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Reducing face touching through haptic feedback: A treatment evaluation against fomite-mediated self-infection

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Abstract

Fomite-mediated self-infection via face touching is an understudied transmission pathway for infectious diseases. We evaluated the effect of computer-mediated vibrotactile cues (presented through experimental bracelets located on one or both hands of the participant) on the frequency of face touching among eight healthy adults in the community. We conducted a treatment evaluation totaling over 25,000 min of video observation. The treatment was evaluated through a multiple-treatment design and hierarchical linear modeling. The one-bracelet intervention did not produce significantly lower levels of face touching across both hands, whereas the two-bracelet intervention did result in significantly lower face touching. The effect increased over repeated presentations of the two-bracelet intervention, with the second implementation producing, on average, 31 fewer face-touching percentual points relative to baseline levels. Dependent on the dynamics of fomite-mediated self-infection via face touching, treatment effects could be of public health significance. The implications for research and practice are discussed.

KEYWORDS

awareness training, computer-mediated behavior modification, COVID-19, face touching, fomites

Although airborne respiratory aerosols are currently thought to be the main transmission pathway for various viruses (Wang et al., 2021), including for the SARS-CoV-2 virus (Centers of Disease Control and Prevention [CDC], 2021a), fomite-mediated transmission remains an important risk (CDC, 2021b). Fomites are inanimate object surfaces where viral particles can remain viable for hours or days. Hand contact with contaminated surfaces poses a risk of infection when subsequently engaging in hand-to-face contact with the mouth, nasopharynx, or eyes. For viruses with high fomite-hand transfer efficiency, like rhinovirus, and high persistence on the skin, like norovirus, the fomite-transmission pathway may be of critical importance (Kraay et al., 2021). Community-based epidemiological studies cannot readily establish the relative contribution to infection risk of several transmission pathways when they operate simultaneously, and most transmission models have focused on human-to-human transmission of the SARS-CoV-2 virus (Ying & O'Clery, 2021). However, recent studies indicate that transmission due to contact with contaminated surfaces may play an important role, particularly in the early stages of an outbreak and in closed environments with high touching rates and numerous available surfaces, including child daycares, schools, nursing homes, and offices (Kraay et al., 2021). Therefore, face touching remains a risk behavior of significant public health interest.

Environmental microbiology studies show that diverse respiratory viruses can remain viable for extended periods. For example, Boone and Gerba (2007) reported that influenza viruses could survive for up to a week on metals and fabrics, and various coronaviruses could remain viable for 3–12 hr on aluminum and the outside of latex gloves. These findings have been replicated for the SARS-CoV-2 virus by Riddell et al. (2020), who reported half-lives of up to 65 hr at normal room temperature.

Several studies conducted in naturalistic settings have indicated that face touching is a high-frequency, high-duration behavior. For example, Kwok et al. (2015) followed a group of medical students and found that they engaged in face touching at an average rate of 23 times per hour. Other studies have indicated that people touch their faces after touching other surfaces in public settings over three times per hour (Alonso et al., 2013). Although some individuals tend to touch their faces more often with their dominant hand, evidence suggests that face touching occurring with both hands is the norm (Dimond & Harris, 1984; Mueller et al., 2019). The high rate of the behavior means that face touching is likely to offset the efficacy of preventative hand washing, as hand washing cannot be expected to occur at a similar rate. Yet, public health advice has typically focused on hand washing rather than face touching. For example, the World Health Organization (2021) and the Centers for Disease Control and Prevention (2021c) published detailed advice on hand washing (but not face touching) during the COVID-19 pandemic.

In an early study, Dimond and Harris (1984) documented the continued occurrence of face touching in barren environments, a primary setting event for other repetitive and habitual behaviors such as nail biting, skin picking, hand mouthing, or stereotypy (Goh et al., 1995; Querim et al., 2013). Low-stimulation environments (e.g., being alone in an empty room) often lead to habitual, repetitive, and stereotypical behaviors. For example, Virues-Ortega et al. (2022) showed that out of 120 cases of problem behavior with an automatic function reviewed, over 50% of such problem behavior occurred most frequently when participants were exposed to low levels of physical and social stimulation (alone and no-interaction functional analysis conditions). The reinforcing stimulus dimension of various problem behaviors with an automatic function may be considerably specific. For example, Goh et al. (1995) showed that hand stimulation (not mouth stimulation) maintained hand mouthing for a small group of individuals with intellectual disability.

Similarly, some aspects of the self-touch stimulus may be inherently reinforcing. Human and self-soothing touch (e.g., placing one hand on the heart or belly, stroking the upper arms) has been found to induce a myriad of physiological and psychological responses that may be related to its reinforcing effect. For example, self-soothing touch can result in lower levels of autonomous activation (as measured by salivary alpha-amylase) while coping with stress (Breines et al., 2015). Similarly, Dreisoerner et al. (2021) have shown that self-soothing touch attenuates cortisol production in individuals exposed to a standardized psychosocial stressor (Trier Social Stress Test). As with some habitual behaviors, emotional distress can also trigger increased face touching (Mueller et al., 2019), further emphasizing its potential sensory, and possibly even self-soothing, function. In summary, the hypothesis that self-touching could be self-soothing would be consistent with the well-documented physiological and emotional effects associated with human touch (Field, 2010).

The fact that face touching is observed among great apes and humans at comparable rates (Suarez & Gallup, 1986) underlines how deeply engrained face touching seems to be in our daily behavior and may also point to unspecified evolutionary functions. For example, a recent hypothesis by Spencer et al. (2021) suggests that frequent face touching may be a natural mechanism for enhancing microbial diversity and preventing dysbiosis (i.e., imbalance in the good bacteria). However, whatever the evolutionary benefits of face touching, they will likely be canceled during a viral pandemic.

The behavior modification literature indicates that repetitive and habitual behavior maintained by sensory feedback can indeed be modified. For example, response blocking by placing the experimenter's hand close to the clients mouth can reduce hand-mouthing attempts (Reid et al., 1993). In addition, wearing a face mask may have a partial blocking effect on face touching (e.g., Liebst et al., 2022). Habit reversal has been found effective for a range of problem behaviors similar in form to face touching, including hair pulling and nail biting (Bate et al., 2011). Awareness training is a critical component of the habit reversal program, which has been proposed to mitigate face touching (Heinicke et al., 2020).

Interestingly, continuous automated feedback has been shown to modulate fine motor skills (Seppelt & Lee, 2019). For example, studies have also shown that haptic feedback (i.e., tactile stimulation contingent on some aspect of human performance) can effectively cue the rhythm of a gross motor behavior like walking pace even in the absence of specific instructions (Maculewicz et al., 2016). A human–computer interaction analysis by Michelin et al. (2021) indicated that auditory, visual, or vibrotactile feedback might be used as cues to alert the individual of the occurrence of face touching, who could then prevent or

TABLE 1 Participant characteristics

#	Gender	Age	Country	Occupation	Hand dominance	A & B phases hand	Camera mount
P1	M	42	Spain	Academic	Left	Right	Chest & head
P2	F	31	Spain	Language therapist	Left	Right	Chest
P3	M	31	Spain	Airline pilot	Right	Right	Chest
P4	M	30	Spain	Hospital psychologist	Right	Left	Chest
P5	M	46	Spain	Historian	Right	Right	Chest
P6	F	25	Belgium	PhD student	Right	Right	Chest
P7	M	34	Spain	Clinical psychologist	Right	Left	Chest
P8	F	34	Spain	Clinical psychologist	Right	Both	Head

Note. P = Participant, M = Male, and F = Female.

stop the behavior. Such an intervention could be construed as a punishment[1] contingency where some form of sensory stimulus or combination of sensory stimuli contingent on face touching could increase the reinforcing value of their subsequent avoidance or removal as an aversive irritant. There is very little literature on using punishment contingencies to reduce repetitive and habitual behavior maintained by sensory feedback. However, Romanczyk (1977) demonstrated that punishing stimuli, delivered both on a fixed-ratio 1 and a variable-ratio 5 schedule, were equally effective at reducing the self-stimulatory behavior in two young children.

The behavioral effects of haptic feedback interventions have not yet been tested or evaluated in naturalistic settings. However, some reports suggest that haptic feedback to the wrist and other body parts is associated with high perceivability, usability, acceptability, and perceived efficacy (Stiede et al., 2022; see also & Ebner-Priemer, 2014). Yet, the potential use of vibrotactile feedback for moderating habitual behaviors such as face touching remains to be evaluated.

The current study presents an intervention conducted in the natural environment using an experimental cuing mobile app and bracelet. The bracelet is designed to emit a vibrotactile stimulus shortly after the occurrence of hand–wrist spatial configurations that are indicative of face-touching events. The study is intended to provide a preliminary evaluation of the potential utility of a computer-mediated cueing mechanism to mitigate face touching among healthy adults in naturalistic settings.

METHOD

Participants and setting

A convenience sample of nine adults was invited to participate in the study, with eight of the nine agreeing to participate. These participants were four males and four females with a mean age of 33.8 years (range: 26–46 years). All participants were healthy adults living at home and were under local statutory lockdowns due to the COVID-19 pandemic at the time of the study (data collection period, September 30, 2020, through December 29, 2020). Participants were located in Spain ($n = 7$) and Belgium ($n = 1$). Except for essential workers, participants only ventured outside daily to buy groceries and exercise. Participants 3 and 4 were considered essential workers in the community. Participants 1 and 2 experienced COVID-19 symptoms during part of the data collection period. Table 1 presents the sociodemographic characteristics of the participants.

The study protocol was approved by the ethics committee of the Universidad Autónoma de Madrid (CEI 106–2062). All participants signed an informed consent form. To preserve the participants' privacy, all video recordings were conducted without audio.

Materials

Motion-sensing vibrotactile bracelet

We used experimental motion-sensing bracelets equipped with an off-the-shelf three-axis accelerometer, smartphone-grade vibrating buzzer, Bluetooth emitter-receiver set, and USB 2.0 compatible battery pack (a mass-production version of the experimental bracelets has now been made commercially available by Toles & Toles, 2021). To operate the bracelets, users were instructed to use the mobile app Immutouch (Toles, 2020). As part of a calibration process, the app identifies any bracelet detected within range and allows the user to record one or more reference hand–wrist positions typical of face-touching events. The device detection of the reference position results in the buzzer activation causing a series of 2-s vibration pulses. If the reference position continues, the device ceases to vibrate after 30 s have elapsed.

Because the vibrotactile stimulus depended on the hand–wrist spatial configurations that were predetermined by each participant to be typical of their face touching, some false-negative events did occur. For example, a false negative may have occurred when engaging in face-touching responses that were topographically different

[1]The term punishment is used here in its technical rather than its colloquial sense.

from the ones used during the calibration process. Similarly, false-positive events occurred when engaging in everyday arm motions that resembled hand–wrist positions used during calibration (e.g., drinking a glass of water or opening a kitchen cabinet).

As part of the calibration process, participants were asked to emulate and record one or two typical face-touching events as reference hand positions. Using multiple reference face-touch events may have reduced false negatives at the cost of increasing false positives. In our experience, one or two reference points could capture most face-touching events while keeping false positives low. Participants were asked to calibrate the bracelets at the beginning of each study phase in which they were actively used (Phases B and C). A video tutorial of the calibration process published by the manufacturer is available from Immutouch (2020). The bracelets were labeled with the words "right" or "left" so that participants always used the same bracelet with the same hand.

A 1-hr sensitivity analysis was performed with Participant 1 (P1) using a 1-hr video, with titles prompting the participant to touch his mouth, nose, or forehead at specified times. Of the 200 cues for engaging in face touching, the participant complied with 194, of which 155 resulted in haptic feedback. Thus, the rate of false-negative events (face-touching occurrences not followed by a vibrotactile stimulus) was 20.1%. Although no false-positive events were documented, the test did not include the cuing of near-face-touching events. The mean delay to onset of the vibrotactile stimulus from a face touch was 1.59 s (range: 0.21–4.77 s).

Even though the sensitivity of the device was not perfect, the applied literature on the use of intermittent punishing stimuli to suppress various problem behaviors suggests that a detection device of imperfect sensitivity may still reduce habitual behavior (e.g., Romanczyk, 1977). However, the reductions may occur more gradually and less effectively (see also Cipani et al., 1991).

Wearable cameras

To detect face-touching events throughout the study, participants wore a chest-mounted sports camera or a head-mounted endoscopic camera. The chest mounts were GoPro Chesty. The head mount was a GoPro Headstrap modified with a 40-cm extension arm that supported an endoscope. Figure 1 shows illustrations of these arrangements. The cameras used with the chest mounts were the GoPro Hero3, GoPro Hero4, and Zunate 4 K Ultra HD. The head-mounted camera was a 4.3-in (~11 cm) Skybasic industrial endoscope. The cameras were pointed toward the participant's head with both the chest- and head-mounted arrangements. The video resolution was

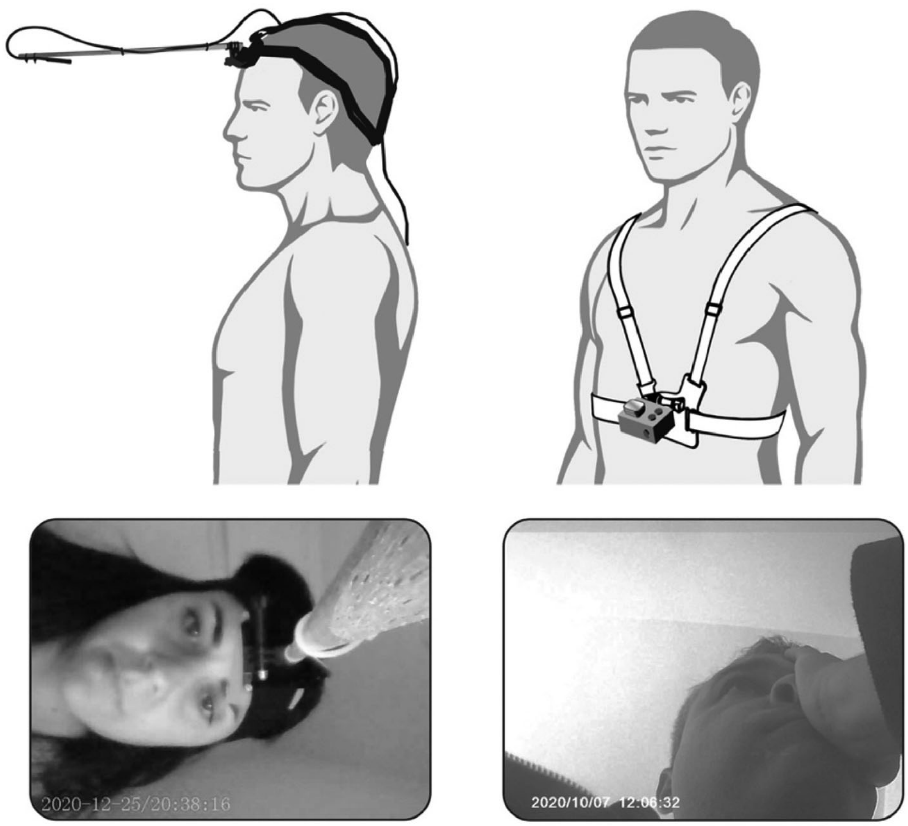

FIGURE 1 Chest- and head-mounted camera arrangements and typical video output

set to 720p. The cameras could record autonomously for over 4 hr without recharging and were equipped with a 256 GB micro-SD card that provided sufficient storage for the complete study protocol of a participant.

Response measurement and interobserver agreement

Research team members with professional training in behavioral observation processed all videos and extracted the events of interest. *Face touching with the right hand* was defined as the participant touching any part of their face or the front part of the neck with any part of their right hand. *Face touching with the left hand* was defined as the participant touching any part of their face or the front part of the neck with any part of their left hand. *Face touching with both hands* was defined as the participant touching any part of their face or the front part of the neck with both hands simultaneously (with any part of the right hand and with any part of the left hand). For practical purposes, the front part of the neck was defined as any part of the neck anterior to the vertical plane of the ears. The following occurrences were considered nonevents: touching the scalp, blowing the nose, washing the face, touching the ear, manipulating hair, putting on earphones, putting on a head covering, using a telephone, and touching the face or head with an object (e.g., pencil). All responses were recorded retrospectively from the videos using a 10-s partial interval observation schedule. The number of right-hand face-touching intervals was determined by summing together the right-hand and both-hands face-touching events. This sum was then divided by the total number of intervals and multiplied by 100 to calculate the percentage of right-hand touching occurrences per larger interval. The same procedure was used to calculate the percentage of left-hand touching occurrences. For graphing purposes, the mean percentage of intervals across 60-min segments was computed (i.e., one data point comprising the mean percentage occurrence across 360 consecutive 10-s intervals). This relatively high level of data aggregation improved the readability of the visual display of the data. Because this approach may artificially limit the natural variability of the behavior, we used 20-min segments for the statistical analyses (20-min bin graphs are available as part of the Supporting Information, Appendix A).

Observers also collected data on five secondary target behaviors as potential disruptors of face touching: moving around, being outdoors, using a phone, wearing a mask, and talking (assessed using lip motion as a proxy). *Moving around* was scored on occasions when the participant was moving around (as opposed to staying still or sitting), as indicated by the unambiguous movement of the image background. Only continuous directional motion that involved a complete or near-complete change of the background image was counted (i.e., riding in a car, neck movements, and swinging and rocking motions were considered nonevents). On occasion, neutral backgrounds without distinct objects prevented identifying motion. After preliminary analyses indicating poor agreement, observers were provided examples and nonexamples of moving around. *Being outdoors* was recorded if the sky was clearly visible at some point in the interval and no walls were visible in the proximity of the subject in the background of the image (being outdoors excluded moving around). *Using the phone* was recorded anytime a participant held a telephone next to his or her ear. The use of wired and wireless headphones or earphones were not instances of *using a phone*. *Wearing a mask* was recorded when the participant was wearing a face mask that fully covered their mouth (i.e., nonevents included wearing a face mask covering just the chin or neck, having a mask hanging from one ear). Lip motion, as a proxy for *talking*, was detected automatically for the two participants wearing head-mounted cameras (P1[2] and P8). A custom Python script divided each video recording into 10-s segments, which were then processed by the OpenFace 2.0 face-tracking software (Baltrušaitis et al., 2018). OpenFace detects the most prominent face within a digital video, compares it with a normalized facial model using 128 key parameters, and estimates the three-dimensional position of each parameter frame by frame. Krause et al. (2020) describe how OpenFace can be used to track speech-relevant lip movements (i.e., a proxy for talking) with digital video (for details, see Supporting Information A, Appendix B). We selected disruptors that involved motion (moving around, being outdoors) or could physically interfere with face touching (using a phone, wearing a mask, and talking). Their selection also had a convenience element because they were all readily observable from the video recordings. The analysis of alternative disruptors might have been possible with a more comprehensive video-capture strategy (e.g., other forms of hand manipulation).

Secondary observers conducted independent behavioral observations of 16 randomly selected baseline and intervention study phases across seven participants (22% of the complete data set). In addition, an intraobserver agreement probe was conducted with one participant (P4) to evaluate the observer's drift. The intraobserver agreement probe was obtained by having an observer code the same footage for a second time after a few days. To calculate interobserver agreement, the total number of all face-touching events for each 10-s interval was compared for the primary and secondary observers. Interobserver agreement for each interval was calculated by dividing the minimum number of events recorded by either observer during the interval by the maximum number of events recorded by the other observer and multiplying by 100. The mean interobserver agreement for each 20-min video segment was then calculated, and the overall mean interobserver agreement across participants and phases was determined (98.1%, range: 93.2%–100%).

The intraobserver agreement probe for P4 produced 100% agreement. Table 2 presents a complete report of the interobserver agreement.

Procedure

After guiding participants through the informed consent process, providing the opportunity to consent, and obtaining consent via digital signatures, participants received a package comprising two bracelets, a compatible smartphone with the bracelet calibration app already installed, and a wearable camera with accessories. All participants underwent an individualized 30-min teleconference induction session with the lead investigator. The lead investigator followed a four-step behavioral skills training approach (i.e., instruction, modeling, practice, and feedback) to assist participants in charging, syncing, calibrating, and wearing the bracelets and wearing and using the video cameras. Participants were instructed to recalibrate the bracelets before each new treatment phase began. Participants were also provided with a document describing all the operations and routines of the bracelets and cameras, details of the sequential phases of the study, and instructions for uploading the data after each phase. Participants were provided with secured file upload links and were asked to upload their video files daily. A backup copy of the files remained on the camera memory card throughout the data collection period.

TABLE 2 Interobserver agreement summary for combined face touching

Participant	Phase	Mean	Range
P1(1)	B2	98.4%	90.2%–100.0%
	C3	99.0%	93.4%–100.0%
P2	A1	95.1%	85.3%–100.0%
	B2	94.7%	86.9%–100.0%
P3	A1	93.2%	72.1%–100.0%
	C2	98.2%	93.3%–100.0%
P4	B1	100.0%	N/A
	A2	100.0%	N/A
P5	A2	99.5%	96.7%–100.0%
	C1	99.6%	96.7%–100.0%
	B3	99.8%	98.4%–100.0%
P6	B3	99.2%	98.2%–100.0%
	C2	99.3%	96.7%–100.0%
	A4	100.0%	N/A
P7	C1	98.3%	89.3%–100.0%
	A2	97.8%	91.8%–100.0%
P8	A1	98.9%	80.3%–100.0%
	C4	99.1%	91.8%–100.0%

Note. Data for P4 are an intraobserver agreement probe obtained by having an observer coding the same footage a second time after a few days. The remainder of the table (P1[1], P2, P3, P5, P7, P8) reports interobserver agreement.

Participants were asked to use the wearable camera for as long as possible, with a minimum recording time of 4 hr per day of any phase for the chest-mounted camera or 2 hr for the head-mounted camera (due to the additional discomfort caused by extended use of the head-mounted equipment). If the accrued recording time within an ongoing phase was less than 4 hr, participants were required to remain within that phase for one or more additional days until the 4-hr criterion was met. Participants were welcomed to remain within a given phase for as long as they wished even after the 4-hr criterion had been met.

Participants were encouraged to record throughout the day during any naturally occurring indoor and outdoor activities, except for eating, drinking, using the bathroom, and sleeping. Eating and drinking were excluded because they were expected to generate frequent false-positive responses from the bracelet(s). To prevent and mitigate any practical or technical challenges, the research team contacted each participant on the first day that they recorded themselves (via phone or instant messaging), and the communication continued intermittently throughout the study and in different phases.

Design

An ABABCBCACAC multiple-treatment reversal design (Experimental Design 1) was used for participants P1, P2, P3, P4, P5, P6, and P8, and a reversal ACAC design (Experimental Design 2) was used for participants P1 and P7 (Morgan & Morgan, 2008). As P1 completed both designs, those are subsequently designated as P1(1) and P1(2). Participants wore one inactive bracelet during the Design 1 baseline phases (A). During the one-bracelet intervention phases (B), participants wore one active bracelet on the same wrist used during baseline. Participants wore one active bracelet on each wrist during the two-bracelet intervention phases (C). During the Design 2 baselines phases (A), participants wore an inactive bracelet on both wrists; during two-bracelet intervention phases (C), an active bracelet was worn on each wrist as in Design 1. The formal notation ABABCBCACAC and ACAC denotes the number and sequence of study phases (e.g., the third "B" is the third one-bracelet phase for participants receiving Design 1).

Design 1 was intended to ascertain the separate and combined effects of wearing one or two bracelets. However, because B phases always preceded C phases in such a multiple-treatment design, a second analysis using Design 2 (albeit just with two participants) helped to determine whether a baseline with two inactive bracelets (compared with the baseline with one inactive bracelet used in Design 1) would be correlated with higher or lower face touching. To minimize any systematic effect of hand dominance, the hand where the bracelet would be worn during the A and B phases of the multiple-treatment design was selected randomly (Table 1).

Statistical analysis

Supplementing visual analysis with statistical models specific to single-case experimental designs may be of particular interest when evaluating a new intervention model in a naturalistic environment where high levels of variability are likely. Statistical analyses can accurately determine the effect of various independent variables and moderators and inform more sophisticated future experimental evaluations. The multiple-treatment and reversal designs used in the current study involved multiple exposures to the three levels of the independent variable for each participant (i.e., baseline, one-bracelet, and two-bracelet intervention) and multiple measurements per participant within each of those levels or phases. The resulting nested data structure needed to be addressed during the data analysis, as observations within one participant are more related to one another relative to observations across participants (see Moeyaert et al., 2014). Therefore, we used hierarchical linear models (HLM) to address several research questions. First, what is the effect size of a one-bracelet intervention (B phases) on overall face-touching behavior? Second, what is the effect size of a two-bracelet intervention (C phases) on overall face-touching behavior? Third, what is the effect of selected moderators on the intervention effect and face touching, regardless of the intervention phase?

A combined face-touching metric (i.e., the percentage of 10-s intervals with either right-, left-, or both-hands face touching over 20-min segments) was used to evaluate the two intervention modalities (one-bracelet and two-bracelet interventions) across the replications of the multiple-treatment reversal design (Design 1). We used an alpha of 0.05 divided by the number of analyses conducted with the same data. All HLM analyses were conducted with SAS for Windows (https://www.sas.com/en_ae/software/stat.html). Graphing and tests of the significance of the slope of the regression lines of predictors were conducted with Prism GraphPad (GraphPad Software, 2021, v. 9.0.1). An extended presentation of the statistical models, including a detailed a posteriori power analysis, used for our analyses in addition to the SAS code used is available from the Supporting Information (Appendices C and D). Readers interested in learning more about the potential uses of HLM for behavior analysts are referred to Becraft et al. (2020) and Virues-Ortega et al. (2023).

Data processing

The complete video collection of the study included 25,200 min of video recordings (approximately 53 hr per participant). Observers received preformatted Microsoft Excel spreadsheets on which to record all target events. An Excel Visual Basic for Applications script was developed to extract the relevant data from all spreadsheets, compute the number of events for each target event for each 10-s interval and 20-min segment, and generate the percentage occurrence scores for graphing and data analysis.

Procedural fidelity

Participants completed a procedural fidelity checklist each day that they videoed themselves. This was provided as an online spreadsheet using Google Sheets. Participants were invited to fill out the checklist describing the primary aspects of the procedure. This information and the videos recorded allowed several procedural fidelity indicators to be calculated. These indicators included the percentage of phases correctly implemented (in the expected order and with the intended number of bracelets), the percentage of phases with minimal video duration (the phases with at least 4 hr of footage), and the percentage of phases with correct bracelet placement (the intended number of bracelets [1 or 2] in their intended location[s] [right, left, or both] and with the intended setting [active vs. inactive]). The percentage of study phases implemented as expected was 96% (P2 implemented the sequence A3-C1-B3 instead of B3-C1-A3). Video recordings were of the minimal prescribed duration in 96% of study phases (P1's B2 and B3 phases were only 3.3 and 3.4 hr, respectively, and P5's C1 phase was 3.7 hr). Participants conducted calibration tests until no false positives or false negatives were detected at the beginning of all B and C phases, excluding P2's B3 phase, for which the participant reported not having conducted the calibration test.

Acceptability and user experience

After completing the study protocol, participants responded to a 16-item visual analog scale to express their agreement with acceptability and usability statements regarding the study they had just completed. The scale ranged from 0–100, with lower scores indicating disagreement and higher scores indicating agreement. In line with the importance of the scope of social validity assessment, the statements covered the goals, procedures, and outcomes of the intervention (Wolf, 1978). Half of the items (Items 2, 4, 5, 9, 10, 12, 14, and 15) were negatively phrased to document the potential for acquiescence bias.

RESULTS

Figures 2 and 3 show the amount of face touching throughout the study. All participants engaged in face touching during baseline. However, there was

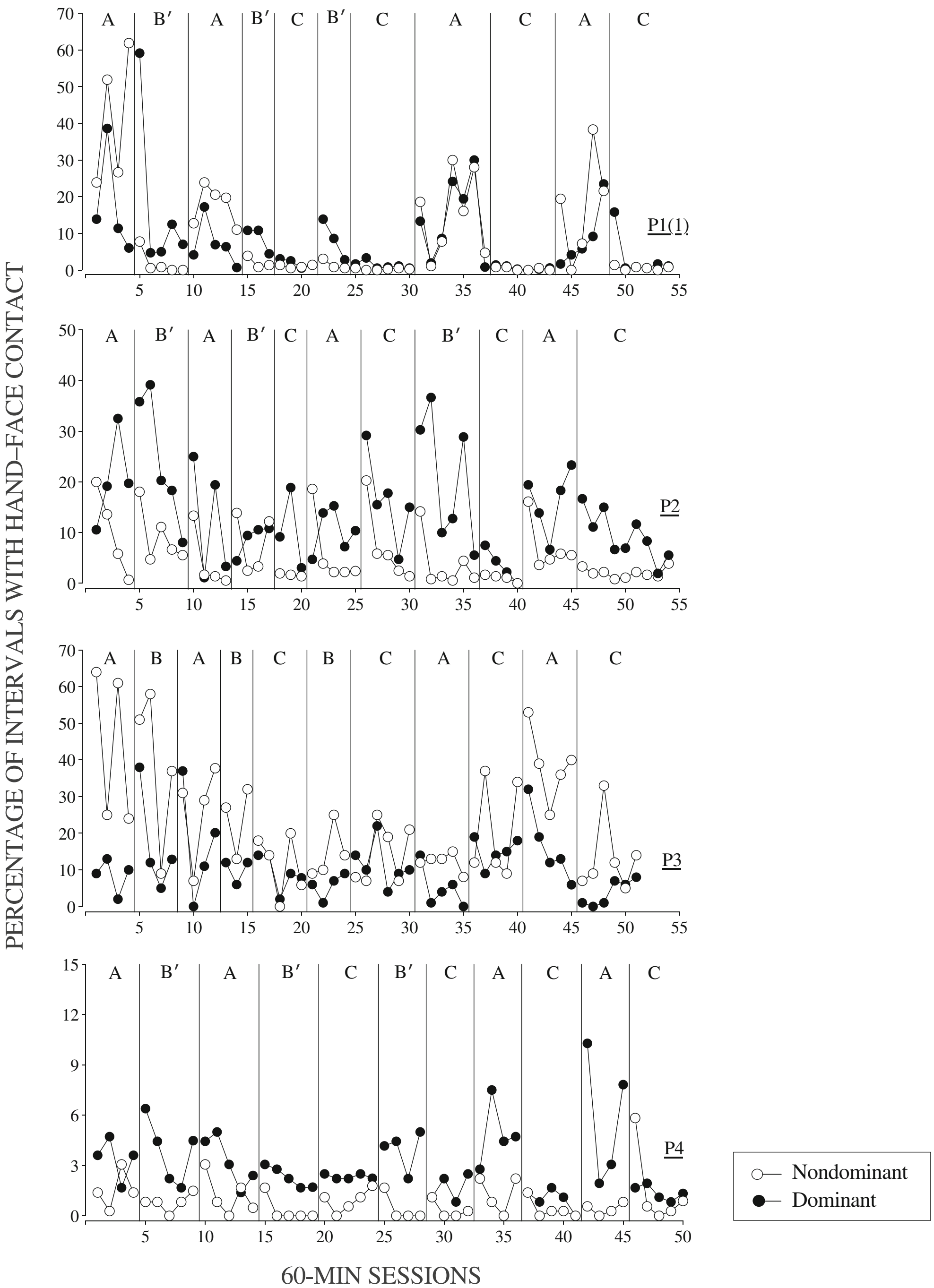

FIGURE 2 Face touching during baseline (A), one-bracelet (B), and two-bracelet phases (C). Bracelet was placed on the dominant hand during B phases and nondominant hand during B′ phases. The *y*-axes are individually scaled.

considerable variability in the mean level of face touching across participants: P2, P3, and P4 showed general, consistent differentiation between the dominant and nondominant hand during baseline, with P2 and P4 presenting relatively higher levels of face touching in the dominant hand across baseline phases. In comparison, P3 showed relatively higher levels of face touching in the nondominant hand. This suggests that hand dominance played a small role in the overall variability of face touching observed in these participants.

One-bracelet intervention

The visual analysis suggests that the one-bracelet intervention (phase B) did not consistently reduce face touching across both hands for any of the participants. The one-bracelet intervention produced an apparent reduction in face touching in the active hand specifically (the hand wearing the active bracelet during B phases) for P1(1), P2, P4, P5, and P6, whereas P3 and P7 did not show a hand-specific effect during one-bracelet phases.

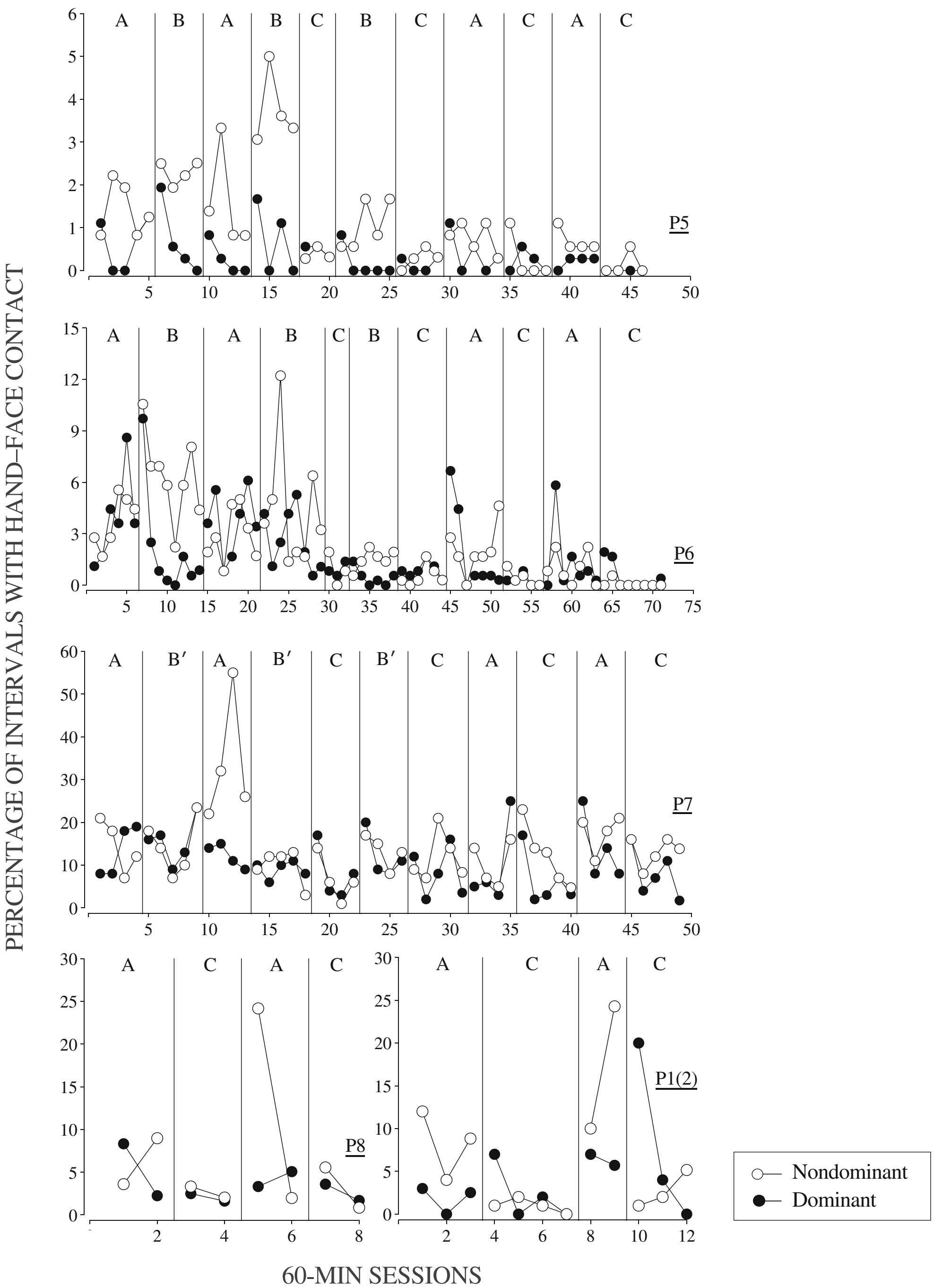

FIGURE 3 Face touching during baseline (A), one-bracelet (B), and two-bracelet phases (C). Bracelet was placed on the dominant hand during B phases and nondominant hand during B′ phases. The *y*-axes are individually scaled.

This hand-specific effect was not apparent in all one-bracelet phases reversals. For example, P4 showed this effect in the second and third but not the first one-bracelet phase. There were near-zero levels of face touching in the active hand during the last one-bracelet phase for P1(1), P2, P4, P5, and P6. However, face touching in the target hand in the preceding baseline phase was relatively low for P2, P4, and P5. The repeated implementation of the one-bracelet intervention did not enhance face touching differentiation across hands. However, P2 and P6 showed differentiation across hands only in the first and third one-bracelet phases. Interestingly, the one-bracelet intervention induced above-baseline face touching in the inactive hand for only one participant (P5), suggesting that compensatory face touching was an unlikely byproduct of the one-bracelet intervention. Consistent with the visual analysis, the HLM did not reveal a significant effect of the one-bracelet intervention over combined face touching. The change in the percentual values of combined face touching between the pooled baseline and intervention phases was −4.86, which was not statistically significant, $\widehat{\theta}_1 = -4.14$; $t(5.86) = -1.57$, $p = .17$.

Two-bracelet intervention

The visual analysis revealed that the two-bracelet intervention induced near-zero levels of face touching across hands only for P1(1), P5, and P6 and small reductions of face touching for P2, P3, P4, and P8. The two-bracelet intervention produced an apparent reduction in responding across hands for all participants except P2 and P4, for whom it reduced nondominant-hand face touching more than dominant-hand face touching. The effect was not always consistent across reversals (P3, P7), and relatively long transition trends may have precluded the full appreciation of the effect in some cases (P2). The ACAC replications of P1(2) and P8 (Figure 3) showed that the two-bracelet intervention could be effective without preceding one-bracelet phases. In line with the visual analysis, the change in percentual values of face touching between the pooled baseline and intervention phases was −6.91 percentual units, which was statistically significant, $\widehat{\theta}_1 = -6.91$; $t(8.86) = -3.49$, $p = .0071$.

Repeated exposures to the two-bracelet intervention

We evaluated whether the effect of the two-bracelet intervention changed over repeated exposures to the intervention. Specifically, we evaluated the intervention effects throughout the multiple-treatment reversal design (BC transitions were not included in this analysis). For example, the decreasing trends for P2 in the dominant hand, during two-bracelet phases, is more apparent in C3 and C4 relative to C1 and C2. In addition, P5 and P6 showed relatively lower levels of face touching during C4 relative to the preceeding two-bracelet phases.

As part of the statistical analyses, we considered changes in both A and C levels over time by assessing phase transitions individually (instead of pooling A and C phases). Given that the visual analysis largely did not reveal strong trends, the analysis model did not include a trend factor. The change in the level of face-touching events between C2 and A3 increased by 2.92 percentual values, $\widehat{\theta}_1 = 2.92$; $t(9.72) = -1.40$, $p = .19$, which was not statistically significant. The amount of face touching between A3 and C3 was reduced by 3.84 percentual values, which was not statistically significant, $\widehat{\theta}_2 = -3.84$; $t(8.96) = -1.56$, $p = .15$. Again, there was an increase in face-touching events between C3 and A4 of 10.91 percentual values, which was statistically significant, $\widehat{\theta}_3 = 10.91$; $t(8.62) = 4.49$, $p = .0017$. Last, there was a significant decrease in face touching between A4 and C4, $\widehat{\theta}_4 = -10.40$; $t(5.92) = -3.26$, $p = .0175$. In line with the visual analysis, these results suggest that the two-bracelet intervention was more successful at decreasing the amount of face touching than the one-bracelet intervention and that the last reversals were more effective than the initial one.

Predictors and moderators

Figure 4 presents a scatter plot of face touching against selected disruptors (predictors) across participants. The tests of the significance of the slope of the regression line indicated that participants were less likely to engage in face touching when they were outdoors, $F(1, 1177) = 6.08$, $p = .0138$, and when they were wearing a mask, $F(1, 1177) = 14.05$, $p = .0002$. The slopes of all other predictors, including moving around, holding a phone, and talking, were not significantly different from zero ($p > .05$). When analyzed as intervention effect moderators, moving around, being outdoors, holding a phone, and wearing a mask did not significantly alter the intervention effect during AB and AC comparisons. Therefore, common daily activities may not affect the effectiveness (or lack thereof) of the one-bracelet and two-bracelet interventions. However, a detailed a posteriori power analysis indicated that the moderator analyses for treatment effects were generally underpowered (Supporting Information, Table C4).

Acceptability and user experience

The results of the acceptability survey are summarized in Figure 5. Overall, participants indicated that the bracelets helped them become aware of face touching (88.8 ± 5.1), reduce face touching at home (90.0 ± 5.7), and reduce contact with potentially contaminated surfaces in general (93.6 ± 3.9). Participants found wearing the bracelets to be compatible with the performance of everyday routines (93.9 ± 3.7) and reported that the vibration was easy to detect (100.0 ± 0.0). In line with our sensitivity analysis, most participants indicated that bracelets produced some false-positive (60.0 ± 11.5) and false-negative (46.3 ± 10.9) vibrotactile cues. All participants agreed that reducing face touching (97.3 ± 1.7) and avoiding contact with potentially contaminated surfaces (97.1 ± 1.9) was essential. About half of the participants expressed high agreement ratings, indicating they were motivated to refrain from face touching after noticing the vibration. Interestingly, some participants reported using alternative behaviors (e.g., interlocking hands, touching hands, touching hair, or moving facial muscles to relieve itching) to help them refrain from face touching (69.3 ± 12.3) and that the bracelets helped them to become aware of habitual behaviors other than face touching (e.g., biting nails, rubbing hair, or poking eyes or ears, 93.6 ± 3.9).

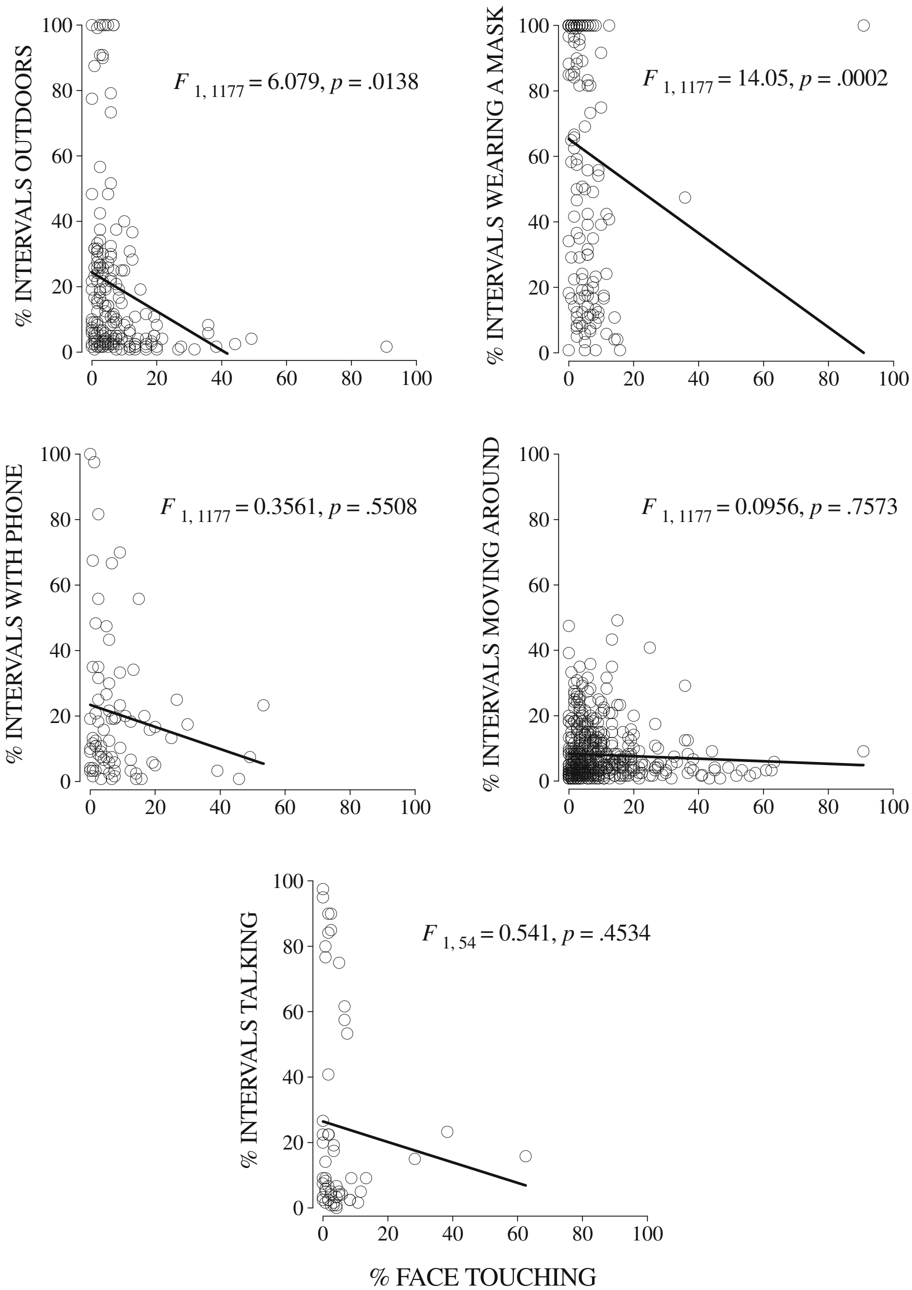

FIGURE 4 Potential disruptors of face touching. All tests of the significance of the slope of the regression line between the percentages of 10-s intervals with the disruptor and face touching over all 20-min segments across participants. Sessions where disruptor equaled zero have been removed from the graphs.

DISCUSSION

This study suggests that it is possible to conduct a naturalistic evaluation of face touching using wearable cameras on a semicontinuous basis during extended baseline and intervention periods. The one-bracelet intervention produced an apparent, sometimes low-magnitude, reduction in face touching for the hand wearing the bracelet for five of the seven participants that underwent the full multiple-treatment reversal design. However, no overall reductive effect of the one-bracelet intervention on overall face touching could be established. The two-bracelet intervention produced significantly lower levels of face touching, and an increasingly reductive effect was observed with repeated implementation of the two-bracelet intervention according to the statistical analysis. Intervention effects were somewhat idiosyncratic, with some participants demonstrating an almost complete reduction of face touching (e.g., P1, P5, and P6) with minimal or no apparent effect ascertained for others (e.g., P3, P4, and P7). In addition, the speed of the effect varied greatly across participants. Variables such as mask

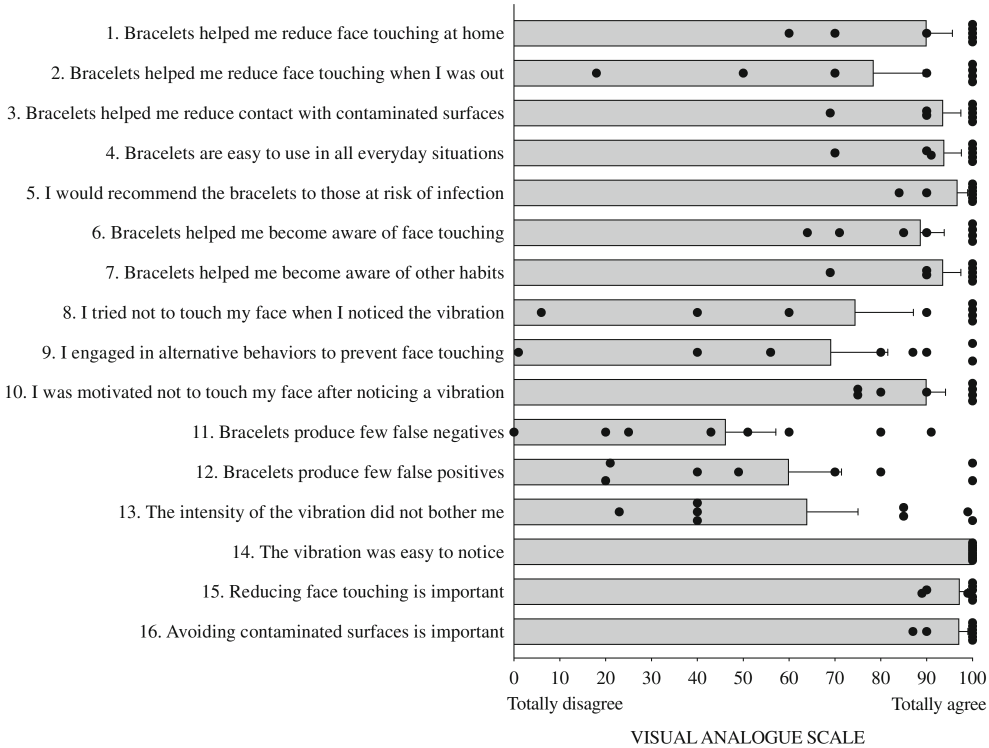

FIGURE 5 Acceptability and user experience. Individual scores, means, and standard errors. Half of the items (i.e., items 2, 4, 5, 9, 10, 12, 14, and 15) were negatively phrased to document the potential for acquiescence bias. For ease of interpretation, all items are positively phrased and scored in the diagram.

wearing, known to disrupt face touching (Chen et al., 2020; Stefaniak et al., 2021), were associated with fewer face-touching events. However, the studied disruptors did not moderate face-touching reduction, indicating some robustness of the intervention effect. It is difficult to rule out the possibility that some or even much of the variability of responding shown by the participants occurred due to individuals engaging in various activities (and perhaps switching between activities) that were not monitored or recorded as disruptors. Although our approach could have been improved by having some rules, parameters, and limits around which activities the participants should engage in during recording sessions, we felt that true naturalistic recording was a positive aspect of the study and strengthened the possible interpretation of results. Nevertheless, the fact that being outdoors and wearing a mask were associated with less face touching is an interesting and important finding, suggesting that such interventions could be targeted only for high(er) risk situations.

This is the first naturalistic assessment of a remedial strategy for face touching conducted to date. Such naturalistic assessments are a critical methodological approach to evaluating high-frequency behaviors of public health interest. Face touching is a surprisingly diverse behavior in terms of its topography. Individuals may touch any area of their face, with one or both hands, using one or several fingers, their palms, the back of the hand, or knuckles. Such heterogeneity in responding adds to the complexity of recording such behavior reliably. Perhaps because of this challenge, face-touching studies in the literature have been limited to survey studies (e.g., Guzek et al., 2020) or studies using behavioral observation with very modest data sets. For example, Lucas et al. (2020) studied the frequency of face touching among pediatric hematology and pediatric oncology health care professionals. However, their results were limited by just 330 min of observation (relative to over 25,000 min of direct observation obtained in this study). Possibly due to the cost of conducting studies in naturalistic settings, the existing cueing-based mitigating strategies for reducing face touching have not been evaluated in such settings or over extended periods (Michelin et al., 2021).

Although the current study established the feasibility of a naturalistic evaluation of face touching and suggested some positive effects for the two-bracelet intervention, future studies ought to evaluate whether the reductive effects documented here translate into reduced risk of fomite-mediated transmission in high-risk environments such as schools, offices, and hospitals (Kraay et al., 2021). To our knowledge, face touching has not been adequately modeled as a transmission vector. The dynamics of face-touch-mediated transmission are critical to evaluate the social significance of the current findings. For example, a linear or dose–response relation between face touching and risk of transmission would suggest that reductions in face touching within the range reported here (i.e., between 15–30 fewer events per hour) could have a sizable effect on risk reduction. Hand washing may be an analog to face touching in this respect. For example, a community transmission study by Beale et al. (2021) indicated that moderate levels of hand washing could lead to over 30% reduction in personal risk of coronavirus infection (adjusted incidence rate ratio = 0.64, $p = .04$). However, the researchers did not find a dose–response relation, meaning that high-frequency hand washing (i.e., above 10 times a day) did not lead to additional reductions in personal risk of infection. In contrast, if we were to assume that the protective effect of reducing face touching is better characterized on a dose–response basis, mitigating strategies such as the one studied here may be of lesser value, particularly among those with relatively high levels of face touching during baseline. Both modeling and community cohort studies are needed to determine the level of risk reduction that may be attributed to every unit of reduced face touching.

We evaluated a purposely minimalistic set of interventions (one-bracelet vs. two-bracelet vibrotactile stimulation contingent on face-touching events) with the conservative goal of ascertaining whether such interventions may lead to the cost-effective reduction of face touching. The optimization of intervention effects may require considerable additional research. Specifically, awareness-training strategies, such as the one evaluated here, are only one of the various components typically included in evidence-based intervention packages for ameliorating habitual behaviors. For example, Miltenberger (2016) recommends combining awareness training with other evidence-based intervention components including competing-response strategies, social support, and motivational procedures (see also Heinicke et al., 2020). Future research may also consider investigating the sensitivity of the motion-sensing device, as well as the delay of the vibrotactile stimulus. Several studies have shown that contingent but intermittent and delayed presentation of putatively aversive stimuli have a deleterious effect on the immediacy and the magnitude of interventions intended to reduce problem behavior in laboratory and clinical studies (Lerman et al., 1997; O'Donnell et al., 2000; see also evidence in support of delayed punishment in Donaldson & Vollmer, 2012; Van Houten & Rolider, 1988). Such findings may explain the delayed and somewhat idiosyncratic patterns of results found among some participants in this study.

It would be interesting to establish whether contingent vibrotactile stimulation's effects result from increased awareness or the product of a mild punishment procedure. In practice, these effects might be difficult to separate because awareness may indeed be established by differential punishment. According to the usability survey, the haptic feedback made participants more aware of the behavior (Figure 5). Future studies could assess an individual's recall of the recent occurrence of the behavior (a proxy to awareness) as a function of contingent haptic feedback while assessing the influence of various intermittent punishment schedules. Presumably, increased awareness may be a function of the number of behavior–feedback pairings, whereas the reductive effects of punishment could be dependent on punishment schedule or punisher magnitude.

The structure of our data set did not allow a receiver-operating-characteristic analysis because there were no "false" events within the reference variable (i.e., true face-touching events) in our sensitivity analysis and the predictor variable (i.e., the occurrence of vibrotactile stimulus) was dichotomic. More comprehensive analyses may be possible using time-based definitions for the reference and predictor variables, possibly by using duration and latency as proxies for the reference and predictor variables, respectively. Specifically, face-touching events of a particular duration could be identified as true events, whereas haptic feedback delay may be characterized as a predictor variable. In addition, adding "false" reference events may be possible by choreographing movements close to face touching without actual hand to face contact. However, it would be challenging to determine the ecological validity of such assessments.[2] False positives would have been important to document. However, these were highly predictable when a participant assumed wrist orientations characteristic of face touching (e.g., reaching for an object in a high cabinet, drinking from a glass, shaving, toothbrushing). For the current preliminary analysis, documenting false-negative events seemed the most practical approach, as false-negative events indicate the ratio or percentage schedule to which participants might have been exposed. Although a false-negative rate of .20 may seem high, it parallels a 1.25 variable ratio (80% of responses reinforced or punished). Some reports suggest that a fixed-ratio 2 punishment schedule (50% of responses punished) may be as effective as continuous punishment (e.g., Uhl, 1967). The applied literature has also found comparable effects of continuous and intermittent punishment under some circumstances, even though much thinner schedules have been evaluated (Donaldson & Vollmer, 2012; Lerman et al., 1997; Romanczyk, 1977).

In summary, future studies could expand on the sensitivity and specificity analyses and potential schedule effects of haptic feedback. These factors are likely to affect the effectiveness and acceptability of the intervention. Indeed, false positives and false negatives noted in the sensitivity analysis and the usability survey may be a potential barrier against a wider adoption of the proposed system. These may be attributed to the indirect detection of the target behavior through wrist orientation instead of the direct detection of hand–face distance. The latter approach might have been more accurate at the

[2]A more acceptable alternative would have been to have a machine-generated data stream, allowing a naturalistic evaluation of both sensitivity and specificity.

cost of requiring an additional apparatus to be attached to the individual's head or neck.

Although small-*N* studies such as this one may be ideal for exploring intervention parameters that could optimize intervention effects, our findings should be replicated and expanded in larger *N* treatment evaluations and randomized controlled trials. Overall, the current analysis presents a preliminary evaluation of a computer-mediated cueing system and its effect on a critical habitual behavior that could be mitigated during epidemics/pandemics where fomite transmission is implicated as a significant concern. It also presents a case study in the automatic detection of human behavior as a technological missing link to control and reduce potentially harmful behavior in naturalistic settings. Larger *N* studies would also be helpful in terms of evaluating sources of between-subject variability and may help to improve the efficacy of an intervention for those who were initially nonresponders or low responders.

Future research should also consider the conditions under which optimizing the technology's precision may depend on specific environmental contexts. For example, the precision of the reference points may be less critical when walking, with perhaps any hand movement that rises to shoulder level triggering the vibrotactile stimulus, but would require increased precision when sitting with multiple reference points being necessary.

The current evaluation suggests that hand–face contact, a potential risk behavior for the transmission of viruses, may be reduced using computer-mediated vibrotactile stimulation in naturalistic settings. A single-bracelet arrangement resulted in either no effect or hand-specific effects that rarely produced significantly lower levels of overall face touching. A two-bracelet arrangement produced a visually apparent effect for most individuals and statistically significant lower levels of face touching but with considerable variability across participants. The overall reductive effect of the two-bracelet intervention increased gradually upon the repeated presentation of the intervention over successive days. The fact that some participants did show a reduction of face touching whereas others showed no appreciable intervention effects suggests that the intervention ought to be optimized further before large-*N* studies can be conducted. This may involve the addition of intervention components that have been shown to be effective in the treatment literature of habitual behaviors.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS APPROVAL

The study protocol was approved by the ethics committee of the Universidad Autónoma de Madrid (CEI 106–2062).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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