Elucidating Diurnal Patterns in Touch Desire using Social Media Data toward Design of Haptic Applications and Displays

Yusuke Ujitoko, Yuki Ban, and Takumi Yokosaka

***Abstract*—Advances in haptic technology have led researchers and engineers to seek out killer applications in which users can enjoy an experience of touch in AR/VR spaces. Such applications will respond appropriately to human desire for haptic experiences (i.e., touch desire) and thus it is essential for researchers and engineers to understand the nature of people's touch desires as they arise in the course of daily life. In this study, we employed Twitter data analysis to investigate a diurnal pattern in touch desire. Our results showed that touch desire identified in and extracted from Twitter texts did reveal a diurnal pattern. Touch desire tended to be at its lowest in the morning and increased as the day progressed. The time at which it peaked varied with the specific target of touch desire. Touch desire in relation to other people and objects reached its peak at night, but touch desire in relation to animals reached its peak at noon. These results were confirmed not only by our Twitter text analysis but also by data from other social media and an online survey. In addition, we found that the diurnal pattern of touch desire for each target shows a strong correlation with that of visual desire for the same target. This suggests that the diurnal pattern of touch desire is not limited to the sense of touch but is common to other sensory desires for each target. Our findings suggest that researchers need to take the time of day into account when investigating touch desire. Our findings also offer valuable insights for developers into the design of haptic applications and displays that takes into account the timing of daily peaks in touch desire.**

***Index Terms*—Haptics, AR/VR, Touch Desire, Diurnal Pattern, Touch, Psychology**

I. Introduction

Over the past few decades, with advances in visual and auditory technologies, the consumer market for augmented and virtual reality (AR/VR) devices has grown significantly. Haptic technology is also a growing sector [1], [2] and is expected to play a crucial role in providing multisensory feedback to enhance the user experience in AR/VR. Although haptic technology has been applied successfully in training (e.g., medical surgery) and assistance (e.g., walking navigation) application domains, there is currently no killer application in the entertainment domain [3]. Haptic researchers and engineers are actively searching for potential applications in AR/VR in which users can enjoy a touch experience.

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We focus on the human desire to touch a range of targets (e.g., other people, animals, and objects). By gaining a deeper understanding of the nature of human desire to touch various kinds of target (hereafter, we refer to this as "touch desire"), haptic researchers and engineers can develop and design experiences that can satisfy the fundamental human desire for touch. This approach has the potential to spark the creation of successful applications using haptic technologies in AR/VR.

While multiple studies have explored the targets of touch desire [4], [5], [6], [7], [8], [9], the situational context of the touch desire for different targets is also an important aspect that must be understood to better support the design or development of haptic displays. For example, as the temporality of the situational context in which we feel a desire for touch changes, the requirements for haptic displays will also change. For instance, haptic displays that satisfy night-time touch desire should prioritize producing minimal noise to prevent causing anti-social disturbance. In contrast, displays that are used during the day do not face this constraint, and may utilize noisier components, such as air pressure compressors. The situational context of touch desire can be explained with reference to the informational elements of the 5W1H (Who, What, Where, When, How, and Why) method.

Among these elements, for the purposes of this study, we focus on the "when" element to highlight the diurnal pattern of touch desire. In recent years, the diurnal patterns of other sensory experiences have been reported in relation to food consumption [10], listening to music [11], and watching videos [12], [13]. In these studies, knowledge of such diurnal patterns was expected to be applied to tasks such as content recommendation or bandwidth control for online streaming services. It is expected that touch desire also exhibits diurnal patterns, and a deeper understanding of them will reveal targets that fulfill and do not fulfill touch desire for each time of day. However, previous studies on touch desire have been conducted under the implicit assumption that the time factor has no influence on touch desire, and thus the time factor was not controlled in the experiments those studies describe.

We utilize Twitter's long-term data on a large scale, on which we can perform an hourly analysis. In recent years, social media has gained attention as a tool for studying people's daily lives [14], [15], [16], [17]. Among the various social media platforms, Twitter [18] is the one that is most widely used in Japan and provides a valuable resource for dataset. It allows researchers to search tweet texts using queries and to extract large amounts of data that cannot be obtained through

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laboratory experiments. Also, tweet texts are less sensitive to experimenter effects and demand characteristics than data obtained in laboratory experiments. On the other hand, there is the possible drawback that the analysis results might be influenced by the characteristics of Twitter texts in general, such as a skewed user population. In this study, we took care to validate the results of our Twitter analysis with other sources in order to enhance the reliability of our findings.

To understand the diurnal patterns of touch desire, we conducted four analyses as follows:

- In Analysis 1, we aimed to identify the common diurnal pattern of touch desire in relation to a range of targets. To this end, we analyzed tweet texts containing the phrase "want to touch " ('sawaritai' in Japanese) posted in the period from 2013 to 2019.
- In Analysis 2, we aimed to verify whether the common diurnal pattern identified in Analysis 1 was specific to Twitter. To this end, we analyzed posts on different social media platforms. See details in Supplementary Note 2.
- In Analysis 3, we aimed to verify whether the diurnal patterns found in Analysis 1 and verified in Analysis 2 were specific to social media. To address this question, we conducted an online survey in which participants were asked to report the timing of their touch desires for different target categories. See details in Supplementary Note 3.
- In Analysis 4, we examined whether the diurnal pattern of touch desire was similar to that of desires in another sensory modality: visual desire. To this end, we analyzed tweet texts containing the phrase "want to see" ('mitai' in Japanese).

Based on the results of the analyses, we discuss implications for the design of haptic applications in AR/VR and haptic displays.

II. Related Work

First, we will introduce previous studies investigating the desire for touch. Then, we will introduce the concept of content analysis using data from Twitter. Lastly, we will introduce previous studies on diurnal patterns.

A. Touch Desire

Several studies have been conducted to clarify the targets that activate people's touch desire [4], [5], [6], [7], [8], [9], [19]. In our previous study, we utilized 150 days of Twitter posts and identified popular targets of touch desire on average over that period [4]. We found, for example, that people desire to stroke the fur or hair of pet animals such as cats and dogs, and desire to hit musical instruments such as drums and keyboards. Klatzky et al. [6] focused on the visual information of both texture and shape, and investigated how visual information can encourage participants to touch an object. In that study, "touch-ability" is defined as the extent to which the visual appearance of an object invites physical contact. Their results showed that objects with smooth surfaces and simple shapes received higher touch-ability scores than those with rough surfaces and complex shapes. Nagano et al. [5] focused on textural properties and investigated how visual information relating to textural properties can invite participant's touch (haptic invitation). In that study, 24 artificial textures were used, each with various differing features (surface colors, gloss, shape type, and ridge/groove width). The results showed that glossiness and surface shape affected the degree of haptic invitation, while surface color did not.

While the above-mentioned experiments were conducted without any specific situational context, touch desire in the context of purchasing has also been investigated. Touch plays an important role in increasing perceived quality as well as purchase likelihood [20], [21], [22], [23]. It has also been established that individuals differ in their need to touch products [24], [25]. Citrin et al. [25] created the "Need for Tactile Input (NTI)" scale and found that higher levels of NTI negatively affect the evaluation of an online shopping experience. Peck and Childers [24] have created another scale that records individual preferences in terms of the need for touch (NFT). The scale consists of two subscales - the instrumental scale, and the autotelic scale. Instrumental NFT corresponds to the discriminative aspects of touch desire, originating from goal-directed motives to play a role in making a judgment about whether to touch or not. In contrast, autotelic NFT corresponds to the affective aspect of touch desire which is related to the hedonic feeling induced by touching a product. Our previous study [4] suggests that the ratio of the affective aspect to the discriminative aspect of the touch desire revealed in Twitter posts is usually dominated by affective touch, which suggests that Twitter users are somewhat autotelic.

B. Content Analysis using Twitter

Content analysis is an empirical research approach based on existing content. Twitter as an information-sharing platform records information shared by users and can reveal their everyday activities. There are a large number of Japanese-language tweets on Twitter, posted by more than 46 million active users. Recently, the text of Twitter posts has been widely used for a variety of purposes, from stock forecasts using sentiment analysis [26] to an estimation of drug consumption [27].

As a content analysis technique, it is known that word frequency lists provide an overview of the occurrence of words or phrases in a piece of text to identify the subject focus of that text. In addition, triangulation of the results with different analyses [28] helps us to strengthen the validity of those results. Following the application of these methods to the Twitter texts we used, we improved the reliability of our results by triangulating them with analyses using data from other sources.

C. Diurnal Patterns

We conducted a comprehensive survey of previous studies on the diurnal pattern of human touch behavior or feelings related to touch, but only found a limited amount of relevant content, related to thermal perception [29] and clinical matters [30], [31]. To the best of our knowledge, there has been no study investigating the diurnal pattern of touch desire.

Recently, it has become possible to use data streamed online to identify diurnal variation in human behavior related to other sensory modalities than touch. Music streaming events on Spotify have been used for the identification of diurnal patterns in music content consumption [11], [32]. In the same way, video streaming events on YouTube have been used for the identification of diurnal patterns in video content consumption [12]. In contrast to these audio and visual senses, however, there are no media that specifically serve the human sense of touch and thus, currently, it is difficult to use data from streaming services to investigate the diurnal pattern of touch-related behavior. Instead of streaming data, the present study attempted to identify the diurnal pattern of touch desire by analyzing the timestamps of the text data posted on Twitter.

III. Analysis 1: Diurnal Pattern of Touch Desire in Tweet Texts

A. Extraction of Tweet Text

We used specific Japanese tweet texts posted between January 1, 2013 and December 31, 2019. Since our earlier study showed a significant interference in the content of these tweet texts due to the COVID-19 pandemic [33], we set the period to end just before the outbreak of COVID-19 at the end of 2019. Tweet texts containing the phrase "sawaritai (want to touch)" were used. Retweets (messages re-posted verbatim by a user that originated from someone else) and replies to tweet texts were excluded. While we also attempted to use other queries, such as "like to touch" or "feel good to touch", in order to indirectly capture the desire to touch, we found that the number of tweet texts extracted by these queries was too small to yield useful results and we did not use these tweet texts in the subsequent analysis. To exclude redundant tweet texts posted by bots, we removed duplicate tweet texts. We also excluded tweet texts that contained URLs to avoid advertising and spam. At this stage, the number of tweet texts was 1,037,119. The tweet texts were a subset of tweet texts used in our previous study [33].

B. Preprocessing of Tweet Text

We performed preprocessing on the tweet texts for analysis. First, hashtags and emojis were stripped from the tweet texts.

Next, we extracted words for touch targets from the tweet texts. Morphological analysis was performed using Juman++ [34], and dependency analysis was performed using KNP [35] to identify the touch target words. In Japanese, the grammatical subject or object of a sentence is often omitted, so it is highly likely that touch target words could not always be identified. In order to validate that the identified touch target words were nouns, we verified them against the word2vec model, chive [36].

Among the tweet texts for which a touch target word was successfully extracted by the aforementioned preprocessing, some did not express an actual desire for physical touch. For example, "touching a mahjong tile" is an idiom in Japanese expressing the intention to play mahjong, rather than a desire to physically touch a mahjong tile. In order to exclude such tweet texts, which could be regarded as noise for the purposes of this study, some kind of automatic filter would have been optimal. However, it was difficult to implement a system that could accurately judge tweet content as noise. Conversely, manually inspecting all the tweet texts would have been an accurate but highly time-consuming procedure. Therefore, in this study, we adopted a third option, using an approach whereby a noisy word list was first drawn up and tweet texts containing words on that list were excluded from the dataset.

Touch target words were translated into English using Google Translate. If a word was not suitable for academic reporting, we retranslated it into a more suitable word. After this series of preprocessing steps, the number of tweet texts selected for analysis was 130,594.

C. Calculation of Tweet Proportion

For our analysis stage, we needed to analyze the occurrence of tweet texts that expressed a touch desire. The challenge was to remove the effect of unintended variations in the total number of tweets posted on Twitter, which depends on several factors such as the number of concurrent active users and the number of tweet texts posted per active user. This removal operation would enable us to distinguish the temporal changes in touch desire from unintended variations resulting from, for example, the temporal change in the number of concurrent active users.

To remove the effect of these unintended variations, we calculated a "tweet proportion", which represents the number of tweet texts that reference touch desire as a proportion of an estimated reference value of the total number of tweets posted on Twitter. Though we would have liked to obtain an accurate count of the total number of tweet texts to calculate this "tweet proportion", Twitter does not make data on the total number of posted tweet texts publicly available. Therefore, following the method adopted in our previous study [33], we chose to roughly estimate a reference value for the total number of Japanese-language tweet texts posted on Twitter (hereinafter, we refer to this estimate as the "pseudo-baseline"). To do this, we counted tweet texts containing the first letter in the Japanese hiragana syllabary, "あ (a)" posted within a randomly selected period of 30 seconds for each hour of the day, and we used these counts as the pseudo-baseline for that hour. In total, the pseudo-baseline was measured 61344 times (= (6 years $\times$ 365 days + 1 year $\times$ 366 days) $\times$ 24 times). See Supplementary Figure 1 for the hourly variations in the pseudo-baseline. We validated the accuracy of the pseudo-baseline as an estimate of the total number of tweets by confirming a high correlation with three other sources (see Supplementary Note 1, Supplementary Figures 2, 3, and 4), obtaining Pearson correlations of at least 0.985 ($p < 0.001$).

Subsequently, the tweet proportion was calculated for analysis using the pseudo-baseline. For instance, the tweet proportion for the period from 1 am to 2 am on January 1st, 2013, was calculated by dividing the number of tweets expressing a touch desire posted during that period by the corresponding pseudo-baseline value.

D. Results

Fig. 1(A) shows the occurrence of the top 20 touch targets as a proportion of all touch targets in tweet texts expressing touch desire, and thus presents the most popular targets of touch desire among Twitter users. The ranking of the most popular touch targets for the seven-year span of the data in this study is consistent with that obtained from our previous Twitter analysis conducted over a period of 150 days (see Fig. 4 in the previous study [4]).

We applied a target-wise normalization to the tweet proportion, obtaining a normalized tweet proportion for each touch target and each hour by dividing each tweet proportion by its mean. Fig. 1(B) shows the diurnal pattern of the normalized tweet proportion per target in terms of the hour of the day. Since the temporal variation of the normalized tweet proportion for these targets appeared to show similar patterns, we wanted to analyze the common diurnal pattern found across many targets. To this end, we analyzed the mean diurnal pattern, which is the diurnal pattern across all targets, as shown in Fig. 1(C) by the black dashed line. The number of samples for each hour represented in the line in the graph was 7 years × 12 months = 84. The graph shows a tendency in the variation of the mean normalized tweet proportion of touch desire. The mean normalized tweet proportion between 10 pm and 2 am was approximately three times larger than that between 5 am and 6 am. To find the statistically significant differences in the mean normalized tweet proportion between hour pairs, we conducted a non-parametric bootstrap analysis [37]. We used bootstrap sampling to calculate 10,000 mean differences in the mean normalized tweet proportions. If the Bonferroni-corrected 95% confidence interval (CI) did not overlap zero, we could conclude that the difference was significant. See Supplementary Figure 5 for the full statistical results. The multiple comparison results show that the normalized tweet proportion was significantly smaller in the morning (5 am-7 am) compared to other time periods. The normalized tweet proportion exhibited a gradual increase from morning to midnight. The normalized tweet proportion reached a local maximum during the lunch-break period (12 noon-2 pm) and a global maximum around the middle of the night (11 pm-2 am).

In addition, we investigated the diurnal pattern of touch desire in relation to the touch target category. Specifically, building on previous studies [4], [33], we manually categorized the target words under six headings: “body part”, “animal”, “object”, “person”, “geometry”, and “temperature”. Table I lists example words for each category. Our previous study [4] provides a detailed justification for this classification. Because the number of tweet texts expressing touch desire towards targets in the “temperature” and “geometry” categories was insufficient (less than 0.5% of all tweet texts expressing touch desire), we excluded these two categories from further analysis.

We applied a target category-wise normalization to the tweet proportion, obtaining the normalized tweet proportion for each target category and each hour by dividing each tweet proportion by its mean. Fig. 1(C) shows the normalized tweet

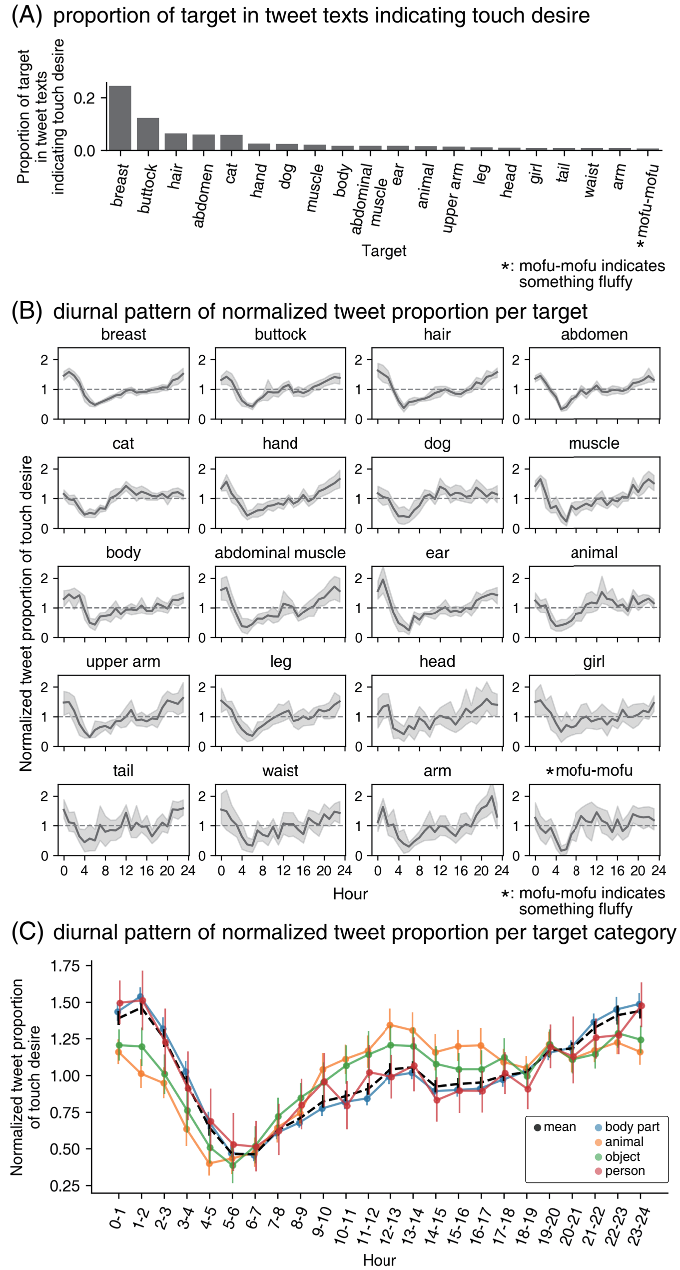

Fig. 1. (A) Proportion of top 20 targets in tweet texts indicating touch desire. (B) Diurnal pattern of normalized tweet proportion per target. (C) Diurnal pattern of normalized tweet proportion of all targets (shown by black dashed line) and those of target category (shown by colored solid lines). Error bars denote 95% CI.

proportions in terms of target category as colored lines. To find the statistically significant differences between hour pairs within each target category, we conducted a non-parametric bootstrap analysis. We used bootstrap sampling to calculate 10,000 mean differences in the mean normalized tweet proportions. If the Bonferroni-corrected 95% CI did not overlap zero, we could conclude that the difference was significant. See full results in Supplementary Figures 6, 7, 8, and 9. The multiple comparison results show the differing characteristics between the target categories. In the case of the “body part” and “person” categories, the diurnal patterns were similar to

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TABLE I
EXAMPLE TARGETS FOR EACH CATEGORY.

categories	example words
body part	hand, hair, buttock, abdomen, ear, tongue, arm, ankle
animal	cat, dog, animal, bird, tiger, sheep, carp, cow, hamster
object	button, keyboard, stamp, card, stroller, stone, iron, clock
person	you, people, them, child, female, character, daughter
geometry	line, ditch, crack, border, edge, region, shape, surface
temperature	warmth, heat, temperature, hot air, body temperature

the mean diurnal pattern (as shown by the black dashed line in Fig. 1(C)), and there was a peak in the middle of the night. In the case of the "object" category, there was also a peak in the middle of the night although the variation is less salient than that for the "body part" and "person" categories. In contrast to the results in these three categories, night-time touch desire for targets in the "animal" category was not significantly higher than it was at noon. In the case of targets in the "animal" category, the normalized tweet proportion reached a peak value around noon (12 pm to 1 pm).

In summary, our findings suggest that the expression of touch desire in tweet texts exhibits a strong diurnal pattern, potentially reflecting the rhythms of human behavior and daily life. However, one might suspect that the observed variation in tweet proportion resulted from factors related to Twitter rather than from genuine variations in touch desire. To further examine this possibility, we conducted follow-up analyses (see Analysis 2 and Analysis 3 in Supplementary Notes 2 and 3). Through these analyses, it was shown that the results of Analysis 1 were not Twitter-specific but were common to other social media and online surveys.

IV. Analysis 4: Diurnal Pattern of Touch Desire and Visual Desire

To better understand the diurnal pattern of touch desire, we wanted to clarify whether, for the popular targets on Twitter, it was specific to the sense of touch or common with that of other sensory desires for the target. Among the other sensory modalities, we focused on visual desire for the comparison because the touch targets extracted in Analysis 1 were all visible. In terms of other sensory modalities, those targets were not necessarily the ones that people encounter in their daily lives. For example, "ears" usually do not make sounds or emit scent, and are not a focus of the sense of taste.

A. Extraction of Tweet Texts Indicating Visual Desire

In this analysis, we compared the diurnal patterns of touch desire and visual desire for the top 20 most popular targets in terms of touch desire identified in the Twitter analysis (see Fig. 1(A) for the top 20 list). We extracted tweet texts that indicated visual desire for the targets by using a query of "want to see [the target]" for each target. For example, we extracted tweet texts indicating visual desire for a hand with the query "want to see a hand ('te wo mitai' in Japanese)".

B. Calculation of Tweet Proportion

We calculated the proportion of tweets mentioning visual desire for each target using a pseudo-baseline, as we did for tweet texts mentioning touch desire in Analysis 1.

C. Results

We calculated the normalized tweet proportion for each target and each hour by dividing each tweet proportion by its mean. Fig. 2 shows the normalized tweet proportion for touch desire and visual desire for each target. Pearson correlation coefficient r of the normalized tweet proportion between touch and visual desires for each target is also shown in the same figure. All the targets had high correlations (> 0.5) and the correlation coefficients were statistically significant except for the tail. This suggests that the diurnal pattern of touch desire reflects the common nature of diurnal patterns in desires independent of the type of sensory modality.

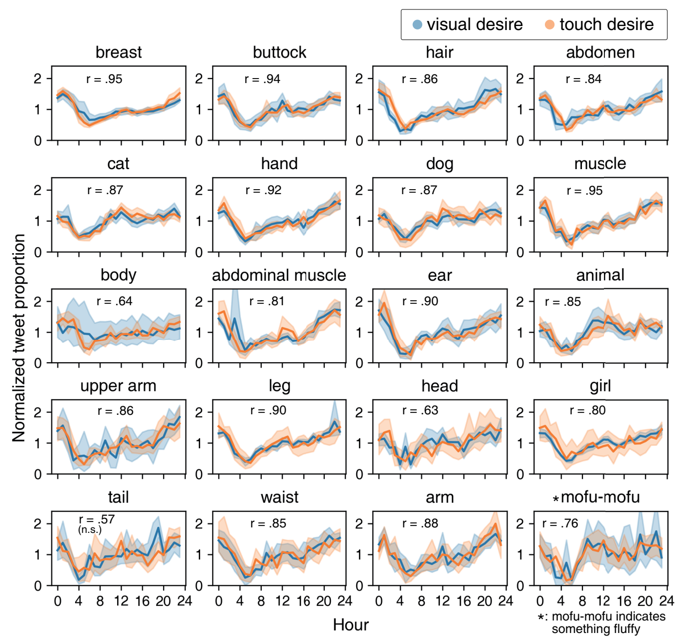

Fig. 2. The normalized tweet proportion of touch and visual desire for each target. Pearson correlation coefficient between touch and visual desire is shown on each graph.

V. Summary of Findings and Limitations

For the first time, we have analyzed the diurnal pattern of touch desire in daily life and discovered a significant diurnal variation. Our analysis of Twitter data revealed that the frequency of touch desire can vary threefold between morning and night. Even so, most of the earlier studies that have investigated touch desire [4], [5], [6], [7], [8], [9] did not focus on its diurnal variation due to an implicit assumption of time invariance. Our results suggest that there may be room for reconsidering this assumption. It would be beneficial for future researchers to control the time of day when conducting experiments. In our previous study, we examined temporal variations in touch desire, focusing on how the COVID-19 outbreak impacted this desire [33]. In that study, we reported

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that the number of tweet texts indicating touch desire toward animate targets increased by a factor of approximately 1.5 after the start of the COVID-19 outbreak (see Fig. 3 in the study [33]), which is a smaller change than that in the diurnal variation we observed in the present study (see Fig. 1(C)). This suggests how closely touch desire is connected with the daily rhythms of our lives.

We found that the diurnal pattern of touch desire changed depending on the target category, which is consistent with a previous study that showed different diurnal patterns in appetite depending on the food category [38]. That study found characteristic diurnal patterns in appetite for high-calorie foods (sweet, salty, starchy foods, fruits, and meats/poultry) but did not find significant diurnal variation in appetite for vegetables. Regarding sensory desires other than appetite, music consumption patterns have been shown to vary depending on the characteristics of the music [32], which indicates that desire related to hearing may also have diurnal patterns that vary depending on the target of hearing. Given these reports, it is suggested that diurnal patterns associated with specific targets may be a common phenomenon for sensory desires.

In our own study, the peak time for animal touch targets was at noon, while the peak time for other target categories, such as objects or body parts, was at night. This highlighted the distinctive nature of the diurnal pattern of touch desire in relation to animals. One speculation as to the reason for a peak in the desire to touch animal targets around noon is that individuals who have pets such as cats and dogs, but are temporarily separated from them due to work or school, may experience an increased touch desire towards their pets during their spare time at noon. This is consistent with a previous study that has noted that physical separation from animate targets can trigger touch desire, as observed during the COVID-19 pandemic [33], although the duration of physical separation periods was different in that study.

We also found a high correlation between diurnal patterns for touch and visual desire. Therefore, we propose that the mechanism behind the diurnal variation of visual desire may be relevant to the diurnal pattern of touch desire. However, to the best of our knowledge, there has been no prior research investigating the diurnal pattern of visual desire that can be referenced. The common factor that affects both of these desires is unclear, but it might be related to something independent of the senses (e.g., environmental factors such as the lighting environment or human factors such as mood [17]).

One limitation of our results is the possible dependency of our data on Japanese culture. Our results were obtained from analyzing Japanese-language social media posts and responses from an online survey of Japanese respondents (see Supplementary Note 3), which may have introduced biases specific to Japanese culture. An earlier study reported that the role of touch varies across cultures [39]; for example, in Italy, hugging and kissing on the cheeks are common and accepted forms of greeting, while in Japan, a proper greeting involves bowing and, generally, physical contact is avoided [40], [41]. Therefore, it is possible that the results of this study may not be generalizable to other cultural contexts. Further research is needed to understand the role of touch in a wider range of cultural contexts.

Another limitation is the experimental design of the online survey (see Supplementary Note 3), which may have influenced the results due to memory bias. Since it was impossible for the crowdsourcing research agency that recruited participants for the online survey to control the time of day that the participants responded to the survey questions, we chose a design in which we asked participants to select the time period during which they desired to touch. If we could develop a method in future studies for conducting an online survey that allowed us to control the time of day that the participants give their responses, the results of the online survey would be more reliable.

The effect of the COVID-19 pandemic on the diurnal pattern is also a matter of interest. A comparison of the results of Analysis 1 and Analysis 3 (see Supplementary Note 3) might provide insights into that effect. In order to rule out any effect of the pandemic for Analysis 1, we used Twitter data from a period prior to the start of the pandemic. The online survey for Analysis 3, however, had to be conducted after the outbreak of the COVID-19. The results of this survey did not reveal major discrepancies with the results of the Twitter analysis, suggesting that the diurnal patterns of touch desire observed in our study may not have been significantly affected by the pandemic.

VI. Implications for Application Design

The findings of this study are relevant to engineering matters, particularly to the design of entertainment applications in which users can enjoy touching certain targets. There are two approaches that developers might adopt in applying our findings regarding diurnal patterns of touch desire to the design of applications:

- A) an approach where developers view diurnal variations favorably and take advantage of diurnal variation
- B) an approach where developers view diurnal variations unfavorably and mitigate the diurnal variations

As an example of the first approach, developers might aim to satisfy touch desire at its daily peak by providing touch events at the most suitable time, which may lead to a reduction of potential stress for individuals in their daily lives. This idea finds support in consumer research [42]. It is known that individuals with a high autotelic need for touch (NFT) often experience stress when touch is unavailable, driven by their hedonic desire to interact physically with a target. If this knowledge is applicable to contexts other than those pertinent to consumer purchasing behavior, causing touch events in AR/VR applications when touch desire is at its peak may effectively reduce users' potential stress. For instance, in social VR applications such as VRChat [43], where users can navigate virtual spaces and engage with virtual avatars, future developments in haptic technology may allow users to experience touch sensations. To reduce potential user stress, developers can strategically optimize touch events by adjusting the placement of virtual touch targets, such as characters or animals, within the social VR worlds.

As another example of the first approach, developers might aim to refine an application's specifications by predicting

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the peak times of anticipated application usage based on the diurnal patterns of touch desire. Consider, for example, applications where users can enjoy touching virtual animals. Our findings indicate that touch desires for animals tend to be higher during lunchtime breaks when people are more likely to be outside, such as at school or work. This suggests the significance of tailoring the application design to reflect the predicted situational context, i.e., outside at lunchtime. In such scenarios, where the user is likely to be in a public space, it would be desirable to create applications that are easily and quickly accessible. Augmented reality (AR) applications may be more suitable than virtual reality (VR) applications since AR allows users to interact with virtual elements while remaining aware of their physical surroundings. For example, an application that enables pet owners to touch and interact with a virtual pet displayed on their desk through AR glasses during lunch breaks would be a user-friendly and appealing solution. By predicting the times when applications will be used, developers can consider specifications that enhance the overall user experience and make the applications more appealing.

In contrast to the first approach, developers adopting the second approach regard the diurnal pattern of touch desire unfavorably. An example might be a developer aiming to equalize the level of touch desire, even though it varies throughout the day, in order to enhance the consistent reproducibility of user experiences. In the context of consumer research, it is known that levels of autotelic NFT, the degree of desire for hedonic touch, influence the purchasing experience in AR applications [44]. Accordingly, there is a possibility that the level of touch desire can influence the user experience in AR/VR applications even if the same haptic stimuli are applied. The consideration of this possibility is particularly important in scenarios where the reproducibility of haptic experiences is crucial, such as the following: applications that let users revisit and relive cherished past moments, even physically interacting with past memories, such as touching their child when they were younger. In such a scenario, if the timing of the user's touch interaction does not align with that in their memory of the original touch event, the level of desire to touch may differ, resulting in varying experiences. It is important to be able to replicate the timing of the user's touch interaction as closely as possible. Without addressing this aspect, there is a possibility that the experience may not have the intended effect.

VII. Implications for Haptic Display Design

Our findings also have significant implications for haptic display design, where numerous design aspects must be considered. According to a book that lists design aspects for haptic displays [45] (see first columns in Table VII), these can be broadly categorized into haptic presentation properties (e.g., degree of freedom, spatial resolution, and temporal resolution) and logistic properties (e.g., portability, environmental requirements, and compatibility with other sensory displays). Design aspects are related to each other and are not independent. For example, "size" and "portability" would be correlated. Also, it is important to note that there are trade-offs between these design aspects. For example, increasing the "degree of freedom" often results in a more complex and bulkier display, potentially compromising its "portability". Requirement definition for design aspects that gives proper consideration to trade-offs between them is essential in the process of designing haptic displays.

If the situational context of a user's interaction with a display, especially the timing of that interaction, is known, developers can gain insights into the requirement definition for design aspects. We comprehensively analyzed all design aspects to determine whether and how the timing of a user's interaction with a display can provide insights for defining requirements (see Table VII). For example, regarding the "Grounding" design aspect, self-grounded displays are preferable if it is expected they will be used outdoors during the day. In such cases, hand-held, exoskeleton, or wearable display types may be more suitable. Conversely, if the displays are expected to be used at home late at night, then world-grounded displays will be acceptable. To give another example, this time relating to "environmental requirements", displays that produce minimal noise to avoid disturbing neighbors will be preferable if they are expected to be used at night. If they are expected to be used during the day, displays generating loud sounds, such as those utilizing air pressure compressors, will be acceptable.

Based on our findings, it is possible to estimate when users are most likely to want to interact with displays that provide a touch experience for certain specific targets. This estimation is grounded in the idea that these displays are more likely to be used during periods when touch desire is heightened. For example, displays that simulate the sensation of touching another person may be more frequently used at night, while displays that simulate the sensation of touching animals may be more commonly used during the day. Some might be concerned that this estimation is made under the assumption of specialized haptic displays for certain targets. We consider this assumption valid on the basis of the following rationale. Since the set of haptic properties to be represented varies depending on the touch target [46], and since current haptic displays can only convey a limited number of haptic properties [47], haptic displays representing specific targets will have to be specialized to those targets. The usage timing of a display that is specialized to a specific target can be estimated based on the diurnal pattern of touch desire for that target.

The combination of the estimated usage timing and the insights for specific design aspects gained from a foreknowledge of the usage timing (as shown in Table VII) helps developers define requirements. Developers can define requirements systematically by following the example process below.

1) Define the target to touch through the display.
2) Gather information regarding the diurnal pattern of touch desire toward the target.
3) Estimate the usage timing of the display based on the diurnal pattern.
4) Utilize Table VII to define requirements for specific design aspects.
5) Define requirements regarding other design aspects.

TABLE II
SUMMARY OF INSIGHTS INTO REQUIREMENTS FOR EACH DESIGN ASPECT [45] OF HAPTIC DISPLAY BASED ON USAGE TIMING OF THE DISPLAY.

Haptic Presentation Properties

Design aspect	Insights into requirements for each design aspect based on the usage timing
Kinesthetic cues	N/A
Tactile cues	N/A
Grounding (self-grounded or world-grounded)	If displays are used during the daytime (outdoors), self-grounded displays (e.g., hand-held, exoskeleton, or wearable types displays) are preferable. If the displays are used late at night (indoors), the world-grounded displays are acceptable.
Number of display channels (how many points of contact with the user's body)	N/A
Degrees of freedom	N/A
Form (shape)	N/A
Fidelity	N/A
Spatial resolution	N/A
Temporal resolution	N/A
Latency tolerance	N/A
Size (size of the display)	If displays are used during the daytime (outdoors), smaller display sizes are preferable. This is related to other aspects such as portability, If the displays are used late at night (indoors), the grounded-type displays are acceptable.

Logistic Properties

Design aspect	Insights into requirements for each design aspect based on the usage timing
User mobility	N/A
Interface with tracking methods	N/A
Environment requirements	If displays are used late at night, displays producing a loud noise are not preferred. For example, displays with pneumatic actuators require air compressors that often make a loud noise, and these would not be suitable in this scenario. If displays are used during the day, displays producing a loud noise may be acceptable.
Associability with other sense displays	N/A
Portability	If displays are used during the day (outdoors), portable displays are preferable. If the displays are used late at night (indoors), unportable displays are acceptable.
Throughput (time required for display attachment/detachment)	If displays are used during a short break from other activities, such as at lunchtime on a work day, displays should be attachable and detachable quickly.
Encumbrance	N/A
Safety	N/A
Cost	N/A

One limitation of this process is the absence of explicit knowledge regarding the location in which the touch desire occurs. We had to infer the location from timing information in order to gain insights into design requirements. Identifying the location of touch desire was a particular challenge in our study because location data was missing from most of the Twitter text data. If future studies can investigate the locational aspect of touch desire, it could be possible to more accurately identify usage situations.

VIII. CONCLUSION

In this study, we used Twitter data analysis to examine the diurnal pattern in touch desire. We found a common diurnal pattern of touch desire toward all targets as well as specific patterns that depended on the target of touch. We obtained similar results using data from other social media platforms and from participants in an online survey. In addition, our findings have engineering implications for haptic applications in AR/VR and haptic display. One potential direction for future research is to determine whether these results can be replicated in other cultural contexts.

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