The LEAPTM Gesture Interface Device and Take-Home Laparoscopic Simulators: A Study of Construct and Concurrent Validity

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The LEAP™ gesture interface device and take-home laparoscopic simulators: a study of construct and concurrent validity.

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Abstract

Aim:

To assess the potential of the LEAP^{TM} infrared motion tracking device to map laparoscopic instrument movement in a simulated environment. Simulator training is optimised when augmented by objective performance feedback. We explore the potential LEAP has to provide this in a way compatible with affordable take-home simulators.

Method:

LEAP and the previously validated InsTrac visual tracking tool mapped expert and novice performances of a standardised simulated laparoscopic task. Ability to distinguish between the two groups (construct validity) and correlation between techniques (concurrent validity) were the primary outcome measures.

Results:

43 expert and 38 novice performances demonstrated significant differences in LEAP-derived metrics for instrument path distance ($p<0.001$), speed ($p=0.002$), acceleration ($p<0.001$), motion smoothness ($p<0.001$) and distance between the instruments ($p=0.019$). Only instrument path distance demonstrated a correlation between LEAP and InsTrac tracking methods (novices: $r=0.663$, $p<0.001$; experts: $r=0.536$ $p<0.001$). Consistency of leap tracking was poor (average % time hands not tracked: 31.9%).

Conclusion:

The LEAP motion device is able to track the movement of hands using instruments in a laparoscopic box simulator. Construct validity is demonstrated by its ability to distinguish novice from expert performances. Only time and instrument path distance demonstrated concurrent validity with an existing tracking method however. A number of limitations to the tracking method used by LEAP have been identified. These need to be addressed before it can be considered an alternative to visual tracking for the delivery of objective performance metrics in take-home laparoscopic simulators.

Introduction / Background

Recent meta-analyses have demonstrated that training in a simple 'box' simulator improves minimally invasive surgical skills (1) (2). This is at least as effective as virtual reality simulation, while being much more readily accessible (3). Box simulator training is optimised when augmented by objective performance feedback, although there is no consensus yet on the best method to provide this (2) (3). A number of techniques have been proposed, including visual tracking using coloured markers on the instruments (4) (5), mapping the outline of the instruments against their background (6) (7), radio-frequency identification devices attached to the instrument shafts (8), electromechanical devices to track movement as the instruments pass through a trochar in the lid of the simulator (9) (10), and 'wireless distributive computing' devices attached to instrument handles (11).

While there are exceptions (4), most of these systems require complex and expensive bespoke hardware and / or software. It is well reported that high costs and poor access to equipment are significant barriers to uptake of simulator training (12) (13). Simple, affordable take-home laparoscopic simulators have been proposed to address this (14). An online search using these terms reveals a growing number of such devices. The ideal motion tracking device would thus be something accessible which works effectively with these take-home simulators.

The 'LEAP motion controller' (Leap Motion, Inc. CA, USA) is a consumer product with an affordable price tag ($89.99). Launched in 2013, it projects infrared (IR) light in an inverted cone approximately 1 meter in diameter and 50cm high. Two IR cameras at either end of the device detect reflected IR light, allowing it to track the three dimensional movement of objects in this space. It has been optimised to detect open hands with fingers spread out and is very sensitive. An independent study found that it has an accuracy as high as 1.2mm when tracking moving fingers (15). This compares to other tracking systems such as the Microsoft Kinnect (Microsoft, CA, USA), which has a standard accuracy of approximately 15mm (16).

It has been suggested that LEAP's 'gesture interface' is the next stage of computer-human interaction, in a spectrum ranging from keyboard to mouse to track-pad to touch screen {Hughes:2014vh} (Figure 1). This technology has the significant advantage that no physical contact is required. As such, a computer could be used with sterile hands, or a smartphone answered while wearing gloves. LEAP connects to personal computers via USB, and has been used in a number of surgical applications including hands-free control of computers and image navigation in theatre (17) (18). These applications use the technology as a means of 'input'.

Figure 1. The spectrum of computer-user interfaces from keyboard to gesture interface, via mouse and touch screen. LEAP (bottom left) is a commercially available gesture interface device.

Here we describe a unique means of using LEAP as an 'output' device. We hypothesised that instrument movement metrics obtained by the LEAP hardware would demonstrate construct validity by being able to distinguish between experienced and novice surgeons; and also concurrent validity by correlating with data obtained from a previously validated visual tracking process.

Method.

We used the LEAP device to monitor the movement of hands holding laparoscopic instruments while performing a standardised simulated laparoscopic task. The instrument movement metrics were compared to simultaneously collected data from a previously validated visual tracking process ('InsTrac', eoSurgical ltd, Edinburgh, UK) (4). In partnership with a software developer (L&T Infotech, Mumbai, India) we developed a custom application that converts the tracking performed by LEAP into movement metric output data. This application uses the LEAP hardware to track the movement of left and right hands, and then exports the data in a .csv file database format. The hand movement metrics we chose to measure were based on those used in previous studies of instrument movement during simulated laparoscopy (6) (Table 1).

Figure 2. LEAP motion controller (bottom left) positioned to detect the movement of hands holding instruments in the eoSim laparoscopic simulator. LEAP transmits a cone of infrared light and detects reflections from objects as they move through this space. The peg-threading task is shown. Note the coloured markers on the instrument tips required for the InsTrac visual tracking process to detect them. We collected the LEAP and InsTrac data simultaneously for each user.

A total of 81 data captures were made from two groups. 38 data captures were performed by ten novices who had never performed laparoscopic surgery, and 43 captures from three experts who all have more than 6 years of laparoscopic operative experience. Both groups performed a standardised simulated laparoscopic task consisting of passing a thread through pegs on the eoSim™ take-home simulator (eoSurgical ltd, Edinburgh, UK). InsTrac visual tracking and the custom LEAP application recorded data simultaneously. All equipment including starting and finishing positions of instruments was standardised for all repetitions (Figure 2). The authors observed all performances. Participants were instructed verbally and shown a demonstration video explaining the task, but no 'warm-up' on the simulator was allowed before data capture.

The movement metrics from InsTrac and LEAP devices were collected in .csv database format. Statistical analysis between the groups and the two different tracking methods was performed using Mann Whitney U tests with 2-tailed p-values and Spearman Rank Correlation assessment (Prism 6 software, GraphPad software Inc., San Diego, CA).

Results

Construct Validity

LEAP detected significantly lower values for experts in the following metrics (median expert vs novice; p=2-tailed Mann Whitney U): time to complete task (33s vs 193s; $p<0.001$), instrument path distance (2.91m vs 16.04m; $p<0.001$), distance between instruments (0.235m vs 0.245m; $p=0.019$) and motion smoothness / 'jerk' (23.0mm/s^3 vs 749.1mm/s^3). Instrument speed (54.0mm/s vs 39.4mm/s; $p=0.002$) and acceleration (2.06mm/s^2 vs 0.88mm/s^2; $p<0.001$) were both significantly higher in the expert group (Figure 3).

Figure 3. The instrument movement metrics detected by LEAP differed significantly between expert and novice groups *(scatter plots with median and interquartile range lines)*.

Concurrent validity

The time to complete the tasks served as a 'positive control' of correlation between the two methods of data capture – ie. they would be expected to be the same. They were, with correlations between methods for novices of r=0.996 (p<0.001) and experts r=0.888 (p<0.001). Of the instrument movement metrics, path distance in the novice group demonstrated a moderate correlation between LEAP and InsTrac (r=0.663, p<0.001). There was a weak correlation between the two instrument tracking methods for path distance in the expert group (r=0.536, p<0.001). There was a great deal of inter-trial variability for the other metrics and no other significant positive correlations between LEAP and InsTrac (Figure 4).

Figure 4. Time to complete the task and instrument path distance demonstrated significant positive correlations between LEAP and InsTrac methods of instrument movement tracking.

Figure 5. No significant positive correlations between LEAP and InsTrac methods of instrument movement tracking were observed for the instrument movement metrics of speed, acceleration, motion smoothness or distance between instruments.

Reliability of LEAP instrument tracking

The custom LEAP data extraction application was designed to include an output of what percentage of the time the device was able to ‘see’ both left and right hands within its visual field. The results of this were generally poor, and varied markedly between trials, despite standardised conditions (Figure 6). The percentage time that the LEAP device was able to ‘see’ both instruments was poor, with a ‘mean time both instruments not’ seen across both groups of 31.9% (range 0%-86.4%).

Figure 6. The % time both instruments were not visible to the LEAP device.

Discussion.

We have demonstrated that it is possible to use the LEAP motion device to track the movement of surgical instruments in a simulated laparoscopic environment. The custom application developed for this study successfully exported these metrics. Construct validity was demonstrated by the ability of the LEAP-detected metrics to distinguish between expert and novice performances. The relatively low purchase cost of the LEAP hardware makes it a potential candidate to deliver objective performance metrics to take-home laparoscopic box simulators in the future.

The findings that time to complete the task, instrument path distance and average distance between instruments as detected by LEAP were significantly lower in the expert group is consistent with previous studies demonstrating improved 'economy of movement' in experienced surgeons (3) (6). The LEAP output recorded significantly higher average instrument speed and acceleration in the expert group, but lower 'jerk' as measured by rate of change of acceleration (mm/s^3). This finding of rapid but smooth movement in experts is consistent with other studies (6), although it may be that there is an 'optimal' degree of smoothness of motion – ie. not too slow, but not excessively jerky (4).

Meta-analysis of instrument movement metrics studies has demonstrated that time taken, path length and number of hand movements are the key valid parameters to assess laparoscopic skill (19). The LEAP hardware and custom software used in this study has demonstrated construct validity by distinguishing between experience levels in two of these three. The application did not record 'number of hand movements' as a discreet metric, but this is something which could be included in future iterations of the software. In its current form then, the LEAP hardware and the software developed in this study has some potential to be used to guide laparoscopic simulator training. It is able to act as a relatively crude assessment of expert and novice performance. Further work is required to assess whether it is capable of the more subtle distinction between groups with less disparate laparoscopic skill levels, as some other instrument tracking methods have been shown to be capable of (11).

Concurrent validity assessed by correlation with the previously validated visual tracking process was only demonstrated for time to complete task and instrument path distance. This is likely due to the significant inter-user variation in time both hands were 'seen' by the LEAP device (Figure 6). This limitation needs to be addressed to make it preferable to the existing InsTrac visual tracking software. We initially intended to place the LEAP device inside the simulator to track the movement of the tips of the surgical instruments. Unfortunately the LEAP device is designed to 'see' human hands. The sensors which detect the reflected infrared light are calibrated to recognize reflections from objects the shape and size of human hands, rather than much smaller reflection signature of surgical instruments. Extensive testing demonstrated that the only way to map movement using the LEAP device was to position it outside the simulator to detect the movement of a surgeons' hands, rather than the instruments inside the box. Furthermore, the LEAP hardware is currently optimised to track 'open' hands with the fingers spread out, and it has been demonstrated to be very accurate at doing this (15). In our study the hands within the LEAP field of view were 'closed' around laparoscopic instrument handles. The LEAP visualizer software presents an image of what the device is 'seeing' (Figure 1). While it is not possible to export quantitative data from this application, qualitative observation confirms that 'closing' a hand causes it to be intermittently lost from the LEAP field of view. The LEAP device appears to be constantly attempting to 'see' fingers, and in doing so introduces an element of noise to the data collection.

The significant differences in performance between expert and novice groups meant that this inter-user variation of tracking reliability did not prevent the metrics from distinguishing between groups. Since this study was performed, an improved version of the LEAP codec has been released. Future work will include re-coding the data output software to use this new operating system and assess whether this improves the reliability of tracking hands holding laparoscopic instruments.

A further limitation of the LEAP device in this context is its inability to distinguish between left and right hands when only one hand is in the field of view. The hardware is programmed to be able to determine 'leftmost' and 'rightmost' hand in its field of view. If the hands cross it is unable to detect this, and if one hand leaves the field of view it is unable to determine which. An assessment of handedness, previously shown to be of merit in tracking surgeons hand movements (20) is thus not possible using the current combination of hardware and software. The LEAP motion device is a technology very much in its infancy and future updates may address this limitation.

Integrating the LEAP device into training with existing box simulators would not be expensive. The hardware is an inexpensive consumer product ($89.99; Leap Motion, Inc. CA, USA) and the software we have developed runs on any recent home computer or laptop. This could be produced commercially for approx. $50 USD. A means of standardising the position of the hardware relative to the surgeons' hands (Figure 2) would be required, which could be achieved with a small plastic frame made to attach to the simulator base. The total additional cost of a LEAP powered laparoscopy trainer would thus only be in the region of $150 more than the simulator alone.

This study has shown that the LEAP motion device is able to track the movement of hands using instruments in a laparoscopic box simulator. Construct validity is demonstrated by its ability to distinguish novice from expert performances. Only time and instrument path distance demonstrated concurrent validity with an existing tracking method however. A number of limitations to the tracking method used by LEAP have been identified. These need to be addressed before it can be considered an alternative to visual tracking for the delivery of objective performance assessment in take-home laparoscopic simulators.

Performance metric	**Unit**
Time to complete task	Seconds (s)
Instrument Path Distance	Metres (m)
Average Instrument Speed	Millimetre per second (mm/s)
Average Instrument Acceleration	Millimetre per second^2 (mm/s^2)
Instrument Motion Smoothness	Millimetre per second^3 (mm/s^3)
Average Distance Between Hands	Metres (m)

Table 1. The instrument movement metrics recorded and exported by custom LEAP motion controller device software.

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The authors would like to thank all study participants for facilitating the data collection.

Conflict of interests.

RWP, PMB, IAMH and MAH have taken steps to address the problem of poor access to surgical simulation tools which they have experienced first-hand as trainees, by designing and manufacturing affordable take-home simulation equipment. They established a company eoSurgical Ltd. (Edinburgh, United Kingdom) (eoSurgical.com) in order to achieve this. RWP, PMB, IAMH and MAH are all shareholders in eoSurgical Ltd. The eoSim take-home laparoscopic simulator used in this study is manufactured by eoSurgical Ltd. The InsTrac software was developed in conjunction with a separate company, Peekabu Studios Ltd. (Edinburgh), and is marketed by eoSurgical Ltd.

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Figure 1. The spectrum of computer-user interfaces from keyboard to gesture interface, via mouse and touch screen. LEAP (bottom left) is a commercially available gesture interface device.
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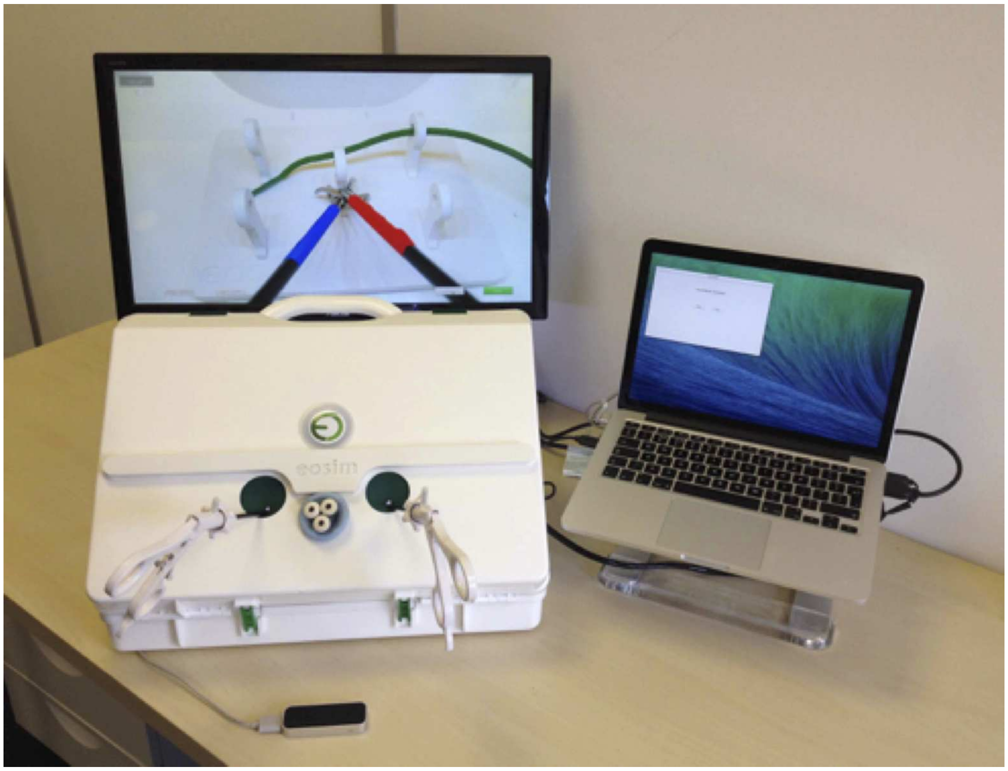

Figure 2. LEAP motion controller (bottom left) positioned to detect the movement of hands holding instruments in the eoSim laparoscopic simulator. LEAP transmits a cone of infrared light and detects reflections from objects as they move through this space. The peg-threading task is shown.
173x132mm (300 x 300 DPI)

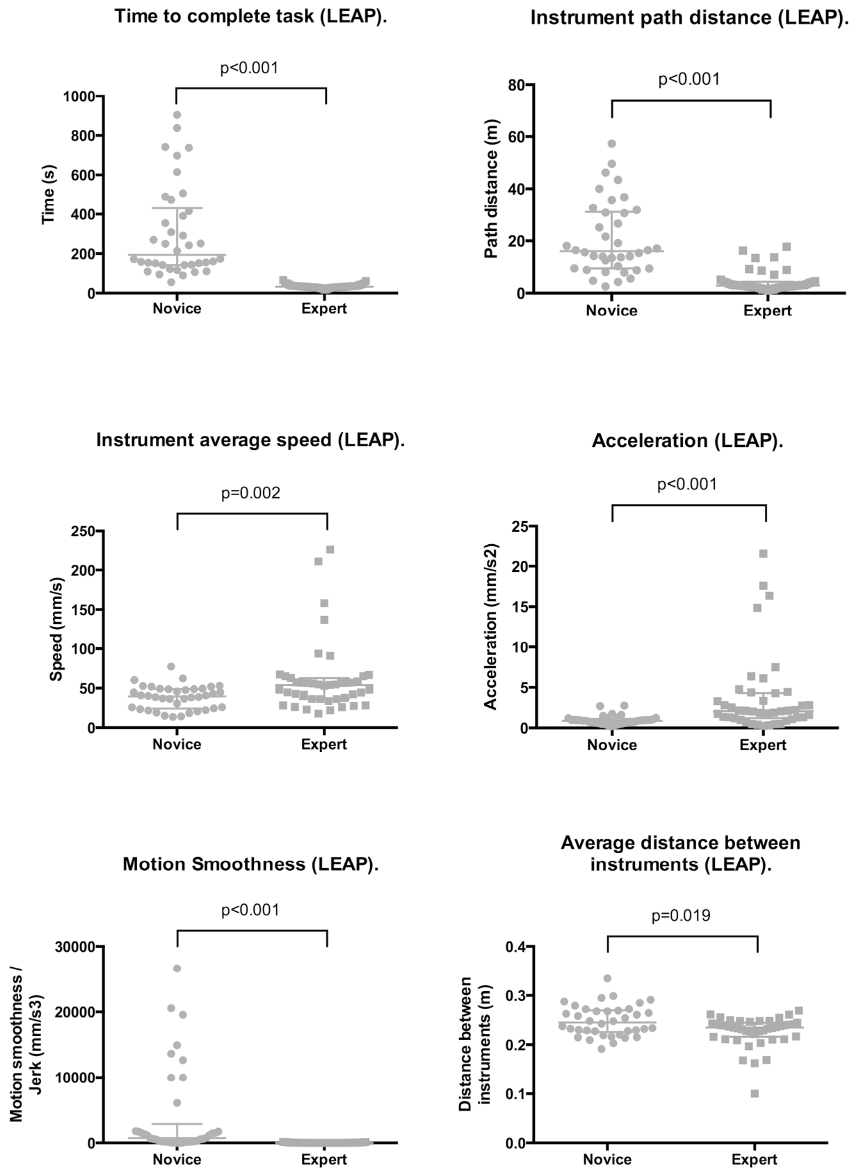

Figure 3. The instrument movement metrics detected by LEAP differed significantly between expert and novice groups (scatter plots with median and interquartile range lines).
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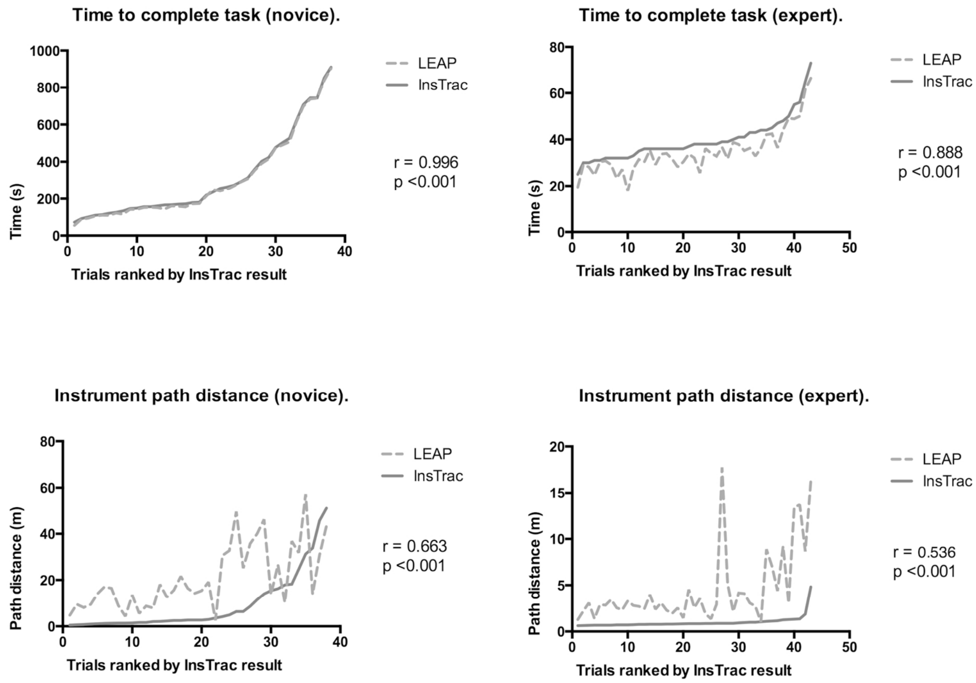

Figure 4. Time to complete the task and instrument path distance demonstrated significant positive correlations between LEAP and InsTrac methods of instrument movement tracking.
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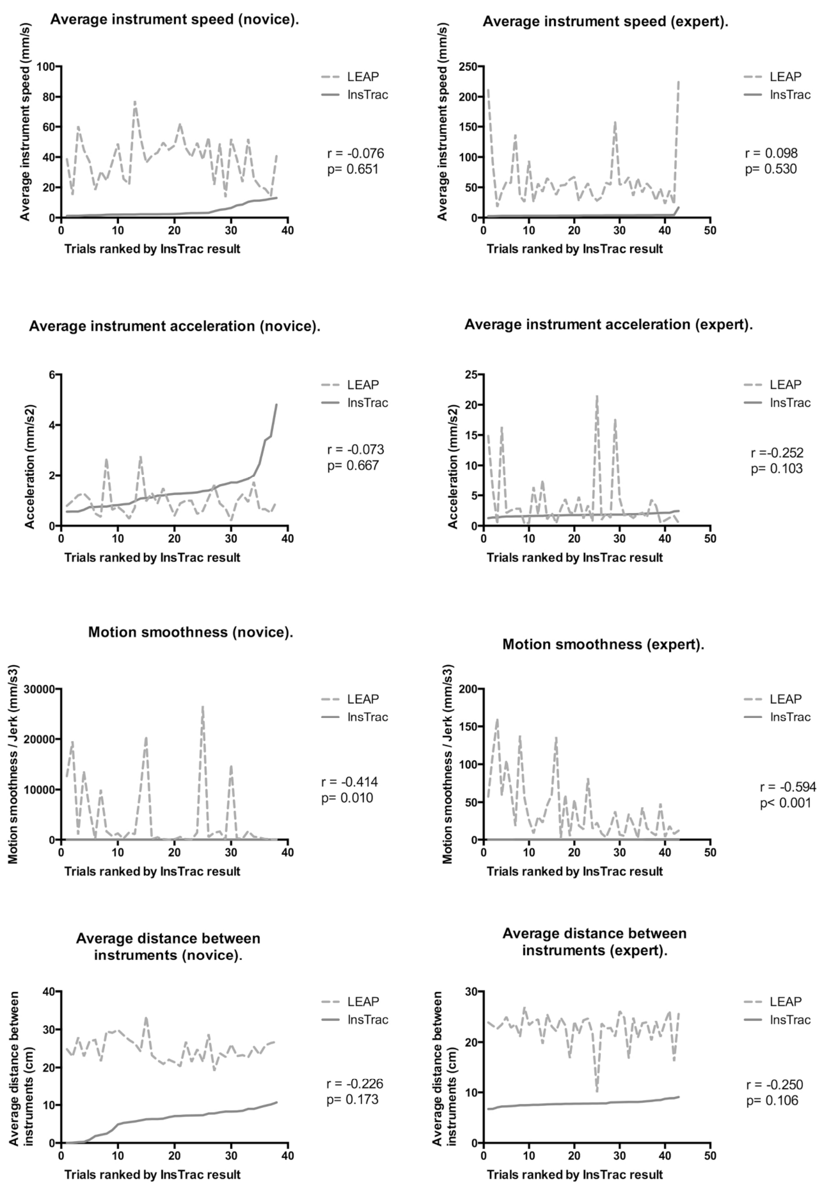

Figure 5. No significant positive correlations between LEAP and InsTrac methods of instrument movement tracking were observed for the instrument movement metrics of speed, acceleration, motion smoothness or distance between instruments.

171x243mm (300 x 300 DPI)

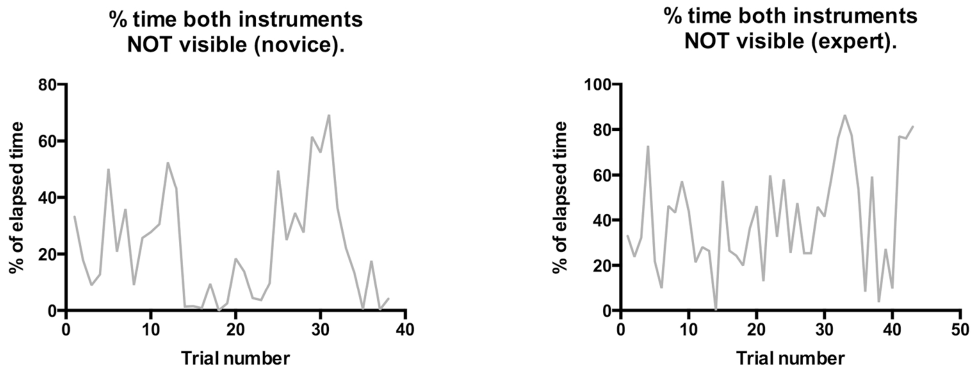

Figure 6. The % time both instruments were not visible to the LEAP device.
156x63mm (300 x 300 DPI)