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Capturing differences in dental training using a virtual reality simulator

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Abstract

Virtual reality simulators are becoming increasingly popular in dental schools across the world. But to what extent do these systems reflect actual dental ability? Addressing this question of construct validity is a fundamental step that is necessary before these systems can be fully integrated into a dental school's curriculum. In this study, we examined the sensitivity of the Simodont (a haptic virtual reality dental simulator) to differences in dental training experience. Two hundred and eighty-nine participants, with 1 (n = 92), 3 (n = 79), 4 (n = 57) and 5 (n = 61) years of dental training, performed a series of tasks upon their first exposure to the simulator. We found statistically significant differences between novice (Year 1) and experienced dental trainees (operationalised as 3 or more years of training), but no differences between performance of experienced trainees with varying levels of experience. This work represents a crucial first-step in understanding the value of haptic virtual reality simulators in dental education.

1 Introduction

Virtual reality (VR) technology is becoming ubiquitous in dental training. The dental discipline has a substantial history of using simulation to facilitate the acquisition of the skills necessary for safe practice (1). Mannequin-based phantom head simulators with typodonts have long been considered as standard pedagogical tools in preclinical teaching (1). More recently, with advances in computing power, VR dental simulators are increasingly adopted to supplement and, potentially, replace traditional methods (2,3).

A step-change in VR simulation has come from the integration of haptic technology into simulators, as these systems have the potential to provide several advantages over conventional approaches. Advantages include the ability to interact with virtual objects through realistic feel and touch (1,4,5). Haptic technology also provides students with the ability to feel the various tooth surfaces through force feedback mechanisms and distinguish between soft and hard tissues- potentially useful pedagogical information (2,3,6). These haptic systems also automatically produce kinematic data (performance production measures) that could be used for objective assessment of task performance - information that is not available in conventional training environments (7).

Whilst there is obvious promise for haptic VR systems, a number of questions regarding the utility of these systems remain (8). Central to these issues is whether the systems relate to real world dentistry as training on these systems needs to ultimately translate to the clinic (9,10). Thus, it is incumbent on the dental education profession to be able to establish the construct validity of a system (11,12) before it is fully integrated into a dental school's curriculum. Indeed, this issue has recently been identified as a research priority for healthcare simulation (13–15).

The Simodont (MOOG, Nieuw-Vennep, Netherlands) is one such current state-of-the-art haptic VR simulator. This system has clear face validity: it provides a virtual environment to practice various dental skills in a 3D oral cavity using virtual teeth, virtual burs and hand instruments. The system also produces convincing visual and auditory effects during performance (e.g. the sound of the hand piece) to enhance the simulation experience and make it more “realistic”(16,17). However, its construct validity - the ability to which it captures the ability and traits it was designed for (11), has not yet been established. To this end, we examined the construct validity of the Simodont using participants with no previous exposure to the simulator to control for a potentially confounding factor of practice effects. We operationalized construct validity as the ability to be able to differentiate between different levels of real-world dental experience.

2 Materials and methods

2.1 Participants

Undergraduate dental students (N = 377) enrolled on the dentistry programme at the School of Dentistry at the University of Leeds attended an induction training session on the Simodont. Data were recorded for Years 1 (n = 92), 3 (n = 79), 4 (n = 57) and 5 (n = 61), and retrieved retrospectively and anonymised (Year 2 data were not recorded; final sample size of 289). The study was approved by the ethics committees based in the School of Dentistry and School of Psychology at the University of Leeds, United Kingdom.

2.2 Simodont

The Simodont is a virtual reality dental simulator that consists of a panel PC user interface, 3D display, haptic display, and foot pedal. The haptic display includes a drill gimbal, hand support, space mouse and mirror gimbal. A realistic experience of the true clinical dental environment is simulated through the visual and audio rendering. This includes a true size display of the instrument and tooth rendered on the 3D screen. The Simodont 'courseware' software (developed by the Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands) provides multiple procedures such as manual dexterity exercises with instant evaluation, operative procedures and crown and bridge preparations for students to practise (22).

2.3 Procedure

As part of induction training on the Simodont, students were provided with an instruction sheet and verbal instructions from a tutor on how to turn on the system, log in and select tasks. Students were asked to adjust the height of the chair and the unit to a position that felt comfortable and wear stereoscopic spectacles. Participants were given an opportunity to ask any questions at any point during the training. Students were then provided with six manual dexterity exercises (displayed on the screen) from which the task–relevant instruments were then selected.

All participants engaged in a manual dexterity exercise, which approximated the basic requirements of most dental procedures. The task involved the use of a dental hand piece to remove a target "red zone", presented as a cross-shape in the middle of a block, whilst attempting to minimise removal of leeway zones (the "safe" outer areas of the block) as much as possible (see

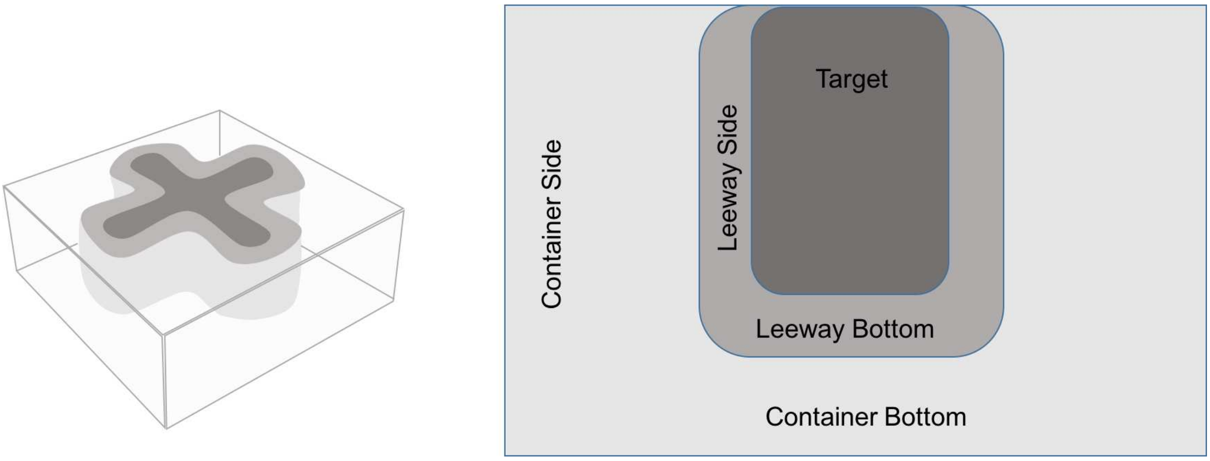

Figure 1 for further details).

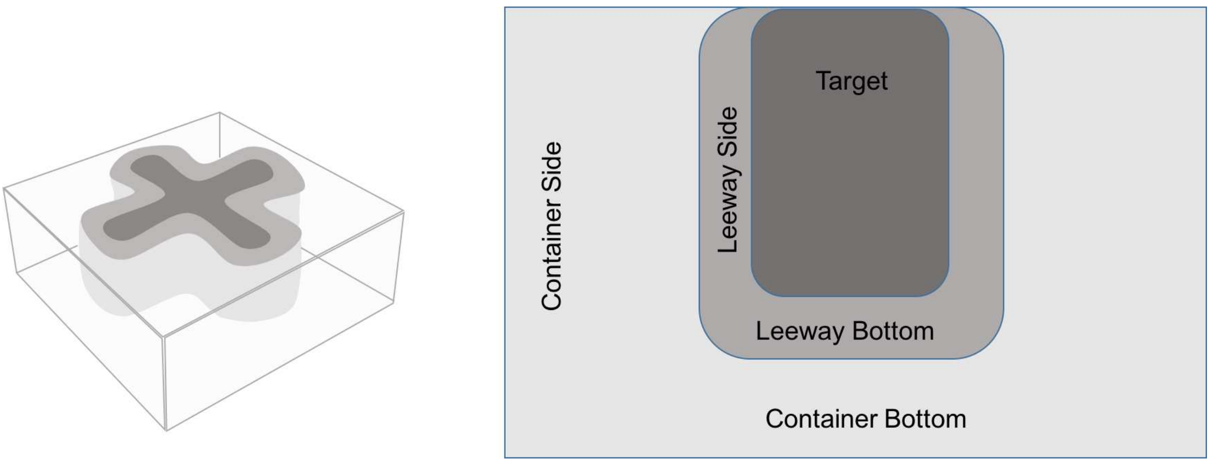

Figure 1. (A) Schematic drawing of one of the abstract shapes available in the manual dexterity training section of the Simodont courseware. **(B)** Cross-section of an exercise illustrating the location of a Target, the area of the Leeway (sides and bottom) and Container (sides and bottom).

Real-time feedback on performance was presented on a computer monitor attached to the device throughout the task. The feedback information included a percentage score for each of the following: target (task completion percentage), error scores (leeway bottom, leeway sides, container bottom and container sides), and drill time (in seconds). Participants were instructed that the aim of the task was to remove a minimum of sixty percent of the red zone without touching the beige zone. Once this had been achieved, the students could stop drilling and end the task. The students were free to take as many attempts as they felt necessary to reach the target score. Only the best performance (target > 60%, not touching the container zone with the shortest time to perform the task) for each participant was used for data analysis.

2.4 Data Analysis

For statistical analysis, we measured performance on four outcome variables: Time (in seconds), Leeway Bottom, Leeway Sides (quantified as percentages) and finally, a Composite Score that captured speed-accuracy trade-offs in performance. The composite measure was calculated by multiplying the log of the sum of the leeway errors (sides + bottom) by the log of the amount of time taken to complete the task- so that lower scores indicate better performance. All variables were tested for normality to ensure the data met requirements for valid analysis of variance (ANOVA). Where data were not-normally distributed, a transformation of the outcome variable was performed. When a significant difference of ANOVA ($p < .05$) was found between the groups, bonferroni corrected post hoc comparisons were performed. Partial eta squared values (η_p^2) are reported to indicate effect size. ANOVAs were conducted using IBM SPSS version 20 (IBM, Armonk, NY) and the linear regression was performed using R version 3.1.3 (R Development Core Team, 2015).

3 Results

A one-way ANOVA was conducted to compare student performance according to their year of progression for all outcome variables. We found a significant main effect of the year of study on the Composite Score [F(3,285) = 6.36, $p < .001$, $\eta_p^2 = .06$], Time [F(3,285) = 7.08, $p < .001$, $\eta_p^2 = .07$], Leeway Bottom [F(3,284) = 8.95, $p < .001$, $\eta_p^2 = .09$], and Leeway Sides [F(3,284) = 7.51, $p < .001$, $\eta_p^2 = .07$]. For brevity, we describe only the statistically significant comparisons for each variable and plot the data in Figure 2.

For the Composite Score, post hoc analysis revealed that Year 1 performance was reliably different to Year 4 (p = .05) and Year 5 ($p < .001$) and Year 3 was significantly different to Year 5 ($p = .008$). For Time, we found that Year 3 students took significantly longer to complete the task relative to Years ($p < .001$). In our error measures, we found that for the Leeway Side variable, Year 1 performance was significantly different to Years 4 ($p = .006$) and 5 ($p < .001$). Year 3 also made more Leeway Side drilling relative to Year 5 (p = .027). This pattern of results was similar in the Leeway Bottom variable, with Year 1 making more drilling in this area relative to Years 4 ($p = .001$) and 5 ($p < .001$). In addition to this, Year 3 performance on this outcome variable compared to Year 5 approached the significance threshold ($p = .056$).

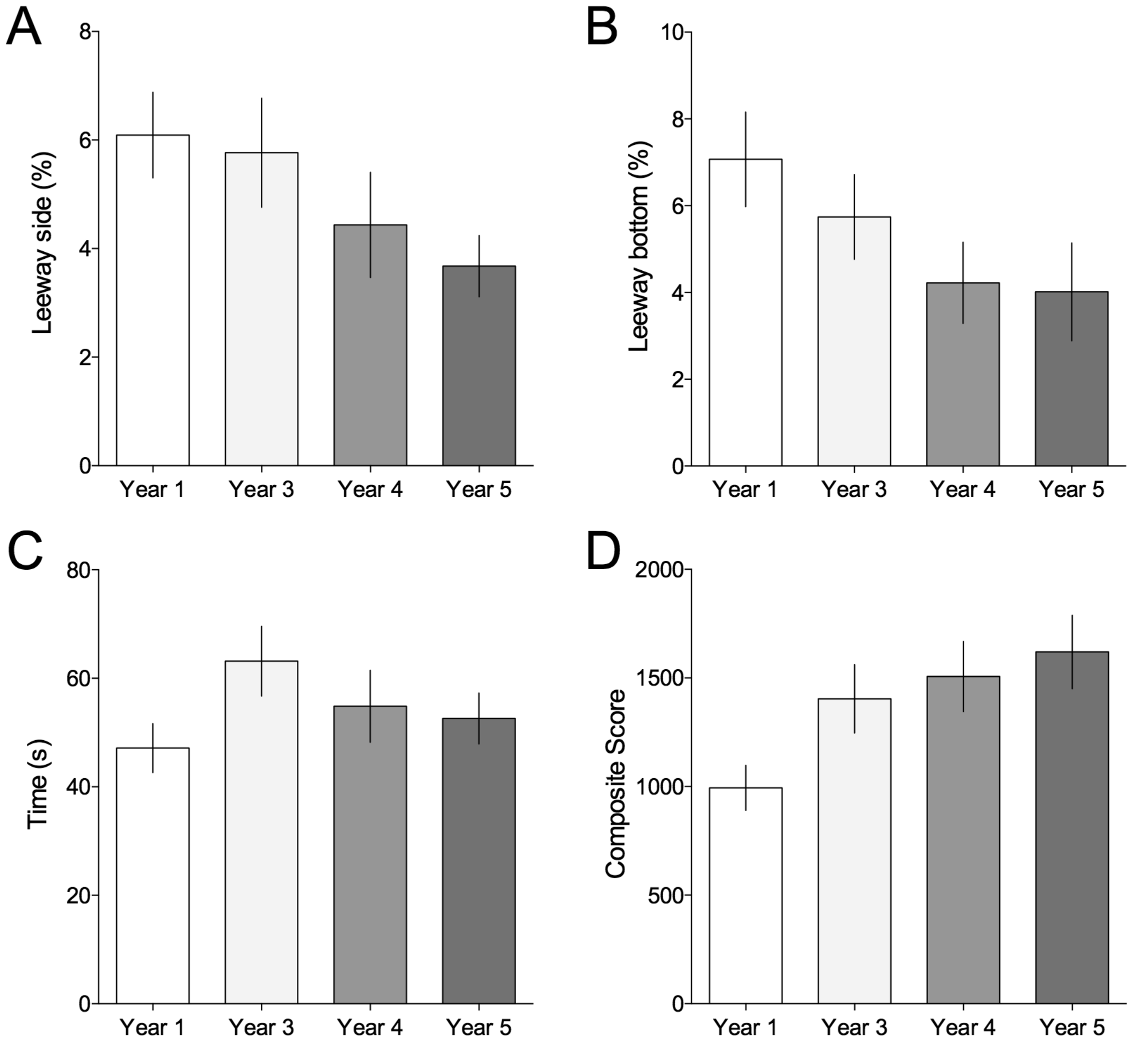

Figure 2. Performance measures a function of Training Year are plotted separately for (A) Leeway Sides; (B) Leeway Bottom, (C) Time; and (D) the Composite Score. Error bars represent 95% confidence intervals.

Finally, we examined whether real-world dental experience could predict performance on this simulator. We used the Composite Score described above and regressed this value against Training Year ($r = -.229$, $p < .001$). We found that Training Year was a statistically significant predictor of performance, although it explained only a small amount of the variance in this measure (see Table 1). The regression analysis indicated that for every 1-unit increase in Training Year, the performance on the Composite Score decreased by the unstandardized beta coefficient value of .519.

Table 1: Predicting VR Performance from Training Year

Variable	B	SE	β	*t*	Sig.	Adjusted R^2
Constant	9.88	0.13		22.65	< .001	
Year	-.519	0.04	-.229	3.99	< .001	.049

4 Discussion

This study investigated the ability of the Simodont VR system to detect differences in motor performance between dental students with different levels of training experience. As far as we are aware, this is the first investigation on the validity of this virtual reality simulator. We found that Year 3, 4 and 5 students scored better than Year 1 in our composite measure of performance. The difference in performance between Years 3, 4 and 5 was not significantly different, although the mean value grew linearly as dental experience increased. For the time taken to complete the task, a significant difference was only found between Year 1 and 3. Specifically, Year 3 took the longest time to complete the task, while Year 1 took the shortest time. Year 4 and 5 took less time to complete the task compared to Year 3. The overall scores and the task duration showed convergent validity. The performance of dental students improved as their level of experience increased. Likewise, the time taken to complete the task decreased as their level of experience increased- as shown by the differences between Years 3, 4 and 5.

These data align well with the current understanding of the stages involved in motor skill acquisition (24). Early learning- which could last from minutes to months- is achieved by the students as they become able to produce movements using less motor planning or preparation time. This shift in the time-accuracy trade-off is a hallmark of motor skill learning, followed by subsequent automatization (skill learning)- which can occur at an execution level (through the formation of a new motor primitive) or at an intermediate level (allowing generation of novel behaviour, hierarchical chunking of actions, sequences and modular representation). The current data show that students take less time to perform a task, but are less accurate at the beginning of dental education. They then start to sacrifice time for accuracy (performing the task takes longer) as demonstrated by the Year 3 results, displaying a speed-accuracy trade-off. This is considered the first phase of learning whereby students try to understand the activity and concentrate on avoiding mistakes (18–21). The time taken to perform the task decreases and accuracy improves as the students gain more experience in years 4 and 5. This could be related to the middle phase of learning; gross mistakes decrease, performance appears smoother, and learners no longer need to concentrate as hard to perform at an acceptable level (18–21). This is in agreement with previous work which reports that performance improves with the amount of practice and is an index of expertise- whereas duration tends to decrease as the performer gains more experience (23,24).

Overall, these findings show that the Simodont is able to capture performance between novice and experienced dental students (such as between Year 1 and Year 4 or between year 1 and year 5), but not between performance of experienced trainees with varying levels of experience (e.g. comparisons between Year 1 and Year 3 or Year 3 and Year 4). It is however, unlikely that there is no real difference between these years as Year 4 and Year 5 receive substantial clinical experience. Moreover, other studies have shown that, in terms of manual dexterity at least, there should be a clear difference between year groups (25). In future work, it may be useful to increase task demands and examine whether the Simodont is sensitive to this manipulation. For example, future studies could ask participants to obtain a higher percentage of target removal and/or lower error rates, introduce visual transformations such as mirror tasks or restrict the amount of time available to complete the task.

Previous studies have also attempted to capture motor performance using simulators (25,26), but have mainly concentrated on broader differences between experience (such as dental students, dentists and non-dentists), whereas our study aimed to capture finer differences in motor performance (between dental student year groups). This approach has allowed us to start the process of establishing the construct validity of the Simodont system.

4.1 Conclusion

In conclusion, the Simodont has shown sensitivity to performance differences between novice and experienced students. Thus, the Simodont has potential in stratifying different levels of dental students' performance (with the performance metrics that it automatically generates). The Simodont has shown convergent validity, suggesting it has good potential for measuring dental performance and educating students. Nevertheless, a variety of tasks of differing difficulty are likely to be required for fine graded discrimination (where easier tasks may have discriminatory ability at the novice end of the spectrum and vice versa). The present study suggests that research on this topic is highly justified and could lead to a step change in dental education practice.

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