding the general function of laugh-like vocalizations observed across mammalian species. Many mammals produce a vocalization that involves rapid panting with an open relaxed mouth, a behavior is thought to be evolutionarily homologous to human laughter (Davila Ross, J Owren, & Zimmermann, 2009; Provine, 2001; Simonet, Versteeg, & Storie, 2005; Van Hooff, 1972; Vettin & Todt, 2005). Rapid panting, which we refer to as proto-laughter, signals harmless intent and perpetuates playful interactions. The signal is vital because social, rough-and-tumble play helps juvenile mammals develop coordination, strength, and a repertoire of social behaviors (Gordon, Burke, Akil, Watson, & Panksepp, 2003; Gordon et al., 2003; Panksepp & Burgdorf, 2003). Despite the fact that play is inherently rewarding (Vanderschuren, Stein, Wiegant, & Van Ree, 1995) and strengthens social bonds (Bekoff, 1984; Spinka, Newberry, & Bekoff, 2001), many play behaviors bear striking resemblance to aggressive adult behaviors such as wrestling, biting, and chasing. Since play behaviors could easily be misinterpreted as aggression, young animals need a way to signal their benign, playful intentions to their playmates and bystanders (Bekoff, 1995; Blomqvist, Mello, & Amundin, 2005). Stereotyped, exaggerated panting likely gained its function as a play signal when the heavy breathing during strenuous bouts of wrestling and chasing became ritualized (Provine, 2001).

The harmlessness-signaling function of laughter is especially apparent when one considers humor, with which laughter is closely associated (Martin, 2010). Many researchers have noted the functional similarity between humor and animal (and human) play (Gervais & Wilson, 2005). Humor results from the resolution of unexpected or potentially threatening stimuli; in other words, humor involves a juxtaposition of threatening or conflicting ideas/behaviors in a safe context (McGraw & Warren, 2010). Laughter in humorous contexts buffers the potential harm of anything said or done, conveys that the laugher understands the harmlessness (they "get" the joke), and convinces others to interpret the context as harmless as well (Owren & Bachorowski, 2003). Grammer and Eibl-Eibesfeldt (1990) further reported that laughter regularly co-occurs with redirection movements also designed to dissolve social tension, such as averted eye gaze.

Several features of laughter underscore its inherently social function. Like mammalian proto-laughter, human laughter occurs almost entirely in real or imagined social contexts (Devereux & Ginsburg, 2001). Unlike most proto-laughter, human laughter is voiced, broadcasting the playfulness of the ongoing interaction to others (Bachorowski, Smoski, & Owren, 2001; Owren & Bachorowski, 2003). Laughter also contains acoustic aberrations that capture and sustain the attention of onlookers, and which occur in other perceptually salient and arousing human and nonhuman affective vocalizations (Bachorowski et al., 2001; Bryant, 2013). In laughing together, people advertise their social bond to bystanders (Bryant & Aktipis, 2014). They may also elicit laughter from onlookers, drawing them in to the play session, as laughter can spread contagiously within social groups (Chapman & Wright, 1976; Dezecache & Dunbar, 2012; Martin & Gray, 1996; Smoski & Bachorowski, 2003). Laughter is frequent even in adulthood because humans continue to regularly engage in play-like behaviors throughout the life-cycle, particularly non-physical forms of play like conversation, creativity, and humor (Panksepp & Biven, 2012).

In sum, both proto-laughter and human laughter serve as social "white flags" that facilitate adaptive playfulness and fosters relationships, cooperation, and group cohesion (Gervais & Wilson, 2005; Mehu & Dunbar, 2008).

Laughter is flexible and diverse

Laughter cannot be taken as an expression of any one affective state (Szameitat, Alter, Szameitat, Darwin, et al., 2009), and previous research has found significant within- and between-person variability in its acoustic form (Bachorowski et al., 2001). Furthermore, despite its likely origin as a play signal, human laughter occurs in contexts other than physical or verbal play. People laugh when they feel nervous, are being tickled (which many find unpleasant), express a complaint (Shaw, Hepburn, & Potter, 2013), are sexually interested (Grammer, 1990), and have experienced the resolution of surprising or fear-inducing events (e.g., babies laughing after a jack-in-the-box pops; Rothbart, 1973).

To make sense of this variability, most research on laughter focuses on the distinction between voluntary and spontaneous laughter (Scott, Lavan, Chen, & McGettigan, 2014; cf. Szameitat, Alter, Szameitat, Wildgruber, et al., 2009). This work categorizes laughter as spontaneous or voluntary according to its neural and physiological underpinnings, as well as the extent to which it can be overridden by speech or inhibited. “Voluntary” does not imply conscious intentionality, as voluntary laughter is often unintentional and automatic; the label instead refers to a form of laughter that is argued to be more easily inhibited, exaggerated, or modified.

Spontaneous laughter is thought to be the first form of laughter to emerge during development, and is even produced by congenitally deaf babies (Eibl-Eibesfeldt, 2017). Spontaneous laughter arises from a phylogenetically ancient play vocalization that resembles animal signals, as described above (Bryant & Aktipis, 2014). It originates from subcortical regions associated with emotion expression (Jürgens, 2002) and has unique physical effects on the body (McGettigan & Scott, 2014). Spontaneous laughter can be difficult to inhibit or override with speech, as anyone who has ever had a laughing fit can attest.

Voluntary laughter, on the other hand, is considered a learned co-opting of spontaneous laughter that has distinct neural, physiological, and acoustic markers (Scott et al., 2014). It involves greater activation of the neural systems involved in speech production, and as such it tends to have more speech-like acoustic properties (Bryant & Aktipis, 2014; Kohler, 2008). Unlike spontaneous laughter, which some scientists argue overrides speech (Lavan, Scott, & McGettigan, 2015), voluntary laughter can punctuate or alternate with speech (Provine, 1993), sometimes even coloring speech itself (Kohler, 2008). While voluntary in the sense that it can be inhibited, such laughter is not necessarily fake or manipulative—non-spontaneous behaviors can still be automatized and honest. Although nonhuman primates produce forms of voluntary laughter, some children diagnosed with Autism Spectrum Disorder do not, suggesting the flexible use of laughter to coordinate social interactions is at least partly learned (Hudenko, Stone, & Bachorowski, 2009).

The voluntary-spontaneous distinction accounts for some variability in the acoustic structure of laughter and the degree to which laughter feels "uncontrollable." However, there is much within-category variability in spontaneous and voluntary laughter (Bachorowski et al., 2001). Other attempts at carving laughter at its natural joints focus on categorizing its different physical forms without proposing functions of each (Bachorowski et al., 2001), or identify the acoustic properties of laughter in specific contexts (e.g., tickling, schadenfreude) without attempting to explain all laughter forms (Szameitat et al., 2009). Thus, a synthesizing and parsimonious account of laughter's various functions is needed, and we propose one in the next section.

Reframing laughter in social functional terms

The present social functional account and related approaches draw from behavioral ecology (Crivelli & Fridlund, 2018; Fischer & Manstead, 2008, 2008; Fogel et al., 1997; Fridlund, 1991; Keltner & Gross, 1999; Mehu & Dunbar, 2008) and deemphasize the internal cognitive and affective states of the expresser, which are the focal points of predominant theories of emotion expression (Barrett, 2006; Bonanno & Mayne, 2001; Ellsworth & Scherer, 2003). Our argument is that because nonverbal expressions and producers' internal affect are only modestly correlated (Fernández-Dols & Crivelli, 2013), we can generate different predictions and perhaps explain more variability about expressions with theories that focus on the social function of an expression (see also Keltner & Haidt, 1999; Van Kleef, 2009).

We apply a functional approach to explain the diversity of sounds produced during laughter, and suggest that people adapt the evolved signal of benign intentions in play to convey subtle, yet distinct, social signals in the service of meeting particular challenges and opportunities of social living (Niedenthal, Mermillod, Maringer, & Hess, 2010). Social signals are adaptive and promote the success of both sender and receiver when they are clear, distinct, and linked to predictable outcomes in a given social context (Bradbury, Vehrencamp, & others, 2011; Leger, 1993). In other words, there should be a strong correlation between a particular nonverbal expression, the behavioral intention[1] it implies, and the response elicited in others by that implied intention. For instance, an "angry" facial expression implies the possibility of aggression (the behavioral intention), which motivates an appropriate response from the target of the expression, be it appeasement or escalation of conflict (Crivelli & Fridlund, 2018). The

[1] Although we discuss the social functions of laughter in terms of "intentions" and "motivations," we do not imply any conscious intentionality or strategy on the part of the expresser. Laughter signals likely upcoming behavior that perceivers recognize and react to accordingly (Fridlund, 2014).

current account is the first to extend the social functional logic to specific forms of laughter (Wiley, 1994).

Within laughter's overarching function of conveying harmless intentions and diffusing social tension, we propose three specific social tasks that it can accomplish (Wood et al., 2017). First, certain forms of laughter *reward* the producer and perceiver, reinforcing behavior and encouraging continued interaction. Second, laughter can take forms and occur at key moments in an interaction so that it signals *affiliation* and nonthreat, ameliorating any social unease. Third, laughter can assert social *dominance* in the sense of "laughing at someone" (Szameitat et al., 2013). This function uses laughter's fundamental tension-easing effect to cushion a message of superiority or punishment. These are the same social tasks accomplished by smiles (Rychlowska et al., 2017), and while they are not the only fundamental tasks of social living (Schaller, Kenrick, Neel, & Neuberg, 2017), we identify them as the tasks best accomplished via a signal of harmless intentions, such as laughter or smiles.

While our formalized three-function perspective on laughter is novel (but see also Szameitat et al., 2013), some ethological evidence already indirectly supports the claim that laughter not only accompanies and perpetuates instances of social play, but also regulates interactions in both the affiliative and disaffiliative (i.e., dominant) directions (Arminen & Halonen, 2007; Eibl-Eibesfeldt, 2017; Glenn, 2003; Griffiths, 1998; Rothgänger, Hauser, Cappellini, & Guidotti, 1998; Szameitat et al., 2013). We examine the proposed social functions of laughter in greater detail before exploring the acoustic features that might signal reward, affiliation, and dominance.

Reward laughter: Reinforcing behaviors and social bonds. Our approach reframes spontaneous laughter as a social reward, thereby focusing on the interactional function rather than the underlying affective or physiological state. This social functional focus also allows voluntary laughter to serve a reward function when it sufficiently approximates the salient acoustic markers of spontaneous laughter. Perceivers' ratings of spontaneity and reward in laughter are strongly positively correlated, supporting our claim that spontaneous-sounding laughter is rewarding (Wood et al., 2017).

We consider reward laughter to be rewarding to the producer and recipient.[2] Laughter serves as a reward for the producer because it is inherently enjoyable (Herring, Burleson, Roberts, & Devine, 2011; Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005) and down-regulates negative emotions (Bloch, Haase, & Levenson, 2014; Keltner & Bonanno, 1997; Yuan, McCarthy, Holley, & Levenson, 2010). Producing laughter in response to humorous stimuli triggers the release of opioids in the brain of the laugher, providing direct evidence of its rewarding value (Dunbar et al., 2012; Manninen et al., 2017).

Listening to the laughter of others, particularly when it is voiced, is also rewarding (Bachorowski & Owren, 2001). This may be because perceivers engage in sensorimotor simulations that partly recreate the state of laughter in themselves (McGettigan et al., 2015; Wood, Rychlowska, Korb, & Niedenthal, 2016). Spontaneous laughter is contagious, enabling the original expresser to trigger laughter, and its accompanying feel-good physiological state, in the recipient (Provine, 2001). Owren and Bachorowski (2003) even argue that laughter evolved to induce positive affect in listeners.

The reward function of spontaneous laughter is also suggested by its cost to the person who produces the laugh. A reward, whether material or social, will increase in value to the

[2] Context, as always, will likely modulate the perceived meaning of a laugh. Presumably the reward laughter of an outgroup member will not be experienced as rewarding in the same way as an ingroup member's, and may even be experienced negatively. Furthermore, reward laughter could be experienced as aversive if it is in response to a behavior that was not intended to be playful (e.g., reward laughter in response to earnest karaoke singing).

recipient as the cost incurred by the giver increases (Larsen & Watson, 2001). As we have already noted, spontaneous laughter is exhausting to produce (McGettigan & Scott, 2014). It induces a state of cataplexy that weakens the body (Overeem, Lammers, & Dijk, 1999), making intense laughter an honest signal that the expresser has harmless intentions, as the signal itself renders them too weak to attack (Bryant & Aktipis, 2014). Social signals that are costly to produce are less likely to be faked (Fitch & Hauser, 2003), and in fact the spasmodic and physically extreme features of spontaneous laughter are difficult to fully recreate intentionally (although some volitional laughter is difficult for perceivers to recognize as such; Wood et al., 2017).

Much evidence supports the proposal that laughter can reinforce behavior. For example, research finds that it reinforces and perpetuates infant-caregiver interactions by eliciting feelings of happiness and love in caregivers (Groh & Roisman, 2009; Riem et al., 2012). Caregivers repeat behaviors that make babies laugh, and babies repeat behaviors that make caregivers laugh (Field, 1979; Rubenstein & Howes, 1979). Co-laughter between people is a reliable sign of social connectedness, as it rewards continued interaction and investment in the relationship (Bryant et al., 2016). Sharing spontaneous, humorous laughter with another person also indicates compatibility and similarity, making the relationship worth pursuing (Curry & Dunbar, 2013).

We have suggested that spontaneous reward laughter during play is the earliest form of laughter both phylogenetically and ontogenetically (Bryant & Aktipis, 2014; Gervais & Wilson, 2005). But, like other human and non-human vocalizations, laughter can also be modulated to elicit different responses from recipients (Pisanski et al., 2016). This modulation is not intentional in the sense of being consciously-controlled, but it is context-dependent and flexible. In particular, we suggest that the original harmlessness signal conveyed by spontaneous rewarding laughter can be co-opted and modulated to convey both affiliation and dominance intentions.

Affiliation laughter: Signaling nonthreat and appeasement. In the present view, humans have ritualized a volitional laugh that conveys the nonthreatening intentions of reward laughter while being much less costly and more flexible to deploy. This laughter variant, which we call affiliation laughter, conveys harmless intentions, but lacks the rewarding features of spontaneous reward laughter.

Researchers have long noted a form of voluntary laughter that lacks spontaneous laughter's acoustic and physiological features, occurs frequently during social interactions, and does not seem to convey or induce positive affect (e.g., Gervais & Wilson, 2005; Glenn, 2003; Grammer & Eibl-Eibesfeldt, 1990; Provine, 1993; Shaw et al., 2013). At different times it has been referred to as conversational laughter (Provine, 2001), polite laughter (Tanaka & Campbell, 2011), speech-laughter (Kohler, 2008), sexual interest laughter (Grammer & Eibl-Eibesfeldt, 1990), and embarrassed laughter (Tanaka & Campbell, 2011). During conversation, it often occurs at the end of utterances (Provine, 1993) and sometimes involves short bouts of voiced, nasal, grunt-like (Tanaka & Campbell, 2011), or breathy bursts (Shaw et al., 2013). It can also involve a closed mouth (Kohler, 2008), aligning with the proposed closed-mouth smile of affiliation (Rychlowska et al., 2017).

Our social functional approach draws from animal ethology and considers the aforementioned laughter variants to be appeasing, affiliative signals (Matsumura & Hayden, 2006). While reward laughter positively strengthens a social bond between producer and recipient, we propose that affiliation laughter serves as a social corrective that maintains the nonthreatening status of an interaction, whether with an acquaintance or a stranger (de Waal, 1986). Affiliation laughter co-opts features of the intense playfulness display of reward laughter to send a subtler message of harmlessness and reassurance. Interestingly, subordinate chimpanzees produce a rapid pant-grunting vocalization when greeting dominant individuals (Sakamaki, 2011)—perhaps this is the chimpanzee equivalent of affiliative "laughter".

Speakers can use affiliative laughter to mitigate possible threatening interpretations of a previous utterance, and listeners can use it to avoid taking the speaker's utterance seriously (Mehu & Dunbar, 2008). Shaw, Hepburn, and Potter (2013) observe that subdued, appeasing laughter is sometimes more effective than "raucous" reward laughter for softening potentially negative impacts of behaviors and statements, as reward laughter might convey inappropriate pleasure at the eliciting event.

Affiliative laughter may be deemed "fake" laughter because it often follows unfunny jokes (Weisfeld, 1993)—but rather than being "fake" in a deceptive sense, the function of such laughter may be to ease tension and acknowledge the joke without *rewarding* the joke-teller (Bell, 2009a). After all, people can generally distinguish between spontaneous and volitional laughter (Bryant & Aktipis, 2014), so it is unlikely that such affiliative laughter is an attempt to trick the joke-teller into thinking the joke was successful (Bell, 2009b).

Gregarious social living demands constant signaling of appeasement, reconciliation, and nonthreat (de Waal, 1986). Like the primate silent bared-tooth display of submission that occurs in contexts including appeasement, reconciliation, affiliation, and reassurance (Mehu & Dunbar, 2008; Van Hooff, 1972), we suggest affiliation laughter is a flexible tool for reducing social tension (Owren & Bachorowski, 2003).[3] Importantly, affiliation laughter does not feel rewarding

[3] The chimpanzee homologue to reward laughter (the relaxed open mouth display), but not the silent bared-tooth display, increases play behavior. However, both displays increase affinitive behavior (Waller & Dunbar, 2005). This parallels the proposed distinction between reward and affiliation laughter: both signal nonthreatening, affiliative attentions, but only reward laughter actually promotes playfulness and reinforces behavior.

to produce or perceive (consider, for instance, embarrassed laughter, Keltner & Buswell, 1997), and instead acts as a release valve that mitigates feelings of social unease or threat.

Dominance laughter: Indirectly challenging hierarchy and enforcing group norms. We identify a third form of laughter that challenges the status or behavior of a target, who can be present or absent. The reasoning behind this third, somewhat counterintuitive form of laughter is as follows. Since laughter is an evolved signal of harmlessness or benign intentions, laughter is especially common in social contexts that are ambiguous or contain potential for threat. Because people often use laughter to *reduce* social tension in such contexts, people learn to associate laughter with the presence of some sort of tension. Laughter can then become a signal that tension exists, rather than just a tool to reduce that tension. We suggest such laughter co-opts the playful signal of laughter and, by including acoustic modifications that convey dominance, creates social tension in response to the target's behavior (Szameitat et al., 2013).

Safely and non-aggressively signaling dominance is a crucial tool for successful living in complex social groups (Smith & Price, 1973). Threat displays among social animals are often ritualized and not intended to cause actual harm (de Waal, 1986), and dominance laughter extends this logic from avoiding physical harm to avoiding relational harm. Laughing to gain status or reprimand another's behavior, rather than verbally or physically aggressing, protects both the immediate relationship and the larger group's impression of the expresser. The folk psychology distinction between "laughing with" and "laughing at" highlights how laughter sometimes serves disaffiliative functions (Griffiths, 1998). In the current framework, laughter experienced as cruel, derisive, taunting, or sardonic (Bryant et al., 1979; Szameitat, Alter, Szameitat, Darwin, et al., 2009) falls under the social function of dominance.[4]

Challenges to social superiors, enforcement of group norms and boundaries, and punishment of transgressors are diluted and more socially acceptable when accomplished with laughter (Eibl-Eibesfeldt, 2017; Grammer & Eibl-Eibesfeldt, 1990; Griffiths, 1998). Using dominance laughter, people can signal their displeasure with or superiority over another person under the guise of play fighting or mock cruelty (Grammer & Eibl-Eibesfeldt, 1990). In a formal social hierarchy, such as a workplace, humor and laughter allow subordinates to signal that social tensions and disagreements exist without risking direct conflict with authority figures (Griffiths, 1998). Dominance laughter allows an individual to challenge a social partner without harming the social bond (Boxer & Cortés-Conde, 1997).

Laughing at another's behavior conveys that the expresser does not take the recipient's behavior seriously, undermining the recipient's status (Grammer & Eibl-Eibesfeldt, 1990). Drew (1987) observed that teasing and associated laughter is often a response to the recipient's "overdone" complaining, bragging, or extolling. Laughter softens the confrontation and "offers [the recipient] a chance to frame the ongoing action as less serious than it might be" (Arminen & Halonen, 2007). Teasing is a relatively indirect and gentle way of eliminating undesirable behaviors. Bryant and colleagues (1983) found that, by the age of 6, ridicule is a more effective deterrent of unwanted behavior than direct commands or suggestions.

When dominance laughter occurs in the presence of other people in addition to the target, it fosters group derision of the target and coordinates group enforcement of norms or group

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[4] We use the label *dominance* to facilitate connections to nonhuman animal communication (Pisanski, Cartei, McGettigan, Raine, & Reby, 2016; Puts, Gaulin, & Verdolini, 2006). We chose not to use the ethological term "agonism," which has more overtly threatening connotations than "dominance." A context-general term like "dominance" is also preferable to context-specific descriptions used in prior laughter work (e.g., "derisive", "taunting", or "segregating laughter" Szameitat et al., 2013). However, we acknowledge the ambiguities of the term (Drews, 1993; Rowell, 1974).

boundaries (Griffiths, 1998). Targets of such group laughter typically do not join in the laughter, but instead take action to counteract or remedy the cause of teasing (Arminen & Halonen, 2007). Insults accompanied by a laughing crowd evoke stronger emotional brain responses (measured as event-related potentials) than do insults presented without laughter, suggesting the amplifying influence of laughter occurs early in processing (Otten, Mann, van Berkum, & Jonas, 2017).

Drawing from existing theories of laughter and humor (Boxer & Cortés-Conde, 1997; Eibl-Eibesfeldt, 2017), we argue dominance laughter serves a social control function that bonds co-laughers and excludes the laughter target, punishing deviant or transgressive behavior (Fischer & Manstead, 2008). Alexander (1986) proposed that ostracizing humor positively alters the status of the expresser and negatively alters the status of the target. While we have described several possible consequences of dominance laughter—correcting social transgressions, enforcing group boundaries, and expressing superiority—we consider them to all be part of the overarching social task of dominance. We therefore expect acoustic similarity in the laughter occurring in all the contexts discussed above.

Dominance laughter will not necessarily be produced by the highest-status or most powerful person. Notably, animals with well-established social status do not frequently exhibit behavioral displays of dominance, because their secure power means they do not need to appeal to third parties with overt vocalizations or posturing (de Waal, 1986). Indeed, laughter produced by high-status fraternity members (compared to the laughter of low-status members) bore greater resemblance to spontaneous reward laughter than to dominance laughter (Oveis, Spectre, Smith, Liu, & Keltner, 2016).

Predicted acoustic properties of reward, affiliation, and dominance laughter

We draw from existing evidence to generate predictions about the acoustic signatures of laughter that accomplish the tasks of reward, affiliation, and dominance. Because the conceptualization of reward laugher aligns closely with the existing accounts of spontaneous laughter, perceiver judgments of reward and spontaneity should be strongly correlated, and the acoustic properties of rewarding and spontaneous laughter should overlap. Predictions about the ways in which laughter might be modulated to serve affiliation and dominance functions follow from observations of nonhuman animal behavior.

Animal and human vocalizations do not gain their social meaning through randomness, but according to their *form-function relationship* (Bryant, 2013; Morton, 1977). The form-function principle suggests that the form vocalizations take reflects the contexts in which they occur and their functions—for instance, proto-laughter evolved to be a recognizable play signal because it sounds like the heavy breathing of playing animals. By this account, predictable acoustic variations sound dominant and affiliative across the evolutionary tree. Consider that large organisms tend to present a greater threat than small organisms. Animals, including humans, exploit this heuristic to flexibly create the impression that they are more or less imposing (Fitch, 2000; Xu & Chuenwattanapranithi, 2007). According to the size code hypothesis, signals of nonthreat, appeasement, and submission (e.g., our characterization of affiliation laughter) involve creating the illusion of a small body size (Briefer, 2012). Signals that convey aggression, dominance, and agonism, conversely, create illusions of a larger body. Animals can accomplish these size illusions by fluffing their feathers or fur, tucking their tails and cowering, and modulating their vocalizations (Dunlop, 2017; Hecht & Horowitz, 2015; Pisanski et al., 2016).

Several acoustic properties correlate with body size and, yet, can be modified to a degree. Larger bodies can produce louder, lower-pitched vocalizations with reduced formant spacing (e.g., lower vowel sounds) and less tonal, noisier sounds (Bryant, 2013). Modulating a vocalization's loudness and pitch involves altering the vocal "source"—the force of the air expelled and laryngeal positioning—which can be accomplished during volitional vocalizations but probably less so during spontaneous laughter (Lavan et al., 2015; Taylor & Reby, 2010). Modulating the formant spacing, on the other hand, largely involves changes to the shape of the oral cavity and the lips, which is feasible even during spontaneous laughter. Humans and nonhuman animals alter these and other properties of their vocalizations to produce aggressive/dominant or submissive/affiliative signals (Pisanski et al., 2016).

Kohler (2008) observed that "giggle" and "titter" laughter is characterized by higher vowel resonances, which convey a smaller body size and submission, while "guffaws" and other low vowel laughs convey dominance. He proposed that a closed mouth would produce a particularly weak-sounding and submissive laugh, as it is quieter and nasalized, further raising the vowel sound. It has also been suggested that affiliative laughter, in addition to having higher vowel sounds, will be breathier (Shaw et al., 2013), which conveys weakness and is attractive to perceivers (Henton & Bladon, 1985; Xu, Lee, Wu, Liu, & Birkholz, 2013). Besides the motivational signal conveyed by the average vowel sound of a vocalization, Myers-Schulz and colleagues (2013) found that relative within-vocalization shifts in formants also influence the emotionality of a vocalization. They showed that nonsense words with downward vowel shifts are more negative/agonistic, while words with upward vowel shifts are more positive/affiliative. All these form-function relations may help explain variability in laughter acoustics.

Overview of the proposed studies

The current work tested the hypothesis that distinct acoustic properties of laughter accomplish the social functions of reward, affiliation, and dominance. Across three studies, participants rated the extent to which laughs convey the social functions (Study 1), judged the similarity of laughs to validated smiles that accomplish the social tasks (Study 2), and produced natural laughter during conversations about videos selected to elicit responses related to the three social functions (Study 3). The three studies complemented each other by emphasizing both laughter perception (Studies 1 and 2) and production (Study 3), and balanced relying on verbal descriptions of the social functions (Studies 1) with a nonverbal perceptual task (Studies 2). We used both inferential statistics-focused linear regression and machine learning to balance *explaining* form-function relationships in laughter with *predicting* the social function of a given laugh (Yarkoni & Westfall, 2017).

Participants (N = 762) in Study 1 judged the extent to which 400 laugh samples mined from a commercial sound effects library conveyed the proposed social functions of reward, affiliation, and dominance. Different acoustic properties (extracted using PRAAT acoustic analysis software) predicted participants' judgments of each social function, with actor sex emerging as a significant moderator across social functions. A random forest machine learning algorithm trained on a subset of the laughs was able to predict with good accuracy the perceived social functions of a separate subset of the laughs based on their acoustic properties. Study 2 (N = 1,089) used the NEXT machine learning platform (Jamieson, Jain, Fernandez, Glattard, & Nowak, 2015; Sievert et al., 2017) to embed a subset of laugh samples from Study 1 in a semantic similarity space shared with smiles identified as rewarding, affiliative, and dominant. The laughs' positions in the semantic space were strongly predicted by their perceived social functional meaning (according to Study 1 participants). Study 2 therefore provided convergent evidence that laughs convey rewarding, affiliative, and dominance signals to different degrees, and did so without relying on the inherently limited verbal descriptions of the social functions.

In Study 3, we examined the attributes, including the acoustic properties, of laughter that pairs of participants (complete recordings for N = 141) produced while watching and discussing video stimuli selected to elicit responses associated with the tasks of reward, affiliation, and dominance. We compared the acoustic properties of laughter in response to each of the three video types and found that laughter during reward-, affiliation-, and dominance-relevant conversations differed systematically on several acoustic variables that converged with Study 1's perceiver-based findings, and with the larger acoustic signaling literature. As in Study 1, gender differences emerged. Unlike Study 1, however, the naturally-occurring laughter from unstructured conversations was too variable for the tested machine learning algorithm to accurately predict their social functional context from acoustics alone.

Combined, these studies work towards explaining the observed variability in laughter's acoustic form and eliciting social contexts. The current social functional framework, and in particular Study 2, provides much-needed integration of smile and laughter theory and research.[5] This approach also generates useful predictions about the adaptive origins and social consequences of nonverbal expressions, going beyond more traditional approaches that focus on the affective or physiological state of the expresser. Because laughter conveys that any accompanying behaviors are harmless, it allows expressers to act upon their social worlds without risking relationships (Gervais & Wilson, 2005).

[5] The most common prior method for integrating smiles and laughter involves categorizing laughter as "Duchenne" or "non-Duchenne," based on the presence of the facial action unit commonly associated with "spontaneous" and "posed" smiles (e.g., Gervais & Wilson, 2005b). This approach is problematic for several reasons, not least of which is the ambiguity of the Duchenne marker (see Martin, Rychlowska, Wood, & Niedenthal, 2017).

Study 1: Acoustic properties predict perceptions of reward, affiliation, and dominance

The first study examined whether people systematically detect distinct social signals in laughter and identified candidate acoustic signatures of laughter that conveys reward, affiliation, and dominance. We presented 400 laughter samples to participants in an online study. In a between-subjects design, we asked participants to rate the degree to which each laugh clip expressed meanings related to reward, affiliation, dominance, or spontaneity. We included the latter in order to compare the current framework to the primary diagnostic dimension in the literature, but we do not consider spontaneity to be a fourth candidate social function. We report results from a linear mixed-effects model approach, which revealed the relationships between individual acoustic variables and participants' judgments. We then report results from a machine learning approach, which demonstrated the combined predictive power of the acoustic properties. Spontaneous laughs are defined by their neural and physiological underpinnings (Bryant & Aktipis, 2014), while social functions are identified by their behavioral outcomes. Thus, participants' judgments about how spontaneous a laugh seems could be orthogonal to or correlated with their social functional judgments.

We chose not to use laughter samples obtained in a lab setting or from a naturalistic database, as both options will always be limited by the social contexts the researchers chose to record. Instead, we used laughter bursts from a professional online sound library (soundsnap.com), with the assumption that a resource for videogame and movie sound editors would include vocalizations meant to convey a wide range of social intentions. We extracted relevant acoustic variables from the laugh samples and used them to predict subjects' social function ratings in a series of linear mixed-effect models with actor sex as a moderator. Each of the social functional dimensions was associated with a distinct acoustic profile, and spontaneity and reward were largely overlapping. Many of the social judgments related to different acoustic properties for male and female vocalizations.

Method

This study was conducted according to the appropriate ethical guidelines and approved by the Institutional Review Board (IRB) at the University of Wisconsin - Madison. Participants were at least 18 years old and were fully informed of what the study involved. Because obtaining signed consent was impractical in the online study, the IRB approved a waiver for signed consent. No sensitive information was collected, and all data were confidential. We analyzed only anonymous data. We report all data exclusions, all manipulations, and all measures. The data and analysis files and all laughter clips are available online (https://osf.io/ca66s/).

Participants and procedure. We recruited 768 online participants on Amazon's Mechanical Turk and TurkPrime to "rate 50 very brief audio clips of people laughing" in exchange for $2 (all participation occurred May 11-12, 2017). Five participants reported audio malfunctions and one participant reported that he did not listen to the sounds before rating them; excluding these participants resulted in a sample of 762 (for participant demographics, see Wood et al., 2017).

After reading the consent information, participants were randomly assigned to judge the degree to which the laugh samples communicated a meaning related to one of the four dimensions (spontaneity n = 172, reward n = 254, affiliation n = 166, dominance n =170). Each participant evaluated the laughs on just one of the four rating scales so experimental demands would not lead them to rate each laugh as high on only one dimension. Due to a programming error, the reward condition was oversampled.

Each participant rated a subsample of 50 laughs randomly drawn from the entire pool of 400 laughs. Each laugh was rated on a given dimension approximately 24 times (762 participants *50 judgments) / (400 laughs * 4 rating dimensions). Instructions asked participants to rely on their "spontaneous impressions" to "rate the extent to which you think the…description fits this clip". The descriptions, which varied across conditions, were accompanied by a 10-point Likert scale (1= "not at all", 10 = "very much"):

- **Spontaneity condition**: "Laughter can sometimes be spontaneous. You could feel that someone's laughter is unintentional and is occurring outside of their control."
- **Reward condition:** "Laughter can sometimes be rewarding. You could feel that someone's laughter means they like something that you did or said."
- **Affiliation condition:** "Laughter can sometimes be reassuring. You could feel that someone's laughter means they are acknowledging you and want you to know they are not threatening."
- **Dominance condition:** "Laughter can sometimes be mocking. You could feel that someone's laughter means at this moment they feel superior to or dominant over you."

After rating 50 laughs, participants answered several demographic and task feedback questions.

Laughter stimuli. To maximize the variability of our laughter sample, we obtained stimuli from Sound Snap, a professional online sound library (soundsnap.com). Sound Snap's voice recordings are licensed by sound designers and producers; as such, they are largely produced in recording studios and often sound artificial. This is particularly important to consider in laughter, as spontaneity strongly influences perceiver judgments. However, we think it is appropriate to use these somewhat artificial stimuli in the current study for two reasons. Firstly, the social functional account is agnostic about the feeling states underlying an expression, instead seeking to identify common social consequences. Secondly, posed and synthetic facial expressions have been instrumental in identifying the action units relevant to certain emotions or social functions (Tracy & Randles, 2011), and distilled, sometimes caricatured expressions often exaggerate the most essential features of an expression (Calder, Young, Rowland, & Perrett, 1997).

On April 19, 2017, we used the following keywords in a Sound Snap search, which returned 598 audio clips: LAUGH* -*BOY* -*GIRL* -CARTOON* -GROUP* -CROWD* -ANIMAL -WOMEN -MEN -LADIES -KID -BAB* -TODDLER* -TALK* -SPEECH -SPEAK* -MANIC (dashes precede excluded keywords). Clips were then eliminated from the initial search return for the following reasons: contained no adult human laughter; contained speech, ambient noise, or multiple speakers; were low-quality vintage recordings; or were tagged with the words "ghost," "clown," "cartoon," or "crazy." This resulted in 400 relevant laughter samples (256 male, 144 female). We then trimmed any silence from the beginning and end of the samples.

Acoustic feature extraction. Eleven acoustic features were extracted from the 400 laugh samples using PRAAT (Boersma & Weenink, 2016). We describe the variables and the motivation for their inclusion below:

- **Duration:** The *duration* of the laughter sample in seconds, log-transformed to correct for positive skew. In at least one study, spontaneous laughter bouts were longer than volitional bouts (Lavan, Scott, & McGettigan, 2015; cf. Bryant & Aktipis, 2014).
- **Intensity:** The mean *intensity*, or loudness, in dB. Greater intensity may be an indicator of reduced inhibition (Oveis et al., 2016) or increased laughter spontaneity (Bryant & Aktipis, 2014).

- **Pitch variables[6]:** *F0 mean* refers to mean fundamental frequency, or pitch, as calculated using PRAAT's auto-correlation technique. *F0 range* is the difference between the lowest and highest F0 for each sample. *Standard deviation of F0 divided by the total duration* (*SD F0 / duration*) of the sample captures the average moment-to-moment variability in pitch; this variable was log-transformed to correct for positive skew. *Slope* is the mean absolute F0 slope, which measures how sharply the pitch changes occur by dividing the difference between a local F0 maximum and minimum (at intervals of .01 seconds) by the duration it takes to go from one to the other. Raised F0 and greater SD F0 / duration and F0 range are associated with spontaneity in laughter. Steeper F0 slopes are associated with high arousal emotion states (Bänziger & Scherer, 2005).
- **Spectral variables:** *Center of gravity* refers to the spectral centroid, which accounts for the weighting of noise across the sample (log-transformed). Changes in center of gravity can correspond to the oral-nasal distinction in vowels (Beddor, 1993) and the perception of vowel height in nasal vowels (Specter Beddor & Hawkins, 1984). More generally, center of gravity is an indicator of the timbre, or brightness, of a sound, with higher centers sounding brighter (Schubert & Wolfe, 2006). Spontaneous laughs in one study had higher centers of gravity than volitional laughs (Lavan et al., 2015). *Harmonics-to-noise ratio* is the average degree of periodicity in dB; a higher value indicates a purer, more tonal sound, and a lower value indicates a noisier vocalization. *Proportion voiced* is the proportion of frames that are voiced as opposed to unvoiced. Voiced segments are nearly periodic, while unvoiced segments are noisier, and include exhalations and snorts (Bachorowski & Owren, 2001). Previous work

[6] To correct for the skewed distribution of pitch variables on a Hertz scale, F0 mean, slope, and F0 range were transformed from Hertz to a semitone scale (12*log(X)), with F0 range calculated as a ratio of the maximum to minimum F0 (12*log(maximum/minimum)) (Bryant & Aktipis, 2014).

showed that spontaneous laughs have more unvoiced segments (Lavan et al., 2015) and longer intervals between voiced bursts (Bryant & Aktipis, 2014) compared to volitional laughs. Laughs intended to portray teasing and schadenfreude have lower harmonics-to-noise ratios than laughter intended to portray tickling (Szameitat, Alter, Szameitat, Darwin, et al., 2009).

- **Formant variables:** *F1 mean* and *F2 mean*, or the first and second formants (transformed to semitones), are peaks in the sound spectrum that help determine the vowel sound of a vocalization. Lowering F1 and raising F2 results in a "higher" vowel (e.g., shifting from /aː/ to /iː/). Spontaneous and rewarding laughter may be expected to feature high F1 means based on previous research (Szameitat, Darwin, Szameitat, Wildgruber, & Alter, 2011), as a higher F1 is associated with higher arousal (Laukka, Juslin, & Bresin, 2005). Raised F2 can convey increased positivity (Goudbeek, Goldman, & Scherer, 2009). A general raising of the vowel sound, which involves increasing the relative dispersion of the first and second formants, creates the illusion of a smaller body size (Lasarcyk & Trouvain, 2008), as formant spacing is much more strongly related to body size than F0 (Fitch, 1997; Pisanski et al., 2014). Furthermore, open vowel sounds are associated with high-arousal calls in monkeys (Snowdon & Teie, 2013). Formant positioning therefore has the potential to predict perceptions of all four social dimensions in laughter (Xu & Chuenwattanapranithi, 2007).

Five laugh samples were removed from subsequent analyses because they had no voiced frames and were therefore missing values for pitch variables. Inspecting the summary statistics suggests participants rated these unvoiced laughs as lower on reward (M = 2.84, SD = 2.23), affiliation (M = 3.04, SD = 2.29), and dominance (M = 4.26, SD =3.23) than the other 395 laughs (mean spontaneity ratings are not noticeably different, M = 4.82, SD = 3.05).

Linear mixed-effect models results and discussion

Analytic plan. We first conducted a series of linear mixed-effect models to identify which acoustic variables predict variability in the social functional ratings. Analyses were conducted in the R environment (R Development Core Team, 2008) using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) for model fitting and the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2015) for calculating denominator degrees of freedom using Satterthwaite's approximations. Separately for each social judgment dimension X acoustic variable combination, we regressed participants' raw responses on the acoustic variable. In all models, we included interactions between the acoustic variable and actor sex, given the sex differences in acoustic properties of laughter (Bachorowski et al., 2001), frequency of "social" laughter (Provine, 1993), and the social acceptability of dominance displays (Brescoll & Uhlmann, 2008). Since multiple observations were made for each laugh sample, we included a by-laugh random intercept. We included by-subject random intercept and random slopes for actor sex and the acoustic variable, since they vary within-subject. In four cases where we encountered model convergence failures, we constrained the covariance between random effects to zero (Brauer & Curtin, 2017). Because we estimated 44 unique models (4 social judgment dimensions X 11 acoustic variables), we controlled the false discovery rate by reporting Benjamini-Hochberg adjusted p values (Benjamini & Hochberg, 1995).

The initial models used centered actor sex (male = -.5, female= .5), but were followed up by models in which actor sex was recoded so that either male or female was coded as zero; this allowed us to identify which acoustic variables predict social judgments specifically for male and female actors. In the following sections we summarize and interpret the significant predictors for each social judgment outcome, but see **Table 1** for all model estimates and **Figure 1** for bivariate plots.

Acoustic features associated with spontaneity and reward. We found judgments of spontaneity and reward to be highly correlated (r = .84) and predicted by many of the same acoustic properties (see **Table 1**, "Spontaneity Models" and "Reward Models"). Increased perceptions of spontaneity and reward were associated with higher F0 means, a feature likely influenced by arousal levels of the expresser and that is observed in research on spontaneous laughter (Bryant & Aktipis, 2014; Lavan et al., 2015). Also replicating previous work (Lavan et al., 2015), laughs high on perceived spontaneity and reward had less voicing.

In addition to having higher F0 means and less voicing, female but not male laughter was perceived as more spontaneous when it was longer in duration (Lavan et al., 2015). This is perhaps due to the fact that females are normatively expected to be, and are, less intrusive with speech and vocalizations (Ten Bosch, Oostdijk, & Boves, 2005). When a female does laugh longer, it may seem to perceivers that the laughter is truly outside of her control, while perceivers may not expect male volitional laughter to be constrained. In contrast to spontaneity, perceptions of reward were predicted by laugh sample duration for both males and females. If future work replicates this pattern, it supports the notion that males are generally less inhibited in their laughter, so variability in male laughter bout length is informative about the social function of a laugh, but not informative of how uncontrollable the laughter is.

We see further sex-specific effects for spontaneity. Compared to females, judgments of male spontaneity were predicted by a more complex pattern: increased F0 slope, higher spectral center of gravity, increased F1 and F2 means, and reduced harmonics-to-noise ratio. Previous work has linked reduced harmonics-to-noise ratio to perceptions of positivity, and increased center of gravity to perceptions of arousal (Lavan et al., 2015). Increased F0 slope (Boersma & Weenink, 2016) and raised F1 means (Schubert & Wolfe, 2006) have been associated with high-arousal emotional states. F2 means are positively related to perceivers' judgments that a vocalization reflects an intense emotion (Schubert & Wolfe, 2006) or a positive affective state (Laukka et al., 2005), and higher F2 creates a higher vowel sound. At least in the current

Table 1. Model estimates from LMEMs predicting social judgments from acoustic variables and their interactions with actor sex.

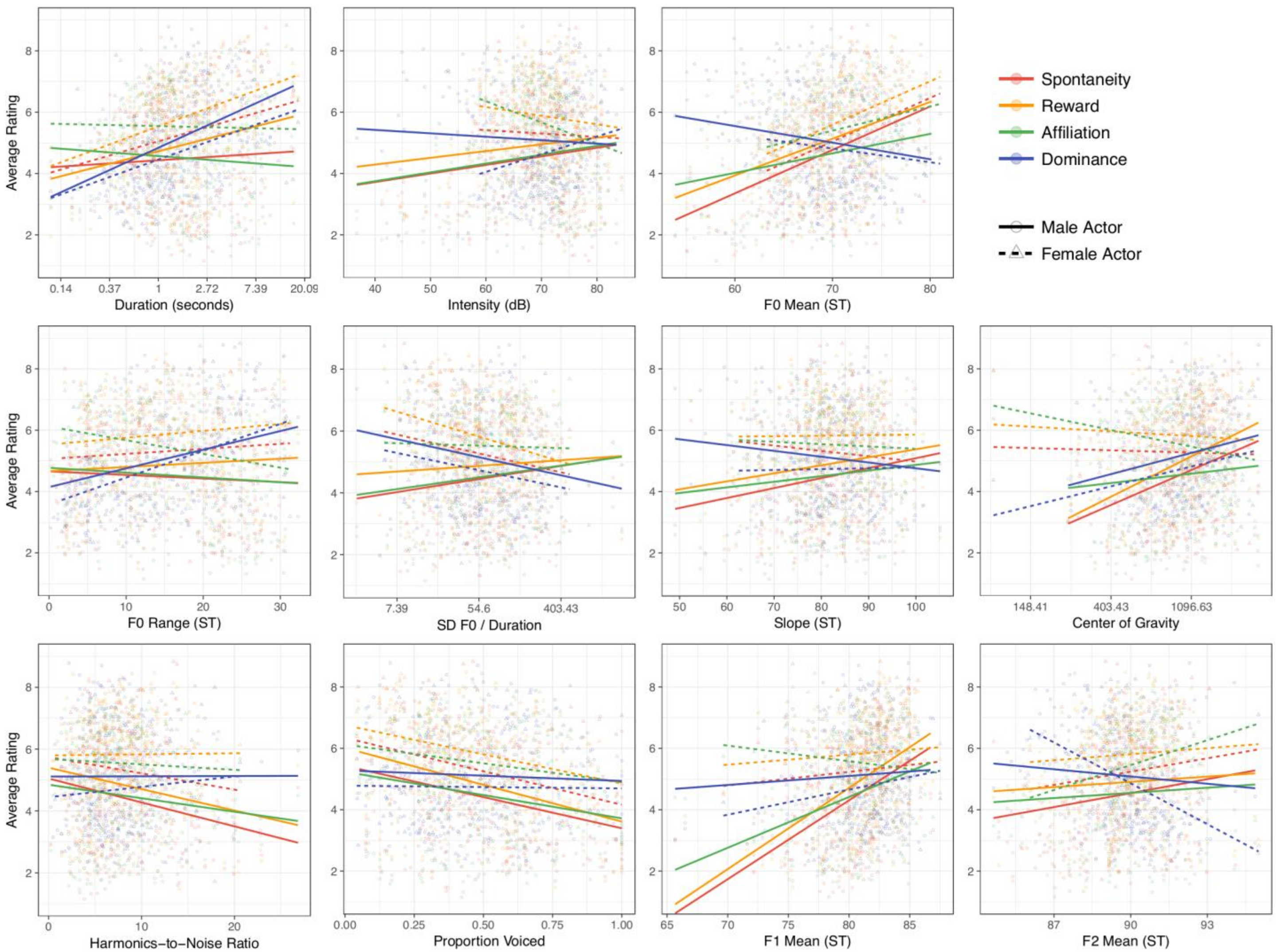
	Spontaneity Models				Reward Models				Affiliation Models				Dominance Models			
Variable	**b**	**SE**	**t**	**adj. p**	**b**	**SE**	**t**	**adj. p**	**b**	**SE**	**t**	**adj. p**	**b**	**SE**	**t**	**adj. p**
Duration*	.238	.095	2.501	.029	.451	.086	5.215	<.001	-.048	.090	-.536	.686	.679	.085	8.013	<.001
Sex Interaction	.266	.170	1.565	.226	.079	.154	.510	.672	.116	.161	.725	.591	-.162	.148	-1.091	.391
Males	.105	.116	.905	.473	.411	.106	3.894	<.001	-.107	.111	-.959	.480	.760	.104	7.314	<.001
Females	.371	.138	2.687	.022	.490	.125	3.916	<.001	.010	.130	.075	.940	.598	.121	4.957	<.001
Intensity	.008	.014	.560	.704	.007	.013	.531	.672	-.024	.013	-1.813	.141	.017	.013	1.256	.318
Sex Interaction	-.028	.027	-1.022	.410	-.033	.024	-1.369	.294	-.106	.025	-4.194	<.001	.042	.026	1.592	.229
Males	.022	.012	1.806	.150	.024	.011	2.093	.077	.028	.011	2.571	.034	-.004	.012	-.334	.813
Females	-.006	.025	-.233	.876	-.010	.023	-.432	.714	-.077	.024	-3.275	.006	.038	.024	1.581	.229
F0 Mean	.138	.020	6.855	<.001	.139	.018	7.560	<.001	.074	.020	3.738	.002	-.050	.020	-2.519	.036
Sex Interaction	.019	.037	.512	.724	.042	.033	1.267	.335	.015	.036	.422	.733	.004	.037	.097	.967
Males	.128	.019	6.853	<.001	.117	.018	6.678	<.001	.066	.019	3.572	.003	-.052	.020	-2.673	.024
Females	.147	.034	4.352	<.001	.160	.030	5.267	<.001	.081	.033	2.486	.038	-.049	.033	-1.462	.264
F0 Range	-.001	.011	-.051	.982	.013	.010	1.197	.362	-.029	.011	-2.740	.023	.076	.010	7.572	<.001
Sex Interaction	.026	.021	1.253	.320	.000	.019	.008	.994	-.024	.019	-1.213	.341	.026	.018	1.431	.264
Males	-.014	.012	-1.104	.372	.012	.012	1.057	.427	-.017	.012	-1.468	.242	.062	.011	5.486	<.001
Females	.013	.018	.710	.601	.013	.016	.773	.541	-.041	.017	-2.450	.038	.089	.015	5.742	<.001
SD F0 / Duration*	-.021	.087	-.238	.876	-.122	.081	-1.504	.255	.058	.081	.723	.591	-.303	.080	-3.798	.001
Sex Interaction	-.347	.167	-2.080	.084	-.391	.153	-2.565	.026	-.226	.153	-1.480	.242	.006	.156	.041	.968
Males	.153	.096	1.594	.223	.073	.090	.816	.540	.171	.089	1.922	.122	-.306	.090	-3.416	.003
Females	-.194	.141	-1.377	.298	-.318	.130	-2.452	.034	-.055	.129	-.424	.733	-.300	.130	-2.312	.058
F0 Slope	.013	.011	1.169	.345	.017	.010	1.697	.181	.006	.010	.539	.686	-.015	.010	-1.431	.264
Sex Interaction	-.026	.021	-1.221	.326	-.016	.019	-.829	.540	-.024	.020	-1.195	.341	.012	.020	.589	.679
Males	.026	.010	2.631	.023	.025	.009	2.739	.017	.017	.009	1.886	.126	-.021	.009	-2.200	.069
Females	.000	.019	-.004	.997	.009	.018	.528	.672	-.006	.018	-.347	.764	-.009	.018	-.486	.746
Center of Gravity*	.437	.173	2.527	.029	.593	.162	3.669	.001	-.107	.171	-.625	.651	.666	.161	4.125	<.001
Sex Interaction	-1.053	.328	-3.208	.005	-1.351	.297	-4.557	<.001	-.783	.306	-2.557	.034	-.286	.313	-.913	.455
Males	.964	.224	4.302	<.001	1.269	.208	6.099	<.001	.285	.215	1.329	.298	.809	.216	3.745	.001
Females	-.089	.252	-.355	.815	-.082	.230	-.357	.738	-.498	.243	-2.050	.097	.523	.233	2.240	.066
Harmonics-to-Noise Ratio	-.070	.021	-3.314	.004	-.028	.019	-1.447	.272	-.031	.019	-1.625	.192	.020	.020	1.003	.422
Sex Interaction	.052	.039	1.311	.304	.080	.036	2.190	.064	.006	.037	.175	.881	.042	.039	1.103	.391
Males	-.094	.023	-4.138	<.001	-.068	.021	-3.217	.004	-.034	.021	-1.639	.192	-.001	.022	-.068	.968
Females	-.044	.034	-1.303	.304	.012	.031	.382	.736	-.028	.031	-.891	.514	.041	.032	1.272	.318
Proportion Voiced	-2.036	.374	-5.447	<.001	-2.007	.340	-5.909	<.001	-1.472	.349	-4.217	<.001	-.339	.366	-.927	.455
Sex Interaction	.256	.702	.364	.815	.633	.643	.984	.462	-.275	.674	-.408	.733	.176	.689	.255	.857
Males	-2.164	.431	-5.023	<.001	-2.324	.392	-5.928	<.001	-1.335	.399	-3.343	.006	-.427	.416	-1.027	.419
Females	-1.908	.583	-3.273	.004	-1.691	.533	-3.172	.004	-1.609	.558	-2.885	.016	-.251	.576	-.436	.768

F1 Mean	.152	.026	5.788	<.001	.140	.024	5.748	<.001	.061	.025	2.477	.038	.054	.026	2.061	.092
Sex Interaction	-.194	.051	-3.800	.001	-.216	.046	-4.685	<.001	-.183	.049	-3.759	.002	.020	.052	.383	.792
Males	.249	.032	7.825	<.001	.249	.029	8.654	<.001	.153	.030	5.159	<.001	.044	.032	1.363	.283
Females	.055	.041	1.346	.303	.030	.037	.812	.540	-.030	.039	-.764	.591	.058	.041	1.422	.264
F2 Mean	.162	.061	2.669	.022	.077	.057	1.362	.294	.178	.057	3.109	.010	-.233	.056	-4.130	<.001
Sex Interaction	-.015	.116	-.128	.941	.073	.106	.687	.585	.221	.108	2.038	.097	-.292	.108	-2.706	.024
Males	.170	.056	3.048	.008	.041	.053	.768	.541	.068	.052	1.313	.298	-.087	.052	-1.668	.212
Females	.155	.105	1.476	.258	.114	.096	1.180	.362	.289	.099	2.923	.016	-.379	.097	-3.891	.001

Footnotes. The first rows for each variable are the model estimates for the main effects (averaged across male and female actors). The second rows are the estimates for the acoustic variable-by-sex interaction terms. The third and fourth rows are the effects of the acoustic variables when the sex term is recoded, so they indicate the effect for males and females, respectively. P values are Benjamini-Hochberg adjusted for multiple comparisons. Significant effects are in color: significant main effects are green, interaction terms are orange, simple effects for male actors are yellow, and simple effects for females are blue. *Indicates a log-transformed variable.

Figure 1 (next page). The relationship between laugh samples' acoustic measures and average participant ratings, separated by actor sex, fitted with ordinary least squares regression.

Footnotes. Each point is a single laugh sample's average score for a given social judgment. Y axes are the degree to which participants thought the description of each social dimension fit the laugh (1=not at all, 10=very much). X-axis tick marks for log-transformed variables are non-linear because they have been converted back to the original unit of measure. ST indicates a pitch variable that has been converted to the semitone scale. Since the plotted regression lines are from simple regressions, they may not perfectly match the coefficients from the reported LMEMs in **Table 1**.


Spontaneity
Reward
Affiliation
Dominance
Male Actor
Female Actor
Average Rating
Duration (seconds)
Intensity (dB)
F0 Mean (ST)
F0 Range (ST)
SD F0 / Duration
Slope (ST)
Center of Gravity
Harmonics-to-Noise Ratio
Proportion Voiced
F1 Mean (ST)
F2 Mean (ST)

stimulus set, judgments of males'—but less so for females'—spontaneity appear to have been guided by biologically-reliable indicators of arousal and valence.

Sex-dependent effects on reward judgments differed from spontaneity for two acoustic variables in addition to bout duration: pitch variability and F2 mean. SD F0 / duration (i.e. pitch variability) was negatively associated with perceptions of female reward. Pitch variability was not predictive of spontaneity judgments here or in previous work (Lavan et al., 2015), although that same study showed that spontaneously-elicited laughter actually features *greater* pitch variability than volitional laughter, a feature perceivers did not seem to pick up on. Future work should determine whether this relationship between pitch variability and perceived reward of female laughter is an artifact of the current study or a feature that distinguishes rewarding functions from outright spontaneity. The male-specific relationship between F2 mean and spontaneity was absent for reward.

Acoustic features associated with affiliation. Perceptions of affiliation, like spontaneity and reward, were associated with higher pitch and reduced voicing for males and females, and a male-specific effect of F1 mean. The remaining acoustic predictors of affiliation judgments were unique to affiliation and sex-specific (see **Table 1**, "Affiliation Models").

Affiliation was the only social judgment predicted by the intensity, or loudness, of a laugh, and exhibited opposite patterns for males and females. Males were judged as conveying appeasement and non-threatening intentions when their laughter was louder, while female laughter sounded more affiliative when it was quieter. If females are expected to be generally more restrained (Fredrickson, Roberts, Noll, Quinn, & Twenge, 1998), then they might be perceived as friendlier and less threatening with quieter laughter, while outgoing-sounding, loud laughter might sound more acceptable and friendlier in males. Indeed, disinhibition is an attractive quality in males (Hugill, Fink, Neave, Besson, & Bunse, 2011). This is speculation and requires follow-up research.

F0 range, or the distance in semitones between the minimum and maximum pitch of a laugh bout, was negatively associated with affiliation judgments for female actors. Threat and high-arousal states in non-human primates are conveyed with large jumps in pitch, while low-arousal vocalizations involve smaller pitch changes (Pisanski et al., 2014). The interaction between sex and spectral center of gravity in the affiliation model was significant, with a larger, more negative simple effect for females, but this female-specific effect was not significant after correcting for multiple comparisons. A lower center of gravity conveys lower arousal and more volitional laughter (Lavan et al., 2015), and might therefore signal non-threatening, soothing intentions.

Further distinguishing affiliation from reward and spontaneity, female laughter with higher F2 means was perceived as more affiliative. Higher second formants occur in positive affective vocalizations in humans (Laukka et al., 2005) and are perceived as a signal of smaller body size, conveying appeasement and submission in animals (Pisanski et al., 2014). Raising F2 produces higher-sounding vowels and can be accentuated with retracted lips: for instance, compared to neutral lips, retracted lips shift the vowel /yː/ up to /iː/ (Lasarcyk & Trouvain, 2008). This suggests a possible relationship between the degree to which a laugh “sounds” like a smile and, at least in females, how affiliative it sounds.

Acoustic features associated with dominance. The only features shared between laughs perceived as highly dominant and laughs perceived as spontaneous/rewarding are longer durations and higher centers of gravity for male actors. Dominance and affiliation are not predicted by any of the same acoustic features and relate to several acoustic variables in opposite directions (see **Table 1**, “Dominance Models”). See **Table 2** for a summary of properties shared by the social dimensions.

Table 2. Summary of distinct and shared acoustic predictors of the four social judgments

	Spontaneity	**Reward**	**Affiliation**	**Dominance**
Spontaneity	↑ Duration (F) ↑ F0 Mean ↑ Slope (M) ↑ Center of Gravity (M) ↓ Harmonics-to-Noise Ratio (M) ↓ Proportion Voiced ↑ F1 Mean (M) ↑ F2 Mean (M)	↑ Duration (F*) ↑ F0 Mean ↑ Slope (M) ↑ Center of Gravity (M) ↓ Harmonics-to-Noise Ratio (M) ↓ Proportion Voiced ↑ F1 Mean (M)	↑ F0 Mean ↓ Proportion Voiced ↑ F1 Mean (M)	↑ Duration (F*) ↑ Center of Gravity (M)
Reward	↑ Duration (F*) ↑ F0 Mean ↑ Slope (M) ↑ Center of Gravity (M) ↓ Harmonics-to-Noise Ratio (M) ↓ Proportion Voiced ↑ F1 Mean (M)	↑ Duration ↑ F0 Mean ↓ SD F0 / Duration (F) ↑ Slope (M) ↑ Center of Gravity (M) ↓ Harmonics-to-Noise Ratio (M) ↓ Proportion Voiced ↑ F1 Mean (M)	↑ F0 Mean ↓ Proportion Voiced ↑ F1 Mean (M)	↑ Duration ↑ Center of Gravity (M)
Affiliation	↑ F0 Mean ↓ Proportion Voiced ↑ F1 Mean (M)	↑ F0 Mean ↓ Proportion Voiced ↑ F1 Mean (M)	Intensity (M↑,F↓) ↑ F0 Mean ↓ F0 Range (F) ↓ Proportion Voiced ↑ F1 Mean (M) ↑ F2 Mean (F)	
Dominance	↑ Duration (F*) ↑ Center of Gravity (M)	↑ Duration ↑ Center of Gravity (M)		↑ Duration ↓ F0 Mean (M) ↑ F0 Range ↓ SD F0 / Duration (M) ↑ Center of Gravity (M) ↓ F2 Mean (F)

Footnotes. Each cell contains the acoustic predictors that were significant and in the same direction for both the row and column social dimension; the diagonal contains all significant predictors for a given social dimension. Variable names followed by an (M) or (F) had significant effects for only one sex. *Indicates a shared effect that predicts one of the social dimensions for both males and females, but predicts the other social dimension for only one sex. Green indicates a positive regression coefficient, and red a negative coefficient; yellow indicates the relationship between the acoustic property and the social dimension is the opposite for males and females.

Lower F0 means and SD F0 / duration both predict perceptions of dominance, but these main effects appear to be driven by male actors. These are properties shared with non-laugh vocalizations that convey dominance and largeness in humans and non-human animals

(Borkowska & Pawlowski, 2011; Hodges-Simeon, Gaulin, & Puts, 2010; Pisanski et al., 2016; Puts, Gaulin, & Verdolini, 2006). In an unsurprising reversal of F2's relationship to perceptions of affiliation in females, female laughs with lower F2 means are perceived as more dominant (the interaction term here is significant, suggesting no effect of F2 on perceptions of male dominance).

More dominant laughs have greater F0 ranges for both males and females. This relationship is unexpected as spontaneous laughter tends to have a greater pitch range than volitional laughter (Bryant & Aktipis, 2014; Lavan et al., 2015), and given the divergence of dominance and spontaneity ratings, we expected dominant laughter to have a lower range. This puzzle may be clarified in future work examining the pitch contour of a laughter bout: laughter conveying dominance and superiority may have a strong downward pitch contour with little variability, like more "dominant" speech utterances (e.g., statements as opposed to questions, Ohala, 1983).

Another surprising (non-)effect on dominance perceptions is harmonics-to-noise ratio. Animal threat vocalizations are typically noisier (Pisanski et al., 2014), and posed laughter intended to portray *schadenfreude* and taunting has been observed to be noisier than laughter portraying tickling and joy (Szameitat, Alter, Szameitat, Darwin, et al., 2009). We should avoid drawing conclusions from this null result, particularly in light of Study 3's findings.

Possible explanations of observed sex differences. There are several potential explanations for why actor sex moderates the relationships between acoustic properties and social judgments. The first possibility is that spontaneous, rewarding, affiliative, and dominant laughs sound different when produced by males versus females (Fitch, 1997). The human vocal apparatus is sexually dimorphic (Puts et al., 2006) and male and female actors modulate different acoustic features to portray laughter in various social contexts (Szameitat, Alter, Szameitat, Darwin, et al., 2009). The second possibility is that, specifically in our laugh sample set, the male and female actors conveyed different social intentions in distinct and, possibly, stereotypical ways, so that if we reproduced the current study using naturalistic laughter, the sex differences would disappear. For instance, it could be that males sometimes convey affiliation in ways similar to females, but this was just not represented in the Sound Snap database. The final possibility is that the sex differences are due to participants' mental models of how males and females sound when they are being spontaneous, rewarding, affiliative, and dominant. In line with this, previous work suggests that male listeners disregard acoustic cues of female laughter spontaneity (McKeown, Sneddon, & Curran, 2014). Regardless of the source of these sex differences, this work highlights sex as an important moderator of social signals, particularly for behaviors like laughter with sexually dimorphic physiology, and when studying highly gendered social tasks like affiliation and dominance.

Possessing versus expressing affiliation and dominance. We must reconcile the acoustic signatures of affiliative laughter here with previous work, which shows that listeners can detect affiliation in dyads (Bryant et al., 2016). This work showed that listeners from many different cultures can detect when co-laughter is between friends or strangers, with laughter between friends involving acoustic features associated with spontaneity. Why, then, does the present work suggest separable acoustic signatures of spontaneity and affiliation? The previous study operationalized "affiliation" as whether co-laughers have an established relationship, while here we operationalize signals of affiliation as cues of appeasement and non-threat. It is sensible that laughter produced in the presence of a friend is more rewarding, as such laughter helps maintain and build close bonds (Gray, Parkinson, & Dunbar, 2015). Affiliative laughter as we define it is a tool for signaling friendliness and benign intentions, and such signals are only necessary when those intentions cannot be inferred or taken for granted. Spontaneous and rewarding co-laughter may indicate a secure social bond, while affiliative co-laughter may indicate bond maintenance or establishment is occurring. Indeed, such a distinction occurs in the facial displays of mandrill monkeys (Otovic, Partan, Bryant, & Hutchinson, 2014).

A similar clarification must be made for dominance. A recent study examined the acoustic properties of laughs emitted by group members possessing different levels of actual power and status as they jokingly teased each other (Oveis et al., 2016). This study revealed a strikingly different pattern of results than those presented here: laughter produced by dominant group members had higher pitch, pitch variability, and intensity, among other outcomes. The dominant laughers, overall, seem to be producing more spontaneous and disinhibited laughs compared to the low-status laughers. As with affiliation, this confusion can be reconciled by realizing that the previous study defined "dominant" individuals as those possessing actual power and status, while we are focused on signals intended to *exert* dominance on others (for a similar distinction in pride displays, see Tracy & Robins, 2007). Such signals are hypothesized to occur when people perceive a discrepancy between their actual and deserved status in the group, or as a way to discount another person's status. This interpretation explains why the previous study with high- and low-status laughers (Oveis et al., 2016) correlated high status with strikingly non-dominant acoustic properties (e.g., higher pitch, which conveys submission and appeasement in most species' communication; Pisanski et al., 2014). In that study, the high-status laughers were secure in their status, and were not in the process of negotiating or correcting the social hierarchy.

Machine learning results and discussion

We then complemented the mixed-effect model approach, which emphasizes interpretability, with a machine learning (ML) model approach, with the aim of maximizing prediction accuracy. We first calculated the average reward, affiliation, and dominance judgment score for each of the 395 voiced laughs and labeled the laughs based on which social dimension it was rated highest on. For instance, if a laugh's average affiliation rating was higher than its average reward and dominance ratings, we gave it the "affiliation" label. 127 laughs were labeled as "reward", 108 as "affiliation," and 159 as "dominance" (1 laugh was excluded because its average affiliation and reward ratings were equal). The goal of the machine learning analyses, which were conducted with the Caret package in R (Kuhn, 2008), was to predict which label or category a laugh belonged to, using only Actor Gender and the 11 acoustic properties as input. We trained a variety of ML algorithms to categorize a random subset of 80% of the 394 laughs, then selected the most accurate algorithm and tested its ability to categorize the remaining 20% of the laughs. The analysis script, output, and necessary data files are online (osf.io/pg9dn).[7]

Data partitioning and preprocessing. We partitioned the laughs into training (80%) and test (20%) sets that maintained the distribution of the laughs across the 3 social functional categories using Caret's createDataPartition function. We then centered and scaled the 12 predictor variables in the training dataset, and centered and scaled the testing dataset against the training dataset.

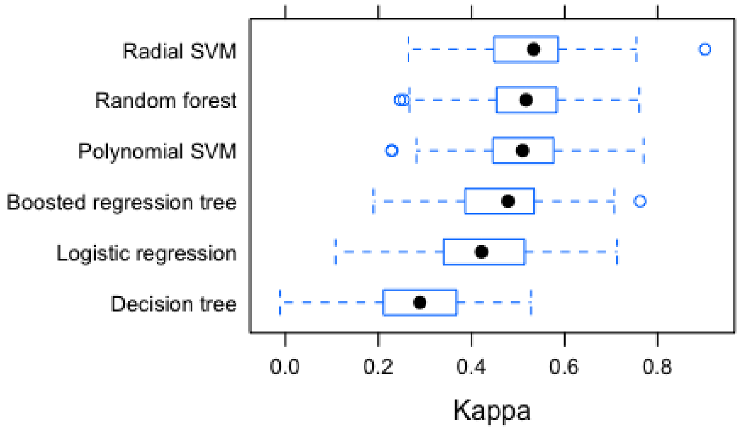
Model training and comparison. We trained all models using repeated 10-fold cross-validation with 10 repetitions, which allowed for the estimation of error. We compared the

[7] The analysis output in the online R Markdown html file does not exactly match the results reported here, which reflect the first iteration of the analyses, due to the stochastic nature of data partitioning and model training. We made an error in setting the random seed initially, making the output non-reproducible.

performance on the training dataset of the following models: multinomial log-linear models fit via neural networks (nnet package Version 7.3-12), decision tree classifier, random forest, boosted regression trees (using the XGBoost algorithm), support vector machine (SVM) with a polynomial kernel, and support vector machine with a radial kernel. The models were chosen to give an initial sense of the predictive power of the combined acoustic variables, as well as how algorithm-dependent the accuracy was. It is likely that there is a discriminative model that would perform better than those reported here, so future work will explore more complex deep learning approaches.

The radial SVM had the highest average training Cohen's kappa coefficient (M_{kappa} = .522), a metric of accuracy that corrects for expected accuracy due to chance (see **Figure 2**). The root mean-squared errors of the kappas for each model were estimated using resampling (using the resamples function from the caret package for R), which allowed us to compute Bonferroni-corrected t-tests comparing the kappas of each model to the other models'. T-tests indicated that the radial SVM's performance was significantly greater than that of the decision tree, logistic regression, and boosted regression tree. However, it was not significantly more accurate than the polynomial kernel (M_{kappa} = .506, see **Table 3**) or random forest (M_{kappa} = .511, number of randomly selected predictors = 2). We chose to use the random forest algorithm on our test dataset since it is more interpretable than either SVM algorithm, as we can see the relative importance each of our predictor variables is playing in generating social functional category predictions (see **Table 4**).

Figure 2. Comparing model performance in categorizing training laughter dataset from Study 1.



Footnotes. Cohen's Kappa coefficients indicating each model's performance on the training dataset. Black points are the mean Kappa, boxes represent the first to third quartile, and whiskers represent the full range of Kappas generated during resampling.

Table 3. Testing differences in model performance in categorizing training laughter dataset.

	Logistic regression	Decision tree	Random forest	Boosted regression tree	Polynomial SVM	Radial SVM
Logistic regression		0.139	-0.085	-0.042	-0.081	-0.096
Decision tree	**<.001**		-0.224	-0.181	-0.220	-0.235
Random forest	**<.001**	**< .001**		0.043	0.004	-0.011
Boosted regression tree	0.094	**< .001**	0.084		-0.038	-0.054
Polynomial SVM	**<.001**	**< .001**	1.000	0.274		-0.016
Radial SVM	**<.001**	**< .001**	1.000	**0.026**	1.000	

Footnotes. The upper diagonal represents the estimated difference between models' Kappa coefficients. The lower diagonal are Bonferroni-corrected *p* values from t tests comparing the models' Kappas, which were generated via resampling. Significant *p* values are in bold.

Table 4. Variable importance in random forest algorithm training.

	Importance
Duration	100
F1 Mean	98.72
Intensity	92.99
F0 Mean	92.8
F0 Range	87.06
Proportion Voiced	78.18
F2 Mean	77.13
Center of Gravity	76.51
SD F0 / Duration	57.67
Slope	51.21
Harmonics-to-Noise Ratio	45.86
Actor Sex	0

Footnotes. The relative importance of each predictor variable, or feature, in a random forest is estimated by permuting the values of the feature in the training dataset and observing how much this increases the overall error in classification (Zhu, Zeng, & Kosorok, 2015). The difference scores are then standardized against each other, with a higher value indicating a variable contributed more to classification. Values calculated with the randomForest R package (Liaw & Wiener, 2002)

Random forest model testing. We next used the trained random forest to label the testing laugh dataset according to their predicted social functional category. The trained algorithm received the test laughs' standardized and centered values for all 12 predictor variables, and classified each laugh as either reward, affiliation, or dominance. Comparing the model's predictions to the actual social function category assignment (based on participants' judgments) indicates how accurately the model was able to predict a laugh's most likely social function from its acoustics alone (see **Table 5**). The model's Cohen's kappa (K=.541) for the test laughs is in the "moderate" range.

Comparing human and ML confusion. Finally, we examined whether the laugh samples miscategorized by the ML algorithm were similarly ambiguous or difficult to categorize for the human judges. The social intentions of a laugher could be considered ambiguous if one of the three judgment dimensions did not win out over the others by a large margin. We forced the laughs into one of the three categories based on whichever social dimension (reward, affiliation, or dominance) participants on average rated it highest on. But a laugh with highly divergent scores (e.g., $M_{\text{reward}} = 9.45$, $M_{\text{affiliation}} = 4.32$, and $M_{\text{dominance}} = 2.94$) is presumably easier for perceivers to process in social functional terms than a laugh with similar scores on each dimension (e.g., $M_{\text{reward}} = 9.45$, $M_{\text{affiliation}} = 9.01$, and $M_{\text{dominance}} = 7.38$).

Table 5. Confusion matrix of random forest-predicted and actual categories of test laughs

Prediction	**Reference**		
	Affiliation	**Dominance**	**Reward**
Affiliation	14 (66.67%)	0 (0%)	4 (16.00%)
Dominance	5 (23.91%)	25 (80.65%)	6 (24.00%)
Reward	2 (9.52%)	6 (19.35%)	15 (60.00%)

Footnotes. Columns represent the “true” social functional category assigned to each of the 77 test laughs, using participants’ average judgments of how rewarding, affiliative, and dominant the laughs sounded. Rows represent the predicted category generated by the random forest machine learning algorithm. The actual number of laugh samples for each cell are reported, followed by the percent of that column represented by the cell. Cohen’s kappa = .541.

For each laugh in the testing set, we calculated the difference between its score on its highest dimension, and the average of its scores on the other two dimensions. We then regressed these difference scores on a variable indicating whether the random forest categorized it correctly or not. The divergence between the highest-rated judgment dimension and the other two dimensions was, on average, .753 units higher for laughs correctly categorized by the random forest algorithm, compared to laughs incorrectly categorized, $SE = .299$, $t(75) = 2.517$, $p = .014$, $\Delta R^2 = 0.078$. This indicates the ML algorithm’s errors were more likely to occur for laughs that were perceived as socially ambiguous, suggesting the algorithm might be useful as a reasonable substitute for human judges in categorizing the most likely social function of novel laughs.

Summary and discussion

This study is an exploratory first step towards a social functional account of laughter. Our account of laughter variability complements the predominant distinction in the literature, spontaneity, which by itself is insufficient to predict what form laughter will take across a variety of social contexts (Keltner & Bonanno, 1997; Mehu & Dunbar, 2008; Provine, 1993; Vettin & Todt, 2004). First, we predicted participants' judgments about the extent to which 400 laughs were spontaneous, rewarding, affiliative, or dominant using 11 acoustic variables. This set of analyses identified the acoustic properties diagnostic of each social judgment. we then trained a random forest machine algorithm to use the acoustic properties of a laugh to predict which social functional dimension participants rated it highest on. This analytic approach sacrificed some model interpretability to estimate the overall predictive power of the chosen acoustic variables. The trained algorithm demonstrated acceptable accuracy in categorizing the test laughs, suggesting such a model could be applied to novel laughter samples to estimate the expressers' social intentions and goals. Further, the algorithm made classification errors on perceptually ambiguous laughs about which human judges might also disagree.

To interpret the results of the current study, similar acoustic features guided perceptions of spontaneity and reward, with just a few exceptions, and some of these acoustic features have been previously identified as diagnostic of spontaneity (Bryant & Aktipis, 2014; Lavan et al., 2015). We therefore suggest spontaneous laughs can serve a rewarding function. Affiliation judgments shared a few characteristics with spontaneity and reward, but several acoustic features distinctly predicted affiliation. Dominance judgments related to the most distinct pattern of acoustic features, often relating to the acoustic variables in direction opposite to the other social judgment dimensions.

Interestingly, actor sex was an important moderator of the relationship between many acoustic properties and perceivers' judgments. Besides the reliable indicators of spontaneity—proportion voiced and F0 mean—female spontaneity and reward judgments were based on a sparser set of predictors (duration and variability, with the latter only predicting reward). A more complex set of variables predict judgments of male spontaneity and reward.

Female laughter that conveys affiliation involves acoustic properties associated with signals of appeasement and friendliness (Lasarcyk & Trouvain, 2008; Laukka et al., 2005), such as raised pitch, raised second formant, and reduced intensity. The pattern of acoustics that convey affiliation in males, meanwhile, bears some resemblance to higher-arousal, more spontaneous states (e.g., greater intensity combined with higher pitch and first formant; Bryant & Aktipis, 2014; Schubert & Wolfe, 2006). Beyond the signatures of dominant intentions shared by males and females, the communication of dominance in males involves lower pitch and higher spectral center of gravity, while in females it involves a lowered vowel (as reflected by F2).

A limitation of the current study is its reliance on verbal descriptions of the social tasks of reward, affiliation, and dominance, which Study 2 addresses. Furthermore, in the current study, we were unable to control for possible non-independence due to the same voice actors producing multiple laugh samples. Besides being statistically problematic, an inability to group samples by actor prevented us from conducting within-producer analyses, which are more sensitive to subtle vocal shifts. Study 3 allowed for such an approach. Another limitation of the sample used is that they were largely posed (albeit by professional voice actors), so the spontaneity dimension was restricted. In our social functional approach, which is agnostic about the underlying internal state or physiology of the expresser, it is arguably most important that the current study's stimuli had variability in perceptions of spontaneity. Still, Study 3 examined whether the same acoustic features convey the three social meanings in naturally-occurring laughter.

Study 2: Semantic similarity of social functional smiles and laughter

In describing prototypical reward, affiliation, and dominance laughter, there are shortcomings inherent to relying on participants' understanding of verbal descriptions of the social functions. Laughter is a nonverbal social signal, the functions and forms of which people rarely verbalize. Furthermore, the current work's social functions do not easily fit folk psychological behavioral categories. Study 2 probed the semantic similarity between laughs and another class of behaviors thought to accomplish the three social tasks—namely, smiles.

Participants judged which of two randomly-selected laugh samples were most similar in social meaning to a target smile. The smile stimuli have been demonstrated to convey meanings associated with reward, affiliation, and dominance and their semantic space has been mapped out in prior work (Martin et al., under review; see **Figure 3**, panel 2). Study 2 participants' smile-laugh similarity judgments were then combined with this prior information about the semantic similarity of the smiles, allowing for the laughs to be located in the smile semantic space. Laughs located closer to smiles of reward, for instance, could be interpreted as conveying rewarding intentions. In this way, we were able to identify laughs perceived as "rewarding," "affiliative," or "dominant" without exposing participants to those inherently limited labels.

We planned to predict the laugh samples' locations in the laugh-smile semantic space using the same acoustic measures as in Studies 1. We hypothesized that the diagnostic acoustic properties from the first study would predict laughter samples' nearness to smiles of reward, affiliation, and dominance. To foreshadow the results, however, the laughter samples were not well-distributed throughout the smile semantic space in the embedding generated in the current study. Simulations suggest that with noisy data (as the current study's data turned out to be), we would have needed about twice as many participant responses. We therefore did not attempt to predict the laughs' locations from their acoustic properties, since the locations were not sufficiently variable. We did, however, use the laughter samples' perceived social function category assignments from Study 1 to predict participants' responses and the laughs' positions in the semantic space.

Method

We report all data exclusions, all manipulations, and all measures. Data and analysis files are available online (osf.io/pg9dn).

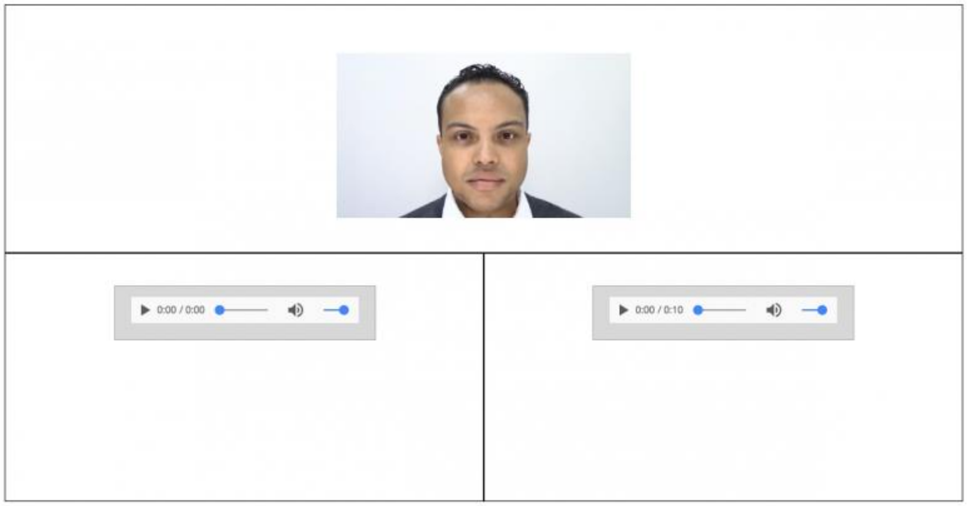
Participants and procedure. Online participants (*N* = 1,089) recruited through Amazon's Mechanical Turk completed 26 trials in exchange for $2. The entire session took about 15 minutes, but only 816 participants completed all 26 trials (participants completed an average of 20 trials). All participant responses are included in the analyses due to the crowd-sourced nature of the paradigm, which is not reliant on complete response sets from any one participant.

The University of Wisconsin-Madison IRB approved the waiving of signed consent since it was an online study. After participants read the consent information sheet, they were instructed, on each trial, to watch the looping smile video (target stimulus) and listen to the two laugh audio clips (response choices) as many times as necessary, and then select whichever of the two laughs was "most similar in meaning" to the smile. They were told, "Do not worry about whether the audio clip sounds like it was made by the exact same person in the video. Try to ignore features like gender and identity, and do not make your decisions based on whether the person's mouth is open in the video. Remember, your task is to select the audio clip that best conveys the same feeling as the facial expression."

The task was hosted on the NEXT crowdsourcing machine learning platform (Jamieson et al., 2015; Sievert et al., 2017). On each randomly-generated trial, participants saw a smile and two audio players, which they could click to play each laugh (see **Figure 3**; laughter and smile stimuli described below). With 50 laughs (which can be combined in 1,225 different ways) and 43 smiles, there were 52,675 possible XAB combinations participants could encounter, so many combinations never occurred for any participants. In addition to the randomly generated trials, 10% of all trials were Validation Trials. Validation trials were a non-random subset of 43 smile-laugh combinations (one per smile video) that allowed us to quantify interrater agreement on specific judgments (see Results). Without intentionally building repeated XAB combinations into the experiment, the odds that a given combination would repeat would be too low for us to inspect the extent to which participants agreed in their judgments.

Laughter and smile stimuli. The 50 laughs were a subsample from the Study 1 laughter set, which were produced by actors for a commercial sound effects library (Soundsnap.com). Based on the social functional category assignments generated from Study 1 participant judgments, the dominance category was under-represented in the laugh stimuli ($n_{dominance}$ = 9 vs n_{reward} = 20 and $n_{affiliation}$ = 20; 1 laugh could not be assigned to a category and was excluded from analyses). The target stimuli were 43 smile videos from 15 professional actors (8 male, 7 female; 7 Black, 8 White) who produced smiles fitting descriptions of the three social functions and, when necessary, received coaching on the specific facial action units involved in reward, affiliation, and dominance smiles, according to Rychlowska et al. (2017). The smile stimuli have been validated as recognizably signaling the three social tasks (Martin et al., under review). Two actors' dominance smiles were of poor quality and were excluded from the current study, resulting in 43 target stimuli.

Figure 3. Sample trial from Study 2.



Footnotes. On each trial in Study 2, participants saw a randomly-selected smile video that looped continuously and was accompanied by two audio players. Participants clicked on each audio player to play the laugh sample, and when they decided which laugh conveyed a feeling most similar to the target smile, they clicked in the corresponding box.

Results

Analytic plan. Before analyzing the results of the smile-laugh similarity embedding, we first used the Validation Trial responses to see the extent to which participants agreed on the "correct" laugh for the validation subset of 43 smile-laugh-laugh XAB combinations. If participants tend to disagree about which of two laughs matches a smile, it would suggest the responses are too noisy to generate a meaningful embedding. After inspecting the validation trial data, we then used linear mixed-effects models to analyze the frequency with which a laugh from any social functional category was paired with a smile from any given social functional category, accounting for the non-independence of responses to the individual laughter stimuli. This enabled us to examine whether participants perceived affiliation smiles, for instance, as conveying similar meanings as affiliation laughs, compared to reward or dominance laughs.

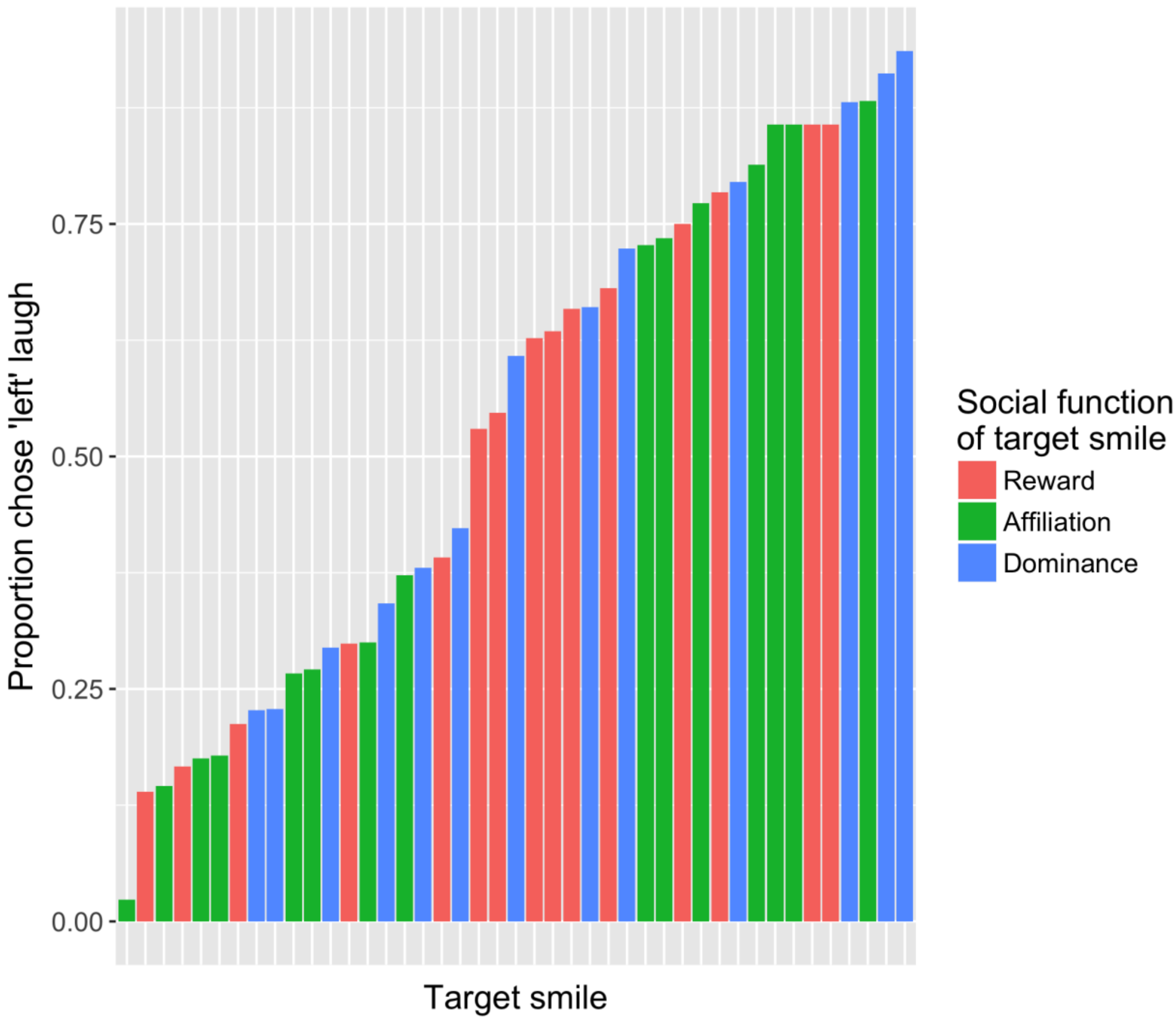
Next, we generated the smile-laughter similarity embedding with the intention of relating laugh samples' locations in the space to their acoustic properties.

Inspecting noise with validation trials. Recall that 10% of trials (2,108 in total) were one of 43 XAB Validation Trial combinations, which were intermixed with the randomly-generated XAB combinations. We inspected the noisiness of participant responses on these trials by plotting, for each of the 43 combinations, the proportion of all trials on which participants chose the laugh on the left side of the screen (**Figure 4**). If there were no noise in participant responses—with participants agreeing perfectly with one another about which laugh in a given validation trial went with the target smile—this plot would resemble a step function, with participants agreeing that the laugh on either the left or the right was the best response. However, as can be seen in **Figure 4**, the data were quite noisy. On about half of the validation trials (n=22), participants disagreed with the majority response 25% or more of the time (i.e., the proportion who responded "left" fell between .25 and .75).

Were smiles paired with laughs associated with the same social function? Recall that on a given trial, a smile was presented with two randomly-selected laugh samples, which could have the same or different social functional category assignments from Study 1. Therefore laughs from all 3 categories were never present on a given trial. Even with idealized stimuli where participants always pick an affiliative laugh (when presented as an option) to go with a particular affiliative smile, that smile will only be paired with an affiliative laugh about 2/3 of the time. This should be kept in mind when interpreting the relative frequencies with which laughs and smiles were paired. Descriptively, as shown in **Figure 5**, reward and affiliation laughs were paired more frequently with "congruent" smiles, but not so for dominance laughs, which were paired more frequently with affiliation smiles.

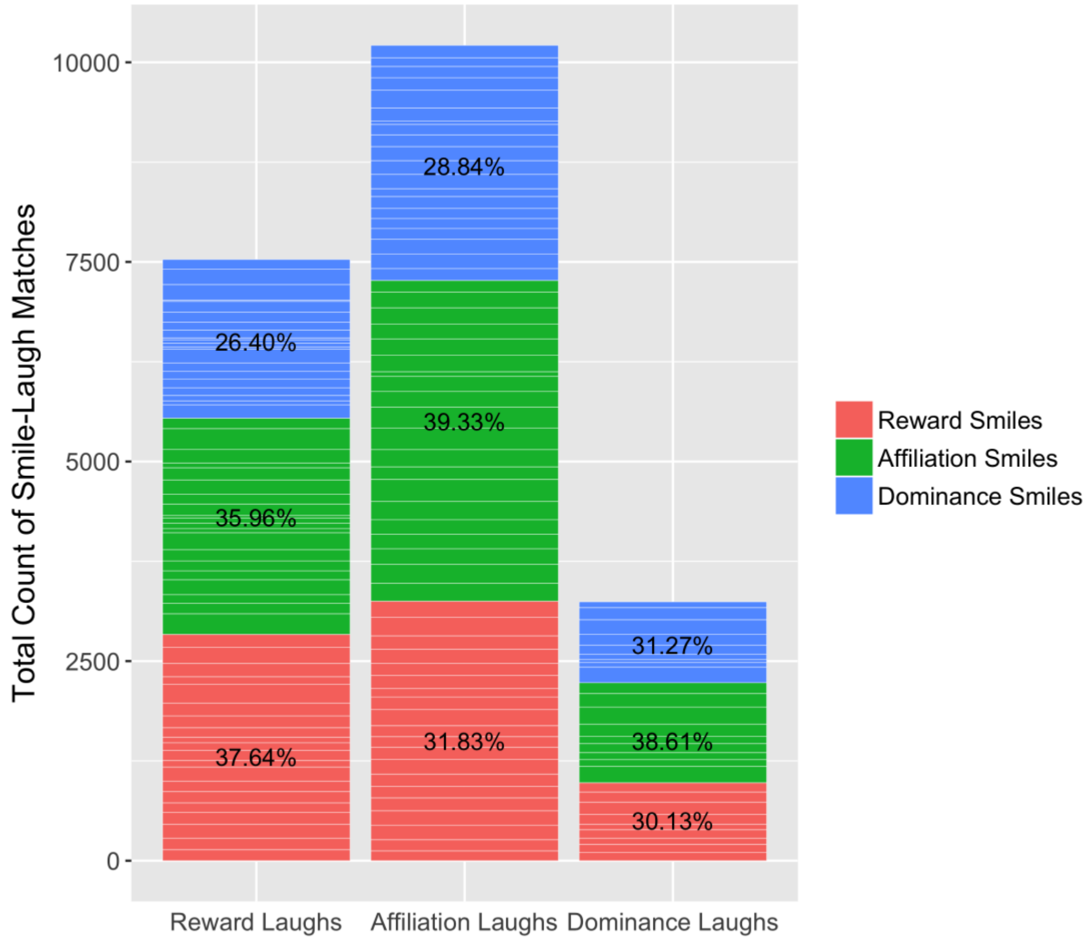
The goal of the following models is to answer this question: are laughs from a given social functional category more likely to be selected in the forced-choice paradigm when paired with a functionally "congruent" smile versus not? For each laugh, we calculated the frequency with which it was paired with smiles from each of the 3 social function categories, resulting in 3

Figure 4. Validation trial response rates.



Footnotes. 43 Validation Trials (one per smile video) with set smile-laugh-laugh combinations were repeated to give an indication of the noisiness of participant responses. The y-axis indicates the proportion of times participants chose the left-hand laugh for each of the 43 validation trial XAB combinations. With no noise perfect agreement across participants, each validation trial combination would have a value of 0 or 1, resulting in the appearance of a step function. However, as seen in the graph, participants did not agree on the best response for many of the validation trials, suggesting a substantial amount of noise exists in the XAB data.

Figure 5. Rate at which smiles from each category were paired with laughs from each category



Note. Columns indicate the laughs' category assignment, while colors indicate the smiles' category assignment. The height of each bar indicates the cumulative total of trials on which laughs from each category were chosen as the best match for smiles from each category. Note that while the number of smiles in each category is nearly balanced (since actors posed the smiles), there were an unbalanced number of laughs representing each category (n_{reward} = 20, $n_{affiliation}$ = 20, $n_{dominance}$ = 9). This imbalance means that it is best to compare the size of bars within a column rather than across columns (percentages reported are total times laughs from each category were paired with smiles from each category, divided by total number of times laughs from that category were chosen). Importantly, although reward laughs and affiliation laughs were slightly more likely to be paired with "congruent" smiles, this was not the case with dominance laughs. The horizontal stripes within each bar indicates individual laugh stimuli's choice frequency. We included this to illustrate that some laughs were chosen more than others, as indicated by thicker stripes. Martin et al. (under review) validated the smile stimuli's category assignment, while the laughter stimuli's category assignment was estimated using participant judgments in Study 1.

Count Scores per laugh as our dependent variable. Since the outcome is a count variable, we used generalized linear mixed-effects models with a Poisson distribution. We regressed Count Scores on the interaction between a Smile Social Function dummy variable and a Laugh Social Function dummy variable, plus all lower order effects, with a by-stimulus random slope for Smile Social Function. For both of our two independent variables, the Smile Social Function dummy variable and the Laugh Social Function dummy variable, we first set the affiliation smile and laugh categories as the reference level. We then releveled them so reward, and then dominance, was the reference level for the smile and laugh dummy variables and re-reran the models. Analyses were conducted using the lme4 package (Bates et al., 2015).

First we will unpack the key coefficients from the model with affiliation as the reference level. Since interaction terms were included in the model, the main effects of Smile and Laugh Social Function are interpreted for affiliation signals in the opposite modality (affiliation is coded as 0). The main effects of Smile ($\chi^2(2) = 43.46$, $p < .001$) and Laugh Categories (($\chi^2(2) = 13.95$, $p < .001$ were both significant and in the expected direction, with affiliation smiles paired more frequently with affiliation laughs than with dominance or reward laughs, $b = -0.393$, $SE = 0.170$, $z = -2.32$, $p = .020$; $b = -0.481$, $SE = 0.134$, $z = -3.60$, $p < .001$, respectively. Similarly, affiliation laughs were paired more frequently with affiliation smiles than dominance or reward smiles, $b = -0.321$, $SE = 0.055$, $z = -5.86$, $p < .001$; $b = -0.190$, $SE = 0.072$, $z = -2.63$, $p = .009$, respectively. The interaction term for the affiliation vs reward Smile and Laugh dummy variables was significant, which can be interpreted as saying that the frequency of selecting reward laughs relative to affiliation laughs was greater when paired with a target smile of reward, rather than affiliation, $b = 0.322$, $SE = 0.104$, $z = 3.11$, $p = .002$. The parallel interaction term for the affiliation vs. dominance dummy variables was not significant, however, which suggests dominance laughs were not chosen significantly more frequently than affiliation laughs when the target was a dominant vs. affiliation smile, p = .617.

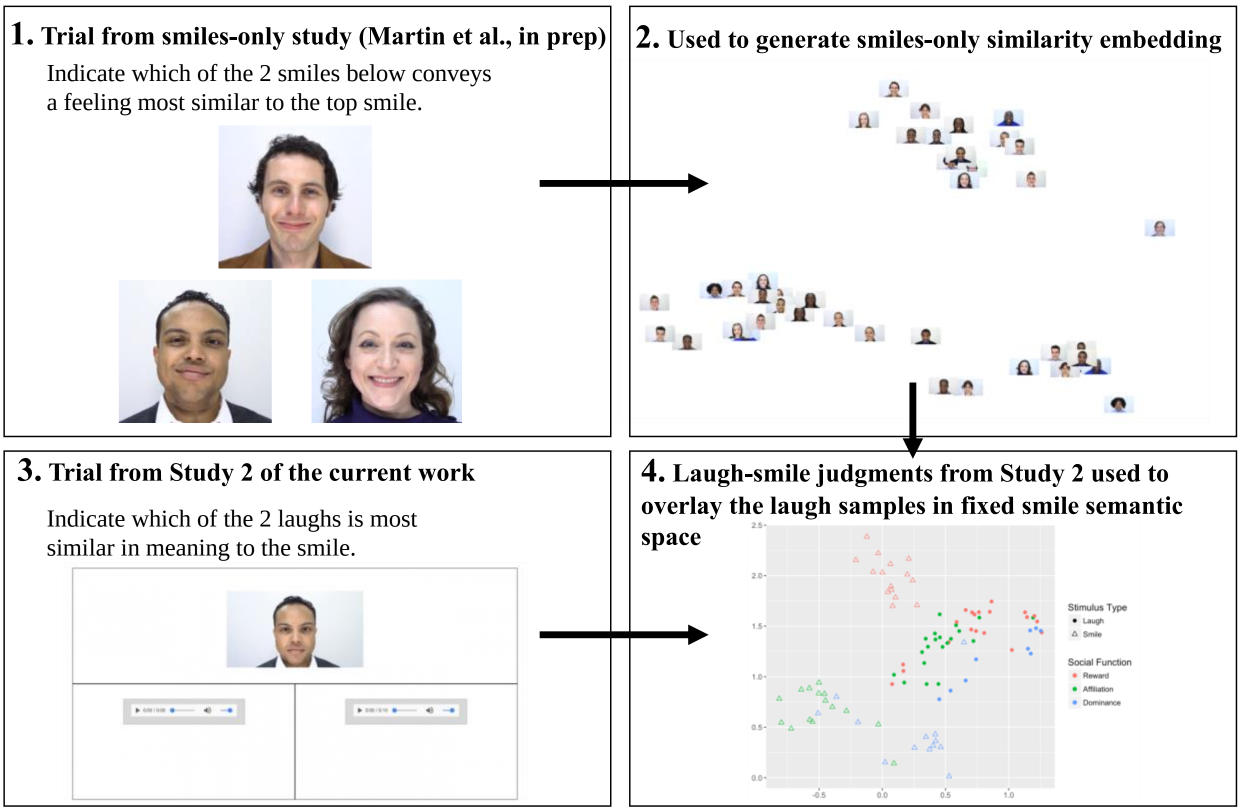
Next we present the results from the model with reward as the reference level for the two dummy variables. The 2 degrees of freedom tests for the dummy coded Smile and Laugh Social Function variables were once again significant, $\chi^2(2) = 41.71$, $p < .001$; $\chi^2(2) = 18.05$, $p < .001$, respectively. The effect of Laugh Function for reward smiles was more complicated than for affiliation smiles, however. As expected, reward smiles were more frequently paired with reward laughs than dominance laughs, b = -0.253, SE = .098, z = -2.58, p = .010. However, they were *less* frequently paired with reward laughs compared to affiliation laughs, b = 0.159, SE = .076, z = 2.10, p = .036. As illustrated by the second bar in **Figure 5**, there was a strong bias towards choosing the affiliation laughs overall. The main effects for Smile Social Function were significant for the reward vs. dominance contrast, b = -0.503, SE = 0.096, z = -5.25, $p < .001$, but slightly over the significance threshold for the reward vs. affiliation contrast, b = -0.132, SE = 0.074, z = -1.77, p = .076. Reward laughs were more frequently paired with reward smiles than dominance smiles, but not significantly more frequently paired with reward than affiliation smiles (again, reflecting the affiliation bias). However, recall the significant interaction term (which is the same with the current dummy variable reference level as the previous): the interaction term suggests that the bias towards picking affiliation laughs was *greater* when the target smile was an affiliation smile compared to a reward smile, which supports the hypothesis (complicated by the affiliation laugh bias). The interaction between the dummy variables comparing reward and dominance was also significant, such that reward laughs are chosen more frequently than dominance laughs when the target is a reward smile, but the opposite is true when the target is a dominance smile, b = 0.442, SE = 0.171, z = 2.58, p =.01.

All relevant interaction terms have been interpreted and do not change when the dummy variables are releveled (although the signs change), but we releveled the variables with dominance as the reference level so the main effects for dominance smiles and laughs could be interpreted. Dominance is the social function on which participant judgments deviated from predictions. Dominant smiles were not paired more frequently with dominant compared to reward (p = .377) or affiliation (p = .109) smiles. Conversely, dominant laughs were not paired more frequently with dominant compared to reward smiles (p = .670) and were actually significantly more frequently paired with *affiliation* than dominance smiles, b = 0.270, SE = .085, z = 3.16, p = .002.

To summarize this first set of analyses for Study 2, when using mixed-effects models that correct for the overall frequency with which a given laughter stimulus was chosen in the forced-choice paradigm, we found partial support for the prediction that people would pair smiles with laughs deemed a priori functionally “congruent.” Reward and affiliation laughs were more frequently chosen when paired with reward and affiliation smiles, respectively, but not so for dominance laughs. It seems that people do not readily draw connections between laughs rated as highly dominant in Study 1 and smiles validated as conveying dominance (Martin et al., under review). Indeed, when we ignore the within-laugh mixed-effect model approach and simply look at the frequency of smile-laugh pair responses, participants picked dominance laughs most frequently when presented with affiliation smiles.

Combined smile-laugh semantic space. Participants’ forced-choice judgments were then used to calculate the distance in a similarity space between all smile and laughter stimuli (see **Figure 6** for a diagram of the steps involved). The smile-laugh semantic similarity embedding incorporated the laugh samples into a preexisting smiles-only embedding estimated in previous work (Martin et al., under review). This approach is preferable to estimating coordinates for the smiles and laughs simultaneously, which would likely result in a cluster of smiles and a separate cluster of laughs (reflecting modality similarity rather than semantic similarity).

Figure 6. Steps to estimating the smile-laugh similarity embedding with NEXT.



Note. The smile stimuli were dynamic videos that loop until the participant responds. Visit the following Dropbox link to view and zoom in on a video version of the embedding: https://www.dropbox.com/s/22lp16umnsmdja8/animatedEmbedding.gif?dl=0 .

Smiles-only study (Martin et al., under review). For each trial in the already-completed smiles-only study (N=240), the target stimulus was one of the smile videos (rather than a laugh sample) and the participant selected which of two other randomly-selected smile videos conveyed a feeling most similar to the target. Participants completed 50 trials in total. Martin et al. (under review) used the participant responses to compute a similarity embedding in 2-

dimensional space, optimized via goodness of fit (Kruskal, 1964) and depicted in panel 2, **Figure 6** (additional dimensions did not improve model performance). The dynamic smile stimuli clustered in this space according to their intended social functional categories (Martin et al., under review). This smile-only embedding was Study 2's starting point.

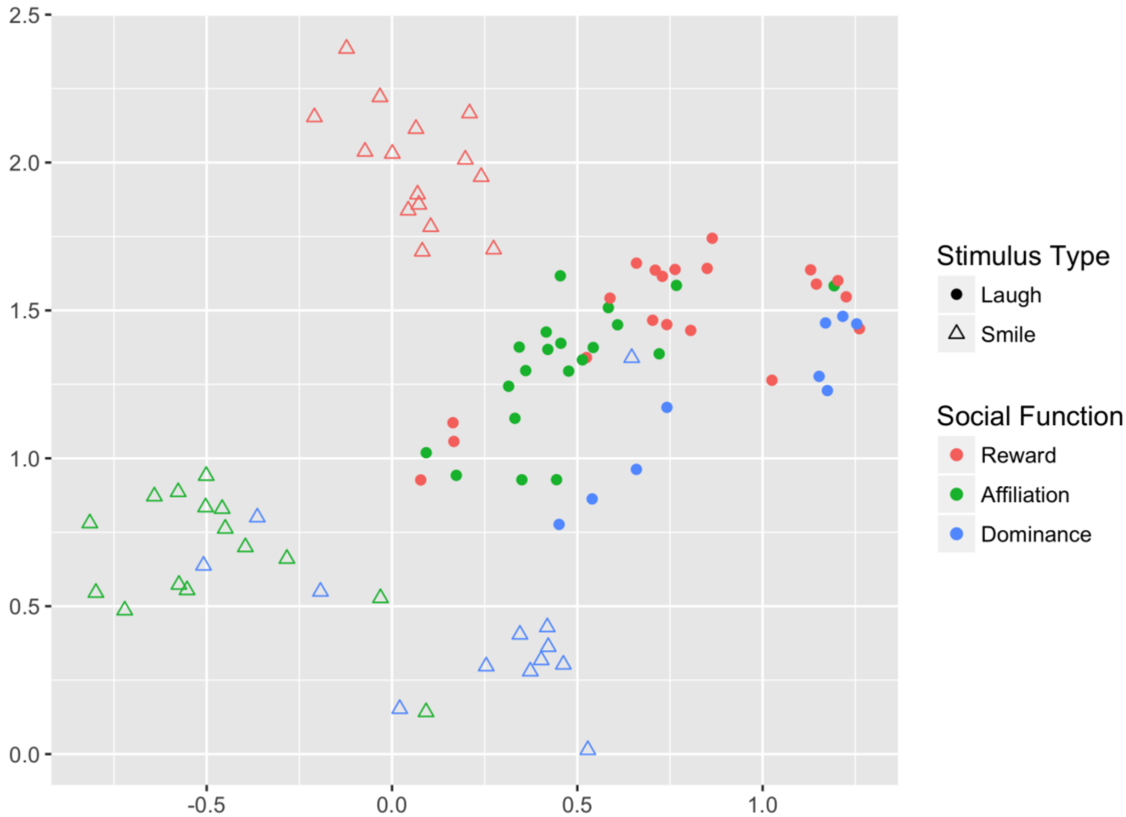
Embedding laughs in the smile semantic space. We then used the smile-laugh triad responses from Study 2 to estimate each laugh's optimal position in the smile space (see **Figure 6** for a diagram of this logic). To estimate the laugh samples' coordinates in the 2-dimensional space we used a machine learning crowd kernel approach that was trained to predict the response for a given XAB smile-laugh-laugh combination, given the current embedding (Tamuz, Liu, Belongie, Shamir, & Kalai, 2011). The smile stimuli coordinates were fixed, and the laugh stimuli's coordinates adjusted based on predictive errors made during the training process.

We conducted simulations using hypothetical smile-laugh datasets in which the "ground truth"—a laugh's "true" coordinates in the 2-D space—were known. We trained a crowd kernel algorithm to predict XAB responses with varying levels of noise and ran trials until the relative error of the algorithm's predictions asymptoted. Across different iterations of the simulation, noise was added to simulated responses with a Gaussian random variable with a standard deviation of 0.2 (low noise), 0.5, or 0.8 (high noise). As the probability increased that X would be paired with A versus B in a given XAB combination, the distance between A and X in the embedding was reduced, such that laughs deemed similar to a given smile moved closer to that smile's coordinates. The relative error in the simulations was calculated by aligning the generated embedding with the "ground truth" embedding using procrustean transformation, and then calculating the error in the embedding. In this way we were able to determine the number of trials that would be necessary to minimize relative error for different levels of noisiness (e.g., under different assumptions of how much participants would agree with each other). Based on these simulations, we decided that 20,000 responses would be sufficient for recovering an embedding using the crowd kernel approach under assumptions of medium noisiness. We ultimately collected 21,940 responses.

The smile-laugh similarity embedding that resulted from participants' responses can be seen in **Figure 7**. Visual inspection of the embedding reveals that the laughs clustered separately from the smiles, rather than embedding throughout the smile space as anticipated. Based on our simulations and given the noisiness of participant responses indicated in **Figure 5**, we would likely need to at least double the number of responses collected to converge on the optimal embedding. We decided not to proceed with the planned analyses predicting the laughs' distance to the smile clusters from their acoustic properties since there is relatively little variance the distribution of the laughs' locations in the embedding.

Relating laughs' positions to their perceived social functions from Study 1. Although the laughs are not well-distributed amongst the smiles in the smile-laugh embedding (**Figure 7**), it appears that the laughs did tend to cluster according to their estimated social meaning (based on Study 1 perceiver judgments). As an exploratory analysis we therefore tested the extent to which the laughs clustered according to social function using Analysis of Similarity (ANOSIM), which is a spatial version of Analysis of Variance (ANOVA) that compares the Euclidian distances between members of the same category to the distance between members of different categories. As is visually apparent in the embedding, the stimuli did indeed cluster by social function assignment (50% dissimilarity ranks within and between classes: reward (n=595) 1418, affiliation (n=595) 1711, dominance (n=231) 1823, between (2765) 2392; $R = .332$, $p = .001$; 999 permutations).

Figure 7. Smile-laugh similarity embedding generated using a crowd kernel technique



Footnotes. The coordinates of the 43 smile stimuli were determined using perceiver judgments in a previous study (Martin et al., under review), and the laugh stimuli's positions in the smile space were determined using Study 2 perceiver judgments of smile-laugh similarity in an XAB task. Stimuli that are closer in space are those that were judged to be more similar in meaning. The smiles' color coding indicates the social function the stimuli were designed to convey (and validated as reliably conveying by Martin et al., under review). The laughs' color coding indicates the social function category they were assigned to based on Study 1 participant judgments. As illustrated, the laughs tended to cluster according to their estimated social meaning (reward, affiliation, or dominance), but they did were not well-integrated with the smiles in the embedding, likely due to the noisiness of participants' responses.

Discussion

Study 2 was designed to test relationships between acoustic properties of laughter and their perceived social functions, potentially converging with Study 1 without relying on verbal probes of the social functions. By asking participants to judge the similarity of a subset of the Study 1 laughter samples to validated smiles of reward, affiliation, and dominance (Martin et al., under review), we planned to embed the laughs in the smile semantic space and predict their proximity to the social functional smiles from their acoustic properties. However, participants frequently disagreed about which laughs fit best with which smile category, resulting in noisy responses. Embedding simulations suggested many more observations would have been necessary to recover the "correct" embedding given the level of observed noise.

The low between-participant agreement suggests that the cross-modal judgments of smile-laugh similarity were more challenging than anticipated. While this could be because smiles and laughs do not convey the same social information, we suggest low-level features of the stimuli may have interfered with participants' judgments of "pure" semantic similarity: for instance, participants may have thought the closed-mouth smiles did not belong with open-mouthed laughter. Cross-identity and especially cross-gender judgments about whether a smile "belongs" with a particular laugh may also be challenging. Future work could overcome the noisiness of this task by collecting twice as many responses, which may allow the laugh samples to distribute themselves sufficiently throughout the smile semantic space to make the planned acoustic analysis feasible. Given the importance of gender throughout the studies presented here, it would be reasonable in future cross-model similarity studies to constrain female and male smiles to be paired with only female and only male laughs, respectively.

Study 2 still provided insights about the perceived social meaning of laughter and the validity of Study 1's results. Analyzing the number of trials on which each laugh was paired with smiles of reward, affiliation, or dominance revealed that laughs assigned to the reward and affiliation categories (using Study 1 participants' responses) were more likely to be paired with reward and affiliation, smiles, respectively. In addition, in the smile semantic space, the laugh samples clustered according to their Study 1 social functional category assignments. In other words, when participants were judging which laughs were most similar to the different smiles, they were relying on similar semantic representations as the participants who judged the social meaning of the laughs. Together, these results suggest that Study 1's social functional category assignments were not just artifacts of the verbal probes, and that smiles and laughter potentially convey overlapping social messages beyond "positivity."

Study 2 required developing a novel adaptation of the NEXT machine learning similarity estimation approach. For the first time in NEXT, judgments for two different sample sets (smiles and laughs) were combined, keeping one constant (smiles) and overlaying the other (laughs) using responses from two separate experiments. This technique may prove useful for developing other similarity embeddings with multiple datasets—in the same or different modalities—thought to contain overlapping perceptual or semantic properties.

Study 3: Naturally-occurring social functional laughter

The first two studies used perceiver-based methods, including a nonverbal approach, to develop models of the acoustic form of reward, affiliation, and dominance laughter. These methods tapped into participants' mental representations of form-function relationships in laughter, which are likely grounded in social reality, but they have limited ecological validity. Study 3 therefore extended the social functional account to naturally-occurring laughter. We developed a novel dyadic video viewing paradigm with the goal of eliciting natural laughter during conversations about humorous stimuli (rated on various dimensions by a separate set of participants in a concurrent study) related to reward, affiliation, and dominance contexts. We then analyzed the acoustic properties of laughter bursts extracted from these naturalistic conversations.

Method

We report all data exclusions, all manipulations, and all measures. Materials, participant laughter clips, humorous video stimuli, data, and analyses are available online (osf.io/pg9dn). We used Qualtrics software (Qualtrics, Provo, UT) for all video presentation and rating tasks.

Participants. Undergraduate Intro to Psychology students participated in exchange for extra credit. To maximize lab efficiency, we over-recruited for the Dyad version of the study and ran extra participants in a Stimulus Rating study, in which they viewed the same humorous videos as in the Dyad Conversation Protocol and rated the degree to which they fit the 3 social functions. Up to 3 same-gender participants were recruited for each study session; if 3 arrived, 1 was randomly assigned to complete the separate Stimulus Rating Protocol, while the other 2 completed the Dyad Conversation Protocol. If 2 participants arrived for a session, they completed the Dyad Conversation Protocol, and if only 1 participant arrived, they completed the Stimulus Rating Protocol.

118 participants completed the Stimulus Rating study (70 female, 41 male, 7 no gender reported; M_{age}= 18.81, SD_{age}= 1.22; 1 Hispanic/Latinx, 110 non-Hispanic/Latinx, 7 did not report; 7 Asian, 3 Black/ African American, 4 White and Asian, 96 White, 8 no race reported). 82 dyads (164 participants) participated in the Dyad Conversation study (94 female, 67 male, 1 nonbinary[8]; M_{age}= 18.82, SD_{age}= 0.74; 20 Hispanic/Latinx, 139 non-Hispanic/Latinx, 4 did not report; 1 American Indian/Alaskan Native, 17 Asian, 1 Asian and Native Hawaiian/Pacific Islander, 2 Black/African American, 1 Native Hawaiian/Pacific Islander, 120 White, 2 White and

[8] The person identifying as gender nonbinary signed up for the female version of the study and worked with a female partner. They also had to identify as female in the Intro to Psych mass survey in order to qualify for the female version of the current study. Since all of my analyses include gender as a moderator or covariate, we could either exclude this person from the analyses or put them in the female category. For purely statistical reasons we elected to include their data and coded them as female, but we acknowledge the limitations of and problems with the dichotomization of gender.

American Indian/Alaska Native, 3 White and Asian, 3 White and Black/African American, 2 White and Black/African American and American Indian/Alaska Native, 5 "other", 5 not reporting. Of the 82 original dyads, 8 experienced computer program failure that resulted in the dyad not being able to complete the task. For 7 dyads, 1 of the participants experienced audio equipment failure, so we analyzed the laughter data from their partners. This resulted in audio data from 67 complete dyads and 7 single participants (N = 141).

Video stimuli. Stimuli were 120 brief humorous videos that research assistants agreed elicited responses associated with the social functions of reward, affiliation, and dominance (40 per social function). 50 videos came from an existing emotion-eliciting database (Cowen & Keltner, 2017) and 70 were found on Youtube. Importantly, videos were included only if they made sense and were humorous without audio, since sound would interfere with the audio recording of participants in the Dyad Conversation Protocol.

For the social function of reward, we selected videos perceived by research assistants to be highly humorous in a straightforward sense, since humor in its "purest" form is rewarding and reinforcing. For affiliation, we selected videos that were somewhat humorous but also elicited responses associated with tenderness, care, empathy, in-group signaling, or cuteness. Affiliative laughter is theoretically meant to soothe, ameliorate, and signal nonthreat or acknowledgment, so videos were selected with these tasks in mind. Finally, the videos selected for the social function of dominance were those that elicited responses of derision, ridicule, wanting to put the person/people "in their place", or feeling that someone "got what they deserved." We reasoned that laughter intended to signal disapproval or dominance would be most likely to occur in response to targets who are judged as inferior but (at least initially) seem unaware of their own inferiority (this genre is referred to as "Fail" videos on Youtube).

Stimulus rating protocol. Participants assigned to the independent stimulus validation task were seated at a computer in a private room and, after learning what the study entailed, gave their informed consent. The instructions said they would “watch 60 brief, humorous videos and rate each of them on 8 different dimensions.” The videos were a random sampling of the 120 videos used in the Dyad Conversation Protocol, presented in random order and without audio. After watching each video participants rated the extent to which they agreed with the following statements (1=Strongly disagree, 7=Strongly agree; associated social functions, in bold, were not shown to participants):

1. This video made me laugh out loud
2. This video was funny
3. I felt close to the person/people in this video (**reward**)[9]
4. I want to spend time with the person/people in this video (**reward**)
5. I felt tenderness for the person/people in this video (**affiliation**)
6. I want to reassure/comfort the person/people in this video (**affiliation**)
7. I felt derision towards the person/people in this video (**dominance**)
8. I am better than the person/people in this video (**dominance**)

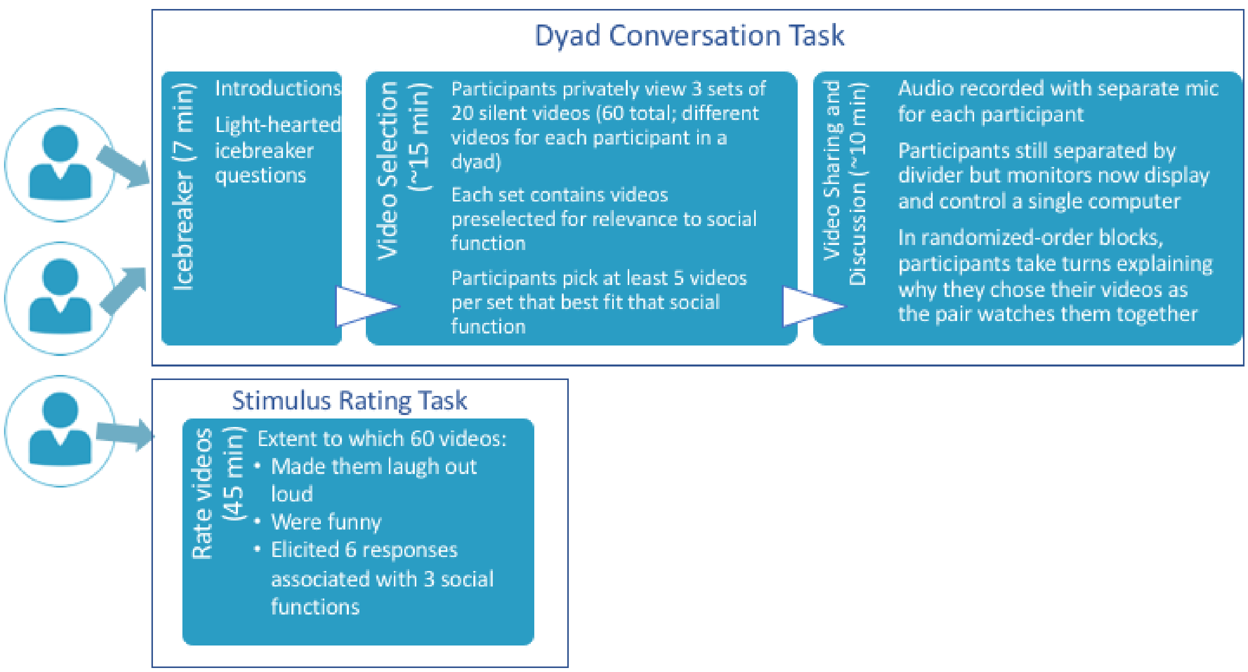
After watching and rating the 60 videos, participants answered a few demographics questions and were debriefed and thanked for their time. The entire session took about 45 minutes.

Dyad conversation protocol. After completing an ice-breaker activity, same-gender pairs of participants independently completed a Video Selection task in which they watched a series of brief humorous videos preselected for their relevance to the social tasks of reward,

[9] In hindsight, items 3 and 4 may have overlapped more with the proposed task of affiliation than the task of reward. Continuing to refine and validate verbal probes into the social functions will be important in future work.

affiliation, and dominance. Participants privately selected their favorite videos from each category, then as a pair took turns describing and watching their selections with their partner while their conversation was audio recorded (Video Sharing and Discussion task, see **Figure 6** for overview of procedure). We developed this paradigm to maximize both the social functional relevance of the videos discussed by the dyads and the amount of laughter generated. The video playlists, already preselected for their relevance to the 3 social functions, were further refined based on how each participant experienced them, ensuring they related meaningfully to the 3 social tasks. We also intended the video selection phase to enhance social pressure to laugh during the dyad phase: participants are potentially more likely to laugh to signal their appreciation for a humorous video if they know their partner chose the video.

Figure 6. Study 3 Procedure.



Ice-breaker activity. Upon arrival to the lab and after being assigned to the Dyad Conversation Protocol, the experimenter explained what the study involved and that it was about "how people understand and talk about humor." Participants gave their informed consent and the pair was then left alone in the lab room to spend 7 minutes on the ice-breaker activity. This task was designed to relax the participants and get them familiar with one another to maximize the likelihood of laughter in the final phase of the study. Each participant received a sheet of paper with a series of questions that they took turns asking each other. They began by saying their names, intended majors, and hometowns, then answered a series light-hearted get-to-know-you questions (18 were provided but pairs rarely completed them all in the 7 minutes; example questions: "If you had a theme song that played whenever you walked into a room full of people, what would it be?"; "What is a song for which you thought you knew the words, but later found out you were wrong?"). The experimenter returned after 7 minutes to move the participants on to the next phase of the study.

Video selection task. Participants then moved to their separate workspaces and the experimenter read the instructions out loud while participants followed along on their computers. Instructions explained that they would be "watching 3 playlists that each contain 20 very short videos.…In each playlist, you'll be asked to pick at least 5 videos (out of 20) that fit a description.…The description changes for each playlist, so read the instructions carefully.…If, by the end of the playlist, you haven't picked at least 5 [videos], you can go back and change some of your answers."

For the Video Sharing and Discussion task to make sense, the participants in a pair saw a different collection of 60 videos. The order of the Reward, Affiliation, and Dominance playlists was randomized across participants, as was the order of the videos within each playlist. After watching each video, they responded "true" or "false" to one of the following prompts (depending on the playlist):

- I feel happiness, amusement, or joy towards the person/object in this video. (**Reward**)
- I feel warmth, friendliness, or care towards the person/object in this video. (**Affiliation**)
- I feel derision, disdain, or mocking towards the person/object in this video. (**Dominance**)

The experimenter remained in the lab room during this task, which typically took about 15 minutes to complete.

Video sharing and discussion task. After both participants finished the Video Selection task, the experimenter used a KVM switch to set both participants' monitors to display and control the same computer. This allowed participants to view stimuli simultaneously while being separated by the partition wall. Not only did the partition improve the quality and separation of the two microphones' recordings, but it also removed participants' ability to communicate with visual nonverbal signals, presumably requiring them to convey more with their voices (and specifically, laughter). The experimenter moved each participant's microphone in front of them and asked them to adjust their posture so they could speak directly into the microphones (see next section for details on audio recording). They then read the instructions for the Video Sharing and Discussion task: "Now that both of you have picked your videos, you will watch them together and discuss why you picked them. Remember that we are interested in how people talk about humorous things, so talk about whatever aspect of the video you want….Before you play each video, the partner who picked the video will be prompted to….explain what the video is about and why you thought it fit that particular description." Before viewing and discussing each video, the participant who originally selected the video was prompted to clearly state the video's identification number into the microphone. After reading the instructions out loud and answering any questions, the experimenter began recording the audio from both mics and left the room so the participants could complete the task in private.

The Qualtrics survey presented a total of 30 videos that the participants selected in the previous task: 5 videos per social function per participant. If participants selected more than 5 videos in the Video Selection task, the software chose 5 of them randomly. The order of the social functions was randomized across dyads, and within a social function block, the order of the two participants was counterbalanced. For instance, Participant A might be prompted first to play and explain her 5 happiness/amusement/joy videos (in random order), then Participant B would play and explain her 5 happiness/amusement/joy videos, then they would move on to the next social function. This task took approximately 15 minutes to complete. Participants then completed a brief demographics survey and were debriefed and thanked for their participation.

Lab setup and audio equipment. The sessions took place in a small, carpeted lab room with sound absorbing foam tacked to the walls near the participants' two desk stations (see **Figure 7**). A 66Hx48W" fabric-covered partition separated the participants' stations, over which the participants could easily hear each other at a conversational level of speaking. Audio was captured with 1ByOne USB microphones (44.1 kHz sampling rate) set to cardioid pattern mode so as to capture a more focused sound stream from the participant next to the mic. A 4" Zramo pop filter was placed between the mics and the participants' mouths to reduce popping sounds during speech and to protect the mics. The mics were mounted on small desktop tripods set on a 6" tall box, which positioned them at a comfortable height for a person of average height. Audio was recorded separately on each participant's computer using Audacity (Version 2.2.1), with the gain set to 10%, and saved as a WAV file. Despite our best attempts to isolate each participant's voice, the distant participant can be heard on the near participant's recording, albeit at orders of magnitudes lower amplitudes.

Figure 7. Lab setup for Study 3 Dyad Conversation Task.

Laughter sampling and acoustic property characterization. Seven trained undergraduate research assistants and I isolated all instances of laughter or speech-laughter from the Video Sharing and Discussion recordings. Laughter is defined as the forced expulsion of air through the vocal cords, which may be unvoiced or voiced, in which case it is heard as a vowel sound occasionally interrupted by a glottal stop (e.g., the pause of airflow in the middle of the expression "uh-oh") or a glottal fricative consonant (/h/; (Nwokah, Hsu, Davies, & Fogel, 1999). We included multi-burst ("ha ha ha") and single-burst ("ha") instances of laughter in the current definition. Speech-laughter is speech colored with the breathing patterns and prosodic markers of laughter, existing somewhere between normal spoken word and pure laughter both physiologically and acoustically (Menezes & Igarashi, 2006; Nwokah et al., 1999). We coded all extracted vocalizations as either laughter or speech-laughter, although the distinction is often not clear-cut. Laughter bursts that immediately preceded, interrupted, or followed speech were coded as laughter; only laughter that occurred during a recognizable word or phrase was coded as speech-laughter. We extracted 4,606 laughter samples in total, 1,013 of which were coded as speech-laughter (to be analyzed in future work). We further coded a subset of 2,269 of the non-speech-laughter samples as voiced (n=1446), unvoiced (n=663), or closed-mouth (n=160). Unvoiced laughs had no discernable voice in them and could be rapid panting, snorts, or wheezes. We labeled a laugh as closed-mouth if it was voiced but sounded as though the speaker's lips were closed, creating a humming sound combined with the forceful exhalation that characterizes laughter.

We then characterized the same acoustic properties as in Study 1 using Praat acoustic analysis software (Boersma & Weenink, 2016). We added the difference between F2 and F1 to the variables included in the analyses, since it is a more accurate indicator of the vowel quality of a vocalization than either formant by itself, but otherwise the procedure for variable extraction was identical to Study 1. Like the other frequency variables, we calculated the F2 Mean – F1 Mean variable in semitones (12*log(F2 Mean / F1 Mean)). As in Study 1, we log-transformed Duration, SD F0 / Duration, and Center of Gravity to correct for positive skew.

Results

Stimulus rating study. We first determined whether the Stimulus Rating task participants responded in expected ways to the videos preselected to elicit responses associated with reward, affiliation, and dominance. To do so, we ran 8 linear mixed-effects models in which we regressed participants' responses to each video on the 8 Stimulus Rating prompts (on scales from 1 = "Strongly disagree" to 7 = "Strongly agree) on dummy-coded variables representing whether the videos were a priori categorized as relevant to Reward, Affiliation, or Dominance (Social Function). We included by-subject and by-stimulus random intercepts and by-subject random slopes since the Social Function variable only varied within-subject and not within-stimulus. The first set of models used Affiliation as the reference level, so to determine how the ratings for Reward and Dominance videos differed, we then set Reward as the reference level and reran the models (see **Table 6** for model estimates). P values were obtained using Satterthwaite approximated numerator degrees of freedom and were then adjusted using the Benjamini-Hochberg false discovery correction approach (Benjamini & Hochberg, 1995).

As anticipated, participants reported feeling more derision towards, feeling they were better than, and wanting to spend time less with people in the Dominance compared to Reward or Affiliation videos. Participants reported finding funnier and laughing out loud more during the Dominance compared to Affiliation videos. Also, as expected, they felt greater tenderness towards people in the Affiliation videos compared to Dominance or Reward videos. Although they wanted to reassure or comfort people more in the Affiliation compared to Reward videos (as expected), they unexpectedly also wanted to reassure or comfort people more in the Dominance videos than in the Reward videos (see **Figure 8** for average ratings).

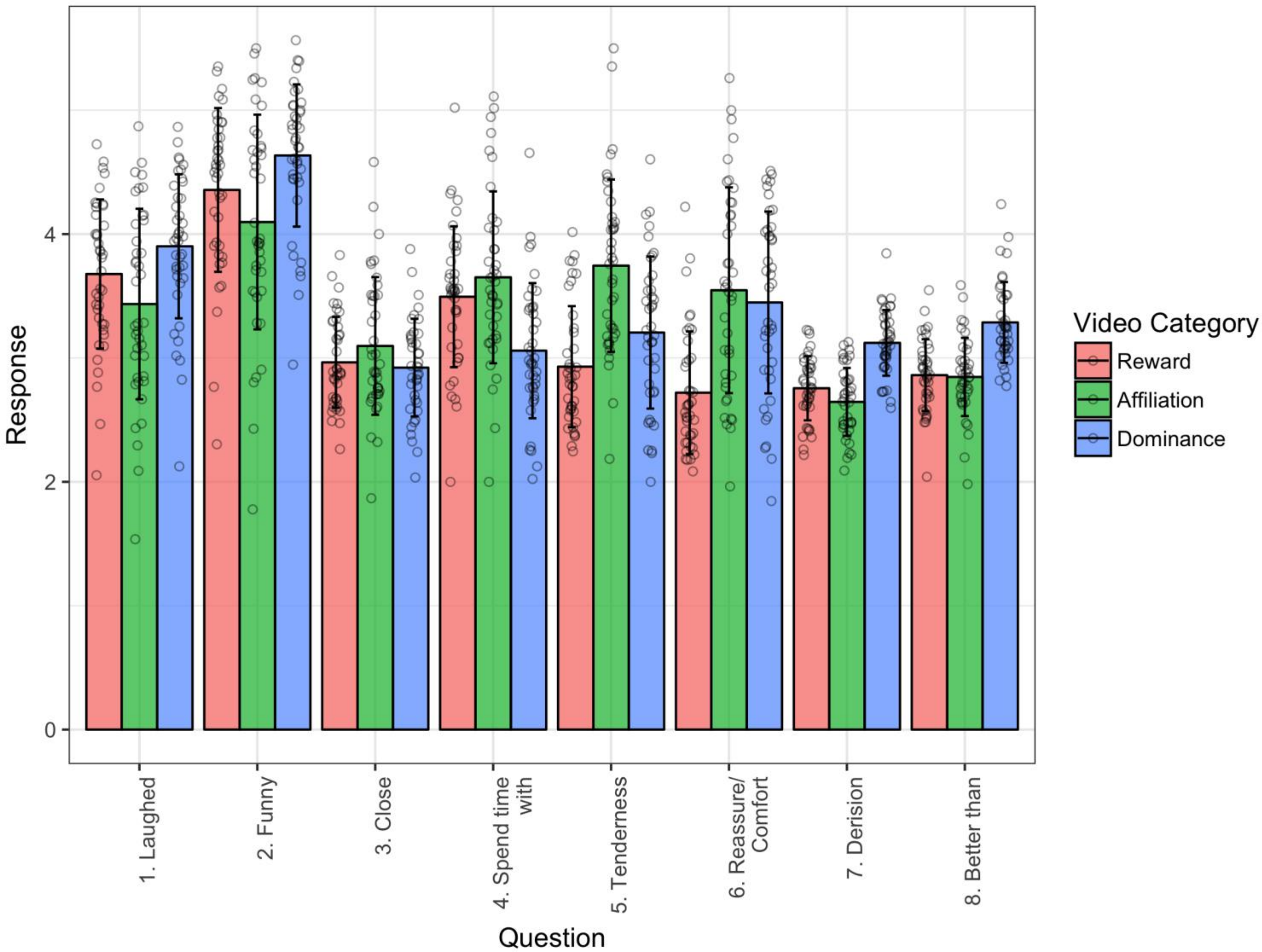
In sum, participants' ratings did not always follow predictions—in particular, the items intended to probe feelings associated with Reward did not distinguish the Reward videos from the Dominance and Affiliation videos. People did not feel closer to or want to spend significantly more time with people in the Reward videos. However, Reward videos were rated *lower* on items intended to capture Dominance- and Affiliation-related responses, suggesting video pre-selection was moderately successful in capturing the social functional constructs. Recall that the Dyad Conversation study included a built-in safeguard in the event that stimuli were not cleanly separable by the three social functions: Dyad participants selected videos that, for them, elicited the target feelings or intentions. Thus, while a limitation to bear in mind, it is not a fatal flaw that the individual stimuli did not always elicit the intended responses, and these results suggest videos were reasonably well-chosen for the 3 social functional categories.

Table 6. Model estimates comparing Study 3 Stimulus Rating participants' judgments about Reward, Affiliation, and Dominance videos.

Prompt	Contrast	b	SE	df	t	p
1. This video made me laugh out loud	Affiliation vs. Dominance	**0.434**	**0.151**	**130.621**	**2.882**	**.005**
	Affiliation vs. Reward	0.212	0.148	123.680	1.434	.154
	Reward vs. Dominance	0.222	0.151	130.206	1.473	.143
2. This video was funny	Affiliation vs. Dominance	**0.508**	**0.164**	**130.134**	**3.089**	**.002**
	Affiliation vs. Reward	0.236	0.163	126.516	1.450	.149
	Reward vs. Dominance	0.271	0.163	125.448	1.670	.098
3. I felt close to the person/people in this video	Affiliation vs. Dominance	-0.181	0.101	134.470	-1.794	.075
	Affiliation vs. Reward	-0.150	0.098	124.740	-1.529	.129
	Reward vs. Dominance	-0.030	0.097	120.980	-0.312	.755
4. I want to spend time with the person/people in this video	Affiliation vs. Dominance	**-0.589**	**0.139**	**132.296**	**-4.237**	**<.001**
	Affiliation vs. Reward	-0.176	0.138	128.401	-1.280	.203
	Reward vs. Dominance	**-0.413**	**0.136**	**122.944**	**-3.035**	**.003**
5. I felt tenderness for the person/people in this video	Affiliation vs. Dominance	**-0.539**	**0.142**	**147.733**	**-3.794**	**<.001**
	Affiliation vs. Reward	**-0.832**	**0.138**	**135.772**	**-6.016**	**<.001**
	Reward vs. Dominance	0.293	0.137	131.208	2.140	.034
6. I want to reassure/comfort the person/people in this video	Affiliation vs. Dominance	-0.090	0.158	127.689	-0.569	.570
	Affiliation vs. Reward	**-0.842**	**0.158**	**128.631**	**-5.330**	**<.001**
	Reward vs. Dominance	**0.753**	**0.160**	**134.662**	**4.699**	**<.001**
7. I felt derision towards the person/people in this video	Affiliation vs. Dominance	**0.462**	**0.072**	**163.533**	**6.424**	**<.001**
	Affiliation vs. Reward	0.121	0.057	109.651	2.141	.035
	Reward vs. Dominance	**0.341**	**0.074**	**165.285**	**4.608**	**<.001**
8. I am better than the person in this video	Affiliation vs. Dominance	**0.421**	**0.072**	**150.217**	**5.815**	**<.001**
	Affiliation vs. Reward	-0.005	0.065	117.503	-0.082	.935
	Reward vs. Dominance	**0.427**	**0.074**	**156.272**	**5.775**	**<.001**

Footnotes. Model estimates from 8 linear mixed-effects models in which participant ratings (on a scale from 1= "Strongly disagree" to 7= "Strongly agree") were regressed on dummy-coded variables comparing videos a priori categorized as relevant to the tasks of Reward, Affiliation, or Dominance. Numerator degrees of freedom were estimated using Satterthwaite approximation. Unadjusted p-values are reported, but bolded coefficients are those with Benjamini-Hochberg adjusted p-values that were below the .05 threshold (Benjamini & Hochberg, 1995).

Figure 8. Average responses to the 8 stimulus rating prompts by video category.



Footnotes. Bar height indicates the average score given to videos from the 3 social functional categories for each of the 8 prompts. Error bars indicate +/- 1 SD and points are individual videos' averaged scores.

Dyad conversation study. Here we first present descriptive statistics of participants' responses in the Video Selection phase of the Dyad Conversation Study (**Table 7)**. We then report analyses of the number of laughs produced by participants in the Video Sharing and Discussion phase, as a function of Social Functional Context (whether they were discussing videos they associated with rewarding, affiliative, or dominant responses) and the Gender of the dyads. We also look at the correlation in laughter frequencies among participants within a dyad to get a sense of how much participants' laughter influenced their partners' laughter frequency. We then report analyses of the acoustic properties of the laugh samples extracted from that phase of the study, following a similar analytic procedure as in Study 1. For the acoustic analyses, we excluded all samples coded as speech-laughter.[10] Finally, as in Study 1, we trained a machine learning algorithm to predict which Social Functional Context a laugh occurred in to get a sense of how well our selected acoustic variables distinguish between the 3 contexts in combination.

Table 7. Descriptive Statistics of Video Selection Responses

Social Functional Context	Mean	SD	Median	Minimum	Maximum
Reward	0.55	0.14	0.57	0.21	0.86
Affiliation	0.46	0.19	0.46	0.11	0.95
Dominance	0.48	0.15	0.47	0.14	0.78

Footnotes. For each of the 120 videos, we calculated the proportion of participants who responded "true," that the video did elicit the feelings associated with the relevant social function. Here we report the descriptive statistics by Social Functional Context of these proportion "true" responses to give a sense of the variability in how much participants agreed a given video fit the intended social function. Across the 3 contexts, average "true" response rates were around 50% (46-55%), suggesting participants were easily able to find at least 5 fitting videos per Social Functional Context (they each saw 20 videos per context).

Number of Laughs. Before examining the acoustic properties of the laughter samples, we analyzed the frequency with which participants laughed as a function of gender and Social Functional Context. We predicted that females (mean total laughs per participant = 38.23, SD = 29.7) would laugh more than male participants (mean total laughs per participant = 28.68, SD = 20.08), based on extensive prior evidence of a gender difference in laughter frequency (Bryant et al., 2016). We also expected an interaction between gender and the effect of Social Functional

[10] Future work that examines the acoustic properties of speech-laughter across the 3 social contexts will need to control for the vowels contained in the speech-laughter. It should also compare speech-laughter to the participants' normal speech.

Context on laughter frequency, with females laughing even more than males in the Affiliation context and males laughing relatively more than females in the Dominance context, based on the expectation that females would tend to be more comfortable expressing tenderness, warmth, and care, and males more comfortable expressing derision, disdain, and mocking (Brody, 2000). To test these predictions, we summarized for each participant the number of times they laughed in the Reward, Affiliation, and Dominance contexts.

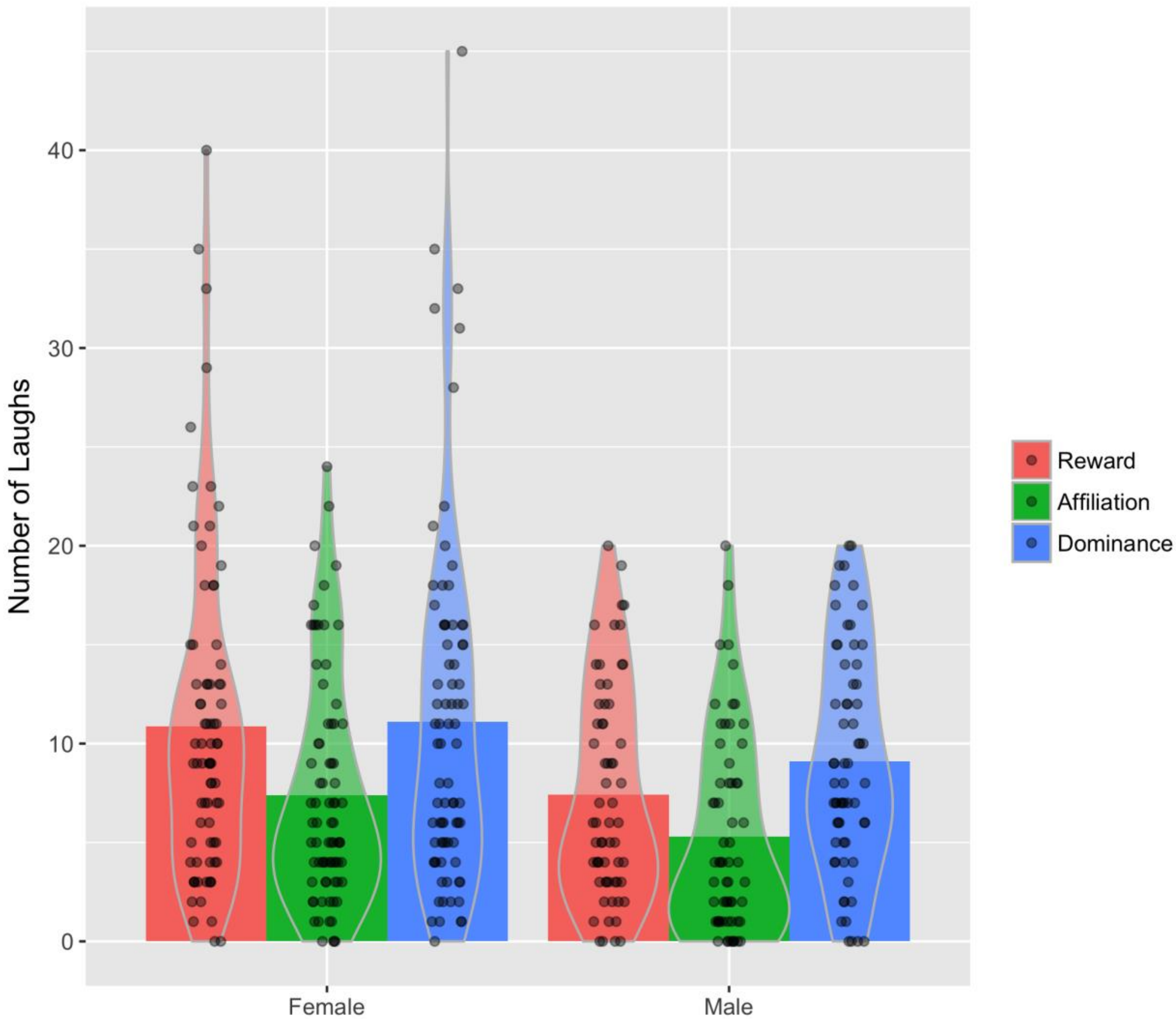
Using a generalized linear mixed-effects model with a Poisson distribution, we regressed Laugh Count on a unit-weighted, centered Gender variable (male = -.5, female = .5), dummy variables comparing the 3 Social Functional Contexts[11], and the interaction between Gender and the dummy variables. We re-ran this model 3 times with each of the 3 Social Functional Contexts as the reference level for the dummy variables. Subjects were fully nested within dyads, and we estimated by-subject/dyad random intercept and random slopes for the Social Functional contrast variables (we constrained the covariance between random effects to 0 to enable model convergence).

The key estimates are reported in **Table 8,** along with unadjusted p values and Benjamini-Hochberg adjusted p values to control the false-discovery rate (Benjamini & Hochberg, 1995). Females laughed significantly more than males, but only in reward video contexts. Controlling for all other variables and averaged between males and females, the model predicted participants to laugh more in reward than dominance video contexts (Reward vs Dominance coefficient), but this trends towards being an even stronger effect for females (Reward vs Dominance * Gender coefficient, which was no longer significant after p values

[11] Models using a dummy variable approach failed to converge even when we took steps to simplify the random effects structure. We chose not to unnest participants from dyads, which probably would have allowed the dummy variable models to converge, since within-dyad laughter frequency is moderately correlated (see next section of analyses).

were adjusted). The marginally significant reward vs. dominance interaction with gender can be seen by the relatively greater proportion of dominance laughs for males compared to females in **Figure 9**. Participants also laughed significantly more in the reward and dominance conditions compared to affiliation context (Affiliation vs Reward and Affiliation vs Dominance coefficients), and these differences were not moderated by participant gender.

Figure 9. Male and female participants' number of laughs across the 3 social functional contexts.



Footnotes. Points are individual participants' Laugh Counts in each Social Functional Context. Solid bars represent the average number of laughs in each context for males and females. Females laughed more than males, but this gender difference was dampened in the dominance context.

Table 8. Model estimates comparing the laughter counts in each social functional context, moderated by dyad gender.

	Estimate	SE	z	p	adj. p
Effect of Gender for Reward	0.351	0.136	2.593	.010	.036
Effect of Gender for Affiliation	0.279	0.163	1.713	.087	.144
Effect of Gender for Dominance	0.170	0.137	1.240	.215	.307
Reward vs Dominance	-0.126	0.050	-2.542	.011	.036
Reward vs Dominance * Gender	-0.181	0.083	-2.196	.028	.056
Affiliation vs Reward	0.280	0.053	5.309	<.001	<.001
Affiliation vs Reward * Gender	0.073	0.084	0.861	.389	.389
Affiliation vs Dominance	0.154	0.063	2.443	.015	.036
Affiliation vs Dominance * Gender	-0.109	0.110	-0.983	.326	.362

Footnotes. Select model estimates from 3 versions of the same generalized linear mixed-effects model with a Poisson distribution in which Laugh Count was regressed on dummy variables comparing the 3 Social Functional Contexts, moderated by the gender of the dyad. Both unadjusted and Benjamini-Hochberg adjusted p values to control the false-discovery rate are reported. Social Functional Context contrast estimates indicate how much more or less participants laughed in the latter context (e.g., the positive estimate for Affiliation vs Dominance indicates that people laughed more in the Dominance than Affiliation context). The interaction with gender terms indicate whether the estimate in the previous row was moderated by participant gender (males = .5, females = .5).

Frequency of human-coded laugh types by social context. We totaled the number of speech-laughs, voiced, unvoiced, and closed-mouth laughs occurred across the 3 social functional contexts (see **Table 9**). Descriptively, speech-laughter appeared to be less frequent in the affiliation video context compared to reward and dominance, and voiced laughter was most frequent in the rewarding video context. Closed-mouth laughs were relatively infrequent, so their slightly greater frequency in the affiliation context may be due to chance (although it aligns with the closed-mouth affiliation smile). Despite the descriptive difference in laugh type frequencies, however, a Pearson's Chi-square test was not significant, $\chi 2$ (4)=6.56, p = .161.[12]

[12] The omnibus nature of this test may not be sensitive to differences within a single stratum, and it does not account for the nonindependence of the laughs observed. We used it simply to get a rough estimate of how uniquely the laugh types—including the rarer closed mouth laughs—occurred in each Social Functional Context.

Table 9. Total number of laughs coded as speech-laughter, voiced, unvoiced, or closed-mouth

	Reward	Affiliation	Dominance
Speech-laughter	367	292	332
Voiced	536	446	464
Unvoiced	224	224	215
Closed-Mouth	52	63	45

Footnotes. All laugh samples that qualified as speech-laughter were coded as such, but only a subset (n=2,269) of the remaining non-speech laughs were coded according to the following categories: voiced, unvoiced, and closed-mouth. Thus while the relative frequencies of speech-laughter in the 3 social functional contexts can be compared to one another, they should not be compared to the frequencies of the non-speech laugh types (of which there were many more than were coded and represented here). While descriptive differences in the frequency of laugh types emerge across the 3 social contexts, a Pearson's Chi-squared test was not significant, $\chi^2(4)=6.56$, $p = .161$.

Partners' influence on number of laughs. We then asked whether the amount a participant laughed depended on their partner's amount of laughter—in other words, was a participant's amount of overall laughter primarily a function of their personality or some other individual attribute, or did it emerge in the dyadic context? To answer this question, we regressed each participants' total Laugh Count on Partner's Laugh Count (group mean-centered), the Gender of the Dyad (male = -.5, female = .5), and the interaction term, using generalized linear regression with a Poisson distribution to handle the count data. The participants' Partner Laugh Count significantly, positively predicted their own Laugh Count, $b = 0.012$, $SE = 0.001$, $t(130) = 19.70$, $p < .001$. Again, females laughed more overall than males, $b = 0.140$, $SE = .032$, $t(130) = 4.35$, $p < .001$, but gender did not moderate the effect of Partner Laugh Count, $p = .999$. In other words, females' laughter frequency was not more influenced by their partners' laughter frequency than was males'. Analyzed even more simply, the bivariate correlation coefficient between the participant and partner Laugh Counts was .508. Thus, participants' overall amount of laughter was strongly correlated with their partners' amount of laughter.

Acoustic properties of laughter in reward, affiliation, and dominance contexts. In a series of 12 analyses, we regressed each of the 12 acoustic variables of interest (see **Table 10** for descriptives of the acoustic variables) on dummy-coded Social Functional Context and its interaction with unit-weighted and centered Gender (male= -.5, female = .5), with by-subject a random intercept and random slopes for Social Functional Context and a by-item (video) random intercept.[13] We first ran 12 separate regressions with Reward as the reference level of Social Functional Context, which provided estimates of the differences between Reward vs Dominance and Reward vs Affiliation. We then recoded Social Functional Context with Affiliation as the reference level, from which we obtained the Affiliation vs Dominance contrast.

Only one Gender * Social Functional Context interaction term was significant, for Intensity: dominance laughs tended to be quieter than rewarding laughs, but this was particularly true for females compared to males, $b = -1.502$, $SE = 0.748$, $t(101.89) = -2.006$, unadjusted $p=.047$. This effect was no longer significant after correcting the false discovery rate, and no other interaction terms were significant. However, we still computed all the simple effects of Context for male and female participants in order to mirror the analyses from Study 1. We did this by recoding Gender as males = 0 and females = 1, and then with females = 0 and males = 1. The model for the SD of F0 Mean / Duration outcome variable failed to converge, so we constrained the covariance of the by-subject random effects to zero (Brauer & Curtin, 2017). Finally, we corrected the false discovery rate (FDR) using by reporting Benjamini-Hochberg

[13] We initially specified the models with by-item random slopes for Gender (which would technically be the maximal model) and with participants fully nested in dyads. However, these models frequently failed to converge across the acoustic outcome variables, so we opted for the simpler structure. We were not interested in the main effect of Gender, since male and female voices tend to differ acoustically for biological reasons, making it appropriate to eliminate the random slope for Gender. Note that for those maximal models that did converge, the effects were largely similar to those reported here.

adjusted p values, although we also report the uncorrected p values in **Table 11** (Benjamini & Hochberg, 1995).

Table 10. Descriptive statistics for the 12 acoustic variables of interest, reported separately for males and females.

		Mean	SD	Median	Minimum	Maximum
Duration (s)	Female	1.24	1.17	0.88	0.08	13.40
	Male	1.20	1.00	0.90	0.14	9.41
Intensity (dB)	Female	53.33	9.08	53.71	27.80	81.76
	Male	50.92	9.36	51.46	25.94	80.85
F0 Mean (ST)	Female	67.96	4.75	67.63	55.42	82.58
	Male	64.39	6.94	62.49	52.76	82.80
F0 Range (ST)	Female	12.49	7.79	11.86	0.00	31.70
	Male	14.34	9.88	12.26	0.00	32.73
SD F0 / Duration (Hz)	Female	125.31	175.18	68.66	0.61	2511.58
	Male	138.67	204.57	55.17	0.11	1917.84
Slope (ST)	Female	82.01	9.27	81.95	40.64	113.90
	Male	79.69	12.68	79.87	35.89	113.19
Center of Gravity (Hz)	Female	826.07	603.80	662.96	28.40	8176.83
	Male	830.51	715.18	621.79	57.40	6082.35
Harmonics-to-Noise Ratio	Female	7.40	3.83	7.18	-3.23	22.84
	Male	5.42	3.72	4.96	-4.26	27.71
Proportion Voiced	Female	0.55	0.24	0.54	0.00	1.00
	Male	0.42	0.23	0.40	0.00	1.00
F1 Mean (ST)	Female	79.54	3.24	79.66	67.96	88.42
	Male	80.83	2.95	80.96	66.20	88.32
F2 Mean (ST)	Female	90.54	1.27	90.55	85.24	94.31
	Male	90.58	1.27	90.62	85.04	94.94
F2 Mean – F1 Mean (ST)	Female	11.00	2.88	10.62	3.89	21.45
	Male	9.75	2.34	9.49	3.79	23.74

Footnotes. s= seconds, dB = decibels, ST = semitones, Hz = Hertz. For those variables that are log-transformed prior to analysis, we report untransformed values in Hz.

The results of the mixed-effects models are summarized next (key model estimates reported in **Table 11**; full model outputs available in supplementary materials). We will refer to laughs as “reward”, “affiliation,” and “dominance” laughs, but strictly speaking, they are the laughs that occurred during the reward, affiliation, and dominance video-viewing contexts. Also note that we discuss effects that were significant before adjustment but not after FDR adjustment. This is because the $p < .05$ threshold with FDR-adjusted p values means that only 5% of all significant effects will be false positives, and a 5% threshold is considered rather stringent for FDR adjustment (Benjamini, Drai, Elmer, Kafkafi, & Golani, 2001). Significant effects that become insignificant after FDR adjustment should be interpreted with extreme caution, but kept in mind for future research (see **Figure 10** for spectrograms of sample laughs).

Affiliation laughs were shorter (Duration) than reward and dominance laughs, although the simple effect was only significant for males. Reward laughs were more intense (Intensity) than affiliation laughs and dominance laughs (the latter was for females only), but the FDR-adjusted p values sank below threshold (adj. *p*s = .068, .077). Dominance laughs had a higher Center of Gravity than reward and affiliation laughs, but the simple effects were not significant for males. After FDR adjustment, the reward vs. dominance contrast was no longer significant (adj. $p = .057$), but the affiliation vs. dominance contrast was still significant. The Harmonics-to-Noise Ratio model indicated that dominance laughs were noisier than reward and affiliation laughs; the simple effect for female participants persisted even after FDR adjustment, but the simple effect for males did not (adj. $p = .061$). Dominance laughs had less voicing (Proportion Voiced) than reward and affiliation laughs, although not significantly for males. Of particular relevance to the size code predictions, the distance between F2 and F1 (F2 Mean – F1 Mean) was bigger for reward compared to dominance laughs (main effect and female simple effect), and for affiliation versus dominance laughs (female simple effect), but the main effect (adj. $p = .148$) and female simple effects (adj *p*s = .068 and .079) became insignificant after FDR adjustment.

Table 11. Model estimates of Social Functional Context effects on acoustic properties of laughter.

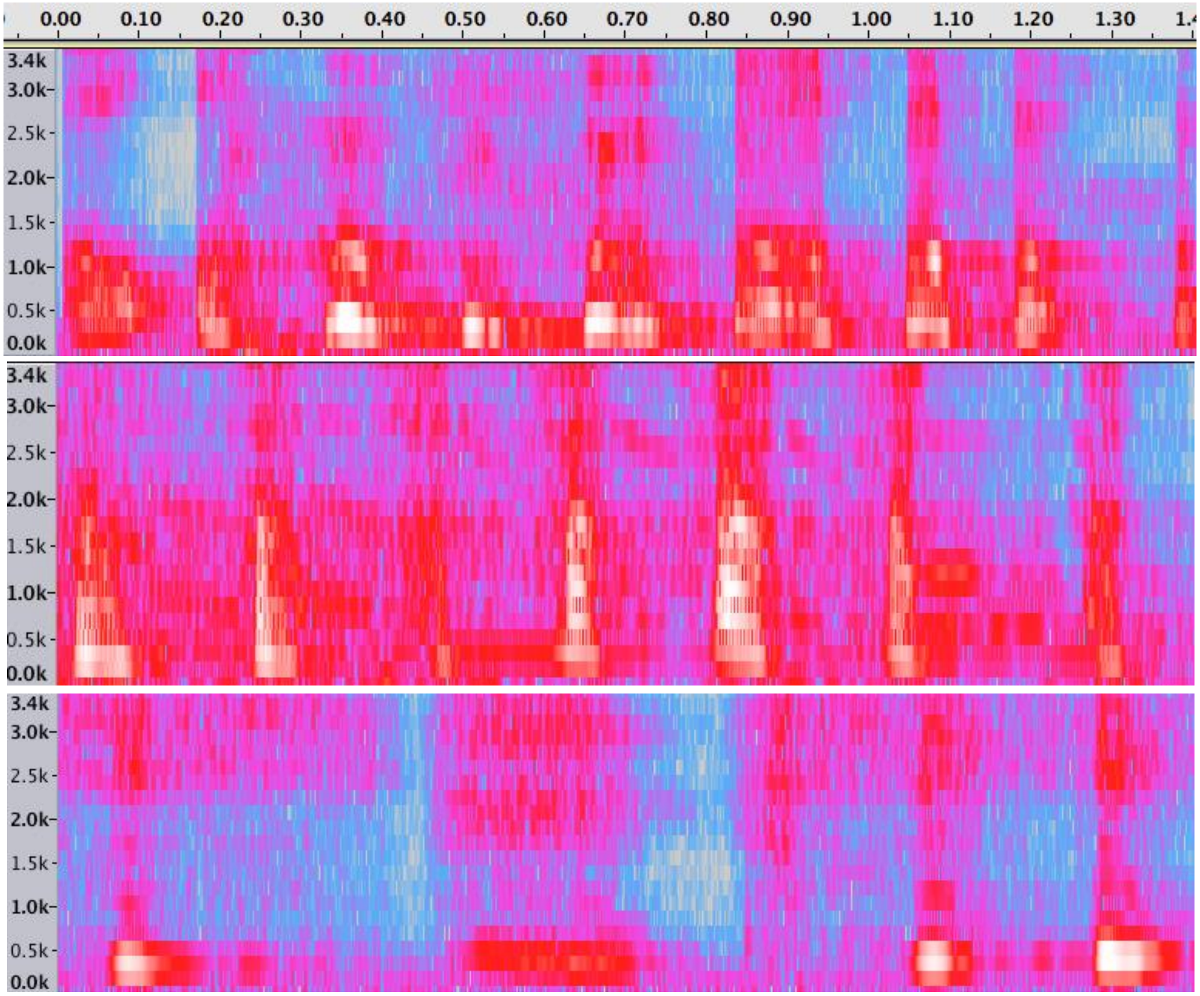
Acoustic Property	Social Context Contrast	Main vs Simple Effect	Estimate	SE	df	t	p	adj. p
Duration	**R vs D**	Main Effect	-0.035	0.034	105.390	-1.042	.300	.338
		Effect for Males	-0.054	0.049	159.431	-1.109	.269	.338
		Effect for Females	-0.017	0.042	119.889	-0.401	.689	.689
	R vs A	Main Effect	-0.123	0.037	114.408	-3.334	**.001***	**.009***
		Effect for Males	-0.167	0.053	158.077	-3.130	**.002***	**.009***
		Effect for Females	-0.078	0.045	122.892	-1.737	.085	.153
	A vs D	Main Effect	0.087	0.034	78.781	2.537	**.013***	**.039***
		Effect for Males	0.113	0.049	111.768	2.303	**.023***	.052
		Effect for Females	0.061	0.042	83.165	1.463	.147	.221
Intensity	**R vs D**	Main Effect	-0.533	0.416	93.196	-1.282	.203	.275
		Effect for Males	0.218	0.597	115.905	0.365	.716	.805
		Effect for Females	-1.284	0.519	97.428	-2.472	**.015***	.068
	R vs A	Main Effect	-1.104	0.416	95.935	-2.653	**.009***	.068
		Effect for Males	-1.048	0.602	126.714	-1.742	.084	.151
		Effect for Females	-1.161	0.513	100.468	-2.264	**.026***	.077
	A vs D	Main Effect	0.571	0.457	108.144	1.251	.214	.275
		Effect for Males	1.266	0.657	125.726	1.927	.056	.127
		Effect for Females	-0.123	0.576	111.901	-0.214	.831	.831
F0 Mean	**R vs D**	Main Effect	0.160	0.295	85.597	0.544	.588	.938
		Effect for Males	0.292	0.423	99.994	0.691	.491	.938
		Effect for Females	0.029	0.364	81.297	0.079	.938	.938
	R vs A	Main Effect	0.042	0.305	80.627	0.139	.890	.938
		Effect for Males	0.428	0.442	91.863	0.967	.336	.938
		Effect for Females	-0.343	0.371	74.557	-0.923	.359	.938
	A vs D	Main Effect	0.118	0.293	71.280	0.402	.689	.938
		Effect for Males	-0.136	0.420	83.034	-0.323	.748	.938
		Effect for Females	0.372	0.359	66.511	1.034	.305	.938
F0 Range	**R vs D**	Main Effect	0.049	0.437	68.841	0.111	.912	.912
		Effect for Males	-0.226	0.638	91.106	-0.354	.724	.912
		Effect for Females	0.323	0.543	68.952	0.596	.553	.862
	R vs A	Main Effect	-0.310	0.411	78.127	-0.755	.452	.862
		Effect for Males	-0.564	0.604	142.612	-0.933	.353	.862
		Effect for Females	-0.056	0.494	87.740	-0.114	.909	.912
	A vs D	Main Effect	0.359	0.413	87.511	0.868	.388	.862
		Effect for Males	0.338	0.600	213.131	0.562	.574	.862
		Effect for Females	0.380	0.506	124.413	0.751	.454	.862
SD F0 / Duration	**R vs D**	Main Effect	0.071	0.058	64.824	1.216	.229	.374
		Effect for Males	0.055	0.088	96.277	0.632	.529	.529
		Effect for Females	0.086	0.073	66.423	1.179	.243	.374

	R vs A	Main Effect	0.077	0.058	69.183	1.323	.190	.374
		Effect for Males	0.102	0.088	111.708	1.158	.249	.374
		Effect for Females	0.052	0.072	71.364	0.720	.474	.529
	A vs D	Main Effect	0.077	0.058	69.183	1.323	.190	.374
		Effect for Males	0.102	0.088	111.707	1.158	.249	.374
		Effect for Females	0.052	0.072	71.364	0.720	.474	.529
F0 Slope	**R vs D**	Main Effect	0.272	0.480	49.614	0.566	.574	.900
		Effect for Males	0.360	0.727	74.140	0.496	.621	.900
		Effect for Females	0.184	0.600	47.076	0.306	.761	.900
	R vs A	Main Effect	-0.120	0.471	62.522	-0.254	.800	.900
		Effect for Males	0.404	0.721	127.335	0.560	.577	.900
		Effect for Females	-0.643	0.573	68.134	-1.121	.266	.900
	A vs D	Main Effect	0.391	0.479	94.791	0.817	.416	.900
		Effect for Males	-0.043	0.726	321.445	-0.060	.952	.952
		Effect for Females	0.826	0.595	151.219	1.388	.167	.900
Center of Gravity	**R vs D**	Main Effect	0.063	0.026	58.848	2.409	**.019***	.057
		Effect for Males	0.053	0.040	90.280	1.346	.182	.272
		Effect for Females	0.073	0.033	62.528	2.198	**.032***	.071
	R vs A	Main Effect	-0.024	0.025	46.694	-0.992	.326	.367
		Effect for Males	-0.012	0.038	81.955	-0.315	.753	.753
		Effect for Females	-0.037	0.030	47.258	-1.220	.229	.294
	A vs D	Main Effect	0.087	0.028	65.352	3.106	**.003***	**.014***
		Effect for Males	0.065	0.042	102.930	1.535	.128	.230
		Effect for Females	0.110	0.036	73.203	3.060	**.003***	**.014***
Harmonics-to-Noise Ratio	**R vs D**	Main Effect	-0.423	0.150	244.335	-2.816	**.005***	**.024***
		Effect for Males	-0.407	0.233	295.602	-1.746	.082	.123
		Effect for Females	-0.440	0.190	188.721	-2.314	**.022***	**.049***
	R vs A	Main Effect	0.165	0.158	143.214	1.049	.296	.381
		Effect for Males	0.190	0.247	171.213	0.769	.443	.474
		Effect for Females	0.141	0.196	111.054	0.719	.474	.474
	A vs D	Main Effect	-0.589	0.181	105.197	-3.245	**.002***	**.014***
		Effect for Males	-0.596	0.278	117.502	-2.146	**.034***	.061
		Effect for Females	-0.581	0.233	90.735	-2.489	**.015***	**.044***
Proportion Voiced	**R vs D**	Main Effect	-0.023	0.010	67.925	-2.354	**.021***	**.048***
		Effect for Males	-0.016	0.015	119.933	-1.080	.282	.368
		Effect for Females	-0.030	0.012	77.182	-2.407	**.018***	**.048***
	R vs A	Main Effect	0.011	0.011	72.054	1.074	.287	.368
		Effect for Males	0.015	0.016	115.081	0.901	.370	.416
		Effect for Females	0.008	0.013	78.071	0.603	.548	.548
	A vs D	Main Effect	-0.034	0.011	80.618	-3.064	**.003***	**.027***
		Effect for Males	-0.031	0.017	126.286	-1.811	.072	.130
		Effect for Females	-0.038	0.014	91.752	-2.629	**.010***	**.045***
F1 Mean	**R vs D**	Main Effect	0.164	0.123	87.249	1.335	.185	.556
		Effect for Males	0.025	0.191	107.123	0.133	.894	.894

		Effect for Females	0.303	0.156	66.408	1.945	.056	.344
	R vs A	Main Effect	0.061	0.131	95.609	0.469	.640	.823
		Effect for Males	0.172	0.204	114.224	0.842	.402	.797
		Effect for Females	-0.049	0.163	74.418	-0.301	.764	.860
	A vs D	Main Effect	0.103	0.153	105.374	0.675	.501	.797
		Effect for Males	-0.146	0.233	115.678	-0.627	.532	.797
		Effect for Females	0.352	0.197	92.968	1.792	.076	.344
F2 Mean	**R vs D**	Main Effect	-0.027	0.055	86.971	-0.492	.624	.802
		Effect for Males	-0.002	0.082	137.959	-0.028	.978	.978
		Effect for Females	-0.052	0.069	97.223	-0.752	.454	.802
	R vs A	Main Effect	0.050	0.061	87.669	0.823	.413	.802
		Effect for Males	0.097	0.092	120.933	1.058	.292	.802
		Effect for Females	0.003	0.076	89.900	0.041	.968	.978
	A vs D	Main Effect	-0.077	0.072	103.329	-1.068	.288	.802
		Effect for Males	-0.100	0.108	124.464	-0.921	.359	.802
		Effect for Females	-0.077	0.072	103.329	-1.068	.288	.802
F2 Mean - F1 Mean	**R vs D**	Main Effect	-0.203	0.103	1093.198	-1.968	**.049***	.148
		Effect for Males	-0.048	0.162	367.630	-0.298	.766	.844
		Effect for Females	-0.358	0.132	168.565	-2.702	**.008***	.068
	R vs A	Main Effect	-0.036	0.114	124.555	-0.314	.754	.844
		Effect for Males	-0.106	0.181	127.884	-0.587	.558	.844
		Effect for Females	0.029	0.146	77.209	0.197	.844	.844
	A vs D	Main Effect	-0.167	0.122	110.483	-1.362	.176	.396
		Effect for Males	0.058	0.190	114.226	0.303	.763	.844
		Effect for Females	-0.386	0.159	77.548	-2.429	**.017***	.079

Footnotes. R=Reward, A=Affiliation, D=Dominance. Estimates from a series of linear mixed-effects models comparing the acoustic properties of laughs in the three Social Functional Contexts. Contrasts are dummy-coded, with the first Context named (e.g., the “A” in “A vs D”) set to 0. The simple effects for males and females were computed by re-running the models with Gender centered over males or females, respectively. Adjusted p values were computed using Benjamini-Hochberg correction. Degrees of freedom were calculated using Satterthwaite's approximations.

Figure 10. Sample laughter spectrograms.

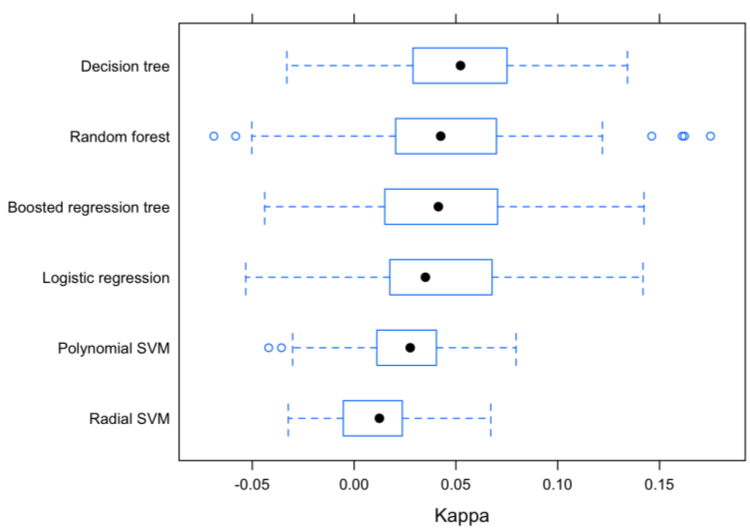


Footnotes. Spectrograms of 3 laugh samples from Study 3. Energy increases as color goes from blue to red to white. Y-axis represents frequency (in Hertz) and x-axis is time (in seconds). Top: female (participant 333) laughter in response to a dominance video (#d04, laugh #2), illustrating a laugh with a clear /o/ vowel ("ho ho ho"). Middle: male (participant 279) laughter in response to an affiliation video (#0720, laugh #1), illustrating a relaxed, wide-mouthed laugh with a /ɑ/ vowel ("ha ha ha"). Bottom: female laughter (participant 280) in response to an affiliation video (#a01, laugh #2), demonstrating a tense /i/ vowel ("he he he", interrupted with an inhalation). Listen to all 3 laughs here: https://uwmadison.box.com/s/aygczonlwrjcocuqguv24wqs7i38hs2q

Machine learning analysis. For all the participants with at least one non-speech-laugh in each of the 3 Social Functional Contexts ($n_{participants}$ = 123, n_{laughs} = 3,403), we standardized the 12 acoustic variables within subject, using each subject's own mean and standard deviation. Standardizing within subject allowed us to adjust for individual variability in vocal properties.

Following an identical procedure to the machine learning analysis in Study 1, we then trained the same set of machine learning algorithms (logistic regression, decision tree, random forest, boosted regression tree, polynomial SVM, and radial SVM) on 80% of the laughter data, with the 20% of the partitioned test data sampled evenly from the 3 Social Functional Contexts. We again calculated the root mean-squared error for each of the algorithms on the training data using resampling, which allowed us to conduct hypothesis tests on the 6 models' differences in performance. The decision tree had the highest mean kappa (but at a very low $M_{kappa} = .052$) on the training data, but since the t-test from the resampling procedure (see Study 1 Results) comparing the kappas for the decision tree and the random forest ($M_{kappa} = .046$) was not significant, we used the random forest for the sake of consistency with Study 1 (see **Figure 11** for resampled kappa descriptive statistics for each trained model).

Figure 11. Comparing model performance in categorizing training laughter data from Study 3.



Footnotes. Cohen's Kappa coefficients indicating each model's performance on the training dataset. Black points are the mean Kappa, boxes represent the first to third quartile, and whiskers represent the full range of Kappas generated during resampling.

When we tested the trained random forest on the partitioned test set of laughter, it was a very poor predictor of the Social Functional Context in which each laugh occurred, Cohen's kappa = .038. Accuracy (.369) was not significantly different from the No Information Rate (.377), which is the accuracy rate if the model randomly guessed the social functional context based on no other knowledge besides the overall distribution of the 3 categories, $p = .667$.

Discussion

Study 3 is the first known manipulation of social contexts for the purpose of examining acoustic differences in laughter. Other work examining acoustic variability in natural laughter has either focused exclusively on indicators of spontaneity (e.g., Bryant et al., 2016), did not manipulate social context but instead relied on raters to identify different categories of laughter (Tanaka & Campbell, 2011), used pre-existing social relationships as proxies of social functions (Oveis et al., 2016), or counted the frequency of laughs without characterizing their acoustic properties (Mehu & Dunbar, 2008). Study 3 is also the first naturalistic test of the social functional account of laughter and smiling—to date, no study has attempted to elicit the proposed signals of reward, affiliation, and dominance in natural social interactions. All prior work has relied on perceiver-based paradigms (Martin et al., under review; Rychlowska et al., 2017; Wood et al., 2017) or posed expressions (Martin et al., under review). The current study was designed to elicit more laughter than typical laboratory conversations might and also encourage shared reward, affiliation, and dominance responses to the humorous stimuli.

The video viewing task was highly successful in eliciting laughter: participants laughed an average of 34 times during the conversation phase, which is much higher than the average rate of laughter during conversation reported in the literature (Scott et al., 2014). The separate stimulus rating task completed by solo participants suggested that the video pre-selection for the

3 social functional categories was moderately successful: the “affiliation” and “dominance” videos were rated higher on functionally relevant dimensions, but the “reward” videos were not. However, the dyad study design had a built-in safeguard, as participants chose a subset of videos for each category that, for them, best elicited responses associated with the tasks of reward, affiliation, and dominance. As evidence that most participants were able to find videos that elicited relevant responses, they tended to choose more than the minimum number of videos for each category (they were required to pick 5 of 20, but typically picked many more).

A number of gender and social functional context effects on laughter frequency emerged. First, females laughed substantially more frequently than males, particularly in response to the reward stimuli. Second, participants laughed more frequently in the reward compared to affiliation and dominance contexts, although males laughed relatively more in the dominance condition compared to females. The gender difference in laughter during a dominance context fits with predictions that male-male dyads will use laughter more to signal dominance (Owren & Bachorowski, 2003). Finally, participants laughed more frequently in the dominance compared to affiliation context. Future work should explore how stimulus-dependent the frequency of laughter across social contexts is.

Converging with substantial work on behavioral alignment, participants’ laughter frequency was strongly correlated with their partner’s laughter frequency. While there are undeniable stable individual differences in how often people laugh, laughter does seem to be contagious (Scott et al., 2014). While here we analyzed total amount of laughter, future re-analyses of the current study could examine whether dyad members’ laughter rates converged over the course of the 15-minute conversation.

Somewhat distinct acoustic profiles emerged for laughter in each of the 3 social functional contexts, and several of findings in the current study converged with the perceiver-based findings in Study 1. Recall that in Study 1, the acoustic variables were predictors and the outcomes were judgments of the degree to which a laugh sample sounded rewarding, affiliative, or dominant. In the current study's analyses, contrasts between the 3 social functions serve as categorical predictors and the acoustic properties are the outcomes. In Study 1, duration was positively related to reward and dominance judgments but not affiliation judgments, and in Study 3, affiliation laughs were shorter than reward and dominance laughs. In Study 1, reward and dominance laughs had higher centers of spectral gravity, while in Study 3, dominance laughs had higher centers of gravity than reward and affiliation laughs. A separate study found that listeners rate speakers as more likeable when their voices have lower centers of gravity (Weiss & Burkhardt, 2010). Producers in the current study may have taken advantage of this effect of center of gravity manipulation to elicit aversive reactions in dominant contexts.

Finally, while no effects for the absolute frequency of the first and second formants emerged in Study 3, the distance between F2 and F1 was smaller in dominance laughs. The distance between the first and second formants corresponds to the vowel height of a vocalization, with "smaller," higher vowels involving greater F1-F2 spacing (and implying a smaller body size). Although the Study 3 effect did not remain significant when we adjusted the p values to control the false discovery rate, it was directly predicted by the size code hypothesis and converges with the relationship between affiliation and dominance judgments and the second formant for female actors in Study 1. Future work should therefore follow up on the size code-inspired hypothesis that producers modify the vowels of their laughter to convey dominance and affiliation.

Several Study 3 findings conflict with perceiver judgments in Study 1. The first has to do with laughter intensity (loudness). The only relationship between social evaluations and intensity in Study 1 was with affiliation and was moderated by gender: female laughter was perceived as more affiliative when it was quieter, while male laughter was perceived as more affiliative when it was louder. In Study 3, on the other hand, reward laughter was more intense than dominance and affiliation laughter (before p values were adjusted). Future work should disentangle this effect, but given prior work linking intensity positively to spontaneity (which Study 1, in turn, relates to perceptions of reward), it seems that rewarding, spontaneous laughter should be louder than affiliative or dominant laughter. Study 1's laugh samples came from unknown and varied recording contexts, so comparisons of absolute amplitude across the Study 1 samples should be interpreted with caution.

Dominance laughs in Study 3 were noisier (lower harmonics-to-noise ratio) than reward and affiliation laughs, but in Study 1, judgments of *reward* in male laughter were positively related to noisiness. We originally predicted dominance to be conveyed with increased noisiness, given the negative relationship between harmonicity and aggressive displays in non-human animals (Pisanski et al., 2016). Larger bodies are capable of producing noisier (less harmonic) vocalizations, so this Study 3 finding converges with size code predictions (Bryant, 2013). Further, in a study in which actors posed laughter for different contexts, the schadenfreude and teasing laughter was noisier than the tickling laughter. Thus, Study 3's harmonics-to-noise findings fit better with the larger acoustic signaling literature than do Study 1's.

The final acoustic variable that related to the proposed social functions differently in Study 1 and Study 3 was the proportion of the laugh that was voiced, as opposed to unvoiced. In Study 1, which involved almost entirely voiced laughter samples, judgments of reward and affiliation increased when laughter contained relatively less voicing. In Study 3, meanwhile, laughter occurring in the *dominance* context contained less voicing. Further, for the subset of Study 3 laughs that were human-coded as either mostly voiced or mostly unvoiced, relatively more reward context laughs were voiced. Converging with Study 3, prior work has found that voiced laughter elicits more positive affect than unvoiced laughter for perceivers, so a negative relationship between voicing and dominance signaling—and conversely, a positive relationship with reward and affiliation signaling—is logical (Bachorowski & Owren, 2001). The discrepancy with Study 1 may be because perceivers' evaluations of a producer's social intentions do not always converge with what producers are actually signaling. It may also be because Study 3 contained substantially more unvoiced laughs. In drawing comparisons between Studies 1 and 3, recall that the laughs in Study 1 were posed and the laughs in Study 3 were natural. The two studies may be sampling from different areas of the laughter space, with one more caricatured and less natural than the other, but both nonetheless informative about form-function relationships in laughter.

One final overarching difference between Study 1 and Study 3 is notable. In Study 1, slightly more acoustic properties significantly predicted simple effects for male producers than for female producers—in other words, perceivers' judgments of reward, affiliation, and dominance were guided by a richer set of acoustic variables for male producers. In Study 3, almost all of the significant simple effects were for females rather than males. Drawing strong conclusions from this would mean over-interpreting null effects that could simply be due to a lack of power (e.g., in Study 3 there were fewer male than female dyads). But future work could follow up on the potential mismatch in laughter production and perception by asking naïve participants to guess whether Study 3 laughter samples occurred in the rewarding, affiliative, or dominant video-viewing contexts, and seeing what acoustic properties guide their judgments and how accurate they are for male and female producers.

Future analyses of Study 3's recordings, which are beyond the scope of the dissertation, will quantify differences between participants' normal speech and their speech-laughter, as well as differences in speech-laughter across the 3 social contexts. A precise analysis will require controlling for the phonemes contained in the utterances. It would also be useful to do a conversation analysis of the participants' speech content to remove some of the variability in the conversational context in which the laughter occurred. For instance, participants' conversations sometimes steered away from the video they were supposed to be discussing, and sometimes they discussed specifically how the video *did not* elicit responses associated with the intended social functional task. Analyzing only those laughs coded as direct responses to the content of the videos might reveal additional acoustic markers of reward, affiliation, and dominance laughter.

The machine learning approach used here was unsuccessful in predicting the social functional contexts of participants' laughter from the 12 acoustic properties. Perhaps naturally-occurring laughter is too acoustically variable, and a model will never be able to estimate the social intentions of individuals from their laughter alone. Once Study 3's participant conversations are analyzed so that only laughs clearly responding to the content of the video stimuli are included, the machine learning models may perform better. Another possibility is that a sophisticated deep learning approach that can represent the within-subjects nature of the data will provide greater predictive traction. Future work will also explore a model that is trained on both perceiver judgments of laughter (i.e., of more exaggerated, actor-produced laughter in Study 1) and laughter produced in known social contexts (i.e., Study 3).

Another limitation of Study 3 is the quality of the audio recordings. Recordings took place in a single room with computers that produced steady, low-intensity sound, observable on the spectrograms. We elected not to use a high-pass filter to reduce this sound, in part because the computer vibrations resonate at higher frequencies that are impossible to filter without distorting human speech. The computer-generated sound is not a problem for the current analyses, as it occurs in all the recordings and analyses were conducted within-subject. However, raw spectrum data from the current study should be interpreted and compared to other studies cautiously. Further limiting the quality of the recordings, the partners' voices can be heard (at a much lower intensity) on each other's recordings, resulting in some contamination of the laughter samples.

To summarize Study 3, several acoustic variables distinguished between the 3 video viewing contexts, particularly the dominance-eliciting context. The 12 variables examined here were insufficient for simple classifiers to be able to predict the social functional context, however. Female dyads tended to laugh more often and their laughter across the 3 contexts was more acoustically distinct, although this could have been because males were underrepresented in the sample. Laughter recorded in contexts relevant to the social tasks of reward, affiliation, and dominance was acoustically variable in ways that largely fit into the existing vocalization literature and, in multiple instances, converged with Study 1.

General discussion

The current work tested a novel proposal that the acoustic form of laughter can be modulated to accomplish distinct social tasks. Over three studies, we used a combination of verbal and nonverbal perceiver judgments, posed and natural laughter, and machine learning to examine the form-function relationship in social laughter. Study 1 used perceiver judgments of a heterogeneous set of actor-produced laugh samples to identify candidate mappings between acoustic forms and signals of reward, affiliation, and dominance. Judgments of reward and perceived spontaneity of laughter were guided by the same acoustic properties and were highly correlated, suggesting spontaneous-sounding laughter is rewarding to perceivers (Bachorowski & Owren, 2001; Lavan et al., 2015). Judgments of reward, affiliation, and dominance were guided by distinct acoustic patterns that enabled a random forest model to predict perceiver judgments with good accuracy.

Study 2 participants did not have high agreement with one another about which social functional smile category was most similar in meaning to the laugh samples used in Study 1. It seems that the cross-modal task of matching subtly different dynamic facial expressions to sequentially-presented vocalization samples is a challenging one. The noisy data meant that Study 2 had insufficient observations to recover the "true" smile-laughter similarity embedding, should one exist, so it will be necessary to collect additional responses in the future. With the current data we nonetheless found support for the social functional categories assigned to the laugh samples based on Study 1 participants' verbal judgments. If participants were entirely unable to extract similar social meaning from smiles and laughter, the laugh samples would not have clustered in the 2-D embedding according to their Study 1 category assignment. Reward and affiliation laughs were more frequently selected as semantically similar to reward and affiliation smiles, respectively, than other combinations of smiles and laughs. Participants did not seem to think dominance laughs belonged with dominance smiles, however. Whether this is because of the biological implausibility of some of the cross-modal mappings or because the dominance laughs and dominance smiles convey different messages should be investigated by using only within-actor (or at least within-gender) smile-laugh pairs. More broadly, Study 2 developed a template for how pre-validated nonverbal signals in one modality (here, smiles) can help identify, without relying on explicit verbal probes, the perceived social functions in another modality (laughter).

Study 3 identified several acoustic properties of laughter that varied systematically and within-subject across conversational contexts. Some of the variables closely mapped onto Study 1, and they were all interpretable based on the existing human and nonhuman vocalization literature. Laughter in the dominance video viewing condition was most distinct from laughter in the other conditions, which is somewhat surprising. Speculatively, the affiliation and reward video contexts may have had too much overlap in terms of the relevant social tasks, which future work using a different laughter elicitation technique could unpack. Future work should code Study 3's laughs according to whether they were responses to the video stimuli rather than tangential conversation. Affiliation laughter, which we have argued subsumes most so-called "social" or "conversational" laughter, likely occurred across the 3 video viewing contexts, allowing the participants to signal agreement with their partner and ease any tension that might arise from discomfort about the video content, uncomfortable pauses in the conversation, technology mishaps, and the like.

Several of the Study 3 acoustic findings converged with size code hypothesis predictions, such as laughter during dominance-eliciting videos having a lower harmonics-to-noise ratio (Pisanski et al., 2014). Even though the first and second formant distance variable did not significantly differ between contexts once we adjusted p values to control the false discovery rate, the pattern was in the direction predicted by the size code hypothesis and related to the second formant finding from Study 1. Size code hypothesis aside, a notable observation emerged as we were extracting the laughter samples. Anecdotally, we found substantial variability in the vowels of non-speech-laughter (for examples, see **Figure 10**). This runs in the face of claims that laughter primarily involves central vowels (/ə/ or /ɑ/, as in prototypical "ha ha" laughter; Szameitat, Alter, Szameitat, Wildgruber, et al., 2009; cf., Szameitat et al., 2011; Tanaka & Campbell, 2011; Urbain & Dutoit, 2011).

Future directions

Another important and still-untapped contribution of Study 3 is the huge number of speech-laughter instances extracted. Some of these are instances of laugh-like prosody coloring speech (Kohler, 2008), but many instances sounded like truly spontaneous and uncontrollable laughter co-occurring with utterances (Nwokah et al., 1999). We suggest that prior claims that uncontrollable laughter inherently overrides speech production systems (Lavan et al., 2015) may be a partial artifact of the laughter elicitation paradigms used in previous work. Study 3 involved a novel paradigm that fostered conversation dense with laughter, which may have encouraged so-called spontaneous laughter to co-occur more regularly with speech. Future work that analyzes the properties of Study 3's speech-laughter sample should pursue these ideas.

The ultimate goal of this work is to be able to accurately predict social outcomes—both in the short-term of an interaction and in the long-term of a relationship—from acoustic analysis of laughter samples. To that end, future work must improve the poor performance of the machine learning models trained on Study 3 data. A more sophisticated deep learning approach and the addition of other acoustic variables would likely improve the predictive performance of models trained on Study 1 and Study 3 data (perhaps in combination). Human perceivers' inferences from the voice rely on more than 11 or 12 "variables," so future work that incorporates more measures will provide a richer picture of rewarding-, affiliative-, and dominant-sounding laughter. Of particular interest are variables that are not automatically obtainable from acoustic analysis software, such as the syllable rate of laughter, within-vocalization shifts in formants, and the pitch contour of a laugh bout, all of which are predicted to be important by the size code hypothesis (Bryant, 2013; Myers-Schulz et al., 2013; Snowdon, 2003). Formant analysis of the vowel portions of laughter, rather than averaged over the entire laugh sample, may also provide a more nuanced picture of how vowel modulation differs as a function of a laugh's social meaning. Still, the fact that the acoustic differences emerged in laughter across the Study 3 social contexts suggests there may be signals contained in the current 12 acoustic variables that a sophisticated classifier could learn to recognize.

It would also be informative to have naïve participants rate the social meaning of Study 3 laughter samples. Because we take a social functional perspective that emphasizes the communicative, social regulatory function of nonverbal behavior, we are most interested in *successful* signals of reward, affiliation, and dominance. Just as the social functional perspective rejects a strong read-out account of nonverbal behavior—that is to say, the idea that expressive behavior is determined entirely by emotional states—we should be careful not to over-emphasize features of the context, such as the content of humorous videos. Not all laughs produced while people are watching derision-worthy videos are expected to serve a dominance-signaling function, for instance. Combining a priori contextual information with naïve perceivers' judgments about laughter elicited in those contexts, and training a classifier on that combined information, may be the best route moving forward.

Conclusion

This dissertation lays the groundwork for developing a behavioral coding system for inferring the social intentions of laughers from acoustic data. Considering laughter makes up, by one estimate, 10% of vocalizations during conversation (Laskowski & Burger, 2007), the ability to accurately infer social motivations and predict future social responses using acoustic properties of laughter would have powerful implications for artificial intelligence, clinical diagnosis, and psychological behavior coding methods.

More generally, the current work demonstrates how a social functional perspective can be used to explain and predict variability in interpersonal behavior. The social functional approach, which draws from human and animal ethology, relates observable communicative acts to observable social behaviors and interpersonal consequences. Interpersonal signals like laughter are indicators of possible future behavior that function to elicit desired responses from recipients. While nonverbal behaviors correlate moderately with self-reported emotions, we suggest we will gain more predictive power by framing nonverbal behaviors as cues that elicit reliable behavioral responses. Once the reliable physical indicators (in the current work, the acoustic properties of a laugh) are identified, researchers can apply a social functional model to naturally-occurring interactions without the need for disruptive and subjective measurement procedures, such as self-report. The current approach can be extended to describe and predict other classes of nonverbal behavior, such as facial expression (we have recently applied it to smiles; Martin et al., 2017), particularly if it is expanded to include other salient tasks of social living beyond reward, affiliation, and dominance.

References

Adelswärd, V. (1989). Laughter and dialogue: The social significance of laughter in institutional discourse. *Nordic Journal of Linguistics*, *12*(2), 107–136.

Alexander, R. D. (1986). Ostracism and indirect reciprocity: The reproductive significance of humor. *Ethology and Sociobiology*, *7*(3–4), 253–270. https://doi.org/10.1016/0162-3095(86)90052-X

Arminen, I., & Halonen, M. (2007). Laughing with and at patients: The roles of laughter in confrontations in addiction group therapy. *Qualitative Report*, *12*(3), 484–513.

Bachorowski, J.-A., & Owren, M. J. (2001). Not all laughs are alike: Voiced but not unvoiced laughter readily elicits positive affect. *Psychological Science*, *12*(3), 252–257.

Bachorowski, J.-A., Smoski, M. J., & Owren, M. J. (2001). The acoustic features of human laughter. *The Journal of the Acoustical Society of America*, *110*(3), 1581–17.

Bänziger, T., & Scherer, K. R. (2005). The role of intonation in emotional expressions. *Speech Communication*, *46*(3), 252–267.

Barrett, L. F. (2006). Are emotions natural kinds? *Perspectives on Psychological Science*, *1*(1), 28–58.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Beddor, P. S. (1993). The perception of nasal vowels. *Nasals, Nasalization, and the Velum*, *5*, 171–196.

Bekoff, M. (1984). Social play behavior. *Bioscience*, *34*(4), 228–233.

Bekoff, M. (1995). Play signals as punctuation: The structure of social play in canids. *Behaviour*, *132*(5/6), 419–429.

Bell, N. D. (2009a). Impolite responses to failed humor. *Humor in Interaction*, 143–163.

Bell, N. D. (2009b). Responses to failed humor. *Journal of Pragmatics*, *41*(9), 1825–1836. https://doi.org/10.1016/j.pragma.2008.10.010

Benjamini, Y., Drai, D., Elmer, G., Kafkafi, N., & Golani, I. (2001). Controlling the false discovery rate in behavior genetics research. *Behavioural Brain Research*, *125*(1), 279–284. https://doi.org/10.1016/S0166-4328(01)00297-2

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, 289–300.

Bloch, L., Haase, C. M., & Levenson, R. W. (2014). Emotion regulation predicts marital satisfaction: More than a wives' tale. *Emotion*, *14*(1), 130.

Blomqvist, C., Mello, I., & Amundin, M. (2005). An acoustic play-fight signal in bottlenose dolphins (Tursiops truncatus) in human care. *Aquatic Mammals*, *31*(2), 187–194.

Boersma, P., & Weenink, D. (2016). *Praat: doing phonetics by computer [computer program]. Version 6.0. 05*.

Bonanno, G. A., & Mayne, T. J. (2001). The future of emotion research. *Emotions: Current Issues and Future Directions*, 398–410.

Borkowska, B., & Pawlowski, B. (2011). Female voice frequency in the context of dominance and attractiveness perception. *Animal Behaviour*, *82*(1), 55–59.

Boxer, D., & Cortés-Conde, F. (1997). From bonding to biting: Conversational joking and identity display. *Journal of Pragmatics*, *27*(3), 275–294. https://doi.org/10.1016/S0378-2166(96)00031-8

Bradbury, J. W. & Vehrencamp, S. L. (2011). *Principles of animal communication* (2nd edition). Sunderland, MA: Sinauer Associates, Inc., Publishers.

Brauer, M., & Curtin, J. J. (2017). Linear Mixed-Effects Models and the Analysis of Nonindependent Data: A Unified Framework to Analyze Categorical and Continuous Independent Variables that Vary Within-Subjects and/or Within-Items. *Psychological Methods*. doi: 10.1037/met0000159

Brescoll, V. L., & Uhlmann, E. L. (2008). Can an angry woman get ahead? Status conferral, gender, and expression of emotion in the workplace. *Psychological Science, 19*(3), 268–275.

Briefer, E. (2012). Vocal expression of emotions in mammals: Mechanisms of production and evidence. *Journal of Zoology*, *288*(1), 1–20.

Brody, L. R. (2000). The socialization of gender differences in emotional expression: Display rules, infant temperament, and differentiation. *Gender and Emotion: Social Psychological Perspectives*, 24–47.

Bryant, G. A. (2013). Animal signals and emotion in music: Coordinating affect across groups. *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00990

Bryant, G. A., & Aktipis, C. A. (2014). The animal nature of spontaneous human laughter. *Evolution and Human Behavior*, *35*(4), 327–335.

Bryant, G. A., Fessler, D. M. T., Fusaroli, R., Clint, E., Aarøe, L., Apicella, C. L., … Zhou, Y. (2016). Detecting affiliation in colaughter across 24 societies. *Proceedings of the*

National Academy of Sciences, *113*(17), 4682–4687. https://doi.org/10.1073/pnas.1524993113

Bryant, J., Brown, D., Parks, S. L., & Zillmann, D. (1983). Children's imitation of a ridiculed model. *Human Communication Research*, *10*(2), 243–255. https://doi.org/10.1111/j.1468-2958.1983.tb00013.x

Bryant, J., Hezel, R., & Zillmann, D. (1979). Humor in children's educational television. *Communication Education*, *28*(1), 49–59.

Calder, A. J., Young, A. W., Rowland, D., & Perrett, D. I. (1997). Computer-Enhanced Emotion in Facial Expressions. *Proceedings: Biological Sciences*, *264*(1383), 919–925.

Chapman, A. J., & Wright, D. S. (1976). Social enhancement of laughter: An experimental analysis of some companion variables. *Journal of Experimental Child Psychology*, *21*(2), 201–218. https://doi.org/10.1016/0022-0965(76)90034-5

Cowen, A. S., & Keltner, D. (2017). Self-report captures 27 distinct categories of emotion bridged by continuous gradients. *Proceedings of the National Academy of Sciences*, *114*(38), E7900–E7909. https://doi.org/10.1073/pnas.1702247114

Crivelli, C., & Fridlund, A. J. (2018). Facial Displays Are Tools for Social Influence. *Trends in Cognitive Sciences*, *22*(5), 388–399. https://doi.org/10.1016/j.tics.2018.02.006

Curry, O. S., & Dunbar, R. I. M. (2013). Sharing a joke: The effects of a similar sense of humor on affiliation and altruism. *Evolution and Human Behavior*, *34*(2), 125–129. https://doi.org/10.1016/j.evolhumbehav.2012.11.003

Davila-Ross, M., Owren, J.M., & Zimmermann, E. (2009). Reconstructing the evolution of laughter in great apes and humans. *Current Biology*, *19*(13), 1106–1111. https://doi.org/10.1016/j.cub.2009.05.028

Davila-Ross, M., Allcock, B., Thomas, C., & Bard, K. A. (2011). Aping expressions? Chimpanzees produce distinct laugh types when responding to laughter of others. *Emotion (Washington, D.C.)*, *11*(5), 1013–1020.

de Gelder, B. (2017). Going native. Emotion science in the twenty-first century. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.01212

de Waal, F. B. M. (1986). The integration of dominance and social bonding in primates. *The Quarterly Review of Biology*, *61*(4), 459–479.

Devereux, P. G., & Ginsburg, G. P. (2001). Sociality effects on the production of laughter. *The Journal of General Psychology*, *128*(2), 227–240. https://doi.org/10.1080/00221300109598910

Dezecache, G., & Dunbar, R. I. M. (2012). Sharing the joke: the size of natural laughter groups. *Evolution and Human Behavior*, *33*(6), 775–779. https://doi.org/10.1016/j.evolhumbehav.2012.07.002

Drew, P. (1987). Po-faced receipts of teases. *Linguistics*, *25*(1), 219–253.

Drews, C. (1993). The concept and definition of dominance in animal behaviour. *Behaviour*, *125*(3), 283–313.

Dunbar, R. I. M., Baron, R., Frangou, A., Pearce, E., van Leeuwen, E. J. C., Stow, J., … van Vugt, M. (2012). Social laughter is correlated with an elevated pain threshold. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1731), 1161–1167. https://doi.org/10.1098/rspb.2011.1373

Dunlop, R. A. (2017). Potential motivational information encoded within humpback whale non-song vocal sounds. *The Journal of the Acoustical Society of America*, *141*(3), 2204–2213.

Eibl-Eibesfeldt, I. (2017). *Human ethology*. New York: Routledge.

Ellsworth, P. C., & Scherer, K. R. (2003). Appraisal processes in emotion. *Handbook of Affective Sciences*, *572*, V595.

Fernández-Dols, J.-M., & Crivelli, C. (2013). Emotion and expression: Naturalistic studies. *Emotion Review*, *5*(1), 24–29.

Field, T. (1979). Games parents play with normal and high-risk infants. *Child Psychiatry & Human Development*, *10*(1), 41–48.

Filippelli, M., Pellegrino, R., Iandelli, I., Misuri, G., Rodarte, J. R., Duranti, R., … Scano, G. (2001). Respiratory dynamics during laughter. *Journal of Applied Physiology*, *90*(4), 1441–1446. https://doi.org/10.1152/jappl.2001.90.4.1441

Fischer, A. H., & Manstead, A. S. R. (2008). Social functions of emotion. In M. Lewis, J. Haviland, & L. Feldman Barrett (Eds.), *Handbook of Emotion* (3rd ed., pp. 456–469). New York: Guilford.

Fitch, W. T. (1997). Vocal tract length and formant frequency dispersion correlate with body size in rhesus macaques. *The Journal of the Acoustical Society of America*, *102*(2), 1213–1222. https://doi.org/10.1121/1.421048

Fitch, W. T. (2000). The evolution of speech: A comparative review. *Trends in Cognitive Sciences*, *4*(7), 258–267.

Fitch, W. T., & Hauser, M. D. (2003). Unpacking "honesty": Vertebrate vocal production and the evolution of acoustic signals. In *Acoustic Communication* (pp. 65–137). New York: Springer. https://doi.org/10.1007/0-387-22762-8_3

Fogel, A., Dickson, K. L., Hsu, H., Messinger, D., Nelson-Goens, G. C., & Nwokah, E. (1997). Communication of smiling and laughter in mother-infant play: Research on emotion from a dynamic systems perspective. *New Directions for Child and Adolescent Development*, *1997*(77), 5–24. https://doi.org/10.1002/cd.23219977702

Fredrickson, B. L., Roberts, T.-A., Noll, S. M., Quinn, D. M., & Twenge, J. M. (1998). That Swimsuit Becomes You: Sex Differences in Self-Objectification, Restrained Eating, and Math Performance. *Journal of Personality and Social Psychology*, *75*(1), 269–284.

Fridlund, A. J. (1991). Evolution and facial action in reflex, social motive, and paralanguage. *Biological Psychology*, *32*(1), 3–100. https://doi.org/10.1016/0301-0511(91)90003-Y

Fridlund, A. J. (2014). *Human facial expression: An evolutionary view*. San Diego, CA: Academic Press.

Gervais, M., & Wilson, D. S. (2005). The evolution and functions of laughter and humor: A synthetic approach. *The Quarterly Review of Biology*, *80*(4), 395–430.

Glenn, P. (2003). *Laughter in interaction* (Vol. 18). Cambridge: Cambridge University Press.

Gordon, N. S., Burke, S., Akil, H., Watson, S. J., & Panksepp, J. (2003). Socially-induced brain 'fertilization': play promotes brain derived neurotrophic factor transcription in the amygdala and dorsolateral frontal cortex in juvenile rats. *Neuroscience Letters*, *341*(1), 17–20.

Goudbeek, M., Goldman, J. P., & Scherer, K. R. (2009). Emotion dimensions and formant position. In *Tenth Annual Conference of the International Speech Communication Association* (pp. 1575-578).

Grammer, K. (1990). Strangers meet: Laughter and nonverbal signs of interest in opposite-sex encounters. *Journal of Nonverbal Behavior*, *14*(4), 209–236. https://doi.org/10.1007/BF00989317

Grammer, K., & Eibl-Eibesfeldt, I. (1990). The ritualisation of laughter. *Natürlichkeit Der Sprache Und Der Kultur*, *18*, 192–214.

Gray, A. W., Parkinson, B., & Dunbar, R. I. (2015). Laughter's influence on the intimacy of self-disclosure. *Human Nature*, *26*(1), 28–43. https://doi.org/10.1007/s12110-015-9225-8

Greengross, G. (2013). Humor and aging - A mini-review. *Gerontology*, *59*(5), 448–453. https://doi.org/10.1159/000351005

Griffiths, L. (1998). Humour as resistance to professional dominance in community mental health teams. *Sociology of Health & Illness*, *20*(6), 874–895. https://doi.org/10.1111/1467-9566.00133

Groh, A. M., & Roisman, G. I. (2009). Adults' autonomic and subjective emotional responses to infant vocalizations: The role of secure base script knowledge. *Developmental Psychology*, *45*(3), 889-893. doi: 10.1037/a0014943

Hecht, J., & Horowitz, A. (2015). Introduction to dog behavior. In *Animal Behaviour for Shelter Veterinarians and Staff* (pp. 5-30). London: Wiley-Blackwell.

Henton, C. G., & Bladon, R. A. W. (1985). Breathiness in normal female speech: Inefficiency versus desirability. *Language & Communication*, *5*(3), 221–227. https://doi.org/10.1016/0271-5309(85)90012-6

Herring, D. R., Burleson, M. H., Roberts, N. A., & Devine, M. J. (2011). Coherent with laughter: Subjective experience, behavior, and physiological responses during amusement and joy. *International Journal of Psychophysiology*, *79*(2), 211–218. https://doi.org/10.1016/j.ijpsycho.2010.10.007

Hodges-Simeon, C. R., Gaulin, S. J., & Puts, D. A. (2010). Different vocal parameters predict perceptions of dominance and attractiveness. *Human Nature*, *21*(4), 406–427.

Hudenko, W. J., Stone, W., & Bachorowski, J.-A. (2009). Laughter differs in children with Autism: An acoustic analysis of laughs produced by children with and without the disorder. *Journal of Autism and Developmental Disorders*, *39*(10), 1392–1400. https://doi.org/10.1007/s10803-009-0752-1

Hugill, N., Fink, B., Neave, N., Besson, A., & Bunse, L. (2011). Women's perception of men's sensation seeking propensity from their dance movements. *Personality and Individual Differences*, *51*(4), 483–487.

Jamieson, K. G., Jain, L., Fernandez, C., Glattard, N. J., & Nowak, R. (2015). Next: A system for real-world development, evaluation, and application of active learning. *Advances in Neural Information Processing Systems*, 2656–2664.

Jürgens, U. (2002). Neural pathways underlying vocal control. *Neuroscience & Biobehavioral Reviews*, *26*(2), 235–258. https://doi.org/10.1016/S0149-7634(01)00068-9

Keltner, D., & Bonanno, G. A. (1997). A study of laughter and dissociation: Distinct correlates of laughter and smiling during bereavement. *Journal of Personality and Social Psychology*, *73*(4), 687-702.

Keltner, D., & Buswell, B. N. (1997). Embarrassment: Its distinct form and appeasement functions. *Psychological Bulletin*, *122*(3), 250-270.

Keltner, D., & Gross, J. J. (1999). Functional accounts of emotions. *Cognition and Emotion*, *13*(5), 467–480.

Keltner, D., & Haidt, J. (1999). Social functions of emotions at four levels of analysis. *Cognition and Emotion*, *13*(5), 505–521. https://doi.org/10.1080/026999399379168

Kohler, K. J. (2008). 'Speech-smile', 'speech-laugh', 'laughter' and their sequencing in dialogic interaction. *Phonetica*, *65*(1–2), 1–18. https://doi.org/10.1159/000130013

Kruskal, J. B. (1964). Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika*, *29*(1), 1–27.

Kuhn, M., & others. (2008). Caret package. *Journal of Statistical Software*, *28*(5), 1–26.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2015). Package ‘lmerTest.’ *R Package, Version 2*.

Larsen, D., & Watson, J. J. (2001). A guide map to the terrain of gift value. *Psychology & Marketing; Hoboken*, *18*(8), 889–906.

Lasarcyk, E., & Trouvain, J. (2008). Spread lips+ raised larynx+ higher f0= smiled speech? An articulatory synthesis approach. *Proceedings of ISSP*, 43–48.

Laskowski, K., & Burger, S. (2007). On the correlation between perceptual and contextual aspects of laughter in meetings. *Proc. ICPhS WS on Phonetics of Laughter*, 55–60.

Laukka, P., Juslin, P., & Bresin, R. (2005). A dimensional approach to vocal expression of emotion. *Cognition & Emotion*, *19*(5), 633–653.

Lavan, N., Scott, S. K., & McGettigan, C. (2015). Laugh like you mean it: Authenticity modulates acoustic, physiological and perceptual properties of laughter. *Journal of Nonverbal Behavior*, *40*(2), 133-149.

Leger, D. W. (1993). Contextual sources of information and responses to animal communication signals. *Psychological Bulletin*, *113*(2), 295-304.

Lewis, M. (1997). The self in self-conscious emotions. *Annals of the New York Academy of Sciences*, *818*(1), 119–142.

Liaw, A., & Wiener, M. (2002). Classification and Regression by randomForest. *R News*, *2*(3), 18–22.

Makagon, M. M., Funayama, E. S., & Owren, M. J. (2008). An acoustic analysis of laughter produced by congenitally deaf and normally hearing college students. *The Journal of the Acoustical Society of America*, *124*(1), 472–12.

Manninen, S., Tuominen, L., Dunbar, R., Karjalainen, T., Hirvonen, J., Arponen, E., … Nummenmaa, L. (2017). Social laughter triggers endogenous opioid release in humans. *Journal of Neuroscience, 37*(25), 6125-6131. https://doi.org/10.1523/JNEUROSCI.0688-16.2017

Martin, G. N., & Gray, C. D. (1996). The effects of audience laughter on men's and women's responses to humor. *The Journal of Social Psychology*. *136*(2), 221-231.

Martin, J., Rychlowska, M., Wood, A., & Niedenthal, P. (2017). Smiles as Multipurpose Social Signals. *Trends in Cognitive Sciences*, *21*(11), 864–877. https://doi.org/10.1016/j.tics.2017.08.007

Martin, J., Wood, A., Cox, W. T. L., Sievert, S., Nowak, R., & Niedenthal, P. (under review). Encoding and decoding of social functional smiles depend on similar morphological features.

Martin, R. A. (2010). *The psychology of humor: An integrative approach*. San Diego: Academic press.

Matsumura, S., & Hayden, T. J. (2006). When should signals of submission be given?–A game theory model. *Journal of Theoretical Biology*, *240*(3), 425–433. https://doi.org/10.1016/j.jtbi.2005.10.002

Mauss, I. B., Levenson, R. W., McCarter, L., Wilhelm, F. H., & Gross, J. J. (2005). The tie that binds? Coherence among emotion experience, behavior, and physiology. *Emotion*, *5*(2), 175-190.

McGettigan, C., & Scott, S. K. (2014). Voluntary and involuntary processes affect the production of verbal and non–verbal signals by the human voice. *Behavioral and Brain Sciences*, *37*(6), 564–565.

McGettigan, C., Walsh, E., Jessop, R., Agnew, Z. K., Sauter, D. A., Warren, J. E., & Scott, S. K. (2015). Individual differences in laughter perception reveal roles for mentalizing and sensorimotor systems in the evaluation of emotional authenticity. *Cerebral Cortex*, *25*(1), 246–257. https://doi.org/10.1093/cercor/bht227

McGraw, A. P., & Warren, C. (2010). Benign violations: Making immoral behavior funny. *Psychological Science*, *21*(8), 1141–1149.

McKeown, G., Sneddon, I., & Curran, W. (2014). Gender differences in the perceptions of genuine and simulated laughter and amused facial expressions. *Emotion Review*, *7*(1), 30–38.

Mehu, M., & Dunbar, R. I. M. (2008). Naturalistic observations of smiling and laughter in human group interactions. *Behaviour*, *145*(12), 1747–1780.

Menezes, C., & Igarashi, Y. (2006). The speech laugh spectrum. *Proc. Speech Production, Brazil*, 157–164.

Morton, E. S. (1977). On the occurrence and significance of motivation-structural rules in some bird and mammal sounds. *The American Naturalist*, *111*(981), 855–869. https://doi.org/10.1086/283219

Myers-Schulz, B., Pujara, M., Wolf, R. C., & Koenigs, M. (2013). Inherent emotional quality of human speech sounds. *Cognition & Emotion*, *27*(6), 1105–1113. https://doi.org/10.1080/02699931.2012.754739

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, *33*(06), 417–433.

Nwokah, E. E., Hsu, H.-C., Davies, P., & Fogel, A. (1999). The Integration of Laughter and Speech in Vocal Communication: A Dynamic Systems Perspective. *Journal of Speech, Language, and Hearing Research*, *42*(4), 880–894. https://doi.org/10.1044/jslhr.4204.880

Nwokah, E. E., Hsu, H.-C., Dobrowolska, O., & Fogel, A. (1994). The development of laughter in mother-infant communication: Timing parameters and temporal sequences. *Infant Behavior and Development*, *17*(1), 23–35. https://doi.org/10.1016/0163-6383(94)90019-1

Ohala, J. J. (1983). Cross-language use of pitch: An ethological view. *Phonetica*, *40*(1), 1–18.

Otovic, P., Partan, S. R., Bryant, J. B., & Hutchinson, E. (2014). Let's call a truce…for now: The silent bared-teeth face expression in Mandrills (Mandrillus sphinx) during baseline and post-conflict conditions. *Ethology*, *120*(11), 1118–1127. https://doi.org/10.1111/eth.12285

Otten, M., Mann, L., van Berkum, J. J. A., & Jonas, K. J. (2017). No laughing matter: How the presence of laughing witnesses changes the perception of insults. *Social Neuroscience*, *12*(2), 182–193. https://doi.org/10.1080/17470919.2016.1162194

Oveis, C., Spectre, A., Smith, P. K., Liu, M. Y., & Keltner, D. (2016). Laughter conveys status. *Journal of Experimental Social Psychology*, *65*, 109–115.

Overeem, S., Lammers, G. J., & Dijk, J. van. (1999). Weak with laughter. *The Lancet*, *354*(9181), 838. https://doi.org/10.1016/S0140-6736(99)80023-3

Owren, M. J., & Bachorowski, J.-A. (2003). Reconsidering the evolution of nonlinguistic communication: The case of laughter. *Journal of Nonverbal Behavior*, *27*(3), 183–200. https://doi.org/10.1023/A:1025394015198

Panksepp, J., & Biven, L. (2012). *The archaeology of mind: Neuroevolutionary origins of human emotions*. New York: WW Norton & Company.

Panksepp, J., & Burgdorf, J. (2003). "Laughing" rats and the evolutionary antecedents of human joy? *Physiology & Behavior*, *79*(3), 533–547.

Pisanski, K., Cartei, V., McGettigan, C., Raine, J., & Reby, D. (2016). Voice modulation: A window into the origins of human vocal control? *Trends in Cognitive Sciences*, *20*(4), 1–15.

Pisanski, K., Fraccaro, P. J., Tigue, C. C., O'Connor, J. J. M., Röder, S., Andrews, P. W., … Feinberg, D. R. (2014). Vocal indicators of body size in men and women: a meta-analysis. *Animal Behaviour*, *95*, 89–99. https://doi.org/10.1016/j.anbehav.2014.06.011

Provine, R. R. (1993). Laughter punctuates speech: Linguistic, social and gender contexts of laughter. *Ethology, 95,* 291-298.

Provine, R. R. (2001). *Laughter: A scientific investigation*. New York: Penguin Books.

Provine, R. R. (2004). Laughing, tickling, and the evolution of speech and self. *Current Directions in Psychological Science*, *13*(6), 215–218. https://doi.org/10.1111/j.0963-7214.2004.00311.x

Puts, D. A., Gaulin, S. J., & Verdolini, K. (2006). Dominance and the evolution of sexual dimorphism in human voice pitch. *Evolution and Human Behavior*, *27*(4), 283–296.

R Development Core Team. (2008). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org

Riem, M. M. E., van IJzendoorn, M. H., Tops, M., Boksem, M. A. S., Rombouts, S. & Bakermans-Kranenburg, M. J. (2012). No laughing matter: Intranasal oxytocin administration changes functional brain connectivity during exposure to infant laughter. *Neuropsychopharmacology*, *37*(5), 1257–1266. https://doi.org/10.1038/npp.2011.313

Riters, L. V. (2012). The role of motivation and reward neural systems in vocal communication in songbirds. *Frontiers in Neuroendocrinology*, *33*(2), 194–209. https://doi.org/10.1016/j.yfrne.2012.04.002

Rothbart, M. K. (1973). Laughter in young children. *Psychological Bulletin*, *80*(3), 247-256.

Rothgänger, H., Hauser, G., Cappellini, A. C., & Guidotti, A. (1998). Analysis of laughter and speech sounds in Italian and German students. *The Science of Nature, 85*(8), 394–402. https://doi.org/10.1007/s001140050522

Rowell, T. E. (1974). The concept of social dominance. *Behavioral Biology*, *11*(2), 131–154. https://doi.org/10.1016/S0091-6773(74)90289-2

Rubenstein, J. L., & Howes, C. (1979). Caregiving and infant behavior in day care and in homes. *Developmental Psychology*, *15*(1), 1-24.

Rychlowska, M., Jack, R. E., Garrod, O. G. B., Schyns, P. G., Martin, J. D., & Niedenthal, P. M. (2017). Functional smiles: Tools for love, sympathy, and war. *Psychological Science, 28*(9), 1259-1270. https://doi.org/10.1177/0956797617706082

Sakamaki, T. (2011). Submissive pant–grunt greeting of female chimpanzees in Mahale Mountains National Park, Tanzania. *African Study Monographs, 32*(1), 25-41.

Schaller, M., Kenrick, D. T., Neel, R., & Neuberg, S. L. (2017). Evolution and human motivation: A fundamental motives framework. *Social and Personality Psychology Compass*, *11*(6), [e12319]. doi: 10.1111/spc3.12319

Schubert, E., & Wolfe, J. (2006). Does timbral brightness scale with frequency and spectral centroid? *Acta Acustica United with Acustica*, *92*(5), 820–825.

Scott, S. K., Lavan, N., Chen, S., & McGettigan, C. (2014). The social life of laughter. *Trends in Cognitive Sciences*, *18*(12), 618–620. https://doi.org/10.1016/j.tics.2014.09.002

Shaw, C., Hepburn, A., & Potter, J. (2013). Having the last laugh: On post-completion laughter particles. In (Eds.) P. Glenn & E. Holt, *Studies of Laughter in Interaction* (pp. 91–106). London: Bloomsbury Academic.

Sievert, S., Ross, D., Jain, L., Jamieson, K., Nowak, R., & Mankoff, R. (2017). NEXT: A system to easily connect crowdsourcing and adaptive data collection. *Proceedings of the 16th Python in Science Conference*, 113-119.

Simonet, P., Versteeg, D., & Storie, D. (2005). Dog-laughter: Recorded playback reduces stress related behavior in shelter dogs. In *Proceedings of the 7th International Conference on Environmental Enrichment*.

Smith, J. M., & Price, G. R. (1973). The logic of animal conflict. *Nature*, *246*(5427), 15–18.

Smoski, M., & Bachorowski, J.-A. (2003). Antiphonal laughter between friends and strangers. *Cognition and Emotion*, *17*(2), 327–340. https://doi.org/10.1080/02699930302296

Snowdon, C. T. (2003). Expression of emotion in nonhuman animals. In (Eds.) R.J. Davidson, K.R. Scherer, & H.H. Goldsmith, *Handbook of Affective Sciences* (pp. 457–480). Oxford: Oxford University Press.

Snowdon, C. T., & Teie, D. (2013). Emotional communication in monkeys: music to their ears? In (Eds.) E. Altenmüller, S. Schmidt, & E. Zimmerman, *The Evolution of Emotional Communication: From Sounds in Nonhuman Mammals to Speech and Music in Man* (pp. 133–151). Oxford: Oxford Scholarship.

Specter Beddor, P., & Hawkins, S. (1984). The "center of gravity" and perceived vowel height. *The Journal of the Acoustical Society of America*, *75*(S1), S86–S87.

Spinka, M., Newberry, R. C., & Bekoff, M. (2001). Mammalian play: Training for the unexpected. *Quarterly Review of Biology*, *76*(2), 141-168.

Sroufe, L. A., & Wunsch, J. P. (1972). The development of laughter in the first year of life. *Child Development*, *43*(4), 1326–1344. https://doi.org/10.2307/1127519

Szameitat, D. P., Alter, K., Szameitat, A. J., Darwin, C. J., Wildgruber, D., Dietrich, S., & Sterr, A. (2009). Differentiation of emotions in laughter at the behavioral level. *Emotion*, *9*(3), 397–405.

Szameitat, D. P., Alter, K., Szameitat, A. J., Wildgruber, D., Sterr, A., & Darwin, C. J. (2009). Acoustic profiles of distinct emotional expressions in laughter. *The Journal of the Acoustical Society of America*, *126*(1), 354–366. https://doi.org/10.1121/1.3139899

Szameitat, D. P., Darwin, C. J., Szameitat, A. J., Wildgruber, D., & Alter, K. (2011). Formant characteristics of human laughter. *Journal of Voice*, *25*(1), 32–37.

Szameitat, D. P., Wildgruber, D., & Alter, K. (2013). Vocal expression of emotions in laughter. In (Eds.) E. Altenmüller, S. Schmidt, & E. Zimmerman, *The Evolution of Emotional Communication: From Sounds in Nonhuman Mammals to Speech and Music in Man* (pp. 191–198). Oxford: Oxford Scholarship.

Tamuz, O., Liu, C., Belongie, S., Shamir, O., & Kalai, A. T. (2011). Adaptively learning the crowd kernel. *ArXiv Preprint ArXiv:1105.1033*.

Tanaka, H., & Campbell, N. (2011). Acoustic features of four types of laughter in natural conversational speech. *Proceedings of the 17th International Congress of Phonetic Sciences*, 1958–1961.

Taylor, A. M., & Reby, D. (2010). The contribution of source–filter theory to mammal vocal communication research. *Journal of Zoology*, *280*(3), 221–236. https://doi.org/10.1111/j.1469-7998.2009.00661.x

Ten Bosch, L., Oostdijk, N., & Boves, L. (2005). On temporal aspects of turn taking in conversational dialogues. *Speech Communication*, *47*(1), 80–86.

Tracy, J. L., & Randles, D. (2011). Four models of basic emotions: a review of Ekman and Cordaro, Izard, Levenson, and Panksepp and Watt. *Emotion Review*, *3*(4), 397–405.

Tracy, J. L., & Robins, R. W. (2007). The psychological structure of pride: a tale of two facets. *Journal of Personality and Social Psychology*, *92*(3), 506.

Urbain, J., & Dutoit, T. (2011). A phonetic analysis of natural laughter, for use in automatic laughter processing systems. In (Eds.) S. D’Mello, A. Graesser, B. Schuller, & J.-C. Martin, *International Conference on Affective Computing and Intelligent Interaction* (pp. 397–406). New York: Springer.

Van Hooff, J. A. (1972). A comparative approach to the phylogeny of laughter and smiling. In (Ed.) R.A. Hinde, *Non-Verbal Communication* (pp. 209-241). Cambridge: University Press.

Van Kleef, G. A. (2009). How emotions regulate social life: The emotions as social information (EASI) model. *Current Directions in Psychological Science*, *18*(3), 184–188. https://doi.org/10.1111/j.1467-8721.2009.01633.x

Vanderschuren, L. J., Stein, E. A., Wiegant, V. M., & Van Ree, J. M. (1995). Social play alters regional brain opioid receptor binding in juvenile rats. *Brain Research*, *680*(1), 148–156.

Vettin, J., & Todt, D. (2004). Laughter in conversation: Features of occurrence and acoustic structure. *Journal of Nonverbal Behavior*, *28*(2), 93–115. https://doi.org/10.1023/B:JONB.0000023654.73558.72

Vettin, J., & Todt, D. (2005). Human laughter, social play, and play vocalizations of non-human primates: An evolutionary approach. *Behaviour*, *142*(2), 217–240. https://doi.org/10.1163/1568539053627640

Waller, B. M., & Dunbar, R. I. M. (2005). Differential behavioural effects of silent bared teeth display and relaxed open mouth display in chimpanzees (Pan troglodytes). *Ethology*, *111*(2), 129–142. https://doi.org/10.1111/j.1439-0310.2004.01045.x

Weisfeld, G. E. (1993). The adaptive value of humor and laughter. *Ethology and Sociobiology*, *14*(2), 141–169. https://doi.org/10.1016/0162-3095(93)90012-7

Weiss, B., & Burkhardt, F. (2010). Voice attributes affecting likability perception. In *Eleventh Annual Conference of the International Speech Communication Association* (pp. 2014-2017).

Wild, B., Rodden, F. A., Grodd, W., & Ruch, W. (2003). Neural correlates of laughter and humour. *Brain*, *126*(10), 2121–2138. https://doi.org/10.1093/brain/awg226

Wiley, R. H. (1994). Errors, exaggeration, and deception in animal communication. In L. Real (Ed.), *Behavioral mechanisms in evolutionary ecology* (pp. 157–189). Chicago, IL: University of Chicago Press.

Wood, A., Martin, J., & Niedenthal, P. (2017). Towards a social functional account of laughter: Acoustic features convey reward, affiliation, and dominance. *PLOS ONE*, *12*(8), e0183811. https://doi.org/10.1371/journal.pone.0183811

Wood, A., & Niedenthal, P. (2018). Developing a social functional account of laughter. *Social and Personality Psychology Compass*, *12*(4). https://doi-org.ezproxy.library.wisc.edu/10.1111/spc3.12383

Wood, A., Rychlowska, M., Korb, S., & Niedenthal, P. (2016). Fashioning the face: Sensorimotor simulation contributes to facial expression recognition. *Trends in Cognitive Sciences*, *20*(3), 227–240. https://doi.org/10.1016/j.tics.2015.12.010

Xu, Y., & Chuenwattanapranithi, S. (2007). Perceiving anger and joy in speech through the size code. In *Proceedings of the International Conference on Phonetic Sciences* (pp. 2105–2108).

Xu, Y., Lee, A., Wu, W.-L., Liu, X., & Birkholz, P. (2013). Human vocal attractiveness as signaled by body size projection. *PLOS ONE*, *8*(4), e62397. https://doi.org/10.1371/journal.pone.0062397

Yarkoni, T., & Westfall, J. (2017). Choosing prediction over explanation in psychology: Lessons from machine learning. *Perspectives in Psychological Science*, *12*(6): 1100-1122, doi: 10.1177/1745691617693393

Yuan, J. W., McCarthy, M., Holley, S. R., & Levenson, R. W. (2010). Physiological down-regulation and positive emotion in marital interaction. *Emotion*, *10*(4), 467-474.

Zhu, R., Zeng, D., & Kosorok, M. R. (2015). Reinforcement Learning Trees. *Journal of the American Statistical Association*, *110*(512), 1770–1784. https://doi.org/10.1080/01621459.2015.1036994

Zuk, G., Boszormenyi-Nagy, I., & Heiman, E. (1963). Some dynamics of laughter during family therapy. *Family Process*, *2*(2), 302–314.