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User acceptance of a touchless sterile system to control virtual orthodontic study models

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Introduction: In this article, we present an evaluation of user acceptance of our innovative hand-gesture–based touchless sterile system for interaction with and control of a set of 3-dimensional digitized orthodontic study models using the Kinect motion-capture sensor (Microsoft, Redmond, Wash). **Methods:** The system was tested on a cohort of 201 participants. Using our validated questionnaire, the participants evaluated 7 hand-gesture–based commands that allowed the user to adjust the model in size, position, and aspect and to switch the image on the screen to view the maxillary arch, the mandibular arch, or models in occlusion. Participants' responses were assessed using Rasch analysis so that their perceptions of the usefulness of the hand gestures for the commands could be directly referenced against their acceptance of the gestures. Their perceptions of the potential value of this system for cross-infection control were also evaluated. **Results:** Most participants endorsed these commands as accurate. Our designated hand gestures for these commands were generally accepted. We also found a positive and significant correlation between our participants' level of awareness of cross infection and their endorsement to use this system in clinical practice. **Conclusions:** This study supports the adoption of this promising development for a sterile touch-free patient record-management system. (Am J Orthod Dentofacial Orthop 2016;149:567-78)

Many countries across the world require electronic patient records.[1] Accessing these records via keyboard, mouse, touch screen, or pad raises the risk of cross infection. Infectious pathogenic microorganisms such as cytomegalovirus, herpes simplex virus types 1 and 2, hepatitis B virus, human immunodeficiency virus, hepatitis C virus, and bacteria that colonize or infect the oral cavity and respiratory tract such as staphylococci, streptococci, and *Mycobacterium tuberculosis* are occupational hazards that can be transmitted by contact, direct or indirect, between dental health care personnel and patients.[2,3] Although gloves are a personal protective barrier between clinicians and patients, they still need to be frequently removed, at some inconvenience, when health care personnel are operating computer input devices during treatment.

This problem of touch-induced risk of cross infection during navigation of medical records may be minimized via a touch-free gesture interface with motion-capture camera devices such as Kinect (Microsoft, Redmond, Wash), with the ability to distinguish color images and the associated depth data, coupled with innovative programming strategies, and has furthered the development of an accurate contact-independent controlling device.[4] This low-cost and easy-to-set-up device may also encourage improved cross-infection prevention in practice, especially in countries where inaffordability is a limiting factor, leading to poorer cross-infection control and safety practices.[5]

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There is a pending patent application on the motion-based sterile image control for dental care (SK/P1423UM/14).
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Prototypes of gesture-based programs for Kinect have been presented for navigation of radiologic images during operating procedures.[6,7] Furthermore, such prototype programs have been successfully pilot tested during surgical procedures while maintaining operator sterility, demonstrating the potential for improved cross-infection strategies.[8,9]

In view of this potential, we have developed a hand-gesture–based program for practical cross-infection control when accessing patients' electronic records in dental settings. Our prototype was designed to facilitate assessment of the 3-dimensional (3D) digitized dental study models from the sagittal, vertical, and transverse planes. The dental study model was chosen as the object of interest for this program because it is commonly used for baseline records, treatment planning, and monitoring changes. Most currently used digital forms of study models reproduce dental features with an acceptable level of clinical accuracy.[10] It is expected that the future of dentistry will involve their use in place of stone study models for easy access and space-saving storage. Our prototype uses Kinect to provide a sterile method for the dentist to naturally and efficiently manipulate the 3D digital study models with specific noncontact hand-gesture commands.

The rationale of this study was to evaluate the developed system as a method to lower the risk of cross infection in clinical practice. We assessed user acceptance of our proposed hand-gesture user interface for interaction and manipulation of a 3D digital object. We investigated whether the prototype accurately discriminated each hand gesture to be translated for each specific command to the program and at the same time whether these gestures and the system were acceptable to the users.

MATERIAL AND METHODS

Ethical approval for this study was obtained from the Medical Ethics Committee, Faculty of Dentistry, University of Malaya, Kuala Lumpur (DF OT1306/0078[U]).

This section describes the building of a robust hand-gesture recognition system using, as the input device, the Kinect sensor, which captures the color image and the depth map at 640 $\times$ 480 pixel resolution. Because the depth sensor of Kinect is an infrared camera, the lighting conditions, the background, and the colors of a patient's skin and clothing have little impact on its performance.[10] In this study, the Kinect sensor was connected via a 2.0 USB connector to an Ideapad Z460 (14-in screen size; Lenovo, Beijing, China), a Core i5-380M processor (Intel, Santa Clara, Calif), a graphic engine (Windows 7 Home Basic; Microsoft), and GeForce with CUDA (Nvidia, Santa Clara, Calif). We used Visual Studio 2010 (Microsoft) with our developed hand-gesture recognition program as detailed in the next paragraph. The aim was to provide a more natural human-computer interface, allowing the dentist to "pick up" the 3D digitized orthodontic study model by moving the hands within the working area, which detects the action as an initiative to move the model, and to "examine" the model by maneuvering the hands in the air.

The system comprises a touchless 2-hand-gesture navigational scheme for 7 commands: translation, zoom in, zoom out, rotate up and down, rotate side to side, select menu, and reset. Translation moves the 3D study model from one location on the screen to another. Zoom in and zoom out increase and reduce the model size, respectively. Rotate up and down refers to the rotation of the model around a horizontal axis, whereas rotate side to side refers to its rotation around a vertical axis. Select menu allows 1 of the 3 options on the right side (menu bars) of the screen to be activated and displayed on the main screen. The options include select the maxillary arch, mandibular arch, or both arches in occlusion. Reset returns the object to its original position and size on the active main screen, as shown in Figure 1, *A*.

The working distance between the Kinect sensor and the participants was approximately 2 meters. Two green circles, representing each hand, appeared onscreen when the users were within the working area (Fig 1, *A*). Detection of unintended movement was avoided by moving the hands out of the working area, as indicated by the disappearance of the green circles. As shown in Figure 1, *B*, translational movement was controlled by moving the left hand in the vertical or horizontal direction. Rotations in the up-and-down and side-to-side directions were achieved by right-hand vertical and horizontal shifts, respectively. For zooming in to the models, the hands moved apart from the center of the body. For zooming out of the models, the hands moved toward the center of the body. Placing the left hand slightly apart from the side of the user's body activated the side menu, as indicated by a color change on the side menu bar. An active cursor then appeared for the right hand to guide toward the desired menu, which is selected by a gentle tapping movement of the hand. Reset was activated when both hands were moved apart slightly from the sides of the body.

Our subject inclusion criteria specified health care associates between 21 and 40 years old with fully functional bilateral hands and good eyesight.

The exclusion criteria included those with medical conditions such as arthritis that may be affected by repetitive hand movements and those, such as epileptics,

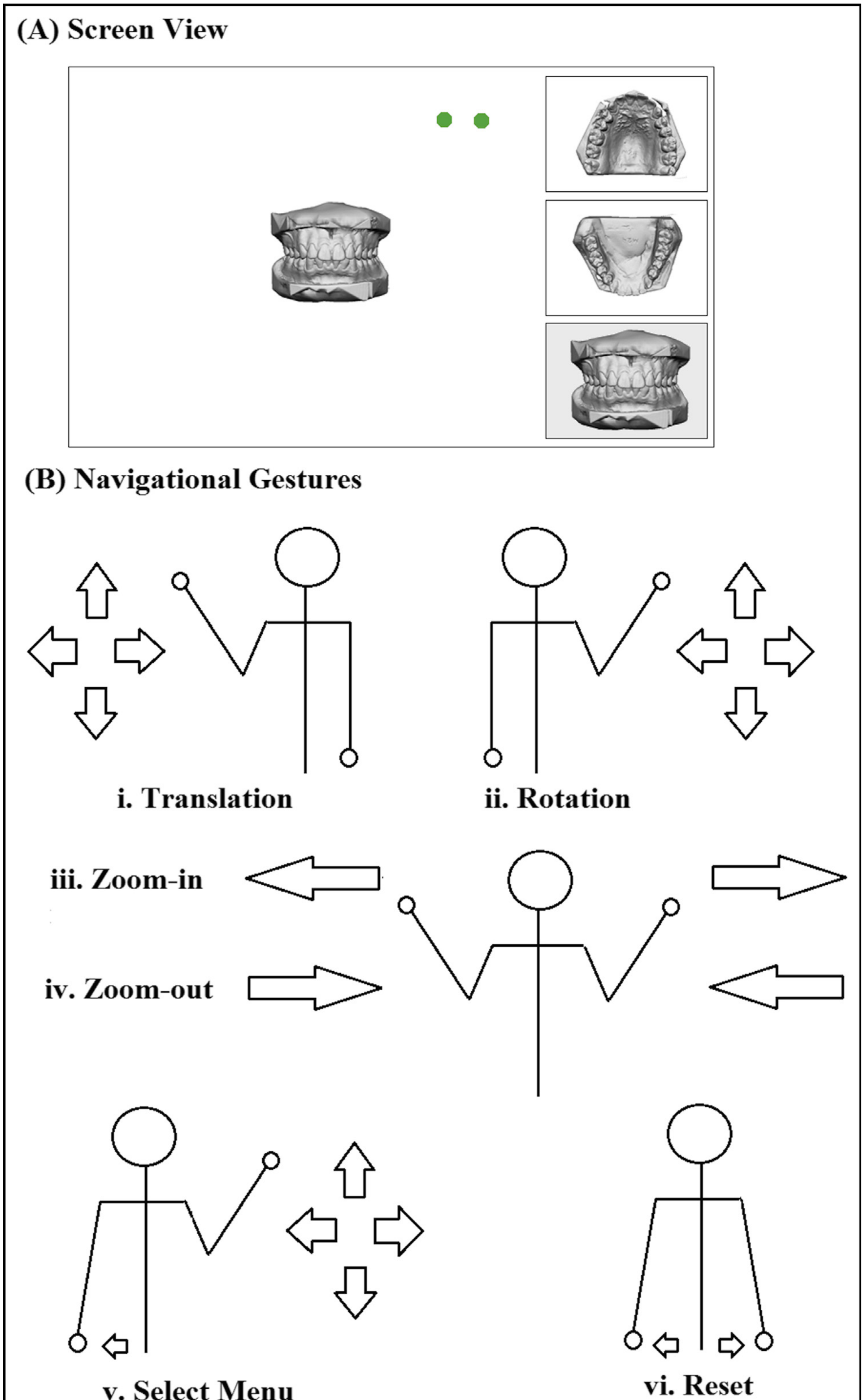

Fig 1. A, Screen as viewed by users with the object to be manipulated in the active section and the menu bars on the right side. Two *green circles* representing each hand appear on the active screen when the user's hands are within the working area. **B,** The commands to be used to move the 3D study model in the active section of the screen.

who may be affected by the displayed images. We also excluded those who could not read English.

Since Rasch analysis was planned for this study, it was estimated that a sample of 108 to 243 participants would be sufficient to give 99% confidence that the estimated value is within ±0.5 logits.[11] For this study, we targeted a sample of 201 participants.[12]

Data collection and instrumentation

The questionnaire comprised 4 parts: part A, demography of the participants; part B, their feedback on the accuracy and comfort with the hand-gesture system; part C, their feedback on suitability, offensiveness, and maintainability of the hand-gesture system; and part D, their perception of the usefulness of the system in relation to cross-infection control. Opinions were inventoried with Likert-scale answers.

In part B, the participants were introduced to the navigation interface of the system. They were allowed to navigate the digital study model freely until they were satisfied with their familiarity of the hand gestures. They were then required to control the model using the appropriate hand gestures according to randomly selected commands called out by the investigator (N.M.S). After they had randomly performed all 7 commands (T1), the process was repeated immediately 2 additional times. The participants later rated their perceived accuracy of the hand-gesture–based commands and their comfort level when performing the hand gestures to achieve the outcome. A 7-point Likert scale was used to rate the perceived accuracy of each participant's use of the gestures, with 1 as "absolutely not able to achieve the action as accurately as desired at all," 4 as "neutral," and 7 as "absolutely able to achieve the action as accurately as desired." Similarly, the level of comfort with which the participants used the system was evaluated with 1 as "extremely uncomfortable," 4 as "neutral," and 7 as "extremely comfortable."

Part C required the participants to rate whether the hand gestures of each command were either suitable or offensive, and whether they should be maintained. Suitability measured the participants' perceptions of the appropriateness of the gestures to their natural intuitiveness of actions to achieve the commands, whereas offensive assessed whether the gestures would be culturally unacceptable. The maintenance question inquired whether they thought that the system is acceptable as it is or whether it should be changed. Participants were also encouraged to suggest other preferred gestures for each command at the end of the questionnaire. Responses were measured using a 7-point Likert scale with 1 as "strongly disagree," 2 as "quite disagree," 3 as "slightly disagree," 4 as "neutral," 5 "slightly agree," 6 as "quite agree," and 7 as "strongly agree."

Finally, they were asked questions that assessed their awareness of cross-infection risks and sought their endorsement of the system for cross-infection control. The awareness subscale comprised 2 item measures: "I am aware that I can get infectious diseases when I go the hospital or clinic (including the dental clinic)" and "I worry that I may get infectious diseases when I go the hospital or clinic (including the dental clinic)." The endorsement subscale comprised 4 item measures: "It is important for the people working at the hospital or clinic (including the dental clinic) to practice good cross-infection control," "The motion-capture camera system may be a practical way as an input device to access patient records on computers," "The motion-capture camera system is a good method to prevent cross infection," and "The use of the motion-capture camera system should be encouraged for cross-infection control." The Likert scales used to rate their answers were similar to those in part C.

The questionnaire was validated for content by 3 experts (N.L.A.K. and 2 others). It was piloted on 20 participants. Minimal language amendments were made for cultural propriety while maintaining the validity of the content. It was further tested on another 20 participants twice at least 7 days apart. One participant dropped out. The questionnaire was considered reliable, since the weighted kappa showed no significant differences for at least 70% of the responses. The validated questionnaire was given to the recruited participants, none of whom had served in the validation studies.

Statistical analysis

Winsteps (version 3.80.1; Winsteps, Beaverton, Ore; available at www.winsteps.com) was used to analyze the raw ordinal ratings. Rasch analysis was used to allow our participants to be ranked along the same linear logit scale of the perceived rated qualities of the items measured.[13]

Rasch analysis estimated the participants' perceived accuracy of the hand-gesture–based commands and comfort level when giving the hand gestures. Participants' perceptions of the attributes of the hand gestures, whether they were "suitable" or "not offensive" (reversed value for the offensive ratings) and should be "maintained" for the related command, were also analyzed using Rasch analysis.

The internal consistency of items measuring the infection-control subscales were acceptable (Cronbach alpha = 0.74 and 0.87, for awareness and endorsement subscales, respectively). We calculated the person measure for each subscale by Rasch analysis. We then assessed the relationship between these subscales by Pearson correlation coefficient and by cross-plotting the person-measure values.

RESULTS

We recruited 201 participants: 89 men and 112 women (mean age, 25.05 years; SD, 4.44 years). They comprised students (62.2%) and temporary (4.0%) and permanent (33.8%) employees at University of Malaya, Kuala Lumpur. The participants' areas of expertise were medicine (55.7%), dentistry (27.9%), nursing (15.9%), or radiology (0.5%). The majority were right-handed (84.1%); others were left-handed (6.5%), mixed-handed (changing hands depending on the task) (8.0%), and ambidextrous (performing any task equally well with both hands) (1.5%).

The mean duration of each hand-gesture–based command was 8.61 seconds (SD, 2.78 seconds).

In the Rasch analysis, the participants' underlying perceived agreeability toward the levels of accuracy and comfort of the hand-gesture–based commands were estimated based on the ratings that they gave to the total number of commands they performed (7 commands repeated trice). Item difficulty measure refers to the Rasch estimate of the level of difficulty of the item (ie, hand-gesture–based command).[13] The measurement of the difficulty of each item was calibrated from the total ratings given to the respective hand-gesture–based command.

Figures 2 and 3 present the Rasch person-item map illustrating the relationship between participants' agreeability to the accuracy and comfort levels of the hand-gesture–based command (*left columns*) and the level of accuracy and comfort of each hand-gesture–based command (*right columns*) on a common logit scale (*central bar*). As a general rule, the mean item difficulty estimate is centered on 0 logits.[13] Participants and items were arranged according to their logit measurements so that the most affirmative person (who gave high ratings to the items) and the most difficult item (which received the lowest ratings) are on the upper section of the map, and the least affirmative person and least difficult item are on the lower section of the map. Thus, the higher the participant is on the map, the more likely he or she would have been to endorse the accuracy or comfort level of the hand-gesture–based commands. Conversely, the lower the item is on the map, the more likely the item would have been to be endorsed by the participants as accurately and comfortably performed.

Figure 2 on accuracy demonstrates the spread of the participants (logit range, 7.69 to 0.35) and the corresponding commands (logit range, 1.76 to −1.68). Most participants (92.0%) had logit scores that were higher (≥1.79) than all commands, indicating that a large proportion of the participants affirmed that they were able to perform the hand-gesture commands accurately. In Figure 3 on comfort level, the distribution also showed that most participants (logit range, 6.97 to −0.75) had higher logit scores than the commands (logit range, 2.09 to −1.69). More than 3 quarters of the participants (77.6%) had logit scores of 2.14 and above. Similarly, this signified that they affirmed that the hand gestures were comfortable for most if not all commands. The reset command had logit scores that were lower than all of the participants' logit values at all 3 attempts (−1.49 to −1.68 for accuracy, and −1.53 to −1.69 for comfort), showing that it was perceived to be the most accurate command and the most comfortable hand-gesture–based command to perform. In contrast, select menu was considered the least accurate (1.76 to 0.95) and the least comfortable (2.09 to 1.21) because it had the highest logit scores among the 7 commands. The other hand-gesture–based commands were perceived to be within 1 SD of the mean item difficulty estimates for both accuracy and comfort.

Figure 4, *A* and *B*, present the category probability curves for the accuracy and comfort level rating scales, respectively. The diagrams show the predicted probability of each participant's response, which is based on the difference between the logit measure estimates of the person and the item of interest. This information aided in determining the probable rating for each item by the most and least affirmative persons.

In our sample, the participant (M143) who was the least affirmative person in rating the accuracy of the commands had a logit value of 0.35, while select menu at T1 (SM1) was perceived as the least accurate command, with a logit score of 1.76. Figure 4, *A* showed that by extrapolating from the difference between person and item (−1.41), this participant had approximately a 50% probability to rate select menu at T1 as 4 (neither accurate nor inaccurate) or less than a 40% probability to rate it as 5 (quite accurate). The probability for this participant to rate it at 3 (slightly inaccurate) was less than 10%. For the comfort level of the hand gestures, the least affirmative participant (F198) had logit scores of −0.75, whereas select menu at T1, perceived as the least comfortable gesture, had a logit value of 2.09. Figure 4, *B* demonstrated that by extrapolating from the difference between person and item (−2.84),

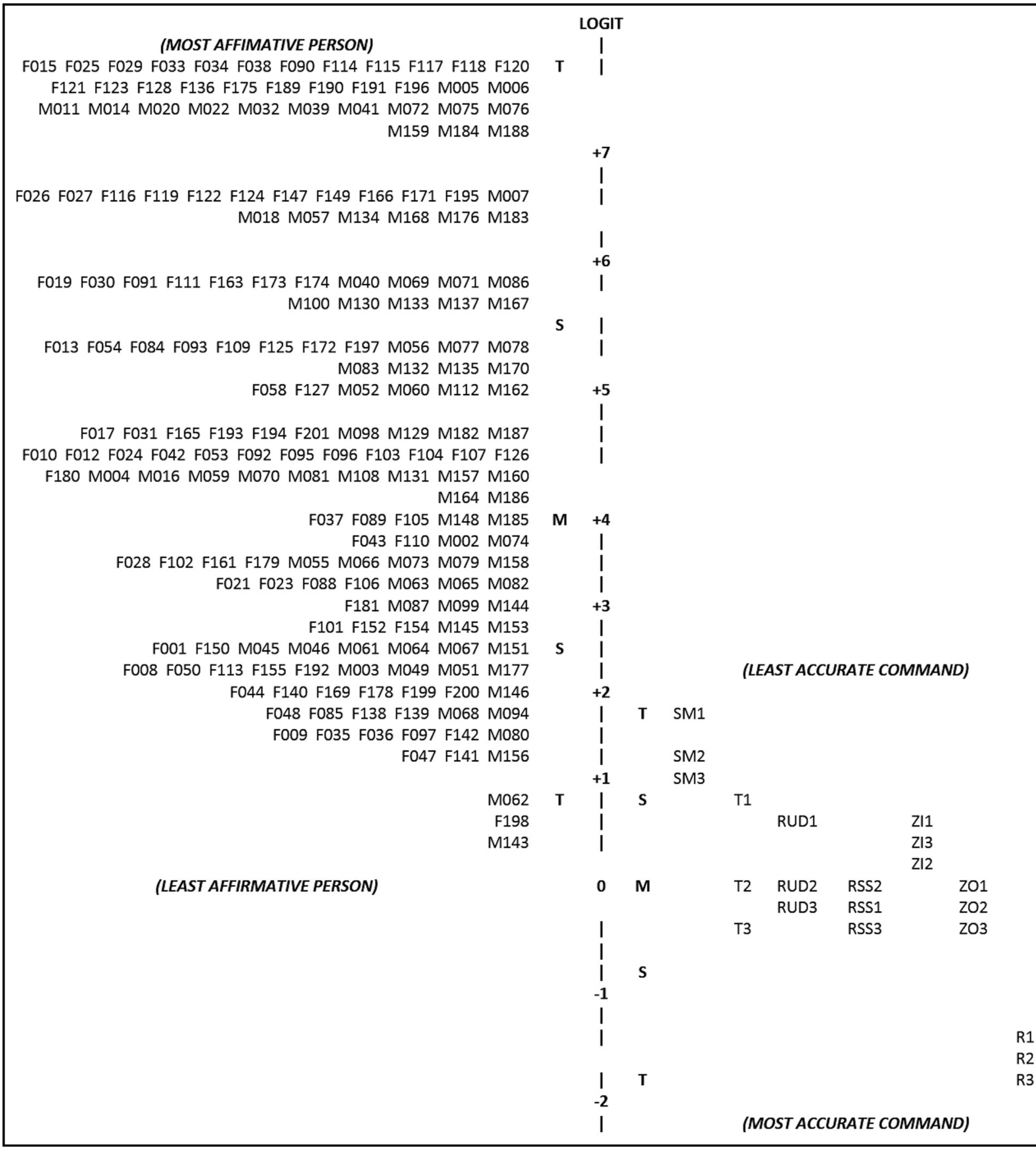

Fig 2. Accuracy of gestures: Locations of participants relative to the commands as mapped against the logit scale for the hand-based gestures to accurately achieve the desired commands. Positions of each participant are distributed on the left of the logit scale with the more affirmative participants at the top and the less affirmative ones at the bottom of the spread. The commands (*items*) are on the right of the scale and arranged so that the command endorsed as the most accurate is at the lower end and the least accurate is at the upper end of the spread. The map aids direct visual comparisons of individual endorsement of each command. *M*, Person mean or item mean; *S*, 1 SD; *T*, 2 SD.

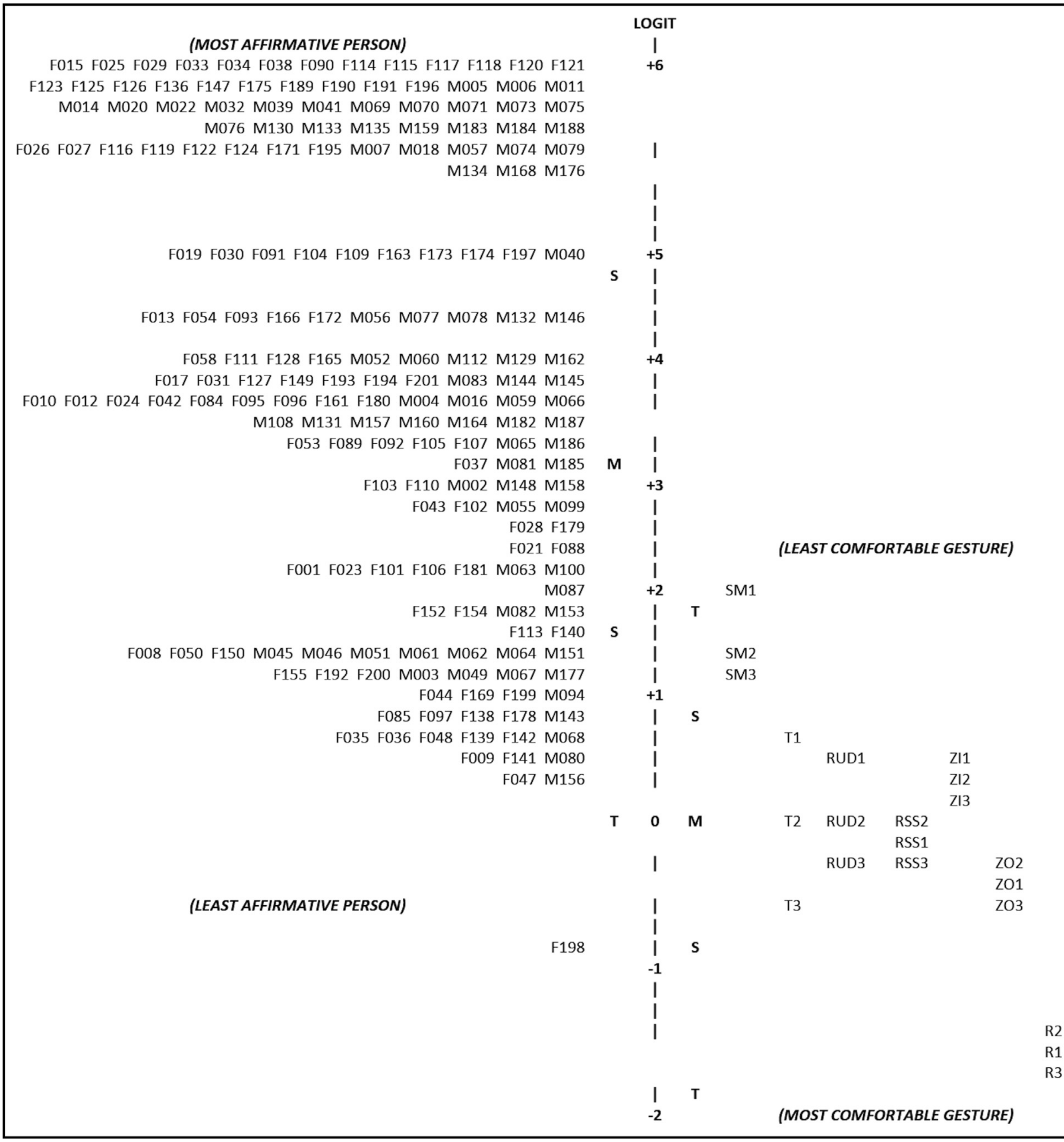

Fig 3. Comfort levels of gestures: Locations of participants relative to the commands as mapped against the logit scale for their assessments of the comfort levels to perform the hand gestures to achieve the commands. Positions of each participant are distributed on the left of the logit scale with the more affirmative participants at the top and the less affirmative ones at the bottom of the spread. The commands (*items*) are on the right of the scale and arranged so that the command endorsed as the most comfortable is at the lower end and the least comfortable is at the upper end of the spread. The map aids direct visual comparison of individual endorsement of each command. *M*, Person mean or item mean; *S*, 1 SD; *T*, 2 SD.

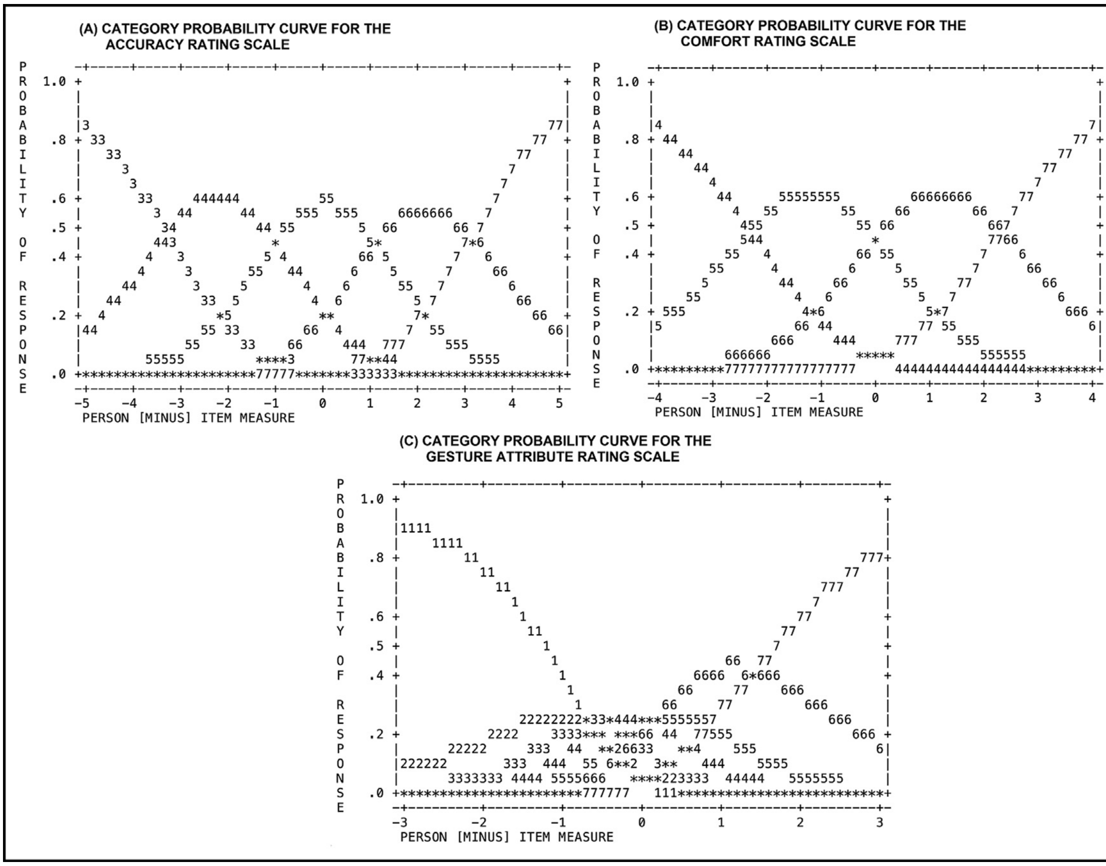

Fig 4. Category probability curves for: **A,** accuracy of the hand-based gestures to achieve the desired commands; **B,** user comfort levels to perform the hand gestures to achieve the commands; **C,** gesture attributes: suitable and inoffensive, and should be maintained by the participants. The expected rating categories by the participants were predicted by first determining the person (individual logit value) minus item measure (command logit value) score. This score was plotted on the diagram to determine the probability of each response (expected rating) for the command selected.

this participant had approximately less than a 60% probability to rate select menu at T1 as 4 (neither comfortable nor uncomfortable) and less than a 40% probability to rate it as 5 (quite comfortable). These findings indicate that despite the ratings as the least accurate and least comfortable hand-gesture–based command, the accuracy and comfort level of the select menu command were still more likely to be rated at 4 (neutral) or above by the participants.

Figure 5 illustrates the person-item map of the participants' agreement with the endorsement levels of the gesture attributes. A large proportion of the participants (77.6%) had logit values (5.74 to 0.85) that were higher than the hand-gesture attributes (0.83 to −0.62), indicating that most of our sample agreed that the hand gestures were suitable and not offensive and should be maintained. Reset, which had the lowest logit values in all 3 categories, was endorsed as the hand gesture that was the most suitable (−0.52) and most inoffensive (−0.62) and should be maintained (−0.34). Select menu was the least endorsed hand-gesture attribute in terms of suitability (0.65) and whether it should be maintained (0.83). Select menu (−0.01) and translation (0.03) were almost equally endorsed as the least-inoffensive hand gestures.

We found that the category probability curves of the rating scale for the gesture attributes were disordered (Fig 4, *C*). The probability that participants would endorse the gesture attributes with the intermediate categories between 2 and 5 was less than 30%. If the difference between the person-to-item logits is more than 1.0 or less than −1.0, there is a higher probability that extreme ratings would be selected. Thus, the 2 least agreeable participants (logit = −0.24) had approximately a 40% probability to rate 1 on the least endorsed attribute: ie, that the select-menu gesture should be maintained (logit = 0.83; person-item measure, −1.07). On the other hand, the more agreeable participants, whose logits were higher than the gesture attributes (increasing positivity on the x-axis), were more likely to rate the attributes at 6 or 7.

We studied the relationships among the attributes of accuracy of the command, gesture comfort, and appropriateness of the gesture. The Pearson correlation coefficient detected a statistically significant correlation (P <0.001) between the person measures for the hand-gesture–based command accuracy and the hand-gesture comfort level (r = 0.917), between the hand-gesture–based command accuracy and the appropriateness of the hand-gesture attributes (r = 0.405), and between the hand-gesture comfort level and the appropriateness of their attributes (r = 0.423).

More than 3 quarters of the participants (77.6%) had person measures (0.99 to 5.91) above the items for awareness of cross infection (0.88 and −0.88), and most participants (91.5%) had measurements (0.87 to 7.63) above the items for endorsement of the usefulness of the touchless system for cross-infection control (0.77 to −1.78).

Figure 6 shows the relationship between the participants' awareness of cross infection and their endorsement of the usefulness of the touchless system for cross-infection control. The best-fit line denotes the trend of the relationship, whereas the 95% confidence interval boundaries signify the reliability estimate of this trend where 95% of the distributed plots lie. The diagram illustrates an increase in the likelihood for participants to endorse the use of this system with increased awareness of cross infection. This relationship was positively correlated (r = 0.492) and statistically significant (P <0.001). However, the 95% reliability estimate of this relationship is wider with increasing values, indicating variability in their likelihood to endorse the use of this system with increasing awareness of cross infection.

DISCUSSION

To our knowledge, this study is the first to evaluate the use of a touchless device to control the 3D virtual study model with a large user sample. Our study demonstrated that users generally agreed that our prototype gesture-specific user interface system was accurate and comfortable to use and that the gestures were socially acceptable, suggesting potential acceptance of this system in clinical settings.

Previous studies have used similar devices to navigate 2-dimensional and 3D radiologic images: ie, computed tomography, magnetic resonance imaging, and plain-film data.[8,9,14,15] Our gesture-specific user interface was developed to facilitate assessment of a virtual study model as naturally as possible. We used the dental study model because it is a type of patient record that is frequently used to aid in assessment of the dentition, treatment planning, and monitoring changes to the occlusion. However, other objects in file formats that are readable by the software, such as radiographic images, may also be used. The programmed commands are based on the practical clinical examination method of dental study models. Usually when examining the dentition, the study models are viewed as single arches or in occlusion. This was done virtually by the select menu command. We may examine the general overall appearance and then closely inspect each tooth and the dental relationships to adjacent structures; this can be done by the zooming in and zooming out commands. Study models are also usually examined in the sagittal, vertical, and transverse planes. These were achieved with the translation and rotation commands. The reset command was made to allow clinicians to swiftly view the virtual study model in the original position and size and thus to save time in the navigation process.

Motion capture cameras that have been studied for sterile gesture interface have included the VC-V4 (Canon, Tokyo, Japan)[14] and the Kinect.[8,9,15-17] In medicine, the camera also has other potential applications: eg, cardiopulmonary resuscitation training,[18] monitoring respiratory motion,[19] and measuring clinically relevant movements in Parkinson's disease.[20] In dentistry, case report series have introduced a desktop-based motion-sensing tracking device (Leap Motion, San Francisco, Calif). However, its claims for acceptability were based on the experiences of only 2 surgeons.[21] The focus of this study was to assess the acceptability of the touchless gestures concept as a method for cross-infection control by a large sample of health care–related subjects who have not had any previous experience with our system. In this study, Kinect was selected because of its low cost and the marketed accuracy of this portable infrared depth-sensing camera. Thus, its cost-effectiveness is a feature that potentially boosts wider acceptance of the system for actual purchase.

The majority of our participants (92.0%) agreed that they could perform the desired commands accurately. This success may be due to the precision of the Kinect sensor in detecting differences between the depth and the color data.[4] However, several factors may have limited the accuracy and comfort levels for the less agreeable participants, such as lower natural dexterity and lack of familiarity and experience with the system. It is possible that the orientation of the arm (elbow or wrist flexion), the height of the sensor compared with the height of the participant, and the field of detection

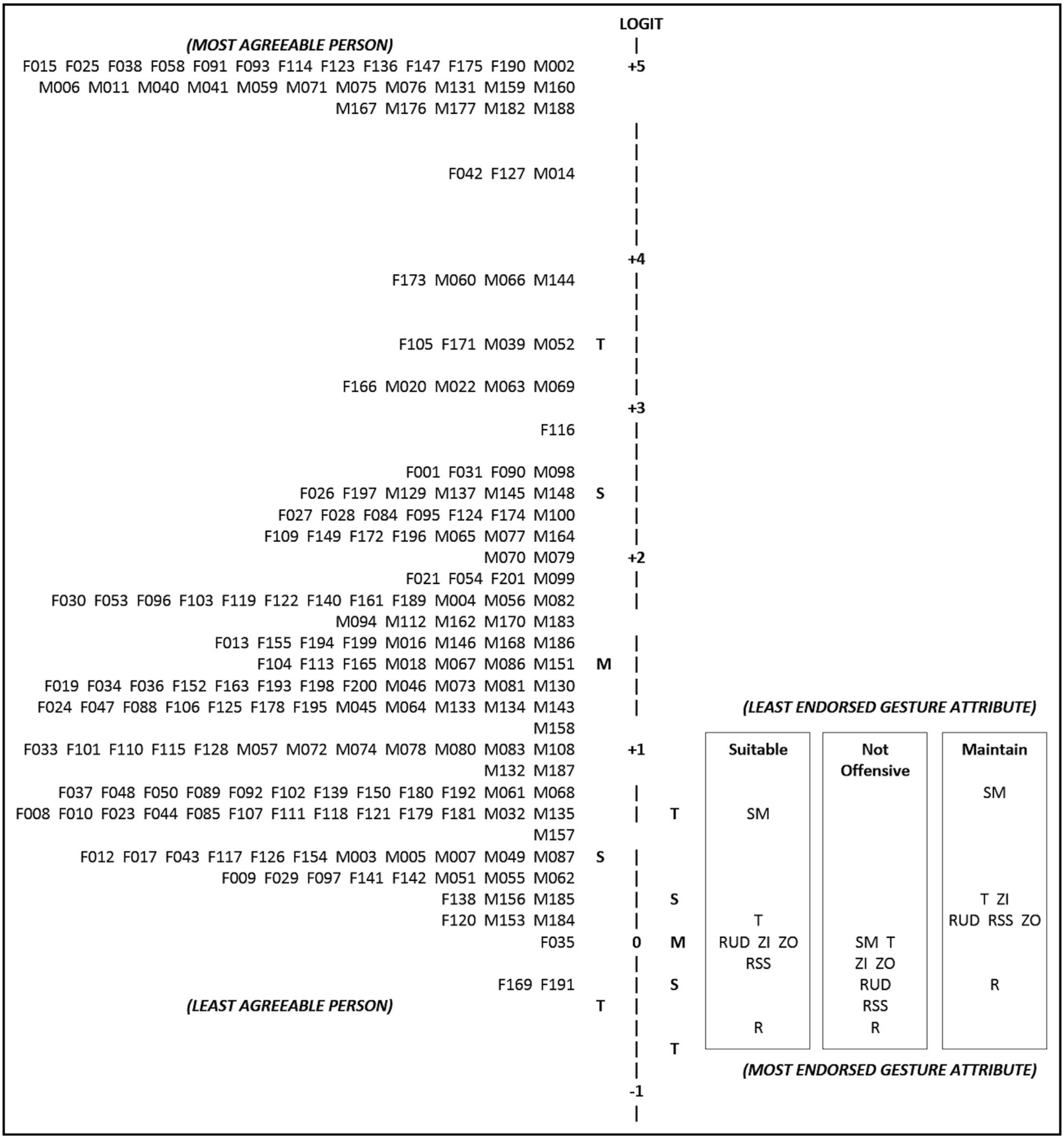

Fig 5. Gesture attributes: Locations of participants relative to the gesture attributes as mapped against the logit scale. Positions of each participant are distributed on the left of the logit scale with the more agreeable participants at the top and the less agreeable ones at the bottom of the spread. The commands (*items*) are on the right of the scale and arranged so that the command most endorsed for its suitability, inoffensiveness, or maintainability is at the lower end and the least endorsed is at the upper end of the spread. The map aids direct visual comparison of individual endorsement toward each command. *M*, Person mean or item mean; *S*, 1 SD; *T*, 2 SD.

may not be universally detectable by the system for some users. Other challenges that have been raised with the Kinect included interference of the infrared depth sensor from the heat of halogen lights in operating rooms,[9] and delay during clinical work if the sensor is placed out of range from the clinical work stations (eg, the camera

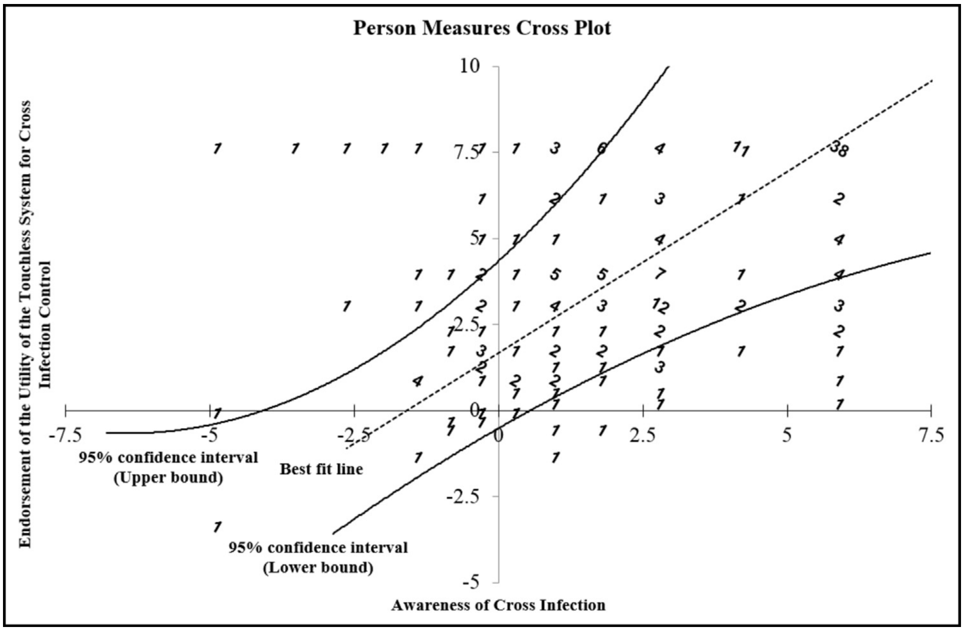

Fig 6. Cross plots showing the relationship between person measures of the cross-infection subscales within a 95% confidence interval. The values denote the number of participants on each plot.

could not be placed at the patient's side for sterile reasons).[14] Our participants also suggested a preference for single-hand rather than dual-hand gestures.

Ideally, these gestures for the commands should be intuitive. Some studies have tried to mimic the gestures common in a person's daily activities. Examples include turning the palm like turning a door knob for zooming in and zooming out commands, moving the palm in left, right, up, and down gestures like turning the pages of a book to browse image databases, dropping the hands to cause the system to enter a "sleep mode," and waving the hands to initiate activation of the system.[14] Our gestures were initially intended to be intuitive, but we found that the increasing number of commands placed limitations on the system's ability to discriminate between the movements of each hand. Thus, we developed unique gestures that would allow the system to distinguish every intended command. Our study demonstrated that most users were able to learn and accept this small set of gestures. It may be that this acceptance is due to their readiness to accept advancements in technology. Nonetheless, we noted that some participants had slight difficulties. This could be due to the short period that they were given to familiarize themselves with the system and to memorize the gestures.

We also assessed the cultural sensitivity of our population toward the proposed gestures. Gestures, like language, are symbolic and culture specific. Our results suggested that the gestures were likely to be inoffensive in our population. We noted variations in our participants' endorsements toward the gesture attributes: select menu was the least endorsed, and reset had the most endorsed attributes. This may be related to the gestures' accuracy and comfort. Our participants who found the gestures accurate and comfortable were likely to endorse the attributes, and they were unlikely to endorse attributes that they found inaccurate and uncomfortable. However, these correlations were moderately significant ($r = 0.405$ and 0.423, respectively). There may be other reasons that contributed to the level of endorsement. Reset may be the most accepted attribute because the gesture was simple and easy to remember, and did not require much change in a person's stance from a resting position. Select menu required a combination of 2 gestures for the left and right hands; this might be more awkward for the less dexterous people. Nonetheless, despite being the least endorsed gesture, the probable rating for select menu was still high.

There are still limitations with our prototype. For this study, our working distance was set at 2 meters, which may limit the clinical application in a dental setting. However, this factor may be taken into consideration to adjust the field of view and the position of the camera to limit the space for interaction to the area as desired by the operator. Second, the gestures involved both hands and were performed while standing. In clinical practice, a dentist usually spends most of his or her time seated adjacent to the dental chair. Further developments will refine the techniques for a more practical dental practice setting. Finger-tracking gestures may also allow the operator to work single-handedly to assess the virtual study model. Iannessi et al[17] in 2014 found that their custom single-hand gesture recognition allowed the operator to have more autonomy in manipulating the image on the screen during surgical procedures. Regardless of the systems used, developers should take into account that the gestures must not only achieve the desired number of commands but also be acceptable culturally and in practice for the intended users.

Most participants (77.6%) were well aware of the risks and dangers of cross infection, since they were involved in health care. There was a consensus on the potential of this system as a method to prevent cross infection, especially for those who were more concerned about it. Our findings suggest that the acceptance of this system in clinical practice could be enhanced with more emphasis on boosting users' awareness of the risks of cross infection.

Our study demonstrated the favorable acceptance of a touchless system with hand-gesture–based commands in a human-computer interaction for future clinical practice. Cross-infection control and safety procedures involve multilevel protocols that are imperative but may generate significant costs.[22] Through the development of such low-cost touch-free systems, we can increase the possibility of cost-effective cross-infection prevention in the dental surgery and the operating theater.

CONCLUSIONS

1. There was a general endorsement that the touchless 2-hand gestures required to move the 3D digital study model with the Kinect were both accurate and comfortable to execute. However, certain gestures were more acceptable than others.
2. Those who had a higher awareness of the importance of cross-infection control were more likely to endorse the use of a touchless input device system in clinical practice.

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