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Warm Hands, Warm Hearts: An Investigation of Physical Warmth as a Prepared Safety Stimulus

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Recent work has demonstrated that social support figures seem to be particularly robust inhibitors of the Pavlovian fear response. Specifically, social support figures appear to act as *prepared safety stimuli*, stimuli that have played an important role in mammalian survival and are thus less easily associated with threat and more able to inhibit the fear response. Given some of the shared behavioral and neural consequences of both social support and physical warmth, as well as the importance of physical warmth for mammalian survival, we conducted a series of examinations designed to examine whether physical warmth is also a prepared safety stimulus. In two studies conducted in human adults, we examined whether a physically warm stimulus was less readily associated with threat (compared to soft or neutral stimuli; Study 1) and was able to inhibit the fear response elicited by other threatening cues (compared to neutral stimuli; Study 2). Results showed that physical warmth resisted association with threat (Study 1) and not only inhibited the fear response but also led to lasting inhibition even after the warm stimulus was removed (Study 2). Together, these studies indicate that physical warmth, like social support, meets the requirements of being a prepared safety stimulus, and they pave the way for future work to clarify the properties that enable cues in this category to naturally inhibit fear responding.

Keywords: physical warmth, safety, prepared stimuli, Pavlovian fear conditioning, social support

Supplemental materials: https://doi.org/10.1037/emo0000925.supp

Recent work has revealed that social support figures have powerful inhibitory effects on both Pavlovian fear learning and fear responding (hereafter referred to simply as fear learning and fear responding; Hornstein & Eisenberger, 2018; Hornstein et al., 2016). Specifically, social support figures are the first demonstrated *prepared safety stimuli*, stimuli that have historically enhanced survival and have therefore come to be less easily associated with threat and able to inhibit fear responding (Hornstein & Eisenberger, 2017; Hornstein et al., 2016, 2018). This combination of effects is unique in the Pavlovian fear conditioning literature, in which inhibitors typically require learning (Rescorla, 1969) and have detrimental effects on long-term fear occurrence and recurrence, leading to enhanced fear acquisition (Dickinson, 1976; Rescorla, 1971) and impaired fear extinction (Leung et al., 2016; Lovibond et al., 2000; Rescorla, 1969). Yet, thus far, social support figures are the only identified members of the prepared safety category, leaving questions as to whether there are other cues endowed with this novel ability to inhibit fear responding without specific training and in both the short- and long-term. Given literature showing overlapping consequences of social connection and physical warmth, not to mention their common, central role in mammalian survival, here we explored whether physical warmth is also a natural inhibitor of the fear response that is able to reduce fear learning.

Importantly, although we use the term "fear" here to embed this work in a long line of research on Pavlovian fear learning processes, we are not using the term fear to refer to the self-reported experience of fear. Instead, we define fear as "emerging from the coordinated action of brain and behavioral systems that evolved for the purpose of defense from environmental dangers" (Fanselow & Pennington, 2018). Moreover, consistent with the large literature on Pavlovian fear conditioning, we use the term "threat" when referring to stimuli that signal danger and the term fear when referring to responses to that threat.

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Within the defensive response system, certain types of cues are considered “prepared” to be associated with and to more readily lead to certain types of behavioral and physiological responses. Hence, preparedness is the ability to more easily associate certain historically survival-relevant stimuli with certain survival-related outcomes (Bolles, 1970; Garcia & Koelling, 1966; Seligman, 1970). In particular, cues that predict harm or threat should more easily become associated with aversive or negative outcomes, and cues that predict safety should less easily become associated with aversive or negative outcomes. Research focused on the contingencies that predict harm or threat have resulted in understanding of *prepared fear stimuli*, cues that have historically threatened survival (e.g., snakes and spiders) and are more easily and robustly associated with aversive outcomes such that once learned to be feared, they typically remain feared (Garcia & Koelling, 1966; Öhman & Mineka, 2001; Seligman, 1971). Only recently, however, have studies started to investigate the contingencies that predict safety and the cues that might be prepared safety stimuli (Hornstein & Eisenberger, 2018).

Social support figures, who play a crucial role in survival by providing care, security, and resources, have been demonstrated to act as prepared safety stimuli. Drawing from tests used to identify the most powerful, learned safety signals (conditioned inhibitors for the fear response; Rescorla, 1969), recent work has examined whether reminders of social-support figures (in the form of pictures) naturally resist becoming associated with threat (retardation-of-acquisition test) and inhibit the fear response elicited by other, threatening cues (summation test; Hornstein & Eisenberger, 2018). Results of this work have demonstrated that social-support cues pass both tests without any specific, in-lab safety training (which is required for conditioned inhibitors) and thus meet the requirements for being prepared safety stimuli (Hornstein et al., 2016). In other words, while typical, learned safety signals only emerge after specific training in the lab and only inhibit fear responding for the specific aversive events with which they were trained (Holland, 1991; Rescorla, 1969), prepared safety stimuli, in this case social-support cues, carry their ability to inhibit fear of novel aversive events into novel experimental sessions. Whether this inhibitory ability is well learned in early life or innately conferred, the unique capability of these cues to inhibit fear across time, context, and various aversive events is notable. Furthermore, this capability is suggestive that these cues play a central role in systems designed to detect and respond to threat, specifically in a protective function.

Interestingly, this work has also revealed that social-support cues specifically, and perhaps prepared safety stimuli in general, have lasting inhibitory effects on the fear response such that even after their removal, there is no return of fear for threatening cues previously paired with images of social-support figures either immediately (Hornstein et al., 2016) or 24 hr later (Hornstein et al., 2018). This is in direct contrast with what is found with typical learned safety signals, which, although they inhibit fear responding while present, prevent fear extinction and lead to return of previous or even higher levels of fear responding upon removal (protection from extinction; Lovibond et al., 2000; Rescorla, 1971). This contrast suggests that prepared safety stimuli may signal safety via a different mechanism and represent a distinct class of safety signals with divergent, and beneficial, effects that lead to lasting fear reduction. These ideas are particularly significant as impaired inhibitory learning and safety signal processing is thought to play a role in disorders such as anxiety and posttraumatic stress disorder (PTSD), leading to the persistence of symptoms following treatment (Craske et al., 2018; Garfinkel et al., 2014). Still, investigations of the prepared safety category are in the early stages, and questions remain as to what other cues might be prepared to be safe and the properties that enable them to naturally inhibit fear responding. Given the importance of physical warmth for social attachment processes in animals (Harlow & Suomi, 1970), the close links between physical warmth and social connection in humans (Inagaki & Eisenberger, 2013; Williams & Bargh, 2008), as well as the central role of physical warmth in mammalian survival, it is possible that physical warmth may also act as a prepared safety stimulus.

Animal and human research suggests that, in addition to meeting basic survival needs, physical warmth may be a critical component of social support or close social contact and thus may have similar effects on fear responding. For instance, although Harlow was best known for his work highlighting the importance of “contact comfort” for social connection and attachment (Harlow, 1958; Harlow & Zimmermann, 1959), his later work demonstrated the importance of physical warmth. Thus, infant monkeys, separated since birth from their mothers, could easily become attached to a warm cloth mother but could not become attached to a cold cloth mother and instead would actively avoid it (Baysinger et al., 1973; Harlow & Suomi, 1970). Additionally, only the warm cloth mother was treated as a source of safety; infants exposed to threat stimuli in the presence of a warm cloth mother would run and cling to her, whereas infants exposed to threat stimuli in the presence of a cold cloth mother would run to and huddle in the corner of the cage away from the cloth mother (Harlow & Suomi, 1970). In fact, based on these findings, some have suggested that the primary importance of contact comfort or softness may actually come from the fact that softness promotes warmth by trapping air and reducing heat loss (Alberts & May, 1984). Hence, these findings highlight the possibility that warmth (and possibly softness, through its ability to promote warmth) is prepared to be associated with social attachment and safety.

Importantly, the link between physical warmth and social contact extends to other animal models as well, including rats and pigeons (Blumberg et al., 1992; Stone et al., 1976; Wasserman, 1973). For instance, rat pups produce isolation distress vocalizations when separated from their mothers, but these can be reduced by simply placing pups in a warm room (though a hot room will increase these distress vocalizations, highlighting the important difference between warmth, which can be comforting, versus heat, which can be aversive; Blumberg et al., 1992). Moreover, pigeons trained to associate a physical warmth reinforcer with a light cue exhibited affiliative or “snuggling” behavior toward the light, and this behavior persisted even when it later prevented physical warmth from occurring (Wasserman, 1973), displaying a robust and persistent link between untrained affiliative responses and cues associated with physical warmth. These findings suggest that warmth may innately foster feelings of social affiliation and comfort, lending itself to more easily become associated with safety.

Work in humans offers support for this view as well, demonstrating that physical warmth has reliable effects on feelings of social connection. Research investigating these effects has shown that the experience of physical warmth can increase feelings of affiliation, social connection, and intimacy (Bargh et al., 2012; Inagaki & Eisenberger, 2013; Williams & Bargh, 2008), reduce feelings of loneliness (Murphy & Standing, 2014), and even increase decisions to trust another (Kang et al., 2011). Moreover, some work has shown that physical warmth is sought out among individuals experiencing low levels of social connection or social rejection (Bargh & Shalev, 2012). Finally, recent work has revealed that physical warmth shares underlying neural circuitry with social connection processes (Inagaki & Eisenberger, 2013), providing additional evidence that social support and physical warmth may share overlapping properties.

In order to investigate whether physical warmth is prepared to be safe, we conducted two studies to investigate whether, like a social-support figure stimulus, a physically warm stimulus was able to pass both tests of a conditioned inhibitor (Rescorla, 1969), but without requiring any specific, in-lab training to do so. In both studies, the physically warm stimulus was a single-use warm pack activated at the start of the experimental session. The choice to use warm packs was based on two factors. First, there is evidence to suggest that localized heat, not warm ambient temperature, is more likely to hold safety properties. Specifically, previous work in rat pups has shown that an odor that was previously paired with a warm object later elicited comfort-seeking behavior in the form of huddling preferences, while an odor that was previously paired with warm air temperature did not (Kojima & Alberts, 2011). Second, the warm pack itself provides a safe method of applying localized heat in the lab setting that is nonthreatening for participants. Thus, while warm packs are only one specific source of physical warmth and therefore contribute limitations to the generalizability of the current results, they are well suited for these initial investigations into the impact of physically warm stimuli on acquired fear associations during Pavlovian fear conditioning.

To assess fear responding, we used skin conductance responses (SCR), a measure of sympathetic nervous system activity. SCR is a well-accepted and frequently used measure of responding within the human Pavlovian fear conditioning paradigm as a gauge of acquired threat associations (Delgado et al., 2006; Lonsdorf et al., 2017). For example, during a conditioning procedure in which two matched images (for which all else has been held constant; i.e., context, valence, preexposure, duration, number of presentations) are repeatedly presented, one with a coterminating shock and one without, any observed differences in responding to these images can be attributed to the impact of the shock pairing. Therefore, higher SCR for the image previously paired with shock (vs. SCR for the image never paired with shock) can be interpreted to stem from the learned expectation that a shock will occur and consequent engagement of the threat-response system. Building on this, safety in the human Pavlovian fear conditioning context is defined as reduced or inhibited expectation of an aversive outcome and distinguished by no engagement of the threat-response system, as measured by lower SCR. Thus, cues that signal safety reduce fear responding.

Using these materials and methods, in Study 1, we tested whether a warm stimulus naturally resisted becoming associated with threat, not coming to elicit a fear response for a novel, uncomfortable shock following an acquisition procedure (retardation-of-acquisition test). Additionally, although it has been suggested that the importance of contact comfort or softness may come from its ability to increase warmth (Alberts & May, 1984), based on the work of Harlow showing the importance of contact comfort during attachment behavior (Harlow, 1958) and the frequent presence of soft sensations at times of comfort, in Study 1, we conducted an exploratory examination of whether a soft stimulus also naturally resisted becoming associated with threat. In Study 2, we tested whether a warm stimulus was able to inhibit fear responding, preventing a fear response from occurring in response to another stimulus already associated with shock (summation test). Together, these studies shed light on the role of physical warmth as a prepared safety stimulus.

Study 1: Examining Whether Physical Warmth Passes the Retardation-of-Acquisition Test

We used a fear acquisition procedure to determine whether typical fear learning occurred for neutral control objects, while fear learning was reduced for a physically warm object. We also explored whether fear learning was reduced for a soft object.

Method

Sample Size Determination

An a priori power analysis was conducted using data from a similar study in which fear acquisition for different stimuli was investigated (in this case, different types of images; Hornstein et al., 2016). Using the findings from this work (Cohen's $f = .74$), the power analysis revealed that we could evaluate the effects of interest using a repeated-measures analysis of variance (ANOVA) to assess the presence of fear responses across conditions during acquisition at greater than 95% power ($\alpha = .05$) using a sample size of $n = 27$ (actual power = .951). Based on this power analysis as well as previous work using similar Pavlovian fear conditioning procedures to assess differences in fear learning (current team: Hornstein et al., 2016, 2018; other research teams: Olsson et al., 2005; Olsson & Phelps, 2004; Phelps et al., 2004; Schiller et al., 2008, 2010), we decided upon a target of $n = 30$ participants for this study.

Participants

Data were analyzed from a total of 31 participants (M age = 20.7, 21 female; 42% Caucasian, 36% Asian/Asian American, 16% Hispanic/Latinx, 3% African/African American, 3% Middle Eastern). In total, 49 participants were enrolled, but data from 18 were excluded due to having incomplete data or uninterpretable physiological responses: Three participants withdrew midsession and did not complete the experimental procedures, nine participants experienced technical errors during their sessions (for five of these participants, no event markers were recorded in the SCR recordings due to hardware malfunction, resulting in no way to determine when stimuli were presented; for the other four, software crashes midsession prevented experimental procedures from being completed), five participants did not have usable SCR (recordings included too much noise to be reliably processed and analyzed), and one participant was considered to be a "low responder" (see below for discussion of this exclusion criterion). All participants were recruited at the University of California, Los Angeles (UCLA), and all experimental procedures were approved by the UCLA Institutional Review Board.

Procedure

Telephone Screening. Prospective participants first completed a brief telephone screening. Participants were excluded from participating if they were pregnant, had a history of mental illness, or were currently taking any mental-health-related medication.

SCR Screening Session. Based on current recommendations (Lonsdorf et al., 2017), eligible participants attended the lab prior to the experimental session to determine if the experimental equipment could detect their SCR, an index of physiological arousal (please see online supplemental materials for more information). Participants for whom SCR could not be detected were excluded from participating in the following experimental session.

Experimental Session. At the beginning of the experimental session, participants underwent a shock calibration procedure to determine level of shock for each participant individually such that shocks were extremely uncomfortable but not painful (please see online supplemental materials for more details). Throughout the experiment, participants' SCR was recorded as a measure of fear responding.

Participants then underwent a fear conditioning session with three stages: habituation, acquisition, and extinction. During the session, different objects were placed in participants' right hands (conditional stimuli [CSs]) in order to generate different tactile conditions: an activated warm pack (physical warmth condition), a fuzzy ball (softness condition), a rubber ball (neutral condition), and a wooden block (second neutral condition to serve as a baseline). For each stage, objects were presented in a pseudorandom order that was counterbalanced across participants, and all objects were placed in participants' hands for 6 s, followed by a 10-s interstimulus interval (ISI; please see online supplemental materials for more discussion of objects chosen).

During the habituation stage, participants were presented with each CS three times, and none of the presentations were reinforced (no shock). This allowed for assessment of baseline arousal due to holding each object, and a comparison revealed no significant differences in baseline arousal across the four CSs (three future CS+s, one future CS−), $F(3, 90) = .315$, $p = .815$, $\eta_p^2 = .010$, indicating that CS+s had no preexisting characteristics that could account for later differences in arousal.

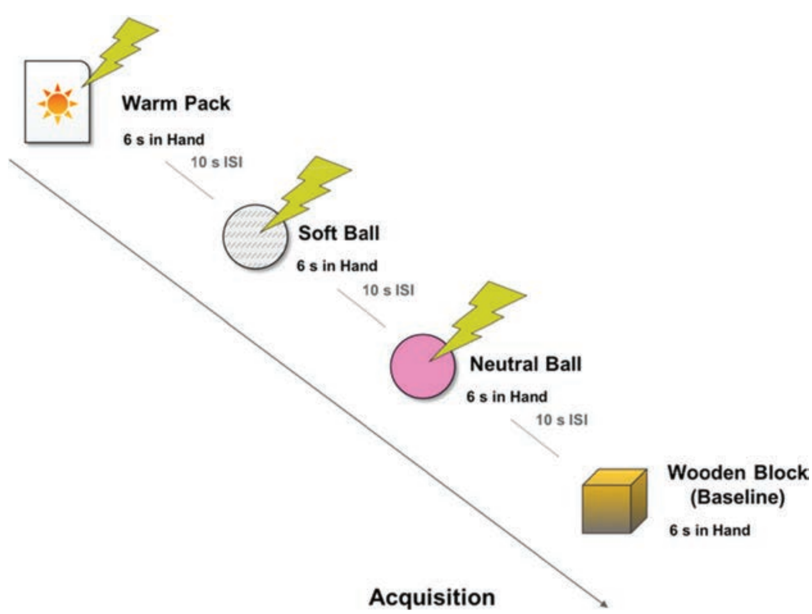
During the acquisition stage, participants were presented with each CS six times: three CSs (warm pack, fuzzy ball, rubber ball) were each presented consistently followed by a coterminating 200-ms electric shock (CS+s: 100% reinforcement schedule), and one CS (wooden block) was never paired with shock (CS−; Figure 1). Participants then had a short break, during which they watched a 5-min video about airplanes. Following this was the extinction stage, during which participants were presented with each CS six times and no shock was administered (it should be noted that use of a 100% reinforcement schedule and similar numbers of trials have been shown to reliably lead to fear acquisition in past research; Hornstein et al., 2016, 2018; Olsson & Phelps, 2004; Olsson et al., 2005).

Data Analysis

Preprocessing. SCR data were preprocessed using recommendations from Figner and Murphy (2011). First, a low-pass filter and smoothing were applied. Peak-to-peak values were then evaluated for each trial (stimulus presentation) by measuring peak-to-peak amplitude in microsiemens (μS) for the largest response that occurred between 0.5 and 4.5 s after a stimulus was placed in a participant's hand. Square root transformations were then used to normalize these measurements.

If a trial occurred during which there was no peak (no rise in SCR during the 0.5–4.5-s response window) or the peak-to-peak

Figure 1
Methods From the Acquisition Stage of Study 1



Note. Different objects were placed in participants' right hands. Warm, soft, and neutral objects were consistently presented with a coterminating 200-ms electric shock (CS+s), and a neutral object was never paired with shock (baseline: CS−). See the online article for the color version of this figure.

amplitude measure did not meet the threshold of .02 μS, the trial was scored as a zero-response trial. If movement occurred during the trial, as noted by the experimenter during the experimental session, that trial was excluded from analysis.

If a participant exhibited peak-to-peak amplitudes that met threshold on fewer than 25% of the trials during the acquisition stage, at the beginning of which they were informed shocks would be co-occurring with certain images and during which shocks were applied on 75% of the trials, they were considered to be "low responders" and were removed from data analysis. This was done in order to exclude such cases in which it is unclear if low numbers of responses are due to low levels of learned fear responding or simply due to lack of attention or low aversiveness of the shock. All exclusion criteria were determined based on previous work and current recommendations for SCR data collection and processing (Figner & Murphy, 2011; Hornstein & Eisenberger, 2017; Hornstein et al., 2016, 2018; Olsson et al., 2005; Schiller et al., 2010).

Scoring. Habituation was evaluated by examining SCR from the entire habituation stage, using a habituation mean for each condition that was calculated by averaging across all of the habituation trials. Acquisition was evaluated by examining SCR from the final 66.67% of the acquisition stage, using an acquisition mean for each condition that was calculated using the final four trials for each condition (CS−, three CS+s; see below for discussion of selection of trials). Postacquisition was evaluated by examining SCR during the very beginning of the extinction stage (directly following the acquisition procedure and before any extinction learning had occurred), using the first trial of the extinction stage for each condition (see below for discussion of selection of trials).

The choice to calculate the acquisition mean using the final four trials of the acquisition stage was made to keep analyses similar to our previous work in which the acquisition mean was calculated using the final 66.67–75% of trials during acquisition. However, if we calculate the acquisition mean using the final 50% of trials during acquisition (final three trials), we see the same pattern of results (please see online supplemental materials for more details).

The choice to use only the first trial of the extinction stage to assess postacquisition responding was made in order to assess fear responding before any extinction learning occurred. However, if we use the first two trials, we see a similar pattern of effects (please see online supplemental materials for more details).

Data Analysis Strategy. For each stage, we ran a within-subjects ANOVA comparing SCR for all CS types (three CS+s: warmth, softness, neutral; one CS−) followed by specific planned comparisons in order to test our hypotheses. Specifically, we tested whether SCR was significantly higher for any CS+ compared to the baseline CS−, indicating the presence of a conditional fear response. In additional analyses, we evaluated differences in SCR across CS+s to assess differences in fear responding across conditions. For all post hoc comparisons, we conducted Benjamini-Hochberg (BH) corrections (Benjamini & Hochberg, 1995; McDonald, 2009) in order to adjust our p values to account for multiple comparisons (presented here along with uncorrected, exact p values).

The presence of a conditional fear response during the acquisition stage was considered to mean that fear was acquired in that condition. Further evaluation of acquisition was conducted using responses from the beginning of the extinction stage; specifically, we assessed responding during the first trial of extinction following the end of the acquisition procedure and ensuing break. The presence of a conditional fear response during this first trial postacquisition was considered to confirm that fear was acquired in that condition.

Results

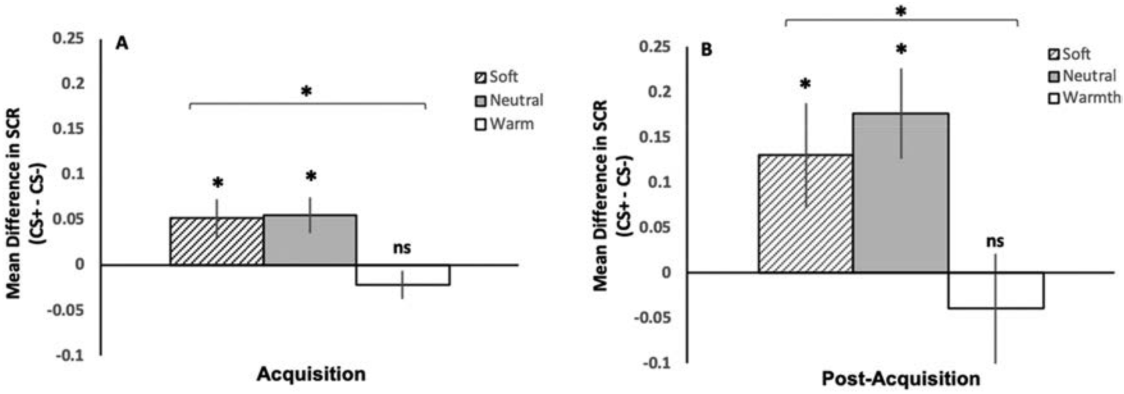
Acquisition Stage

Results from the acquisition stage showed there was a significant difference in fear learning across conditions (warmth CS+, soft CS+, neutral CS+, and neutral CS−), $F(3, 90) = 8.607$, $p < .001$, $\eta_p^2 = .277$ (obtained Cohen's $f = .62$). Post hoc analyses first examined whether a fear response was acquired in each condition. These analyses revealed that SCR was significantly higher for both the soft stimulus CS+ ($M = .179$ μS, $SD = .149$ μS) and the neutral stimulus CS+ ($M = .183$ μS, $SD = .151$ μS) compared to the neutral stimulus CS− ($M = .127$ μS, $SD = .101$ μS; softness: $p_{BH} = .020$, $p_{uncorrected} = .012$, 95% CI [−.091, −.012]; neutral: $p_{BH} = .020$, $p_{uncorrected} = .013$, [−.098, −.013]), indicating that conditional fear was acquired in both the softness and neutral conditions, but not for the warm stimulus CS+ ($M = .106$ μS, $SD = .101$ μS) compared to the CS− ($p_{BH} = .203$, $p_{uncorrected} = .169$; [−.10, .053]), indicating no conditional fear was acquired in the warmth condition (all reported confidence intervals here and throughout the article are constructed around the difference of the sample means). Additional comparisons revealed that SCR was significantly higher for the soft and neutral stimulus CS+s compared to the warm stimulus CS+ (softness: $p_{BH} < .001$, $p_{uncorrected} = .001$, [−.110, −.037]; neutral: $p_{BH} < .001$, $p_{uncorrected} = .001$, [−.117, −.037]) but that there was no difference in SCR across the soft and neutral stimulus CS+s ($p_{BH} = .833$, $p_{uncorrected} = .833$; [−.038, .031]), (please see Figure 2A).

Postacquisition (Extinction Stage)

This pattern of results persisted beyond the acquisition stage. Examination of SCR during the first trial of the extinction stage demonstrated that there was a significant difference in fear responding occurring across all conditional stimuli (three CS+s, one CS−), $F(3, 90) = 6.46$, $p = .001$, $\eta_p^2 = 117$. Post hoc analyses revealed that SCR was significantly higher for both the soft stimulus CS+ ($M = .287$ μS, $SD = .343$ μS) and the neutral stimulus CS+ ($M = .117$ μS, $SD = .234$ μS) compared to the neutral stimulus CS− ($M = .157$ μS, $SD = .251$ μS; softness: $p_{BH} = .048$, $p_{uncorrected} = .032$, 95% CI [−.249, −.012]; neutral: $p_{BH} = .006$, $p_{uncorrected} = .001$, [−.279, −.074]), while there was no difference in SCR for the warm stimulus CS+ ($M = .117$ μS, $SD = .234$ μS) compared to the CS− ($p_{BH} = .521$, $p_{uncorrected} = .521$, [−.085, .164]), indicating that a conditional fear response continued to be elicited by both soft and neutral CS+s but none was elicited by the warm CS+. Additional comparisons revealed that SCR remained signficantly higher for both the soft and neutral CS+s compared to the warm CS+ (softness: $p_{BH} = .034$, $p_{uncorrected} = .017$, [−.307, −.033]; neutral: $p_{BH} = .003$, $p_{uncorrected} = .001$, [−.329, −.102]), yet there was no difference across the soft and neutral stimulus CS+s ($p_{BH} = .440$, $p_{uncorrected} = .367$, [−.149, .057]). These results demonstrate that while other tactile stimuli can become associated with threat, physical warmth resists becoming associated with a fear response and therefore passes the retardation-of-acquisition test (please see Figure 2B).

Figure 2
Results From the Acquisition and Postacquisition (Extinction) Stages of Study 1



Note. All error bars indicate standard error. Asterisks indicate a significant difference score ($p < .05$), and "ns" indicates no significant difference. SCR = skin conductance responses; CS = conditional stimulus. Panel A: Acquisition stage: Results show that a conditional fear response was acquired for soft and neutral stimuli, but not for warm stimuli, demonstrating that physical warmth passes the retardation-of-acquisition test. Panel B: Postacquisition (extinction) stage: Results show that soft and neutral stimuli continue to elicit a conditional fear response, while none is elicited by warm stimuli.

It is noteworthy that the soft stimulus did not pass the retardation-of-acquisition test. This could be taken to indicate that the "contact comfort" component of many warm stimuli, while pleasurable, is not necessary or sufficient for a stimulus to be prepared to be safe. However, the soft stimulus used for the current work, a fuzzy ball, was simply placed in participants' hands, which may not have fully created the feeling of softness brushing the skin or may have compressed the material and reduced its softness. Additionally, to the extent that softness provides safety through its ability to promote warmth, the kind of soft stimulus used (i.e., a soft ball) may not have been well suited to promote warmth (i.e., as opposed to a soft blanket). Therefore, it cannot be conclusively determined whether softness is not prepared to be safe. However, due to the different types of stimuli that may be needed to more thoroughly test this question (moving a material across the skin as opposed to placing an object in the hand or using a warm blanket instead of a soft ball), we completed Study 2 using only warm and neutral stimuli. Thus, further work is required to determine whether softness is a member of the prepared safety category.

Study 2: Examining Whether Physical Warmth Passes the Summation Test

Following Study 1, we went on to examine whether physical warmth passes the summation test. Specifically, we used a summation procedure to examine whether fear responding associated with separate cues was inhibited when participants held warm, but not neutral, stimuli.

Method

Sample Size Determination

An a priori power analysis was conducted using data from a similar study in which the effect of added stimuli on fear responding to CS+s was investigated (in this case, the added stimuli were different types of images; Hornstein et al., 2016). Using the findings from this work (Cohen's $f = .58$), we conducted a power analysis that revealed that we could evaluate the effects of interest using a repeated-measures ANOVA to assess whether a conditional fear response was present during summation at greater than 95% power ($\alpha = .05$) using a sample size of $n = 20$ (actual power = .952). Based on this power analysis as well as previous work examining the effects of added stimuli on fear inhibition (Lovibond et al., 2000: $n = 26$ [Study 1], $n = 20$ [Study 2]; Hornstein et al., 2018: $n = 30$), we selected a target of $n = 30$ participants for this study.

Participants

Data were analyzed from a total of 30 participants (*M* age = 20.6, 22 female; 47% Caucasian, 27% Asian/Asian American, 23% Hispanic/Latinx, 3% African/African American). In total, 45 participants were enrolled, but data from 15 were excluded due to having incomplete data, uninterpretable physiological responses, or not having acquired a conditional fear response for both CS+s: Two participants dropped out, two participants did not have usable SCR data, two participants were considered to be "low responders," and nine participants did not acquire conditional fear responses to both CS+s during the acquisition procedures (please see discussion of this exclusion criterion below). All participants were recruited at UCLA, and all procedures were approved by the UCLA Institutional Review Board.

Procedure

Telephone & SCR Screening. Participant screening procedures used in Study 1 were also used in Study 2. In particular, the telephone screening and SCR screening session were used to determine participant eligibility based on criteria desribed in Study 2.

Experimental Session. At the beginning of the experimental session, the shock calibration procedure was conducted as described in Study 1. Participants then went through a fear conditioning session with four different stages: habituation, acquisition, summation, and test. During all stages, participants were presented with three images of neutral objects (CSs: cup, stool, clock), two of which were consistently paired with shock during the acquisition stage (CS+s: stool, clock) and one of which was never paired with shock (CS−: cup; Figure 3A). During the following summation stage, each neutral-image CS+ was consistently copresented with the placement of an object in participants' hands to generate different conditions: A warm pack was used to create a warmth-paired condition (CS+/warm stimulus), and a rubber ball was used to create a neutral-paired condition (CS+/neutral stimulus). In addition, in order to create a baseline for comparison, the CS− was paired with a wooden block to create a neutral-paired-baseline condition (CS−/neutral stimulus; Figure 3B). For each stage, CSs or CS/object pairings were presented in a pseudorandom order that was counterbalanced across participants, and all CS or CS/object presentations were 10 s long, followed by a 20-s ISI (these presentations and ISIs were lengthened to reduce generalization of the object pairings across CSs).

During the habituation stage, participants viewed three nonreinforced presentations of each neutral-image CS to allow for assessment of baseline arousal to these images. Comparisons revealed no differences in baseline arousal across the CSs (two future CS+s and one future CS−), $F(2, 58) = 1.273$, $p = .288$, $\eta_p^2 = .042$.

During the acquisition stage, participants viewed four presentations of two CS images consistently paired with a coterminating 200-ms electric shock (CS+s: stool, clock; 100% reinforcement schedule) and eight presentations of one CS never paired with shock (CS−: cup). Participants then had a short break, during which they watched a 3-min video clip about airplanes. Following this was the summation stage, during which participants viewed four nonreinforced presentations of each CS+ consistently paired with one object (warm pack, rubber ball) and of the CS− consistently paired with one object (wooden block). Each object was placed in participants' hands for the entire duration of its paired CS presentation. The CS+/stimulus pairings were counterbalanced across participants such that each CS+ type was equally paired with each object (warm pack, rubber ball) and the CS− was always paired with the neutral wooden block, resulting in three conditions as described above: warmth paired (CS+/warm stimulus), neutral paired (CS+/neutral stimulus), and neutral-paired baseline (CS−/neutral stimulus). Participants then watched another 3-min video clip about airplanes.

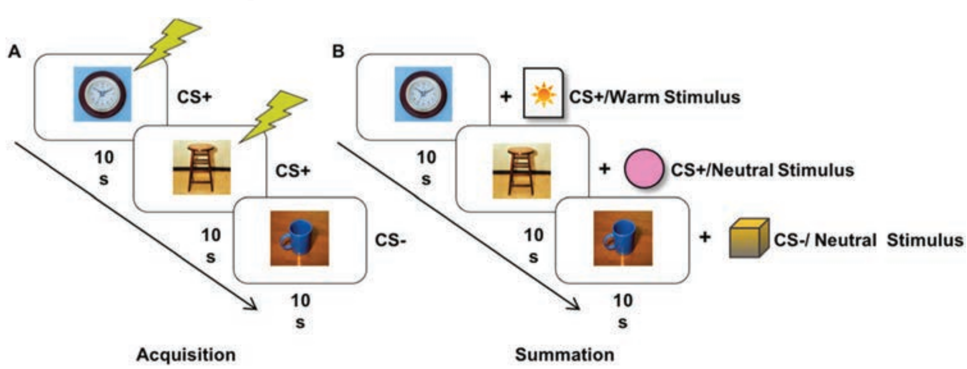
The final stage was the test stage. During this stage, participants viewed four nonreinforced presentations of each original CS+ and the CS− images alone, with no objects presented.

Data Analysis

Preprocessing. The same preprocessing procedures as described in Study 1 were used in Study 2, with the following addition. Because we were interested in assessing the impact of tactile conditions on inhibition of acquired fear responses during summation, it was necessary that participants first acquire a conditional fear response to all CS+s for which we were later evaluating fear inhibition and extinction. Thus, for each participant, we assessed whether fear acquisition occurred for both neutral CS+s (stool, clock) by comparing the acquisition mean for each CS+ to that of the CS− (cup). If an acquisition mean for either CS+ was not higher than that of the CS− (CS+ > CS−), then the participant's data was excluded from further analysis. This resulted in the exclusion of data from nine participants (one did not acquire a fear response for either CS+, and eight acquired fear responses for one but not both CS+s).

Scoring. Habituation was evaluated by examining SCR from the entire habituation stage, using a habituation mean for each condition that was calculated by averaging across all of the habituation trials. Acquisition was evaluated by examining SCR from the final 75% of the acquisition stage, using an acquisition mean that was calculated using the final six out eight trials for the CS− and the final three out of four trials for the CS+s. Summation was evaluated by examining the beginning of the summation stage—the first trials during which CS+s and CS−s were presented with

Figure 3
Procedures From the Acquisition and Summation Stages of Study 2



Note. Panel A: During the acquisition stage, two neutral-image conditional stimuli (CSs) were consistently presented with a coterminating 200-ms electric shock (CS+s), and one was never paired with shock (CS−). Panel B: During the summation stage, different objects were placed in participants' hands when each image was presented, and no shock occurred. One CS+ was paired with a warm stimulus, one CS+ was paired with a neutral stimulus, and the CS− was presented with a second neutral stimulus. Not pictured is the test stage during which all CSs were presented on their own once more in the absence of any objects or shock. The clock, stool, and cup pictures shown here were used in the actual study and were taken from the International Affective Picture Set. See the online article for the color version of this figure.

paired stimuli in the absence of shock—using summation means that were calculated by averaging across the first two trials for each condition. Although we used the first two trials of summation here to match procedures used in previous studies (Hornstein et al., 2016, 2018), the same pattern of effects is found if we use only the first trial (please see online supplemental materials for details). Return of the fear response was evaluated by examining SCR during the very beginning of the test stage (directly following the summation procedure and before any extinction learning had occurred), using the first trial of the test stage for each condition. This scoring procedure uses the same format as those used in previous summation studies (Hornstein et al., 2016, 2018).

Data Analysis Strategy. As mentioned above, in order to ensure that each CS+ elicited a conditional fear response that could later be inhibited during the summation stage or return during the test stage, we determined whether each participant acquired a fear response for each of the two CS+s by assessing whether the acquisition mean was greater for each CS+ than the CS− (CS+ − CS− > 0; if a fear response was not acquired for both CS+s, a participant's data was excluded from further analysis). Acquisition means for the included participants were analyzed to confirm that a conditional fear response was present for each of the two CS+s later to be paired with warm or neutral objects. These analyses revealed a difference in fear learning across all CSs (two CS+s, one CS−), $F(2, 58) = 44.00$, $p < .001$, $\eta_p^2 = .603$, and follow-up comparisons revealed that SCR was significantly higher for the CS+ later to be paired with a neutral object (M = .245 μS, SD = .121 μS) and the CS+ later to be paired with a warm object (M = .274 μS, SD = .149 μS) compared to the CS− (M = .111 μS, SD = .101 μS; warm: $p_{BH} < .001$, $p_{uncorrected} < .001$, 95% CI [−.203, −.124]; neutral: $p_{BH} < .001$, $p_{uncorrected} = .001$, [−.180, −.107]), but there was no difference across the two CS+s ($p_{BH} = .324$, $p_{uncorrected} = .324$, [−.021, .061]), indicating that fear acquisition occurred and was equivalent in both conditions.

For each stage, we ran a within-subjects ANOVA to assess differences in responding across the CS-object pairings (summation) or neutral-image CSs (test), followed by specific planned comparisons in order to test our hypotheses by assessing whether a fear response occurred in each pairing condition—comparing SCR for each CS+/object pairing or CS+ to the baseline CS−/object pairing or CS−. An additional comparison was conducted to assess differences in fear responding across CS+ pairing conditions. For all post hoc comparisons, we conducted BH corrections in order to adjust our p values to account for multiple comparisons (presented here along with uncorrected, exact p values).

For the summation stage, these analyses were conducted using summation means to determine if the fear response for each CS+ was inhibited, indicated by no significant difference in SCR for a CS+/object pairing compared to SCR for the CS−/object pairing. Conversely, it was considered that no inhibition occurred (a fear response was present) if this difference was significant.

For the test stage, these analyses were conducted using the first trial of the test stage. This was done to determine if a conditional fear response was present for each CS+ when it was presented alone once again (with the object pairing removed), indicated by significantly higher SCR for a CS+ than the CS−.

Results

Summation Stage

Results from the summation procedure showed that there was a difference in fear responding across the three CS/stimulus pairing types (CS+/warm stimulus, CS+/neutral stimulus, CS−/neutral stimulus), $F(2, 58) = 8.33$, $p = .001$, $\eta_p^2 = .223$ (obtained Cohen's f = .54). Post hoc analyses revealed that SCR was significantly higher for the CS+/neutral object pairing (M = .423 μS, SD = .225 μS) compared to the CS−/neutral object pairing (M = .342 μS, SD = .210 μS; $p_{BH} = .041$, $p_{uncorrected} = .027$, 95% CI [−.153, −.010]), indicating that a fear response was present for previously learned threat cues paired with a neutral stimulus and that SCR was marginally lower for the CS+/warm object paring (M = .278 μS, SD = .260 μS) compared to the CS-/neutral object pairing ($p_{BH} = .069$, $p_{uncorrected} = .069$, [−.005, .131]), indicating that no fear response was present for cues paired with a warm stimulus. Thus, inhibition occurred in the warmth paired condition but not in the neutral paired condition. An additional comparison revealed that SCR was significantly higher for the CS+/neutral object pairing than for the CS+/warm object pairing ($p_{BH} = .003$, $p_{uncorrected} = .001$, [−.223, −.067]).

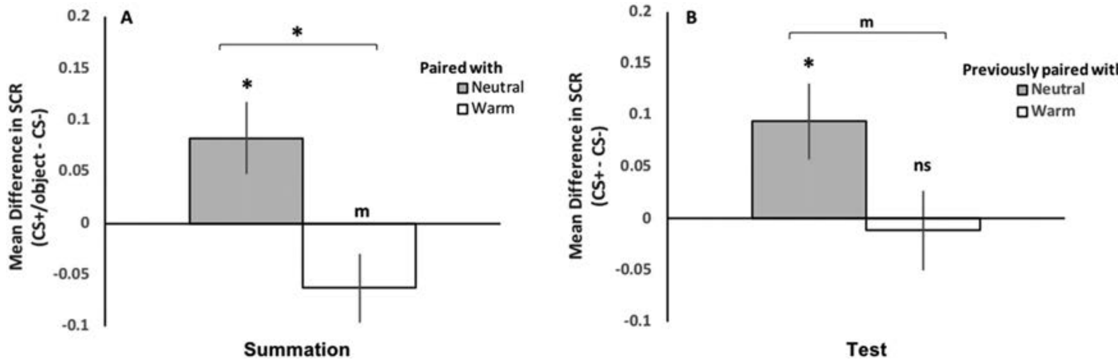
It is interesting to note that SCR in response to the CS+/warm stimulus pairing was marginally lower than SCR for the baseline CS−/neutral stimulus pairing, an effect that continued throughout the summation stage (please see online supplemental materials for trial-by-trial data), suggesting that the warm stimulus may have particularly strong inhibitory properties. Data from Study 1 revealed that this inhibition is not due to a physiological response to the warm stimulus itself as participants in Study 1 did not exhibit any differences in SCR compared to soft or neutral stimuli when holding the same warm stimulus during the habituation stage. These results demonstrate that while other tactile stimuli do not inhibit fear responding, physical warmth does inhibit fear responding and therefore passes the summation test.

Test Stage

Interestingly, examination of fear responding following the removal of the paired tactile stimuli, when the previously learned CS+s were presented on their own once more, revealed a difference in fear responding across all CS-pairing conditions (two CS+s, one CS−) $F(2, 58) = 3.69$, $p = .033$, $\eta_p^2 = .111$. Post hoc analyses revealed that there remained significantly higher levels of SCR for CS+s previously paired with a neutral object (M = .220 μS, SD = .249 μS) compared to the CS− previously paired with a neutral object (M = .126 μS, SD = .192 μS; $p_{BH} = .051$, $p_{uncorrected} = .017$, 95% CI [−.169, −.018]) and no significant difference in SCR for CS+s previously paired with a warm object (M = .115 μS, SD = .173 μS) compared to the CS− ($p_{BH} = .770$, $p_{uncorrected} = .770$, [−.068, .091]). This pattern of effects shows that physical warmth leads to lasting inhibition of the fear response (Figure 4B). An additional comparison revealed that SCR was marginally higher for the CS+ previously paired with a neutral object than the CS+ previously paired with a warm object ($p_{BH} = .076$, $p_{uncorrected} = .051$, [−.211, .000]). These results, as well as the results of the retardation-of-acquisition and summation tests discussed above, mirror those for social-support figures, which also pass both the retardation-of-acquisition and summation tests and lead to a

Figure 4

Results From the Summation and Test Stages of Study 2



Note. All error bars indicate standard error. Asterisks indicate a significant difference score ($p < .05$), "m" indicates a marginal difference score ($p < .1$), and "ns" indicates no significant difference. SCR = skin conductance responses; CS = conditional stimulus. Panel A: Summation stage: Results show that conditional fear responding was inhibited in the warmth condition, but not in the neutral condition, demonstrating that physical warmth passes the summation test. Panel B: Test stage: Results show that a return of the conditional fear response occurred in the neutral condition, but not in the warmth condition.

lasting inhibition of the fear response (Hornstein et al., 2016, 2018). As noted earlier, these latter effects are counter to what would be expected of typical, learned safety signals, which are similarly able to inhibit fear responding while present but lead to return of previous or even higher levels of fear responding once they are removed (Lovibond et al., 2000; Rescorla, 1971), a divergence that may offer a clue as to the characteristics of members of the prepared safety category.

Discussion

Together, the results of these studies reveal that physical warmth resists becoming associated with a fear response (Study 1) and inhibits the fear response (Study 2), demonstrating that physical warmth passes both the retardation-of-acquisition and summation tests without any prior safety training. These findings have important implications. First, they demonstrate that physical warmth meets the requirements for membership in the recently established prepared safety category, extending the number of known prepared safety stimuli. Second, they reveal that physical warmth holds the same lasting inhibitory effects as those held by social-support figures (Hornstein et al., 2016, 2018), suggesting that these effects may be common to members of the prepared safety category. Third, they suggest that a closer investigation of shared properties of physical warmth and social connection may provide insight into the characteristics of these cues that endow them membership in the prepared safety category and shed light on mechanisms underlying prepared safety effects. In particular, the results of the current work highlight several next steps that should be taken to build understanding of prepared safety.

One crucial avenue of exploration involves investigations to reveal the full picture of the processes and mechanisms that enable prepared safety effects. Importantly, future examinations must investigate the processes underlying the powerful long-term fear-reduction effects of physical warmth and social support cues (Hornstein & Eisenberger, 2017; Hornstein et al., 2018; current work).

One potential explanation for these effects can be found in evidence that experiences of physical warmth and social support share underlying neurobiological mechanisms. In both cases, it is thought that these mechanisms have evolved to ensure access to physical warmth and social connections by motivating organisms to seek out such experiences and reinforcing them when they occur (Inagaki & Eisenberger, 2013; Rolls et al., 2008). In particular, opioid processes have been shown to play an important role in regulating physical warmth (Adler et al., 1988), maintaining social bonds (Nelson & Panksepp, 1998), and supporting warmth-induced feelings of social connection (Inagaki et al., 2015). The overlapping role of the opioid system in experiences of physical warmth and social support (Inagaki & Eisenberger, 2013) combined with its well-demonstrated importance in the error correction circuit that supports Pavlovian fear conditioning (providing the negative feedback necessary for fear learning to occur; Fanselow, 1998) is strongly suggestive that engagement of this system may play an important role in prepared safety. Notably, while prepared safety stimuli are thought to increase opioid activity, learned safety signals actually decrease opioid sensitivity (Wiertelak et al., 1992), a distinction that may explain the divergence in the effects of learned and prepared safety cues on long-term fear reduction. By increasing opioid release during fear conditioning processes, prepared safety stimuli may be able to manipulate the error-correction calculations that drive the formation of fear associations.

Additionally, a closer exploration of the affective mechanisms underlying prepared safety effects is important. In particular, recent questions have been raised as to whether the inhibitory effects of social support and physical warmth are driven solely by safety or whether the reward processes that may have developed to reinforce and maintain access to these survival-enhancing stimuli also play a role, perhaps by augmenting the reward-related experience of relief (Hornstein et al., 2021). Parsing apart the contributions of safety and reward processes will shed light on when and for whom the fear-reducing effects of prepared safety stimuli will have the most impact.

Beyond underlying mechanisms, the current work also makes possible initial examinations of the bases of prepared safety effects. It is important to note that in prior investigations of prepared safety stimuli (Hornstein et al., 2016) as well as the current work, preparedness is tested by determining if a cue with no prior, specific safety association with a particular aversive outcome in a particular context is endowed with the ability to spontaneously inhibit fear responding for that outcome in that context. These properties set these cues apart, for learned safety signals primarily inhibit fear responding only for the specific aversive event with which they are trained, in the specific context in which they were trained (Lovibond et al., 2000; Rescorla, 1969). Furthermore, inhibitory transfer, the ability of a safety signal for one aversive event (e.g., a tone signaling that an aversive shock will not occur) to inhibit fear responding for a different aversive event (e.g., an aversive noise), is extremely limited (Holland, 1991). Therefore, the ability of prepared safety stimuli to inhibit fear responding in response to novel aversive events in unfamiliar contexts is noteworthy. However, whether the root of this endowed ability is innate or well learned through early life or cultural experiences is still unclear. Indeed, while the occurrence of the prepared fear category in mammals is often described as innate (Mineka & Öhman, 2002; Seligman, 1971), there has been some debate as to whether the prepared fear effects are rooted in culturally learned cognitive biases as opposed to biological factors (Davey, 1995), and similar questions regarding the source of prepared safety stimuli remain unanswered. Thus, with the expansion of the prepared safety category, future work must probe potential shared psychological and physiological characteristics of these stimuli to explore whether the root of prepared safety lies in innate processes or well-learned associations.

Finally, further investigation of the members of the prepared safety category, both identified and conjectured, is required. In particular, although the results of the current work showed that softness could indeed become associated with threat during Study 1, these results cannot be interpreted to indicate that softness does not belong in the prepared safety category. Indeed, the soft stimulus used in the current work was simply placed in participants' hands and not brushed along the skin (as may be necessary to impart the physical sensation of softness) and therefore may not have been imbued with the qualities of soft experiences that enable them to provide comfort and bring to mind support or safety. Therefore, further investigation of whether soft sensations belong in the prepared safety category is needed. Furthermore, investigations building on the current work to explore the boundaries and effects of physical warmth as a prepared safety stimulus would be useful. This should include future work to determine if the effects demonstrated in the present studies generalize to other types of physically warm experiences. Here, we used a warm pack to create the sensation of warmth but did not isolate the pack itself from the experience of physical warmth. Therefore, examinations of whether other types of warm objects or ambient temperature lead to similar patterns of inhibition are required. Additionally, these initial examinations were conducted in relatively modest sample sizes, and thus more work examining these questions in larger samples is required. However, the consistency of the findings of the present work with those of previous investigations of prepared safety are suggestive and pave the way for future examinations of the role of physical warmth as a member of the prepared safety category.

These investigations and others directly contribute to understanding of fear development and regulation, yet they have the potential to do much more than simply contribute to theory—they also have the potential to shed light on the benefit of prepared safety stimuli in contributing to well-being. The ability of these stimuli to bring about lasting reductions in fear responding is significant for individuals with all types of anxiety disorders, which are marked by deficits in safety learning (Craske et al., 2018), and may be especially impactful for individuals with PTSD, for whom the inability to learn about and distinguish safety cues and safe environments remains an obstacle to treatment (Garfinkel et al., 2014; Jovanovic et al., 2012). To date, the most successful treatments for these disorders rely on the inhibitory learning that drives fear extinction (exposure therapies; Craske et al., 2014, 2018; Rachman, 1989), but even these therapies are only partially effective. In particular, these treatments are extremely aversive to complete, and for those who do complete them, the phenomenon of relapse (return of fears and fear responses following a period of abatement) is extremely common in patients with anxiety, and the phenomenon of renewal (return of fears and fear responses outside of the therapeutic context) is especially pronounced in patients with PTSD, limiting the success of extinction-based therapies in leading to long-term improvement in symptoms (Bouton & Bolles, 1979; Garfinkel et al., 2014; Vervliet et al., 2013).

The lasting inhibitory effects of prepared safety stimuli suggest that the presence of these cues may be uniquely poised to mitigate the limitations of current treatments and improve therapeutic outcomes by generating a never-before-seen combination of effects. In particular, while typical, learned safety signals can reduce the aversiveness of treatment procedures, they ultimately impair long-term fear reduction (Craske et al., 2018; Lovibond et al., 2000). However, prepared safety stimuli appear able to both reduce the aversiveness of treatment procedures and enhance long-term fear reduction. Importantly, given the increased risk for feelings of social isolation that can accompany fear-related disorders, the current work demonstrates that these beneficial effects can be achieved even for individuals lacking strong social bonds via the presence of physical warmth. Thus, further examination of how, when, and why prepared safety stimuli lead to lasting inhibition of the fear response will illuminate the potential of these cues to augment current treatments designed to reduce harmful or disruptive fear.

In the current work, we sought to broaden the recently established category of prepared safety by examining whether physical warmth is a prepared safety stimulus. This work has not only revealed that physical warmth is indeed a member of the prepared safety category but, in combination with previous investigations, has also revealed that instead of simply performing the same functions as learned safety signals, prepared safety stimuli appear to be a distinct type of safety signal with unexpected and beneficial effects on long-term fear reduction. This distinction may be due to differing underlying mechanisms by which learned safety signals and prepared safety stimuli inhibit fear responding. Specifically, the underlying neurobiological systems that are central to reinforcing and maintaining access to prepared safety stimuli diverge from those active during typical safety signaling and overlap with those that drive Pavlovian fear conditioning processes, possibly creating an avenue by which prepared safety stimuli are able to both inhibit fear in the moment and bring about reductions in fear in the long term. Given the implications of the prepared safety category for advancing understanding of Pavlovian fear conditioning processes as well as methods to augment current treatment of fear-related disorders, we argue that further discussion and exploration of prepared safety is essential.

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