Construct validity of eoSim - a low-cost and portable laparoscopic simulator

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Construct validity of eoSim - a low-cost and portable laparoscopic simulator

Purpose: To examine the construct validity of the low-cost, portable laparoscopic simulator eoSim using motion analysis.

Methods: Novice and experienced surgeons (≤ 100 and > 100 laparoscopic procedures performed, respectively) completed four tasks on the eoSim using the SurgTrac software: intracorporeal suture and tie, tube ligation, peg capping and precision cutting. The following metrics were recorded: Time to complete task, distance traveled, handedness (left- versus right hand use), time off-screen, distance between instrument tips, speed, acceleration and motion smoothness.

Results: Compared to novices (n = 22), experienced surgeons (n = 14) completed tasks in less time ($p \leq 0.025$), except when performing peg capping ($p = 0.052$). On all tasks, they also scored lower on the distance metric ($p \leq 0.001$). Differences in handedness (left hand compared between groups, right hand compared between groups) were found to be significant for three tasks ($p \leq 0.025$). In general, the experienced group made greater use of their left hand than the novice group.

Conclusion: The eoSim can differentiate between experienced and novice surgeons on the tasks intracorporeal suture and tie, tube ligation and precision cutting, thus providing a convenient method for surgical departments to implement testing of their surgeons' basic laparoscopic skills.

Keywords: eoSim, technical skills, laparoscopy, simulators, motion metrics.

Introduction

Laparoscopy is the standard approach in many surgical procedures. Surgeons are required to develop a specific set of technical skills to perform laparoscopic surgery. Some of the challenges facing a surgeon when performing laparoscopy are non-intuitive, such as a two-dimensional visualization of a three-dimensional operating field, a reduced degree of freedom, a limited/an altered tactile feedback and the fulcrum effect (i.e. the instrument tips move in the opposite direction of the surgeon's hands due to a pivot point) [1-3].

For surgeons to acquire these basic skills, while in the operating theater, is controversial due to safety concerns for patients, particularly in light of the increased demand for time-efficiency, and due to the limited opportunity for objective evaluation and feedback

[3]. Laparoscopic simulators offer a unique opportunity to continuously practice and evaluate technical skills in a standardized manner, without compromising patient safety [4]. Laparoscopic simulation training has been shown to improve technical skills compared to no supplementary training outside the operating theater [3, 5, 6], and importantly, these skills are transferred back into the operating theater [3, 7-11].

The assessment of technical skills has traditionally been carried out in an apprenticeship setting, in which assessments are mostly subjective and lack standardization [11, 12]. Objective assessment using simulators is a useful tool in the surgical training. Bad habits are hard to break, but with early objective assessment, candidates will get a chance to change these habits. Objective assessment is also crucial with regard to patient safety; a surgeon who lacks basic technical skills can put a patient undergoing surgery at risk of adverse outcomes [13].

There is a wide variety of simulators on the marked, ranging from virtual reality (VR) simulators to box-trainers, several of which have already been validated [14]. VR simulators are based on computer-generated environments and can simulate both basic tasks and full procedures. They have the benefit of objective scoring without a supervisor present, but they do not replicate the tactile feedback of real-life surgery, and they are both costly and stationary [15]. Augmented reality trainers combine features from VR simulators and box-trainers, subjecting the user to a combination of computer-generated environments and physical objects. Thus, they provide realistic tactile feedback and objective assessment. Prices vary, but are comparable to the cost of VR simulators [13-15]. Box-trainers, on the other hand, can be portable, relatively inexpensive and they provide realistic tactile feedback. However, they usually do not offer a built-in objective performance assessment [13-15]. Already validated checklists and global rating scores can be used for accurate scoring [16, 17], but this method is time-consuming and requires a supervisor to be present.

EoSim is a low-cost and portable box-trainer, with a built-in, video-based tracking software called SurgTrac that measures time- and motion metrics without requiring the presence of a supervisor. In SurgTrac, computer analysis of the instrument motions is achieved through the tracking of colored markings on the distal ends of the instruments, respectively blue for left hand and red for right hand. The previous version of the box-trainer used the tracking software InsTrac. SurgTrac uses the same technology as InsTrac, but some changes in motion metrics have been made; the metric working area is removed, and the metrics distance between instrument tips and handedness have been added [18].

EoSim, with the tracking software InsTrac, has demonstrated to have construct validity, for tasks such as precision cutting, intracorporeal suturing, threading strings through hoops and objects transfer. It has also been shown to have concurrent validity with the already established Fundamentals of Laparoscopic surgery (FLS™) simulator, as well as content validity [18-20]. Construct validity measures the degree of how well a test measures what it is supposed to measure, and construct validity is often claimed if a simulator manages to discriminate between experienced surgeons and novice surgeons [19, 21].

In this study, we tested the construct validity of the eoSim simulator combined with its new SurgTrac software, on the basis of its potential to serve as an easily accessible and objective assessment tool for testing the technical skills of surgeons. To our knowledge, this is the first study investigating the construct validity of the eoSim with its new software, SurgTrac.

Material and Methods

Participants

Participants were recruited from the Department of Gastrointestinal Surgery at Oslo University Hospital and during a course in basic laparoscopic skills, held at the National Advisory Unit for Advanced Laparoscopic Surgery at Trondheim University Hospital. A consent form and a questionnaire were completed on site. The questionnaire documented the following: years of experience, number of laparoscopic procedures performed, and dominant hand. Based on the self-reported numbers of laparoscopic procedures performed, the participants were stratified to a novice group (≤ 100 procedures) and an experienced group (> 100 procedures).

eoSim

The eoSim simulator (eoSurgical™ Ltd., Edinburgh, United Kingdom) was set up in the standard configuration, connected to a Microsoft Surface Pro 4 tablet computer (Figure 1). Performance was scored using the SurgTrac scoring system, which included the following metrics; time, distance, handedness, off-screen, distance between, speed, acceleration and motion smoothness (Table 1) [22].

Tasks

All participants performed four basic skill tasks on the eoSim, with the equipment included in the box-trainer. The tasks were performed as described in the demonstration videos, which the participant watched before commencing each task. Participants were instructed on which instrument to hold in which hand, regardless of their dominant hands. At least one of the authors behind this study was available during the testing, in case of technical issues with the box-trainers. Aiming to assess basic laparoscopic skills, task that were considered representative of real-life surgery were selected from the eoSim course material (Figure 1):

(1) Intracorporeal suture and tie: Place and tie one simple suture.

(2) Tube ligation: Apply two surgical extracorporeal knots to a tube at premarked points, then divide in between.

(3) Peg capping: Place the tips of five glove fingers over the five pegs.

(4) Precision cutting: Cut a paper accurately nine times to the marked areas.

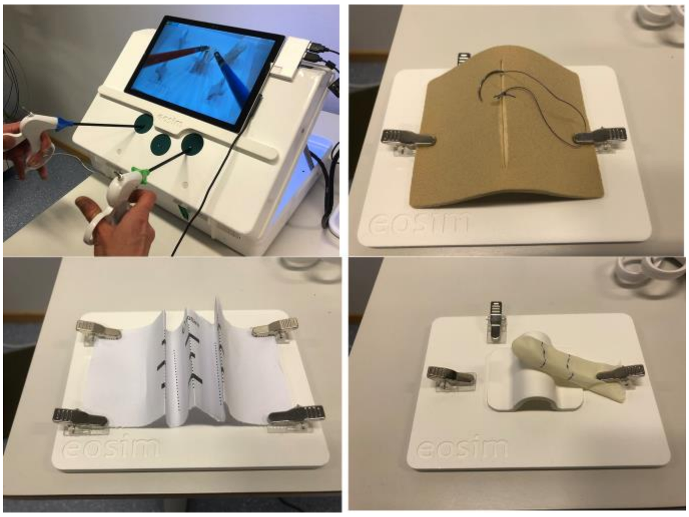

Figure 1. Task performed on the eoSim. The four tasks. From top left to bottom right: Peg capping, intracorporeal suture and tie, precision cutting and tube ligation.

Ethical approval was obtained from Oslo University Hospital´s Department of Personal Data Protection and the Norwegian Center for Research Data (NSD).

Statistical analysis was performed in SPSS (Ver. 1.0.0.701, 64-bit), using the two-tailed Mann-Whitney test to examine the significance of differences between groups. A p value of ≤ 0.05 was considered significant.

Results

Thirty-six participants were included in the study. Twenty-two participants were stratified to the novice group. In this group all participants but one, reported to have performed fifty or fewer laparoscopic procedures. The participants in the novice group had experience from different surgical fields: general-, gastrointestinal-, gynecologic-, urologic-, thoracic-, vascular- and breast/endocrine surgery. Fourteen participants were stratified to the experienced group, of which all had training in general surgery, and some were further specialized in pediatric-, urologic- or gastrointestinal surgery. Thirty candidates reported that they were right-handed, four candidates reported that they were left-handed and two candidates reported that they were ambidextrous.

The metric time to complete a task was lower for participants in the experienced group compared to the novice group on all four tasks. Significant differences were found for the tasks suture and tie, tube ligation and precision cutting ($p \leq 0.025$), whereas the task peg capping had a p value just above the set threshold for significance ($p = 0.052$) (Figure 2 A).

The distances between the left-hand and right-hand instrument tips were shorter for the experienced group than for the novice group, and these differences were significant in two of four tasks: tube ligation and peg capping ($p \leq 0.006$) (Figure 2 B).

The total distance (Figure 2 C) and total instrument speed (Figure 2 D) were significantly lower in the experienced group than in the novice group on all tasks ($p \leq 0.001$ and $p \leq 0.009$, respectively). Both groups displayed longer distances and higher speeds of the right-hand instrument compared to the left-hand instrument, except in the tasks peg capping and precision cutting, in which the experienced group displayed longer distances and higher speeds for the left-hand instrument, compared to the right-hand instrument (Table 2).

The metric handedness, which compared left hand use between groups and right hand use between groups, was significantly different on three of four tasks ($p \leq 0.025$). The experienced group made greater use of their left hand than the novice group on all four tasks, but while performing tube ligation this difference was not significant ($p = 0.083$). While the experienced group generally displayed a more even distribution between hands, being nearly ambidextrous when performing suture and tie and precision cutting, this was not the case on the peg capping task. On this task, the novice group was nearly ambidextrous (Figure 3).

No significant differences were found between groups for the metrics off-screen, acceleration and motion smoothness (Table 2).

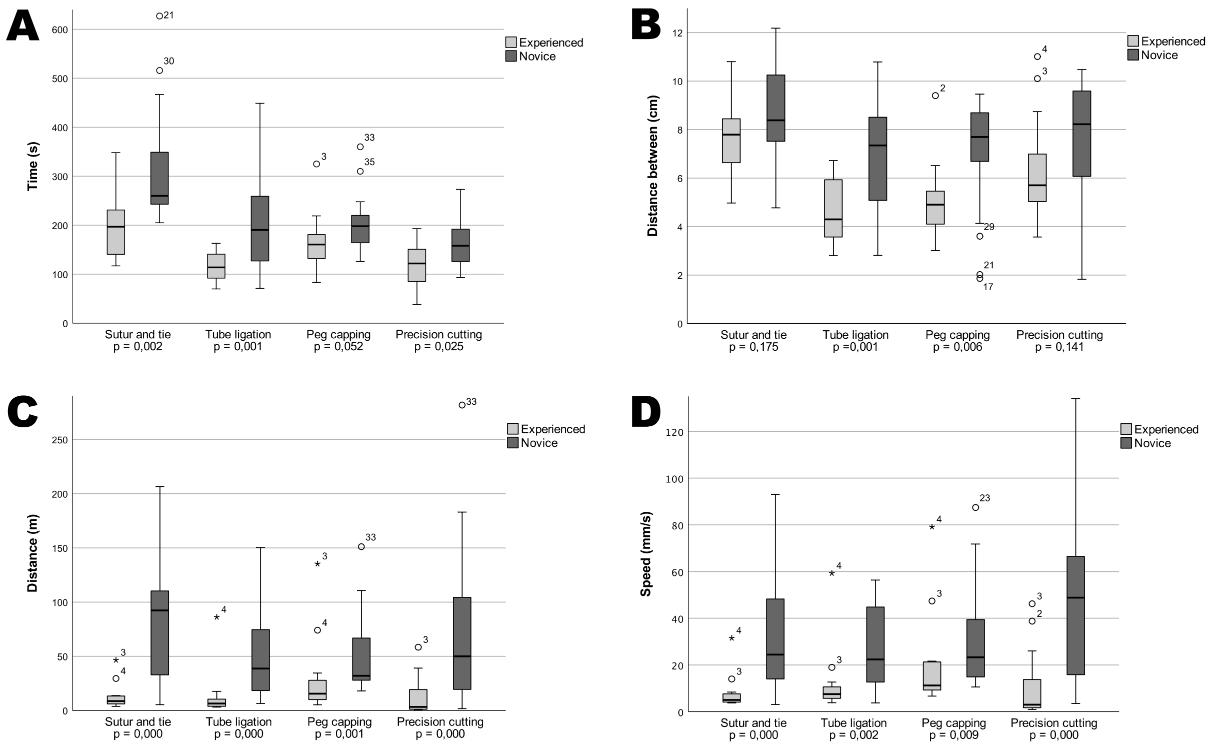

Figure 2. Motion metrics.

A) Time to complete tasks in seconds. Medians, interquartile ranges and p values. Points represent outliers.

B) Distance between the instrument tips for each task, in centimeters. Medians, interquartile ranges and p values. Points represent outliers.

C) Total distance traveled by instrument tips for each task, in meters. Medians, interquartile ranges and p values. Circles represent outliers and asterisks represent extreme outliers, i.e. values more than three times the heights of the boxes.

D) Total instrument speed for each task, in millimeters per second. Medians, interquartile ranges and p values. Circles represent outliers and asterisks represent extreme outliers, i.e. values more than three times the heights of the boxes.

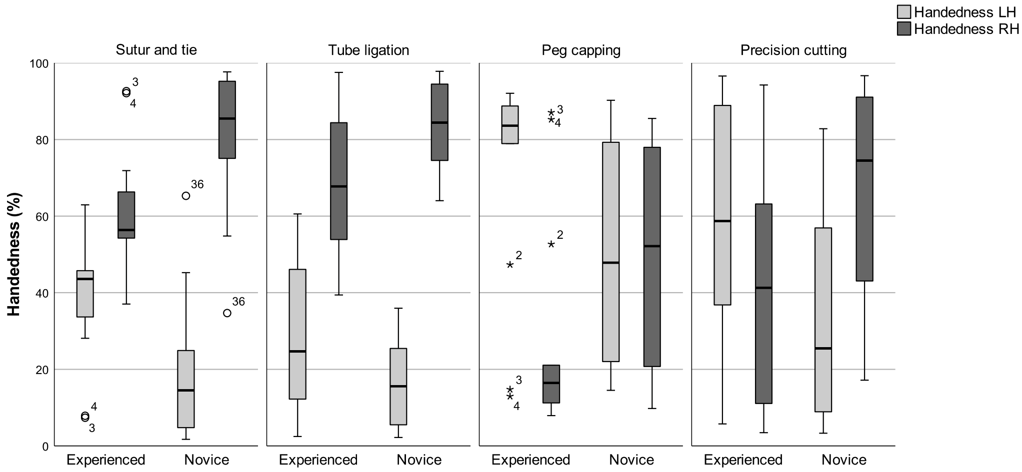

Figure 3. Handedness.

Handedness; the percentages of left hand use and right hand use, shown for each group on all four tasks. Medians and interquartile ranges.

Discussion

The eoSim showed construct validity on three of four tasks: suture and tie, tube ligation and precision cutting, using the metrics time, total distance, handedness and total speed. These metrics have shown to distinguish between experience levels in other studies as well [18-20].

Suture and precision cutting are tasks that previously have shown construct validity on the eoSim, as well as on other simulators [13, 20, 23]. Zendejas et al. suggest that tube ligation lacks discriminatory ability [24], and the reason for our opposite findings regarding this task could be attributed to a small study population. Peg capping did not display a clear discriminatory ability for neither time nor handedness. These results could be the effect of a small study population as well. However, the fact that the novice group was nearly ambidextrous when performing this task and also displayed similar values for left hand and right hand distances, was unexpected. This could be explained by a less rigid and standardized approach to complete this task, compared to the other tasks, e.g. precision cutting, in which all candidates held the scissor in the right hand. Thus, it is difficult to conclude on the discriminatory ability of the task peg capping. Further studies are needed to determine if this task is adequate for testing technical skills among surgeons.

Two of the metrics that showed discriminatory ability in this study were time-related measurements; time to complete task and speed of instrument tips. The time metric has previously been validated [13, 20, 25-29], but the speed metric has lacked discriminatory abilities in several studies [18, 20, 28], although exceptions to this trend have been reported [30]. Datta et al. suggest that the speed of hand movement is secondary to the economy of hand movement. The reason why the speed metric may not be able to discriminate, but the time metric can, could be that experienced surgeons are more task-oriented in their movements. Hence, while the speed of hand movement is not significantly higher, the task is completed in less time [31]. But are these time-related metrics suitable for testing laparoscopic skills alone and do they give any information about the quality of a surgeon's technical skill? The time to complete a task has previously shown strong correlation with good surgical performance [32]. Xeroulis et al suggest, however, that the learning curve for operating speed is shorter than the learning curve for accuracy [32]. Thus, if objective testing of technical skills exclusively is to rely on time-related measurements, and not on an assessment of accuracy, one may overestimate surgeons' technical skills.

The distance metric showed discriminatory ability and has also been validated in previous studies [13, 18, 20, 25-30, 33]. The lower total distances the instruments travel in the hands of experienced surgeons compared to novice surgeons could indicate that experienced surgeons carry out more efficient, task-oriented movements, losing less distance to random movements. The ability of the distance metric to quantify these acquired movement patterns suggests that it provides an adequate evaluation of accuracy.

As expected, there was a greater degree of ambidexterity in the experienced group. We did not discriminate between dominant and non-dominant hands because the performed tasks were standardized and all candidates, regardless of their preference, performed the tasks in the same manner, e.g. all participants held the needle with the right hand instrument when suturing. This finding is consistent with previous studies, highlighting the greater degree of ambidexterity in experienced surgeons [18, 29].

We did not find any significant difference in the metric motion smoothness between groups. Motion smoothness is a measure of the rate of changes in acceleration. There is conflicting evidence in the literature regarding the discriminatory ability of this metric, [13, 18, 20, 25-28, 33] indicating that further studies are needed to determine the usefulness of this metric as an objective measurement of technical skills.

Earlier studies have shown no significant differences in the metrics distance between instrument tips, acceleration or off-screen time, [18, 20] which is in coherence with our findings. Taken together, these findings indicate that these metrics cannot be recommended for testing surgical skills.

A challenging part of testing surgical skills is defining the level of experience of participants, since there are no standards [34]. Previous studies have used 100 laparoscopic procedures performed as their cut-off for expert level [19, 27, 33], but the number of procedures performed by a participant is a non-objective measure of experience. However, since no standard cut-off has been defined, the dependence of the study outcome on group allocation can be identified as a general limitation in this study and others seeking to objectively assess technical skills among surgeons at different levels of experience.

There were a few outliers for every metric, some of them representing the same candidates. This may indicate that these candidates were not as skilled as could be expected, compared to the other candidates in the same group. However, the outliers could also indicate technical issues in the eoSim and in the SurgTrac software. Being a portable, low-cost simulator, may increase the risk of technical issues compared to other stationary and more expensive simulators. On the other hand, the eoSim simulator offers the possibility to save the recorded video on completion of a task, which provides an opportunity to go through the video post-testing if the motion metrics do not seem to be in coherence with the candidate's performance. There were more outliers in the novice group than in the experienced group. The greater variance of the data points in the novice group is in keeping with other studies [18, 25, 30]. A larger participant population in this study could have provided further information about this.

Surgeons are required to master basic laparoscopic skills before performing safe real-life surgery, in order to prevent unnecessary errors. To that end, the eoSim is a highly accessible simulator that can be used in objective testing of basic laparoscopic skills, such as intracorporeal suture and tie, tube ligation and precision cutting.

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Declaration of interest

None.

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Disclosure statement

Mansoor, Våpenstad, Mårvik, Glomsaker and Bliksøen have no conflicts of interest or financial ties to disclose.

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Table 1. Motion metrics measured by SurgTrac software [22].

Metric	Definition	Unit
Time	Time to complete a task.	Seconds (s)
Distance	Total distance traveled by instruments.	Meters (m)
Handedness	Distribution between right hand and left hand use. A distribution close to 50/50 shows ambidexterity.	Percent (%)
Off screen	Percentage of the total time in which the tip of an instrument is out of the field of view.	Percent (%)
Distance between	Distance between left hand and right hand instrument tips. A low value demonstrates control of the instrument.	Centimeters (cm)
Speed	Speed of instrument tip.	Millimeters per second (mm/s)
Acceleration	Instrument speed variation.	Millimeters per second squared (mm/s^2)
Motion smoothness	Changes in instrument acceleration caused by sudden movements.	Millimeters per second cubed (mm/s^3)

For the metrics distance, speed, acceleration and motion smoothness, the software produces separate scores for right-hand and left-hand instruments, as well as a total score for both.

Table 2. Motion metrics for left-hand and right-hand instruments.

	Task 1: Suture and tie			Task 2: Tube ligation			Task 3: Peg capping			Task 4: Precision cutting		
Motion metrics	**Experienced**	**Novice**	**p**	**Experienced**	**Novice**	**p**	**Experienced**	**Novice**	**p**	**Experienced**	**Novice**	**p**
Distance LH	3,14 (3,06)	8,19 (4,64)	0,000	1,59 (1,13)	4,45 (4,89)	0,002	13,17 (9,31)	19,00 (6,97)	0,004	1,78 (8,13)	10,81 (14,14)	0,009
Distance RH	5,24 (4,01)	55,88 (100,66)	0,000	4,75 (5,32)	31,75 (62,67)	0,000	2,27 (5,41)	20,16 (52,51)	0,001	0,70 (1,03)	38,89 (67,05)	0,000
Off screen LH	4,74 (10,69)	0,82(12,26)	0,096	0,00 (0,02)	0,00 (0,00)	0,959	0,00 (0,31)	0,00 (0,01)	0,495	10,67 (18,46)	3,22 (12,29)	0,578
Off screen RH	4,66 (9,74)	2,68 (19,40)	0,258	23,76 (24,83)	0,45 (3,22)	0,000	28,04 (23,36)	1,66 (26,08)	0,013	6,21 (13,74)	2,29 (21,93)	0,860
Speed LH	4,04 (1,59)	5,58 (3,33)	0,058	3,47 (2,74)	5,21 (2,06)	0,033	15,12 (8,23)	20,66 (4,88)	0,026	2,77 (13,83)	19,35 (22,22)	0,010
Speed RH	6,04 (6,08)	43,72 (74,23)	0,000	9,98 (12,76)	39,31 (63,40)	0,003	4,45 (6,95)	23,35 (57,38)	0,003	1,50 (1,64)	69,29 (86,60)	0,000
Acceleration LH	2,11 (0,65)	1,74 (0,78)	0,096	1,12 (0,38)	1,32 (0,59)	0,017	1,95 (0,75)	2,66 (0,71)	0,000	0,99 (0,53)	2,89 (1,05)	0,000
Acceleration RH	2,55 (1,04)	4,07 (4,13)	0,152	2,84 (1,44)	4,21 (2,20)	0,056	1,73 (1,12)	2,10 (2,31)	0,454	0,85 (0,92)	3,47 (2,54)	0,000
Motion smoothness LH	0,03 (0,02)	0,01 (0,02)	0,001	0,03 (0,02)	0,02 (0,02)	0,023	0,04 (0,04)	0,05 (0,01)	0,263	0,02 (0,03)	0,04 (0,03)	0,030
Motion smoothness RH	0,04 (0,05)	0,03 (0,04)	0,308	0,09 (0,08)	0,06 (0,10)	0,377	0,03 (0,04)	0,03 (0,05)	0,678	0,02 (0,05)	0,08 (0,08)	0,014

Medians, interquartile ranges and *p* values. LH: Left hand, RH: Right hand.

Figure legends

Figure 1. Task performed on the eoSim.

The four tasks. From top left to bottom right: Peg capping, intracorporeal suture and tie, precision cutting and tube ligation.

Figure 2. Motion metrics.

A) Time to complete tasks in seconds. Medians, interquartile ranges and *p* values. Points represent outliers.

B) Distance between the instrument tips for each task, in centimeters. Medians, interquartile ranges and *p* values. Points represent outliers.

C) Total distance traveled by instrument tips for each task, in meters. Medians, interquartile ranges and *p* values. Circles represent outliers and asterisks represent extreme outliers, i.e. values more than three times the heights of the boxes.

D) Total instrument speed for each task, in millimeters per second. Medians, interquartile ranges and *p* values. Circles represent outliers and asterisks represent extreme outliers, i.e. values more than three times the heights of the boxes.

Figure 3. Handedness.

Handedness; the percentages of left hand use and right hand use, shown for each group on all four tasks. Medians and interquartile ranges.