Modeling the Timing and Duration of Grip Behavior to Express Emotions for a Social Robot

Xiqian Zheng, Masahiro Shiomi, Takashi Minato, and Hiroshi Ishiguro

***Abstract*—This letter addresses the effects of grip timing to express a robot's emotions to people while they are watching a video stimulus together. Past studies on human-robot touch interaction focused on the types of touch behaviors for expressing a robot's emotion, but timing factors have received less attention. In this letter, we conducted data collection to investigate the appropriate grip timing to express heartwarming and horror emotions. Participants identified touch (grip) timing and durations by using a robot while they are watching video stimuli. Typically, they preferred a grip timing before a climax for horror videos but after a climax for heartwarming videos. We modeled the timing and durations by a fitting approach to probabilistic distribution to reproduce human-like touch behaviors, and also we implemented the models to an android robot.**

***Index Terms*—Human-robot interaction, touch interaction.**

I. Introduction

Expression of emotional behaviors is an essential capability for social robots that interact with people in daily settings. Many robotics researchers have focused on developing robot hardware with enough degrees of freedoms (DOFs) to express various emotions by facial expressions [1]–[4], whole-body motions [5], [6], and voice characteristics [7], [8] as well as models that express appropriate emotions in interaction contexts [9], [10]. These studies mainly used humanoid robots because human-like appearances and modalities are easily understandable for humans, but emotion expression models are not limited to such human-like robots. Several researchers have focused on expressing emotions using non-human-like robots with lighting modalities and motion designs [11], [12].

In the context of emotion expressions, touch behavior design is an essential topic for human-robot interaction because people themselves often use touch behaviors to express or emphasize emotions [13]–[15]. Such emotional expressions via touch behaviors have essential roles in human-human interaction in the context of well-being [16]–[18], as well as both mental and physical benefits [19]–[22]. Although past studies focused on using touch interaction mixed with facial expressions and voices, recent robots can express happy/sad emotions more strongly and naturally by considering touch characteristics to express intimacy [23], [24]. Therefore, understanding touch characteristics to express emotions would be helpful for the behavior designs of social robots to realize more natural and acceptable affective interaction with people.

We are interested in the appropriate timing and duration of touch interaction to express emotions because it influences the naturalness and strength of the conveyed emotions from others. For example, people may immediately touch each other when they feel scared or surprised, e.g., watching a horror movie together, since negative emotional stimuli, such as anger and fear images, elicit a more rapid response compared to other emotional stimuli [25], [26]. Such effects might be related to deciding fight or flight actions [27] and also will be related to proactive and short reactions. On the other hand, when they are deeply moved by a movie, their touch timing might be delayed until after the climax because the continuation time of heartwarming emotion is relatively long after evoking it compared to negative emotions [28], [29].

However, even though these past studies investigated the effectiveness of such touch characteristics as type, length, and place [23], [24], it remains unknown when a robot should touch a person to express its emotions appropriately. A few studies conducted experiments that involved touch interaction where participants watched movies with robots. Still, unfortunately, these studies also focused less on touch timing for conveying specific emotions from robots because these studies mainly focused on robot's warmth or touching effects [30], [31].

Based on these considerations, we are developing a model to identify appropriate touch timing to express emotions with social robots. First, we conducted a data collection to gather both timing and duration data of grip behaviors to express heartwarming and horror emotions. Next, we developed probabilistic models to identify appropriate grip timing for these two emotions, implemented the two models to a robot, and confirmed whether the robots could reproduce grip timing and durations based on the models. For this purpose, we used an android robot [2] (Fig. 1). This study tries to answer this question:

- How should a robot touch a person to express impressions of heartwarming and horror?

Manuscript received June 4, 2020; accepted October 20, 2020. Date of publication November 6, 2020; date of current version November 16, 2020. This letter was recommended for publication by Associate Editor H. S. Ahn and Editor D. Lee upon evaluation of the Reviewers' comments. This work was supported in part by JST CREST under Grant JPMJCR18A1, Japan, in part by the JST ERATO Ishiguro Symbiotic Human Robot Interaction Project under Grant JPMJER1401, and in part by JSPS KAKENHI under Grant 20K11915. *(Corresponding author: Xiqian Zheng.)*

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This letter has supplementary downloadable material available at https://ieeexplore.ieee.org, provided by the authors.

Digital Object Identifier 10.1109/LRA.2020.3036372

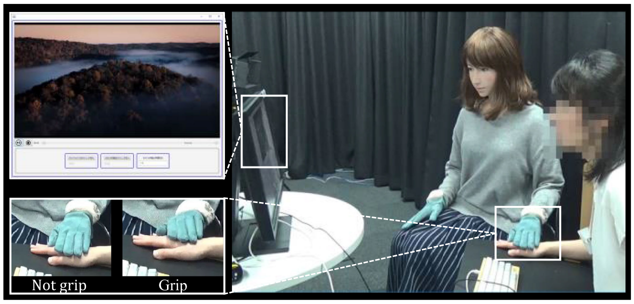


Fig. 1. Participant and ERICA watch a video together.

II. Target Emotions, Robot and Touch Behavior

A. Experiment Settings and Target Emotion

In this study, we investigate appropriate touch timing to express emotions. For this purpose, sharing contexts is important for people to evaluate the appropriateness of touch timing. In particular, such timing depends on a situation to arouse emotion. Therefore, we prepared a situation where participants and the robot together watched videos, which were used as visual stimuli.

We note that such video-induction experiment settings are commonly used to arouse specific emotions [32], [33], and we also followed a similar setting. Moreover, past studies thoroughly investigated what emotions can be aroused by a video stimulus [34], [35]. Participants reported that eight emotions are explicitly evoked by movie stimuli: happiness, anger, disgust, fear, no-response (neutral), sadness, surprise, and contentment.

Next, we chose the target emotions to investigate appropriate touch timings. Since past studies in human-robot interaction focused on emotional expressions [3], [36]–[40], we focused on positive emotions (typically happiness) because they are an essential emotion to build friendly relationships with others with whom we interact. For example, past studies implemented functions to express happiness for social robots and showed positive effects in long-term human-robot interaction [41], [42]. Based on these results and following past studies, we decided to use videos for the experiment, which would be likely to arouse heartwarming feelings. We also chose to use heartwarming videos as there is a large number to choose from, enabling easy preparation of experimental video materials.

We simultaneously focused on a negative emotion (e.g., fear and sadness) as a counterpart to positive emotions. For this purpose, we used horror as a second target emotion. Similar to heartwarming movies, many existing horror (an intense feeling of fear) movies have similar merit to us. Moreover, a study on Japanese perceived emotions related to deeply heartwarming situations reported that Japanese people feel both happy and sad when they are moved [28]. Therefore, to avoid any effects caused by mixing happy and sad emotions in our comparison of positive/negative emotions, we did not use a sad emotion as a counterpart to positive emotions

In summary, we used heartwarming or horror videos for data collection. The collected data is used to model appropriate touch timing to express the robot's heartwarming feeling or horror feelings.

B. Robot Setup

Similar to past studies that investigated human-robot touch interaction in the context of emotion expressions [23], [24], we need a robot that can express various touch behaviors and has a human-like appearance. We used ERICA [2], a feminine appearance android that has ten degrees of freedom (DOF) for her each arm. The motion control system can update the target positions of each actuator every 50 milliseconds. We used gloves on ERICA to avoid mismatched feelings between its appearance and touch feeling because ERICA's skin is a silicone-based design even though its appearance is human-like.

C. Touch Behavior Design

To decide what touch behaviors should be used to convey a feeling of heartwarming or horror, first, we consider the target body part of the touch. According to a past study that investigated the specific relationship maps of body regions where social touch is allowed, the hands are the most acceptable regions to be touched by another person, regardless of the relationship [43]. Therefore, ERICA touches the hands of the participants.

To create a natural social feeling in our experiment scenario, i.e., participants watch videos with ERICA. ERICA sat next to the participants (Fig. 1). We placed markers on a table to indicate where the participants should put their palms and forearms to guarantee that they all experienced the same interactions with identical touch behaviors.

Concerning touch behaviors, we followed similar settings of past studies that used a video stimulus to investigate touch effects [30], [31], [44], where the robot's hand is always touching the participants' hands. We employed a grip behavior because the robot can easily control the start/end timing in a contact situation. As support evidence, a past study also used a gripping behavior in a similar experiment setting for a remote-touch device [45].

In summary, participants in this study were always touched by ERICA when she conveyed specific emotions. In the data collection, we gathered data about the appropriate grip timing and touch durations of ERICA's grip to develop models for each emotion.

III. Modeling of Ouch Timing and Duration

A. Data Collection

1) Overview: For watching each video with ERICA, we directly gathered three pieces of information from the participants: the most appropriate climax timing of that video, t_{climax}; the timing for when the robot should start its grip as a reaction (or anticipation) to the climax, t_{touch}; and the grip's duration, Δt. We also calculated $\Delta t_{\mathrm{start}}$ (i.e., $t_{\mathrm{climax}} - t_{\mathrm{touch}}$), which is the difference between the touch and climax as the timing features (Fig. 2).

The participants identified appropriate grip-timing characteristics when they sequentially watched video clips with ERICA. During this watching process, they input the grip timing (t_{touch}) and duration (Δt) for each video that they felt best expressed the invoked emotions that related to the video's content. They also reported the climax timing (i.e., t_{climax}) for each video to model the touch behaviors.

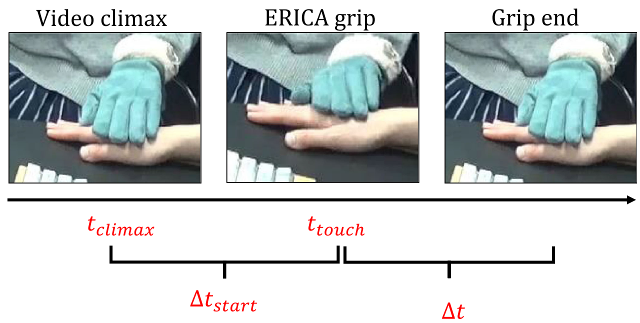


Fig. 2. Illustration of $\mathrm{t_{climax}}$, $\mathrm{t_{touch}}$, $\Delta \mathrm{t_{start}}$ and Δt.

For the video stimulus, we selected six clips from the trailers of commercial movies or advertisements from YouTube.[1] Since our target emotions are heartwarming or horror, we prepared three videos for each category and edited them from between 98 to 159 s (M = 118.3 s, SD = 26.2 s) for the data collection.

2) Procedure: We gave our participants a brief introduction to the experiment and explained that we are collecting their impressions about how the robot should convey emotions by touching. We obtained written consent from them. Our institution's ethics committee approved this research.

The participants sat on the left of ERICA. We calibrated the positions of the table and markers to guarantee that all participants experienced identical touch behaviors. After the experiment started, ERICA put her left hand on the participant's right hand (Fig. 1). We explicitly verified that the participants were correctly perceiving the grip behavior of the robot. We placed a computer monitor in front of the participants with a user interface to play the video clips.

The participants input three items on the user interface: $\mathrm{t_{climax}}$, $\mathrm{t_{touch}}$, and Δt (Fig. 1). After inputting these values and replaying the video clip, ERICA reacted by gripping based on these parameters. Our participants were allowed to watch the video, to modify these values, and to test ERICA's behaviors an unlimited number of times until they were confident that the timings were optimal. We explicitly verified that all participants did not have the experience to watch the movies beforehand and whether the participants felt that there was a climax in a video. Once the participants were satisfied with the parameter adjustments, they repeated the procedure for the remaining clips. We adopted a counterbalance design to play either the first three horror videos or the heartwarming videos and then vice versa.

3) Participant: We recruited through a local (Japan) commercial recruiting company 48 people (24 females and 24 males). Their ages ranged from 20 to 49. All of the participants are native Japanese speakers. They had diverse backgrounds, such as students and business people. None of them had ever watched videos with an android.

B. Hypotheses and Predictions

For the modeling of touch characteristics to convey specific emotions, we hypothesized that the characteristics would be different between heartwarming (positive) and horror (negative) emotions. Past studies about heartwarming emotions reported that the continuation time of heartwarming emotion is relatively long after evoking it compared to negative emotions [28], [29]. It may cause retroactive and relatively long reactions after a climax timing. On the other hand, negative emotional stimulus makes a rapid response compared to other emotional stimuli [25], [26]. It may cause proactive and relatively short reactions before a climax timing because increasing the level of fearfulness will be related to deciding fight or flight actions [27]. Based on these considerations, we made the following three hypotheses about grip timing and durations.

Prediction 1: The $\mathrm{t_{touch}}$ for heartwarming emotion will be later from the $\mathrm{t_{climax}}$ compared to the $\mathrm{t_{touch}}$ for horror emotion.

Prediction 2: The $\Delta \mathrm{t_{start}}$ is positive for heartwarming emotions (i.e., $\mathrm{t_{touch}}$ occurs after $\mathrm{t_{climax}}$), while it is negative for horror emotion (i.e., $\mathrm{t_{touch}}$ occurs before $\mathrm{t_{climax}}$)

Prediction 3: The Δt for heartwarming emotion will be longer compared to the Δt for horror emotion.

IV. Results, Modeling, and Implementation

Our data collection gathered 288 $\mathrm{t_{climax}}$, $\mathrm{t_{touch}}$, and Δt items and calculated the $\Delta \mathrm{t_{start}}$ data from 48 participants with six videos. We excluded 20 items due to hardware troubles of our robot during the data collection. In total, 266 items were valid. Due to large variance of them, we calculated the Z scores of each $\Delta \mathrm{t_{start}}$ and Δt and selected those within a range of plus and minus three. This eliminated two outliers in each category, resulting in 262 items for modeling.

A. Analysis of t_{climax}, and t_{touch} for Each Video

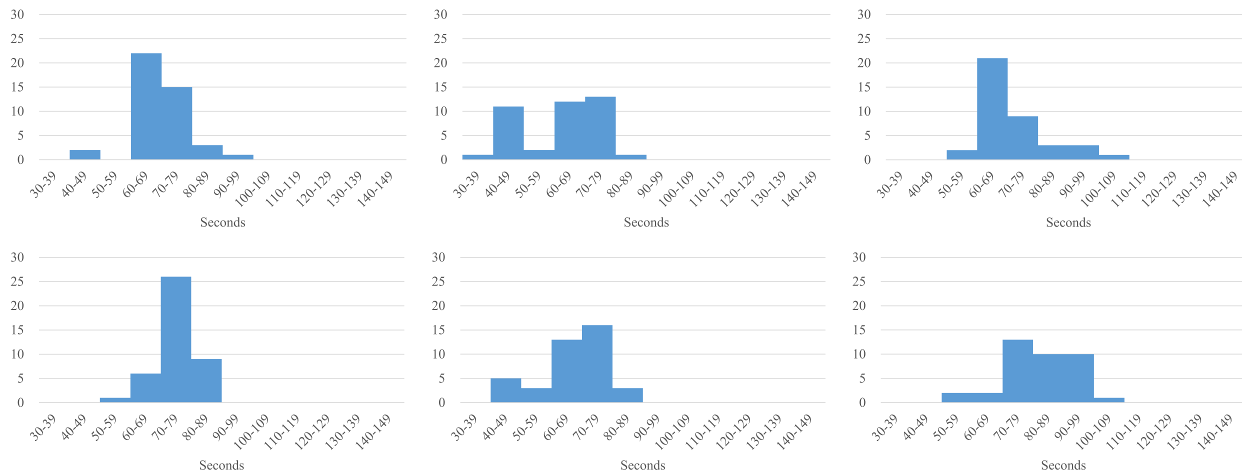
Figs. 3 and 4 show the histograms of $\mathrm{t_{climax}}$ and $\mathrm{t_{touch}}$ for each heartwarming/horror video. As shown in the Fig. 3, most of the participants selected similar climax timing during the data collection, although a part of participants defined different climax timing (e.g., the horror video 1 has two peaks as climax timing).

Moreover, these figures show that $\mathrm{t_{touch}}$ are relatively shifted later (heartwarming) and earlier (horror) compared to $\mathrm{t_{climax}}$ distributions. These results would suggest that participants have different opinions on where the climax is, but their preferred grip timing are influenced by the video categories.

B. Analysis of Δt_{start}, and Δt

Figs. 5 and 6 show the histograms of $\Delta \mathrm{t_{start}}$ and Δt for all the heartwarming/horror videos. Differences based on the clip category suggest that people have different assumptions about appropriate grip timing, typically, before the climax for horror and after for heartwarming. This also suggests that people's interpretation of when a robot should react to a climax might be based on video types. In addition, the distributions of $\Delta \mathrm{t_{start}}$ acquired from horror clips were wider but high kurtosis than those from watching the heartwarming clips.

[1] https://youtu.be/PFhQhpR5Z8M, https://youtu.be/r1gz-m5Ai_E, https://youtu.be/b2MH-yxIR4Y, https://youtu.be/4LYK0rTjlM8, https://youtu.be/dCPiAOiKSyo, https://youtu.be/gXfLl3qYy0k

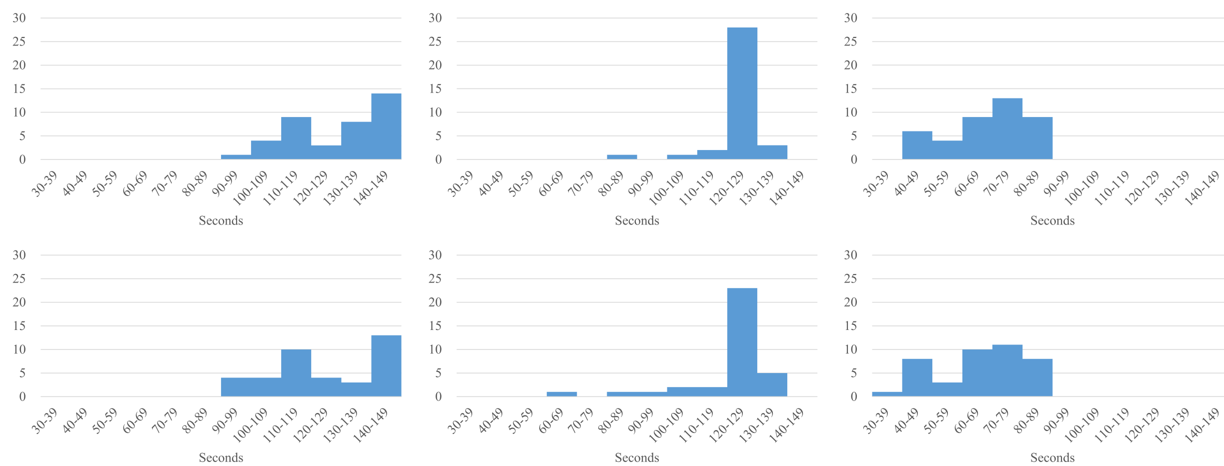


(a) t_{climax} and t_{touch} of heartwarming video 1, S.D: 8.3 and 6.7

(b) t_{climax} and t_{touch} of heartwarming video 2, S.D: 12.3 and 11.3

(c) t_{climax} and t_{touch} of heartwarming video 3, S.D: 11.3 and 11.0

Fig. 3. Histogram of tclimax (upper) and ttouch (lower) for heartwarming videos.



(a) t_{climax} and t_{touch} of horror video 1, S.D: 14.5 and 16.0

(b) t_{climax} and t_{touch} of horror video 2, S.D: 11.8 and 16.0

(c) t_{climax} and t_{touch} of horror video 3, S.D: 13.6 and 15.0

Fig. 4. Histogram of tclimax (upper) and ttouch (lower) for horror videos.

These results suggested that when anticipating the climax of a horror video, e.g., a jump scare, people expect an empathetic robot to touch them immediately before the scary scene. On the other hand, people tend to anticipate that an empathetic robot should touch them after an emotional moment during a heartwarming video.

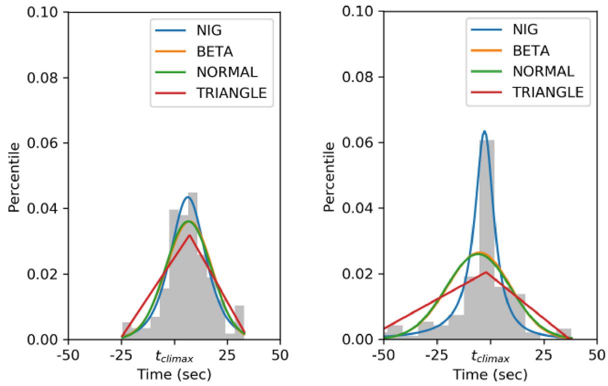
We conducted a one-way repeated ANOVA as a statistical analysis to identify the effects of clip categories on grip timing (i.e., $\Delta t_{\mathtt{start}}$). The results showed a significant difference in the video category factor ($F(1, 132) = 33.797$, $p < 0.001$, *partial* $\eta^2 = 0.204$). For Δt, we also conducted a one-way repeated measures ANOVA whose results showed a significant difference in the video category factor ($F(1, 132) = 7.226$, $p = 0.008$, *partial* $\eta^2 = 0.052$). These results showed that predictions 1, 2, and 3 are supported.

We also calculated the number of cases where the touch started before the climax timing, but the touch duration lasted over the climax timing (heartwarming videos: 20 out of 27 cases, horror videos: 56 out of 76 cases). We conducted a binominal test and found that most touch durations lasted beyond the climax timing (heartwarming: $p = 0.019$, horror: $p < 0.001$). Thus, using a touch duration that lasts beyond the climax timing would be important to reproduce grip behaviors.

C. Modeling Grip Timing

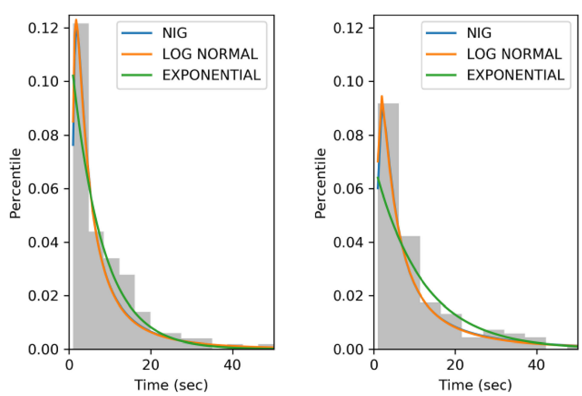
The participants showed different grip timings due to the video categories, and typical differences found by histograms mainly reflected whether the grip timing was before or after the climax and its range. To deal with mathematical modeling, we used a fitting approach with probabilistic functions.

To model grip timing, we compared the $\Delta t_{\mathtt{start}}$ histograms and probability distribution functions, including normal, beta, triangle, and normal-inversed Gaussian (NIG), and calculated



(a) Heartwarming videos **(b) Horror videos**

Fig. 5. Histogram and fitting results of $\Delta t_{\mathrm{start}}$.



(a) Heartwarming videos **(b) Horror videos**

Fig. 6. Histogram and fitting results of Δt.

TABLE I
R^2 AND PARAMETERS OF NIG MODEL FOR TIMING

	R^2 for heart-warming videos	R^2 for horror videos
NIG	0.830	0.837
Beta	0.781	0.589
Normal	0.803	0.579
Triangle	0.667	0.404

	Heart-warming	Horror
α	1.603	0.137
β	0.043	-0.068
μ	6.154	-0.554
δ	13.780	5.539
mean	6.525	-3.710
std	10.890	7.838

their R squared values (R^2). Since the NIG showed a higher R^2 than the other functions, we chose the NIG with the parameters, as shown in Table I.

D. Modeling Touch Duration

Similar to the grip timing, the participants showed different touch durations due to the video categories, and typical differences found by histograms mainly reflected whether the touch duration was longer or shorter in heartwarming and horror categories.

TABLE II
R^2 AND PARAMETERS OF NIG MODEL FOR THE DURATION

	R^2 for heart-warming videos	R^2 for horror videos
NIG	0.650	0.966
Log.	0.698	0.963
Exp.	0.778	0.921

	Heart-warming	Horror
α	29.405	74.972
β	29.398	74.970
μ	0.109	-0.044
δ	0.186	0.082
mean	8.525	12.857
std	10.441	18.640

To model touch duration, due to different shapes of the data distribution, as shown in Fig. 6, we compared the Δt with several probability distribution functions, including NIG, log-normal, and exponential distributions. Among the fitted results shown in Table II, NIG also showed the best fitting results. Therefore, we also use the NIG model to model touch duration as well as the grip timing.

E. Implementation

Based on analyses, we implemented heartwarming/horror NIG models in ERICA. Based on the video's category information, she decided $\Delta t_{\mathrm{start}}$ using the corresponding heartwarming/horror NIG models. She also used the pre-defined t_{climax} of the video and the selected $\Delta t_{\mathrm{start}}$ to decide the grip timing when she is watching a video with a person. The robot also maintains its griping behavior using the Δt of the corresponding model. To increase the realism of the situation, we enabled an idle movement function for her [2]. Without interfering with her touch behaviors, ERICA can breathe, make micro-body movements, and blink when watching the videos. Finally, we tested the developed system and confirmed that the robot autonomously decides the grip timing and durations based on the video information.

V. DISCUSSION

A. Cultural Differences for Touch Interaction

In this study, we conducted data collection with Japanese participants in a laboratory setting. Therefore, we focused on a study on Japanese perceived emotions [28], which reported that Japanese people feel both happy and sad when they are moved. However, touch interaction is quite different due to cultural effects [48], [49] and situation, [50], [51] as well as emotional expressions in nonverbal behaviors [52], [53]. In addition, several cultures rarely use touch behaviors to convey emotions. These differences suggest that people might not have the same reactions to the same videos due to their cultural background.

On the other hand, the modeling of touch characteristics such as timing and duration, would help realize more natural touch interaction for social robots, regardless of cultural differences. Of course, additional data collections would be needed to use this approach with different culture because our study only used the collected data with Japanese participants.

B. *Different Modalities and Touch Characteristics*

This study only focused on grip timing and duration to convey emotions in human-robot touch interaction. However, such other modalities in verbal/non-verbal behaviors as facial expressions [1]–[4], whole-body gestures [5], [6], and voice characteristics like tone or pitch [7], [8] are also critical in real settings. Mixing different modalities might increase the perceived empathy, but heeding appropriate behavior designs of each modality is needed to avoid mismatch expressions.

One possible characteristic of grip behavior is force. For example, when people convey horror emotions via touch behaviors, the force will be stronger than usual touch behavior. Investigating the relationships between forces and conveyed emotions could be possible by using a force sensor with a similar experiment procedure of our study.

In this study, we employed a grip behavior that conveyed both heartwarming and horror emotions. Other characteristics, such as pressure (e.g., strength) or touched part (e.g., touching a person's upper arm), might also influence the perceived impressions. Although the focus of this study is to model appropriate grip timing, investigating integrated multi-modal effects is another potential future works. Moreover, we did not consider other touch behaviors such as patting or rubbing in this study. Therefore, an additional evaluation would be important to deal with the no-touch situation and touch timing without grip behavior.

C. *Gender, Appearance, and Age Effects*

Gender would obviously have influenced both the emotional expressions and the perceived emotions from the same stimulus [54], [55]. In human-human interaction, social expectations of expressing horror to a partner and heartwarming emotions could be different due to gender factors [56], [57]. These results suggest that a grip behavior from a masculine-looking android might be perceived differently in emotional expression compared to a feminine-looking android. Although such gender effects are beyond this study's scope, interesting future work might investigate the effects of perceived robot's gender using masculine-looking androids [58], [59]. Using different female-looking android [60] and/or mixing of human-like and machine-like robots would provide additional knowledge about the relationships between touch, appearance, and conveyed emotions [61].

The robot's appearances also influenced interacting with people's perceived feelings. We only used ERICA that that has a human-like appearance robot, but the use of mechanical appearance robots such as Pepper, Nao, and Baxter would provide different impressions. In addition, perceived emotions and conveyed emotions would be different due to the appearances of the robot. For example, if people thought that such mechanical robots would not have emotions, their perceived feelings towards robot's touch would be different compared to a human-like appearance robot.

Another possible effect is people's ages. A past study reported that senior citizens preferred female robots in the contexts of human likeness [62]. Another study reported that senior citizens preferred Pepper compared to android robots [63]. On the other hand, robots for children such as therapy or educational support have cute and adorable designs [64], [65]; too realistic human-like appearances and adult size body may decrease children's acceptance.

D. *Evaluation of the Models*

In this study, we proposed gripping behavior models to convey specific emotions via the data collection and implemented the models to the robot. One of the possible future work is to evaluate the models via evaluation experiments with the participants. For this purpose, using both original videos and new videos would be important to evaluate the models' robustness. The use of different data sets is a popular way to evaluate a newly developed system. If the system only showed better performance toward known data, the system's effectiveness is quite limited.

Another possible evaluation setting is to use more simple models to decide grip timing and duration. Even though our modeling is based on the collected data from human participants, $\mathrm{t_{touch}}$ may either be before or after the climax for both horror and heartwarming movies due to high variances of them. Therefore, using more simple models, such as selecting $\mathrm{t_{touch}}$ that is just before/after climax timing for horror and heartwarming movies, is one possible choice from the implementation perspective.

E. *Prior Knowledge About Climax Timing*

In this study, the participants designed the grip timing and touch duration based on the climax timing. For horror videos, most of the participants preferred touch behaviors before climax timing. This proactive behavior design might express a kind of proactive coping behavior toward a predictable climax timing.

Such prior knowledge about the climax would realize a more human-like reaction, but it also has one possible concern in the evaluation context. Because our model used the climax timing to decide grip timing and duration, it means that the robot already knows the videos' climax. On the other hand, participants for the evaluation experiment will not know the climax. Therefore, their prior-knowledge is different from the participants in the data collection and the robot. This difference might influence the evaluation.

For example, in the data collection, the participants preferred grip timing after the climax for heartwarming videos because they could know the climax. On the other hand, if the participants did not know when the climax will appear in the video, the robot's grip behaviors may provide positive effects even if the grip timing is before the climax. Because participants can imply such behavior as a proactive behavior toward a coming of climax timing. This effect is a kind of chicken-and-egg problem; to design touch behaviors related to climax, the climax timing should be known. However, if people did not know climax, there perceived feeling toward such climax-timing based behaviors will be different.

F. Limitations

In this study, we only used a specific android robot with a female appearance. Therefore, before generalizing the results from our study, we must test different types of robots, as described in Section VI.C. In addition, the android in this study has hands that resemble human hands and can perform gripping behaviors. For robots without such as a hand structure, other touch characteristics must be considered.

We only used heartwarming and horror videos as emotional stimuli because these emotions are typically used in human-robot interaction studies as well as in human science literature. Investigating appropriate grip timing for different emotions with different video stimuli is needed to convey such emotions by touch.

VI. Conclusion

We focused on appropriate grip timing and duration in the context of conveying heartwarming and horror emotions by touch interaction. For modeling grip timing characteristics, first, we conducted a data collection to gather appropriate touch behavior data. Forty-eight participants directly identify touch behaviors of a robot using heartwarming and horror videos as emotional stimuli.

Based on the collected data, we used normal-inversed Gaussian (NIG) distribution functions to fit the histograms of grip timing for expressing heartwarming/horror emotions by touch. Our models respectively show the grip timing after or before the climax timing for heartwarming or horror videos. We demonstrated the robot's behaviors by using the developed models. This knowledge will contribute to the emotional touch interaction design of social robots.

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