Learning Complex Motor Procedures like Minimally Invasive Surgery

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Abstract Minimally Invasive Surgery (MIS) plays a vital role in the medical world and is experiencing increasing patient demand. MIS requires a different set of skills than open surgery. We begin with the conception that single cognitive abilities individually cannot predict predisposition in acquiring MIS skills. We assess whether learning and performance can be predicted between tasks similar to MIS. In this study 4 tasks (buzz wire, drawing through a mirror, origami and a surgical knot) were performed by 40 participants over 20 trials. Individual learning curves for the 4 tasks investigating the learning rate, previous training and the estimated maximum performance resulted into finding only 1 good correlation on the estimated maximum performance between drawing and origami of r = .852 with a CI of [0.44, 0.94]. The conclusion can be drawn that viewing the learning of complex motor procedures holistically is not better for predicting predisposition. If the tasks were derived from the same cognitive component or talent, stronger correlations between the tasks would have been found. The theoretical implications are discussed.

Keywords Dexterity · Holistic · Learning curve · Minimally Invasive Surgery · Prediction

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Over the past two decades Minimally Invasive Surgery (MIS) has started to play a vital role in the medical world. MIS uses technology to reduce tissue damage during surgery. The patient demand has grown tremendously and surgeons have rapidly been trying to embrace this new technique. It is extremely important that surgeons learn to perform MIS correctly, due to patients' lives being at stake and the amount of money and time it takes to train a surgeon (Walther et al. 1999). MIS however, relies on a very different set of challenging skills than those necessary for preforming average open surgery. MIS requires a surgeon to make several small incisions and to insert thin tubes named trocars. With a miniature camera the surgeon can view the (internal) procedure magnified on video monitors. Through the trocars, specialized instruments are placed to perform the procedure. MIS is basically surgery without the scars or with significantly smaller scars (Hamad and Curet. 2010). The difficulties in learning MIS are specifically due to the tactile sensation, the distance which separates the surgeon's hands from the patient and the limitation of 3D visualization where the surgeons must learn to interpret 3D structures like organs from 2D displays on a screen (Gallagher, Cowie et al. 2003; Hamad & Curet. 2010). Learning MIS procedures depends on a number of ergonomic factors which are related to the equipment, training factors and human (cognitive) factors (Gallagher et al. 2003).

The assumption currently made by many is that by assessing the cognitive abilities separately, a person's disposition for learning MIS skills can be predicted. Different studies have shown that certain human cognitive abilities, like perceptual ability and visuo-spatial ability, are related to the duration of training necessary to reach proficiency in performing MIS (Schlickum, Hedman et al. 2011; Groenier, Schraagen et al. 2014). However, according to other studies like that of Veenman, Wilhelm & Beishuizen (2004) assessing single cognitive abilities apart from each other does *not* predict the learning rate or the amount of training needed to reach proficiency on for instance MIS tasks. Groenier et al. (2014) state that the different individual cognitive abilities only mediated some aspects of performance on MIS tasks while they were being examined independently. The study of Groenier et al. (2014) concludes that the relationship between cognitive aptitude and MIS performance is complex. A suggestion is made that more general cognitive and reasoning abilities might be more important.

Taking this suggestion into account, perhaps the assessment of a person's aptitude to acquire complex motor procedure skills should be done by using everyday dexterity tasks (handiness tasks). Apparently, predicting MIS skills by investigating the cognitive abilities separately gives no conclusive results. The main focus now lies on if it is possible to predict the performance and learning of one task with another task and thereby taking on a more holistic[1] approach, instead of assessing the cognitive abilities separate from each other. In the case of positive results, there is a high chance that learning complex motor procedures such as MIS can be predicted.

Holistic Processing

Holistic processing is something humans do every day. It is how we interact with the world and how we make sense of the stimuli we receive. When researching how people process faces, results imply holistic processing (Richler, Gauthier et al. 2008). According to a study of Lorenz et al. (2014) when people learn how to interact with a machine a holistic approach is used. Learning haptic skills in a holistic manner proved to work better then when learning haptic skills in an analytic manner (Schwarzer, Küfer & Wilkening. 1999). So in many aspects of learning, people often rely on a holistic approach. Evidently, if people rely on a holistic approach for learning haptic skills, perhaps in the case of predicting proficiency in MIS tasks we must investigate proficiency in other related tasks instead of viewing the different cognitive abilities separately.

Development of Motor Skills

As described briefly before, there has been a lot of research on predicting development of MIS motor skills. A substantial amount of the studies focus on finding which cognitive tests might be able to predict surgical skills. Many of these studies show conflicting results. One review states that only visual-spatial perception is an effective predictor of learning surgical skills (Maan, Darzi & Aggarwal, 2012), another study states that the spatial abilities in general are important in selection and training (Langlois, Bellamare, Touloude & Wells. 2015). In a review of Kelvin et al. (2016) the results state that aptitude tests in general are associated with laparoscopic skills and that simulators seem to have the best potential for assessment of future surgical skills, however expensive they might be. In again another study of Louridas, Quinn and Grantcharov (2015) statements are made that selection of surgical trainees by predicting their technical skill performance is appealing, but not reliable. They did find that higher spatial ability and previous experience were associated with significantly better laparoscopic

[1] Considering the whole of something or someone and not in separate parts or aspects. In this case looking at the whole instead of different cognitive abilities apart from each other.

performance. They also concluded that to predict the acquisition of skills for laparoscopic surgery a number of innate abilities along with their inherent interactions must not be forgotten. This mentioning of taking innate abilities into account is that to which this study refers to as a general talent[2].

When considering the results published by Groenier et al. (2015) on cognitive abilities in laparoscopic simulator training, no significant correlation was found between reaching proficiency and any of the cognitive abilities (visual-spatial ability, spatial memory, perceptual speed or reasoning). Performance on duration, damage and motion efficiency improved with the number of sessions, however none of the cognitive abilities correlated significantly with the amount of the sessions necessary for proficiency. Across duration, damage and motion efficiency different cognitive abilities seemed significant, however once the effects of other covariates and the fixed factors simulator and session were taken into account, the abilities diminished and were no longer significant. In this study a multiple regression analysis was also performed and showed that the cognitive abilities, when taken together, didn’t predict the learning curve significantly for either duration, damage or motion efficiency. This means that cognitive aptitude (or ability) had no effect on the learning curve steepness throughout the sessions. However weak, Groenier et al (2014) was still able to conclude that visuo-spatial ability was essential in the early learning stages of MIS. These results reveal that the relationship between MIS performance and cognitive aptitude is weak and complex. Groenier et al. recommend in their publications that cognitive testing could be combined with psychomotor skill testing (on MIS simulator). This could be used to develop individualized training programs. They also conclude that visual-spatial ability might be the best (of the other abilities) predictor of individual learning curves differences (Groenier et al. 2014).

Reviewing all these different results Louridas et al. (2016) conclude that “to date, no single test has been shown to reliably predict the technical performance of surgical trainees”. Ultimately we can conclude out of these contradicting findings that no solution has yet been found to the problem of predicting surgical skills (laparoscopic skills). After this observation that single cognitive abilities are not able to predict aptitude in motor skills, perhaps learning

[2] Cognitive element which is responsible for the performance in tasks, tests etc. General talent assumes that there is 1 overall talent responsible for the performance on all the tasks, tests etc.

and performance can be predicted between more similar tasks. But how would one decide which tasks to choose for measuring surgical skills when keeping prediction of MIS skills in mind?

Dexterity as Measurement of Surgical Skills

In the surgical world it is not standard procedure to make the applicants undergo dexterity testing. Dexterity testing entails assessing one's handiness and skilfulness in for instance hand-eye coordination tasks. Goldberg et al. (2008) researched if scores and medical school class rank correlated with performance on dexterity tests. Results showed that motor skills (dexterity) slightly but significantly correlate with class rank ($r = 0.20$). No confidence intervals were given, however this association was considered significant ($p = 0.039$). These motor skills had been attained by playing dexterity games in the past, like video games or by participating in former dexterity activities, like sewing or cooking. Performing laparoscopic surgery requires excellent hand-eye coordination. Video games also require hand-eye coordination and according to several studies, prediction of laparoscopic skills could indeed be done by assessing one's video game aptitude.

More studies like that of Goldberg (2008) have been performed. For instance the study of Rosser et al. (2007) which states that laparoscopic surgeons benefit from video game training. Surgeons who play video games for more than 3 hours per week performed significantly better than surgeons who didn't. Another outcome of this study was that a surgeon's game experience is an even better predictor of surgical skill than the amount of years of practice or amount of operations completed. Suggestions were made that video games could be used as a warming up for laparoscopic surgeons of that special surgeon specific games could be developed which would work even better (Rosser, Lynch, Haskamp, Yalif, Gentile, & Giammaria. 2004).

But why would dexterity tasks be able to predict MIS skills better than separate cognitive skill tasks? A dexterity task (for instance a video game) has, besides the obvious spatial and sensory motor skills, a high level of cognitive complexity. Many cognitive abilities are used when playing and learning a game or task. If someone is proficient in dexterity games, they often score higher on other dexterity games. The learning curve of both games is similar and predictions may be made about the performance of other dexterity games or tasks (Green & Bavelier. 2006). Why not regard learning MIS skills as learning a new dexterity task? One of the main differences between normal dexterity tasks and games is the fulcrum effect, but if this would be integrated in the task, perhaps predictions are possible.

Fulcrum effect

A major aspect of why MIS and laparoscopic surgery are so difficult, is the fulcrum effect. This is the inversion and scaling of the surgeon's own movements which cause challenges. Due to the tool endpoints which move in opposite directions of the hands of the surgeon, this effect makes laparoscopic surgery a non-intuitive and difficult to learn motor skill. The surgeon must be able to rotate his movements to the illustrations he sees on the screen. Therefore, the Fulcrum effect has a very harmful influence on the development of surgical skills. Subjects make significantly more and worse mistakes when working under Fulcrum circumstances than subjects who don't have to work under Fulcrum circumstances (Gallagher et al. 1998).

Because this is a very difficult to learn motor skill many tools for evaluating these skills are being tested. Virtual reality proves to function as a useful objective assessment tool, however there is no evidence of any tool able to assess if someone has a predisposition for learning this set of skills (Gallagher et al. 2001).

Learning Curve and Deliberate Practice Research

Researching how people learn complex motor procedures is done by investigating the learning curve for different tasks related to MIS. The use of the learning curve is quite standard for cognitive psychology. It shows the relationship between practice and experience. Most tasks are completed faster with more practice, which gives a learning curve. The pattern is a quick improvement followed by less and less improvements while the practice trials continue, otherwise known as a negative acceleration. Even though the participants receive the same dexterity tasks, different strategies may be used across the different participants. Because of this, the learning curves of the participants are viewed individually and are not grouped (Ritter & Schooler. 2001).

Individual learning effects for skill acquisition are represented with a learning curve. The exponential function is claimed to fit analysis of individual subjects better than the power law (Heathcote, Brown & Mewhort. 2000). The power law is claimed to fit the analysis of different strategies for mental tasks better. The power law of practice is a specific type of learning curve on the performance which claims that the logarithm of reaction time per task diminishes in a linear fashion according to the logarithm of the amount practice trials performed (Delaney, Reder & Staszewski. 1998). However in this case the exponential function is used to investigate the individual learning curves, because according to Heathcote et al (2000) an individual-level dataset is better fit using an exponential function. The Exponential function states that an improvement in skill is best during initial attempts, and gradually evens out as can be seen in fig. 1.

The learning curve will be investigated in three different stages. First of all, the slope which shows the learning rate. Secondly, the previous training and last, the Asymptote which shows the estimated maximum performance. These three different stages will be investigated separately from each other to give a better distinction of what the results mean in relation to the learning process.

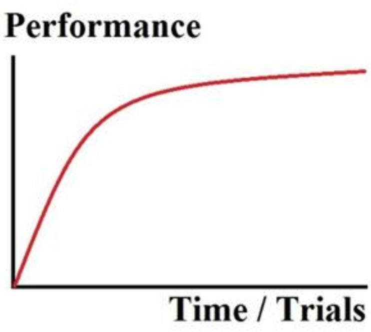

Fig. 1 Exponential learning curve performance vs. time

High performance on for instance MIS is often traced back to training. This is visible in a learning curve as mentioned before. However, this 'high' performance which can be observed can be traced back to active engagement which comes from Deliberate Practice (DP). Training often just focusses on improving certain tasks, where DP also involves the provision of feedback which is immediately given, includes time for problem solving and also evaluation. DP also encompasses opportunities for repeating the task to refine it (Ericsson. 2008).

Ericsson (2008) concludes in his study about Deliberate Practice: "Educators should therefore create training opportunities for DP, appropriate for a given individual at given level of skill development. Performers may then make the necessary adjustments to improve specific aspects of performance to assure that attained changes will be successfully integrated into representative performance." This conclusion has been taken to heart in the design of the current study investigating the learning curve of tasks related to MIS where the use of DP in encouraged.

Tasks and correlation

As mentioned before, focusing on just one cognitive component per task has been done before and has failed to produce solid statements. A more holistic way of approaching the question if there is such a thing as a predisposition for learning surgical skills is to find a general talent. In this study, an attempt will be made to find this general talent by letting a person perform 4 different tasks, all of which require several psychomotor skills. To be able to compare the results between a sufficient amount of tasks, but to keep the experiment from taking too long, 4 tasks were chosen. The tasks have been selected in the pilot study and are discussed further there. A participant will have ultimately performed these 4 experiments. This participant will show an individual learning curve for all 4 tasks. If this person also shows a positive correlation between these 4 learning curves, this will almost definitely mean that there is a general talent. The question then is if it is able to determine with these 4 learning curves and correlations if this person is a quick learner and if he or she does in fact have a predisposition to learn surgical skills required in MIS. This would mean that there would indeed be a way to determine if for instance a young medical student will later on be good or bad at learning MIS. However, if no correlation is found, this will also have meaningful implications. In this case there would in fact be no predisposition and therefore no general talent to learn surgical skills. This would mean that there would be no way to determine if for instance a young medical student will later on be good or bad at learning MIS.

Research question

Before trying to predict the learning and performance of MIS, the question should be asked if it is even possible to predict one task with another. We are trying to find a relation between the 4 tasks in either the learning process, the maximum performance or the previous training. In order to investigate if viewing the learning of complex motor procedures holistically, by simply letting a person learn a complex task, is better for predicting predisposition in learning complex motor skills, the following research question is asked:

How do 4 similar tasks, derived from MIS skills, correlate with each other in previous training, learning rate and the estimated maximum performance?

We expect that there will be a strong correlation between the tasks, considering the literature which shows that many cognitive abilities are intertwined and that focussing on one ability does not accurately predict surgical skills later on in someone's profession.

Conclusion

In Minimally Invasive Surgery, objectively assessing a person’s psychomotor skills has proven to be difficult but achievable. However, it is at least as important to determine a person’s predisposition for learning these skills. This has been researched before, but no results have been found stating there is or isn’t such a thing as a predisposition for learning these skills. For this study, a learning curve for 4 different tasks will be examined to determine if a correlation between task-specific learning curves can be found. These tasks are focussed on dexterity as measurements of surgical skills. These tasks encompass different skills and don’t focus on only one cognitive component. This would mean that in the case of a correlation, a holistic way of viewing the learning of complex motor procedures is better and that it is best predicted by simply letting a person learn a complex task.

Pilot Study

In order to determine the tasks which will be used in this study, a pilot study was performed to analyse 5 different tasks. These tasks were performed by 4 young adults. These participants were part of the research team of this study. One task which showed difficulties in performing and of which the results were difficult to interpret was left out of the study. The learning curve of these participants was determined by the time a participant needed to complete the task over 20 trials. The participants were motivated to complete the task as fast as possible. Once the participant was at the 10th and 17th trial they received feedback on how many trials remained.

Procedure

The Buzz wire task required a steady hand and concentration. The participant had to follow a metal wire with a handle and had to try to avoid touching the metal wire. Once the participant (by accident) touched the metal wire with the handle an electrical circuit was created which turned on a small (red) light. These errors were recorded along with the time the participants needed to complete the Buzz Wire. See figure 2.

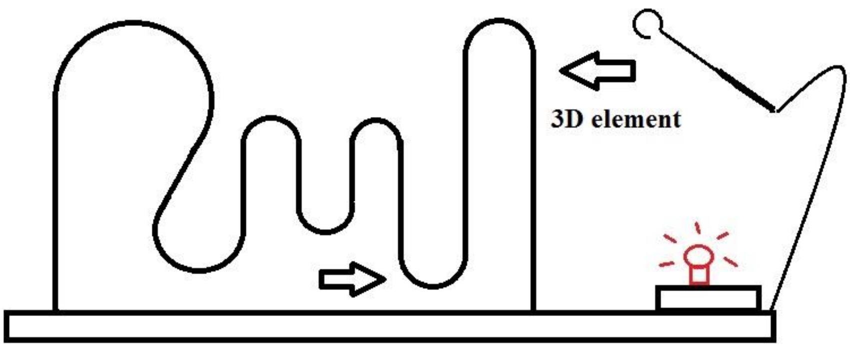

Fig. 2 Buzz Wire task

The Drawing task required the participant to draw a shape by looking through a mirror. They were not able to see what they were drawing and how, except through a mirror in front of them. The participants had to try to stay in between the lines of the shape. The shape contained straight corners as well as curves. See figure 3.

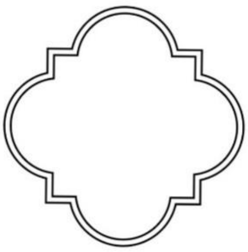

Fig. 3 Mirror Drawing shape

The Duncan Loop is a type of sailors knot. The participants were able to see the knot beforehand. They also received an explanatory picture which showed them how to make the knot. See figure 4. The Duncan loop had the requirement to be able to shift up and down the rope.

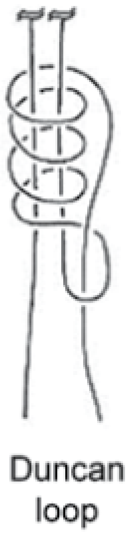

Fig. 4 Duncan Loop task

Folding an Origami fox was the fourth task. The participants received an illustration which explained how to make the origami fox. See figure 5. The origami foxes had the requirement to be able to remain standing on the table.

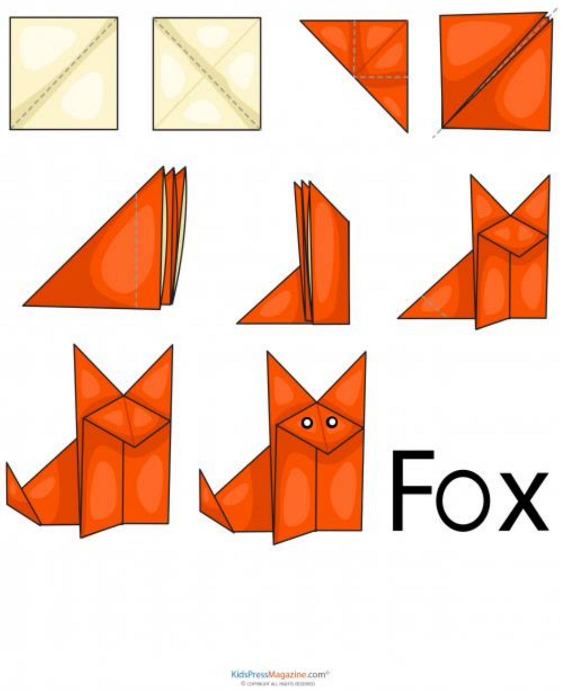

Fig. 5 Origami task

The final task consisted of making a star shape with a rubber band. See figure 6. The participants were shown an instructional video and with this they had to make the star as fast as possible.

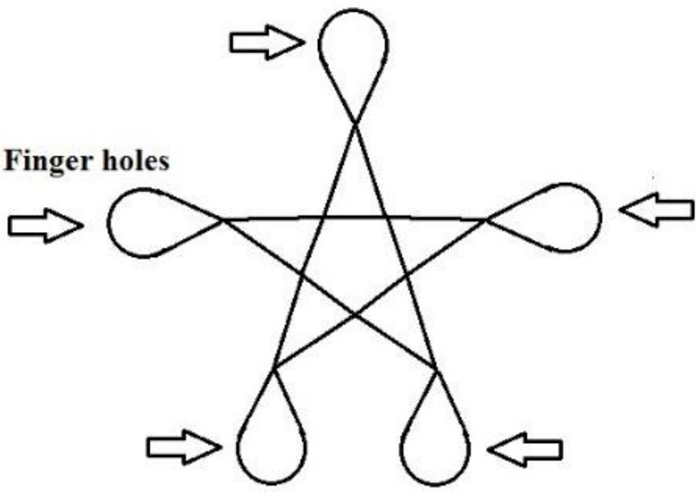

Fig. 6 Rubber band task

Analysis

The association between practice and performance dependent on participant and task was plotted per task. The outliers were filtered out. As can be seen in figure 6 the Buzz Wire shows an overall steady learning curve. A disadvantage of this task is the amount of errors which can differ per participant. The errors will not be analysed in this study. They were reported and may be used in further research. A drawback was the fact that some participants change their strategy during the task. This is visible in the fluctuation in the plot below. The Buzz Wire is used in this study because it requires the participants to use their visual spatial ability and motor skills. It represents MIS surgery quite well in regard to the tools and stability which are necessary.

The drawing task shows the best learning curve of the 5 tasks. It also has the least amount of fluctuations. The drawing task is used in this study because besides the learning curve, it represents the fulcrum effect. Drawing through a mirror resembles a surgeon performing MIS through a 2D screen.

The Duncan loop shows a very steep learning curve. The Duncan loop is also used in this study. The amount of trials however, will be reduced to 10 because of the rapid learning curve all the participants showed. The Duncan Loop measures the participant’s ability to perform visual spatial tasks, just like the surgeons in MIS have to perform.

The Origami’s learning curve resembles that of the Buzz Wire. The learning curve looks good, however the participants usually change strategy halfway and this accounts for the bump in the curve seen in figure 6. The Origami task will be used in this research because it requires motor skills and visual spatial ability also required in MIS.

The Rubber Band task will be left out of this study due to a number of factors. This task had the most fluctuations of all 5 tasks and also the most outliers. The learning curve shown in figure 7 has filtered out most of these outliers and shows a nice learning curve. However the explanation of this task is very difficult. It consists of a video which can be paused and played at request of the participant. An illustration simply did not suffice. Once the participants understood the instruction and tried to perform faster, they often made mistakes which caused major outliers. These drawbacks simply did not outweigh the advantages and therefore this task is not used in this study.

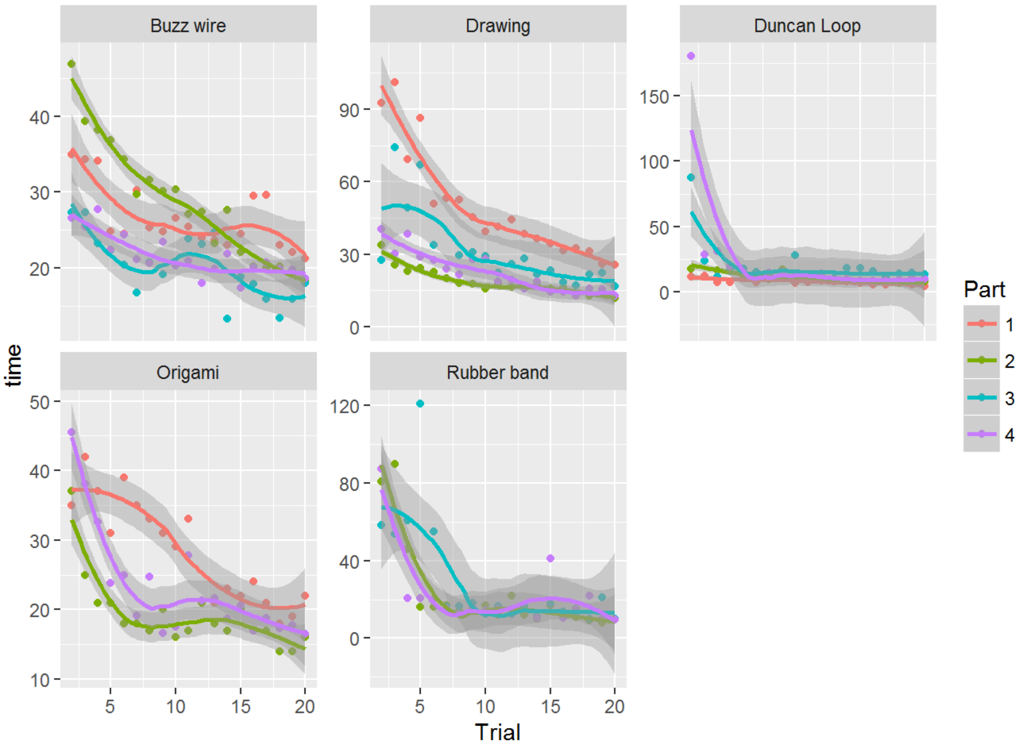

Fig. 7 Rough learning curves of the performance for the tasks; Buzz Wire, Drawing, Duncan Loop, Origami and Rubber Band

Summary of the Pilot Study

All 5 tasks resemble MIS surgery. However, due to instructional advantages, the following 4 tasks were chosen; Buzz Wire, Drawing, Duncan Loop and Origami. The Rubber Band has been left out due to the amount of mistakes which were made by the participants which caused major outliers and the instructional disadvantages.

Methods

Participants

We recruited 40 participants (8 male, 32 female) with a mean age of 28,1 years (SD = 14.0) from different professional backgrounds. Most however (n = 32) were students at the University of Twente while the other 8 participants had a job. 36 Participants reported being right-handed where 3 reported being left-handed and 1 participant using both. Participants were all in good health and had no restrictions in movement or sight etc. The participants came from either the Netherlands (n = 26) or Germany (n = 14).

Materials

A small interview was held with the participants asking about demographics, left- or right handedness, feelings toward working with one's hands and frustration when working with one's hands. As described in the pilot study section the following materials were used per participant for the 4 tasks: a self-made buzz wire, mirror with a box and 20 pages with a shape, rope (1m), and 20 square pages (21cm x 21cm). Every task had a small instructional story consisting of 3 sentences stating what was expected and what to do in case of questions. 3 Questions were asked after every task about the participants experience, preferences and judgement of their own results. Each task would be measured in seconds with a stopwatch and these time recordings were written down.

Procedure

Participants were told about the study and how the experiment would show learning curves across the 4 tasks. Devices or such which could bother the experiment would be asked to be switched off. The examiner would then proceed to ask them a number of demographic questions. If a participant was right handed instead of left, the examiner would explain that there would be no difference in how to perform the tasks. Beforehand, for every participant there was a set order of tasks. Each participant performed the 4 tasks of which the order was pre-organized so every experiment had a different order of tasks. This was to prevent fatigue and boredom from influencing one specific task. Before starting the task, an informed consent was signed an the participant would receive the instructions and ask questions if necessary. The task was then placed before participant and rules would be stated on when to start (when examiner says 'go' for instance). The examiner would right down the time needed to complete the task. For the Buzz Wire, Origami and Mirror drawing task the number of trials were 20. For the Duncan Loop the number of trials was 10. The examiner was to pay attention to irregularities in behaviour or strategy, for instance someone sighing or outing frustration. This was noted along with the time and in which trial it occurred. Codes were used to note strategy and behaviour differences in an efficient and quick manner. See appendix 1 for the instructions and coding of strategy and behaviour differences. Halfway through the trials the examiner would let the participant know he was halfway. Also at trial number 17 (or 7) the participant was encouraged to do his or her best, seeing as he or she was almost finished. After the trials the participants were asked about their personal previous experience of the task they had just completed. Between tasks the participants received 5 minutes break in which the examiner could set up the following task (including instruction and page for examiner for noting time etcetera). After completing each task the participant would be asked about how they would estimate their performance on that task. Once all 4 tasks were finished, the participants were asked about which tasks they liked most and how they would rate their overall performance.

Data Analysis

The data was recorded in time units. With a non-linear mixed effects model 1 learning curve, consisting of 3 parameters, was developed per sequence. 40 participants x 4 tasks produce 160 individual sequences estimated. These sequences were divided in the 3 parameters over which a pair-wise correlation was performed. The 3 parameters consist of previous training, learning rate and maximum performance. This experiment had a within subject design, for it had only one group of different participants. All participants were exposed to the same tasks in a different order to prevent bias.

Measures

Measurements were made over multiple aspects. First of all, the time was measured with a stopwatch. Besides the time measurement, the mistakes made during the task were also observed and noted. In appendix 1 the instruction for the examiner can be found. For the Buzz Wire the mistakes were when the participant touched the wire with the handle. A red light would burn for approximately 1 second and the amount of mistakes was summed up per trial. The Drawing task had 3 categories of messiness which was observed and noted. After each trial the examiner would determine if the drawing was within the lines (v), if it was not at all within the lines (x) or if it was in between (v/x). For the Duncan Loop task the same rating (v,x or v/x) was used to determine if the knot was neat enough. The main requirement was that the knot was able to move up and down (typical for this specific knot). The Origami task shared this rating too (v,x or v/x) which would be determined by how well the fox was folded. The main requirement for the Origami was that the folded fox was able to stay up straight without falling over.

Results

How do 4 similar tasks, derived from MIS skills, correlate with each other in previous training, learning rate and the estimated maximum performance? The learning curves for the 4 tasks (Buzz Wire, Mirror Drawing, Origami and Duncan Loop) were investigated in 3 parameters of the learning curve: The slope (a), the previous training (b) and the asymptote (c). The three sections were divided into individual datasets so the tasks could be investigated per section. The confidence intervals show us with which certainty the correlation can be interpreted and within which bounds it actually lies. The numbers seen in the tables and graphs are the variances among individuals between tasks. To be able to interpret the correlations, different levels are introduced according to rules of George & Mallery (2003). A correlation $\geq$ 0.9 is considered 'excellent', $\geq$ 0.8 'good', $\geq$ 0.7 'acceptable', $\geq$ 0.6 'questionable', $\geq$ 0.5 'poor', and $\leq$ is considered 'unacceptable' or 'weak' (George & Mallery. 2003).

Learning Rate (Slope)

	Mean	Std. Deviation	Minimum	Maximum
Buzz Wire	-.15	.07	-.32	.04
Drawing	-.05	.11	-.19	.33
Duncan Loop	-.19	.24	-.13	.84
Origami	-.01	.13	-.24	.32

Table 1. Descriptive Statistics Learning Rate

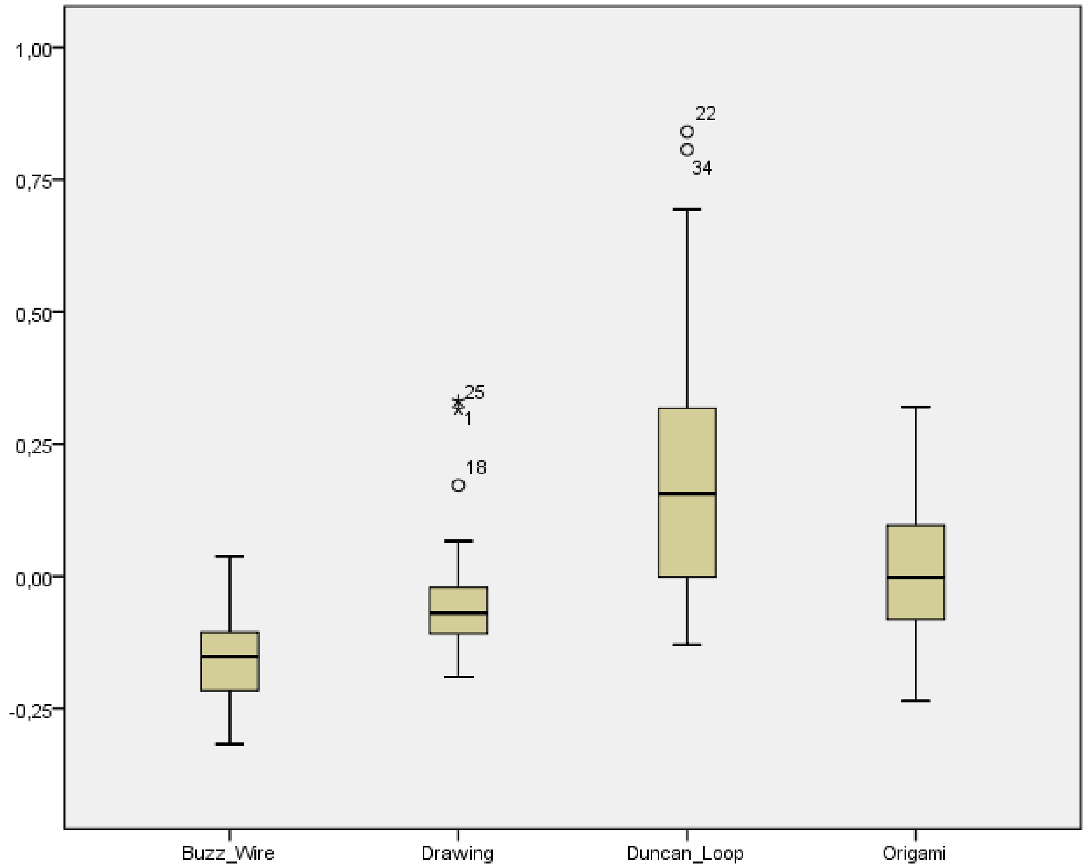

Fig. 8 Boxplot Means of the Learning Rates

The descriptive statistics give an idea of how different the tasks are per parameter. In case of the learning rate (slope) it can be noticed that there is no big distribution. Duncan Loop has more reach than the other tasks, but they remain between -.32 and .84.

	Buzz wire	Drawing	Duncan loop	Origami
Buzz wire	-			
Drawing	0,390[0.14, 0.63]	-		
Duncan loop	0,258[0.02, 0.51]	0,109[-0.18, 0.44]	-	
Origami	0,021[-0.24, 0.27]	0.160[-0.09, 0.47]	0,081[-0.02, 0.23]	-

Table 2 Correlations and Confidence intervals on the Learning Rates for the 4 tasks

A weak correlation was found between the tasks Drawing and Buzz Wire of p = .390. Even though .390 is the most likely value, the confidence intervals also reveal that the correlation may be .63 which would mean that the association between the Buzz Wire task and Drawing are at least questionable. According to the confidence intervals the (maximum) association which may be between Buzz Wire and Duncan Loop (.51), Duncan Loop and Drawing (.44) and between Origami and Drawing (.47) are poor, yet considerable. However, this statement is rather uncertain when regarding the range of the confidence interval. No tangible results were found in the learning rates for the 4 tasks.

Estimated Maximum Performance

	Mean	Std. Deviation	Minimum	Maximum
Buzz Wire	3.84	11.01	-9.61	48.50
Drawing	7.75	18.85	-11.43	82.34
Duncan Loop	-13.30	6.85	-18.95	19.26
Origami	2.21	11.52	-11.26	53.46

Table 3 Descriptive Statistics Asymptote

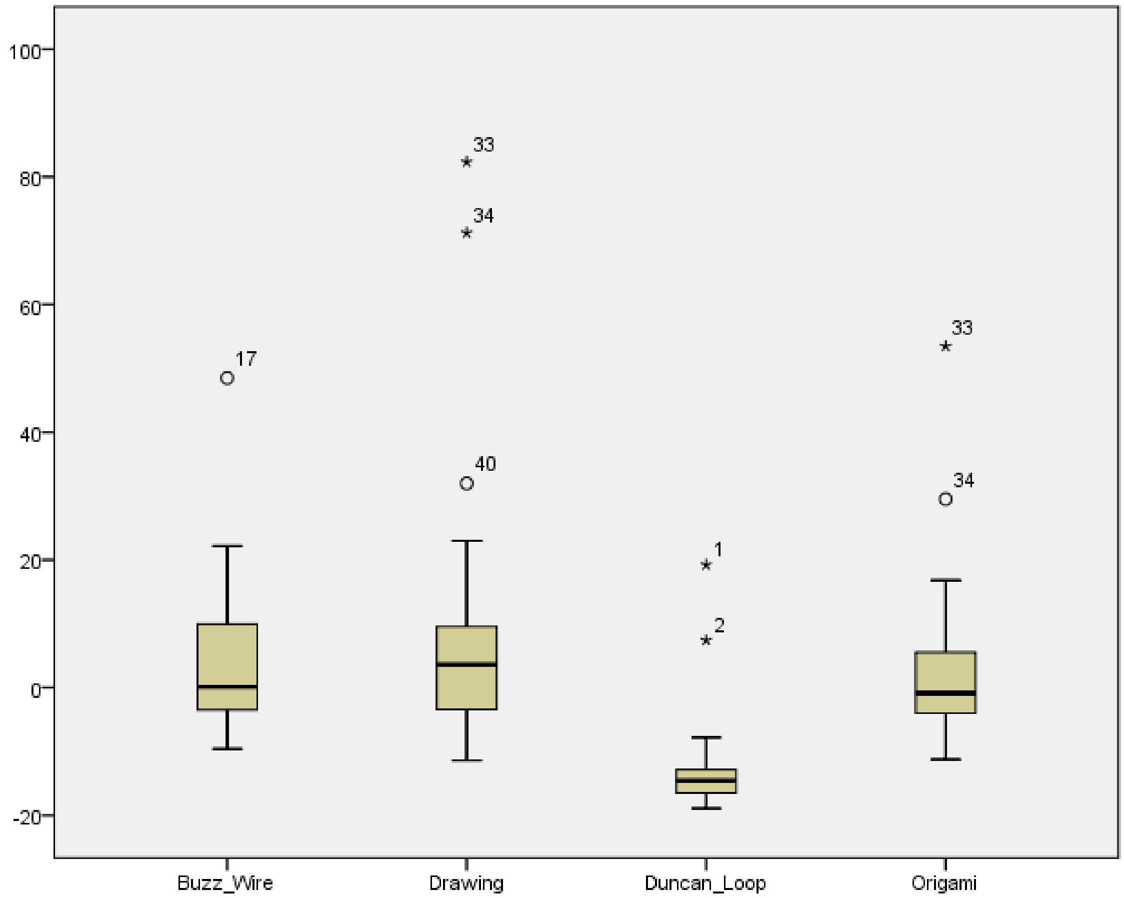

Fig. 9 Boxplot Means of the Estimated Maximum Performances

The Maximum Performance is predicted by combining the last three rough scores. In case of the estimated maximum performance (asymptote) it can be noticed that there are some outliers, for Buzz Wire less than for Drawing. The results also show that Duncan Loop scores are quite a lot lower than the other tasks with a mean of -13.30, whereas Drawing has the highest mean of 7.75. There is quite some distribution between tasks and when looking at the correlations described below it can be noticed that Duncan Loop has the lowest correlations in combination with the other tasks.

	Buzz wire	Drawing	Duncan loop	Origami
Buzz wire	-			
Drawing	0.066 [0.20, 0.36]	-		
Duncan loop	0.043[-0.25, 0.27]	0.026[-0.12, 0.27]	-	
Origami	0.033[-0.17, 0.38]	0.852[0.44, 0.94]	0.165[-0.05, 0.44]	-

Table 4 Correlations and Confidence intervals on the Maximum Performance for the 4 tasks

An almost excellent correlation was found between the tasks Drawing and Origami of .852. As mentioned before, even though .852 is the most likely value, the confidence intervals also reveal that the correlation may be .94 which would mean that the association between the Origami task and the Drawing task might be even better than excellent. However, the confidence interval also reveals that the minimum correlation lies at .44 which is weak. Lowest point of the confidence interval aside, it is quite safe to say that there is a good correlation between Drawing and Origami. Figure 10 gives a visual representation of the correlation between the Drawing task and the Origami task. The strong association between Drawing and Origami shows that, with high certainty and reliability, the maximum performance of one task can (quite accurately) be predicted by investigating a person's maximum performance of the other task. This can also be done by estimating the maximum performance on the basis of incomplete learning. In regard to MIS, if the asymptote of these tasks would also positively correlate to the asymptote of laparoscopy, one would be able to determine if someone is ultimately even able to reach high scores before starting the actual MIS task.

Other correlations worth considering according to the confidence intervals can be found between the Duncan Loop task and the Origami task, which according to the confidence interval has a maximum correlation of .44. This would mean that there might be a weak but considerable association between these two tasks in the estimated maximum performance (asymptote).

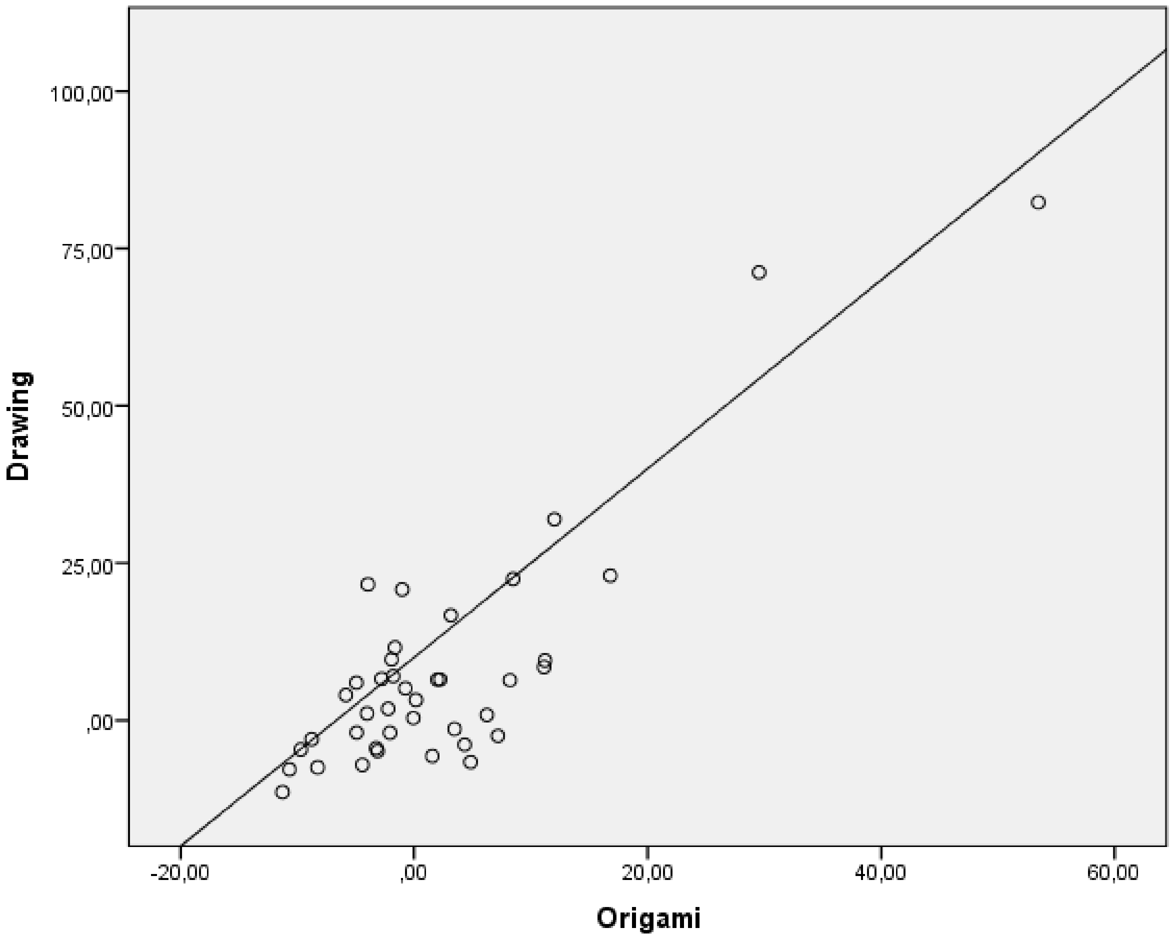

Fig. 10 Representation of the correlation between the Asymptotes of the tasks Drawing and Origami (.852)

Previous Training

	Mean	Std. Deviation	Minimum	Maximum
Buzz Wire	.52	2.56	-7.10	3.42
Drawing	-1.38	2.91	-7.99	3.75
Duncan Loop	2.21	2.23	-5.12	5.05
Origami	-1.34	2.62	-8.65	2.25

Table 5. Descriptive Statistics Previous Training

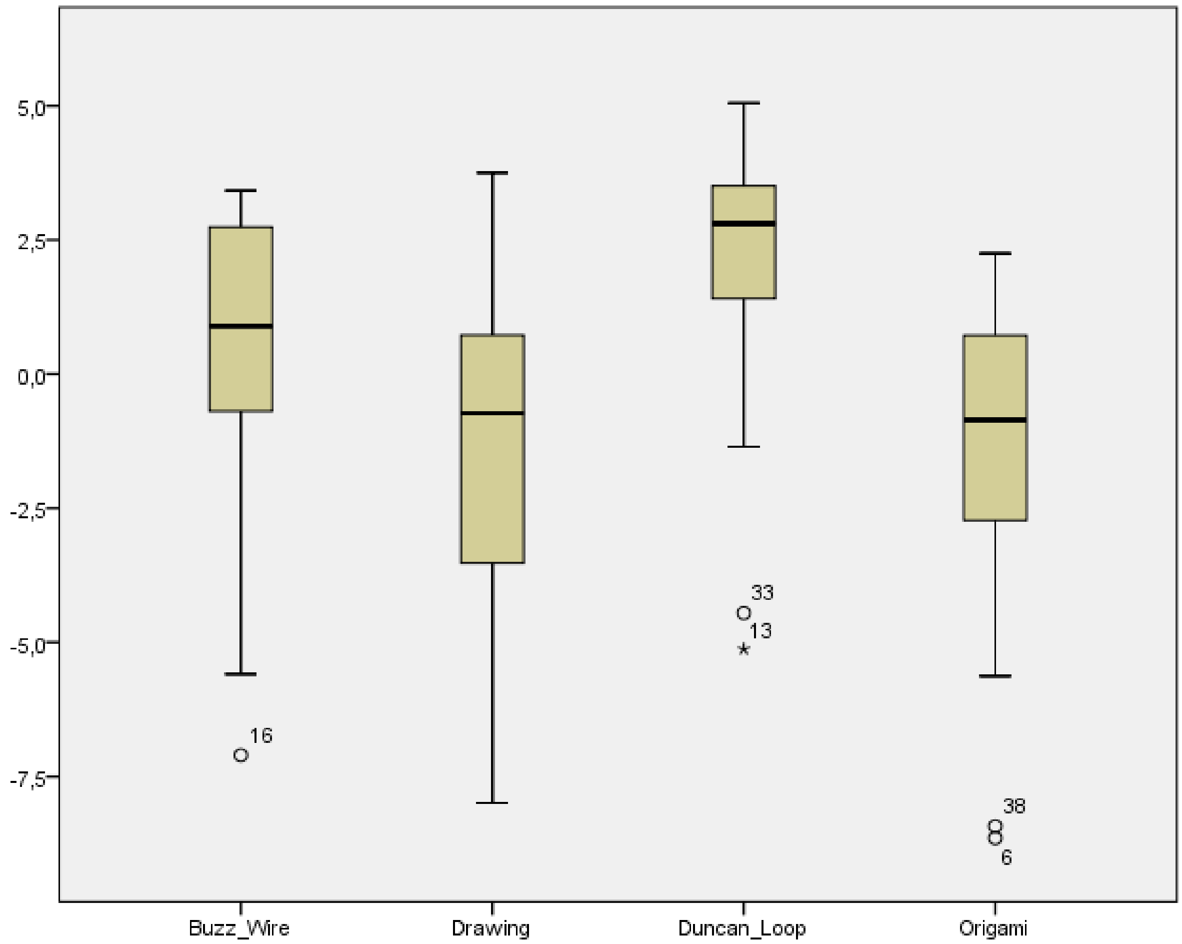

Fig. 11 Boxplot Means of the Previous Training

In case of the previous training it can be noticed that there is a small distribution between tasks. When looking at the boxplot (fig. 11) it can be seen that all four tasks have quite a large range and that their means are relatively close to each other. However the Duncan Loop range is somewhat different from the other 3 tasks in the fact that it is smaller and higher. Similar to the maximum performance correlations, Duncan Loop has the lowest correlations and the smallest confidence interval.

	Buzz wire	Drawing	Duncan loop	Origami
Buzz wire	-			
Drawing	-0,063[-0.43, 0.40]	-		
Duncan loop	0.165[-0.52, -0.02]	0.001[-0.17, 0.29]	-	
Origami	0.092 [-0.39, 0.27]	-0.293[-0.14, 0.43]	0,034[-0.25, 0.45]	-

Table 6 Correlations and Confidence intervals on the Previous Training for the 4 tasks

Only weak correlations are found in the previous training part of the learning curve. According to the confidence intervals the correlation is mentionable (at its maximum) between Drawing and Buzz Wire (.40), Origami and Drawing (.43) and between Origami and Duncan Loop (.45). These weak correlations in the previous training mean that it is not (or only slightly) possible to predict the previous training results of one of these tests by looking at the previous training results of another test.

Discussion

Is viewing the learning of complex motor procedures holistically, by simply letting a person learn a complex task, better for predicting predisposition in learning complex motor skills? In order to be able to answer this question the following research question was composed:

How do 4 similar tasks, derived from MIS skills, correlate with each other in previous training, learning rate and the estimated maximum performance?

Results show that for the previous training and learning rate, there were some weak or poor correlations, none of which implications can be made about predicting other tasks. It is not possible, in our case, to predict someone's previous training on the basis of the learning curve of another task. The same goes for the learning rate. It is not possible, for these 4 tasks, to predict how fast and in which way someone will learn the task. These results imply that it isn't better to view the learning of complex motor procedures, in this case tasks resembling MIS, holistically. Simply looking at how someone learns a complex task is not a better way of predicting predisposition in learning other complex motor procedures in comparison to viewing the cognitive abilities separate.

Besides the fact that we cannot predict how fast and in which way a trainee will learn the skills, the trainee will therefore also not be able to receive objective feedback related to their progress and their skills during the training period (Chaudhry, Sutton, Wood, Stone & McCloy. 1999). The results are nevertheless meaningful. One excellent correlation was found in the estimated maximum performance between Drawing and Origami which means that these two tasks are performed with the same talent, as referred to in this study. This also implies that different talents are used for the other 2 tasks, otherwise they would have shown strong correlations too. If learning were holistic, the tasks would be derived from the same talent(s) and stronger correlations would have been found. Therefore, when observing that these 4 tasks are performed by a different cognitive 'talent', it is with great probability that we can say that laparoscopy is performed with again a different talent, see figure 12. It is also possible that laparoscopic skills come from talent A, B or C. It would be interesting to research if these tasks are positively correlated to an actual laparoscopy task. Figure 12 also shows that under the different talents there cannot be 1 set of skills. If this were the case, the talents would be related and the correlations would be higher on the tasks. When one set of skills, such as for instance visuo-spatial ability, is indeed as important for the acquisition of surgical skills as stated in many studies, we would have found higher correlations on the tasks. If all talents would be derived from the same skillset, there would be either less different talents, or a strong correlation between them, which in its turn would result into higher correlations between the tasks.

This puts assumptions made in the research of Groenier et al. (2014) into question which state that visuo-spatial ability is essential in the early learning stage of MIS and that this ability or skill is related to the competency and the quality of complex motor procedures like MIS. In the review of Anastakis (2000), different conclusions of different studies are reviewed in regard to the relation of visuo-spatial ability and surgical skills. The end conclusion of this review is that there is no strong consensus about the link between visuo-spatial ability and surgical skills. This review confirms this conclusion and after considering the results of this study the following question can be asked: If visuo-spatial ability was related to surgical skills, how can we have found such low correlations between the different tasks? An explanation could be that the effect of visuo-spatial ability is much lower than thought, or that the 4 tasks in this study are simply not as related to MIS as presumed.

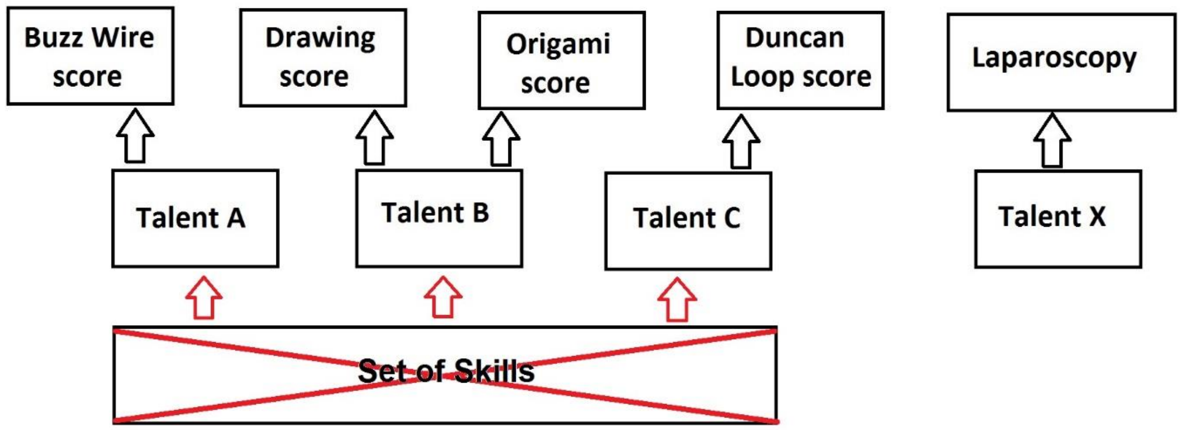

Fig. 12 Representation of the Correlations and the different Talents involved

So where do we stand now? We have established that, if the correlation between drawing and origami is indeed $\geq$ 0.8 for the maximum performance, these 2 tasks can be used to predict the maximum performance of the other task as can be seen in figure 13. So in this case it is indeed possible to make predictions based on another task. However when keeping the confidence interval in mind, the correlation might also be $\geq$ 0.5 as visualized in the second graph of figure 13. This would mean that this is not possible and that one task cannot be predicted by another in whichever aspect of the learning curve. When looking at the difference between the correlation $\geq$ 0.8 and that of $\geq$ 0.5, we can see that in the second scenario the distribution would be a lot bigger and that it would be very hard to predict how someone would score on the task when looking at the performance of the other task. Implications would then be that viewing the learning of complex motor procedures holistically is not better than with separate cognitive abilities.

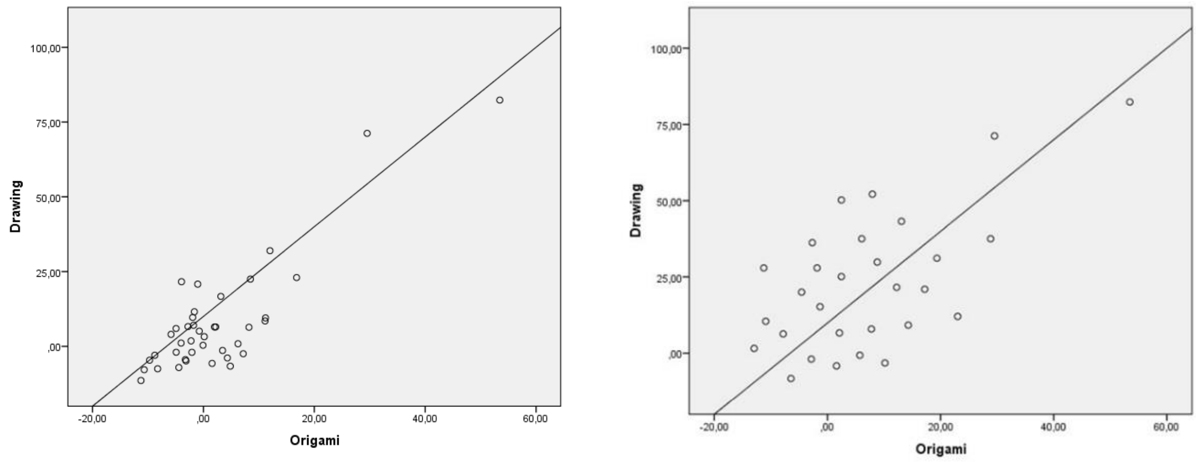

Fig. 13 Correlation between Drawing and Origami $\geq$ 0.8 (left) and proposed correlation $\geq$ 0.5 (right)

Still, how can the tasks Drawing and Origami have such a high correlation on the estimated maximum performance when disregarding the lower bound of the confidence interval? These two tasks are performed with the same talent but might also possibly be the only ones using the same set of skills. Both tasks use mental rotation but one in 2D and the other in 3D. When considering these 2 tasks in relation to Minimally Invasive Surgery, the conversion from 2D images to 3D action is indeed the main difficulty in MIS (Gallagher, Cowie et al. 2003; Hamad & Curet. 2010). This makes this specific finding extra interesting. That what is so difficult to learn is that which correlates highest in the performance. So what can be said about this excellent correlation between these 2 tasks? The correlation was only found in the asymptote which means that the underlying talent, perhaps mental rotation, only accounts for the maximum performance. It seems obvious that if someone is good at mental rotation and converting 2D images to 3D this person would have a disposition for performing MIS. However, now it has become clear that if someone is good at 2D tasks, this person is also good at 3D tasks. Further research could focus on the conversion from 2D to 3D and the other way around. This might shed more light on the underlying talent and set of skills. Further research may also explore this finding deeper and perform a thorough cognitive task analysis to uncover from which set of skills the high correlation is derived (Clark et al. 2008). This could then be linked to MIS and possibly a new prediction method for proficiency in MIS could be developed.

This scenario is very idyllic but possible. The problem yet remains that besides the high correlation between drawing and origami no further strong correlation was found between the other tasks in the learning rate, previous training or estimated maximum performance. This is a big problem, because being able to make these kinds of predictions of the learning rate or the maximum performance level would have a huge impact on the medical world. One of both would already have a big impact. Imagine being able to predict if a student is even capable of reaching a certain level of performance in laparoscopic tasks? Saving their time and money and that of the training facility, declining the weaker who have no potential. This might seem crude and somewhat presumptuous for the people who want to learn these surgical skills, but looking at the greater picture it would save a lot of time, effort and money. The fact is that currently a lot of money is being spent on training (future) surgeons which may not even be able to reach proficiency in the procedure. Besides this large amount of money spent on their training program, the most important reason is definitely the lives which are at stake. In the past decade in the Netherlands alone, a country which is really far in their healthcare system, the mortality rate for laparoscopy is 4.4%. Putting this into perspective, 4 to 5 of every 100 people die from this surgery. In 90% of the cases the technique of the surgeon was at fault (Bakker et al. 2016). The demand is increasing for this procedure due to its advantages, which makes it even more important that the performing surgeons are trained properly and that the selection procedure for surgeons becomes more adjusted to predicting if a person can even reach a certain proficiency level.

Besides investigating the previously mentioned talent which may have caused the excellent correlation between drawing and origami, a whole new approach might have to be embraced. One could look into making the MIS simulators cheaper and more accessible for selection procedures and trainees. Another potential research could be set up around investigating if the previous training can predict maximum performance or learning rate of a similar task. That would mean that we would not need the estimated maximum performance of one task to predict the estimated maximum performance of another task. Perhaps the previous training could predict the maximum performance of the same task or that of another similar task. The same could be done for predicting maximum performance by looking at the learning rate.

Concerning the low correlations found on the other 2 parameters, it could be the case that this study is flawed and that the limitations of the study account for the low correlations. The main limitation of this study is that, besides the 4 tasks, a laparoscopic task should have also been performed by the participants. This would have immediately shown if one or multiple, tasks share a same talent necessary for performing the task. However having the participants also partake in a laparoscopy simulator would, besides the fact that it is not the same as a real surgery, have cost a lot more and would have taken up more time. Performing these 4 tasks already took up about 2 hours per participant. So it would have been possible and it would have been ideal, but it would also have brought its own problems with it too.

Another limitation regarding the tasks is the way the mistakes were included in the scores. Participants would for instance have more mistakes in the Buzz Wire task, but might have been faster while others had no mistakes and were slower. This was not taken into account during the analysis. The same goes for all 4 tasks. Another limitation was the difference in the researchers. 4 Different people conducted the study and had not practiced together. Agreements were made about when to start the time and how to score mistakes. The interrater reliability however was not tested. Besides this, Origami, Drawing and the Duncan Loop all use mental rotation whereas Buzz Wire's only 3D aspect could be found in the motor dexterity part.

One part of the study which could be seen as a limitation, but is actually quite positive is the compilation of participants. A large part was made up of students or people in their 20's. This may seem like a negative aspect of the study, but the training of MIS is also only done by students, mostly in their 20's. However, when leaving out the MIS aspect of the research question and focussing only on finding a correlation between tasks, the compilation of the participants may seem narrow and biased.

In conclusion, predicting the talent and surgical skills is very complex but also very important. Current selection procedures are not successful in predicting if a certain trainee is worth all the time and money which is being spent on teaching skills. This study takes up a whole new perspective with actual tasks instead of testing the cognitive abilities apart from each other. Investigating the learning of complex motor procedures is not done best by viewing it holistically. However shared talents have been identified in the maximum performance between two tasks which shows us that it is possible to find a predicting task for a surgical task. The selection of trainees is one step closer to being more efficient than it is now a days.

References

Anastakis, D. J., Hamstra, S. J., & Matsumoto, E. D. (2000). Visual-spatial abilities in surgical training. *The American journal of surgery*, **179**(6), 469-471.

Bakker, I. S., Snijders, H. S., Grossmann, I., Karsten, T. M., Havenga, K., & Wiggers, T. (2016). High mortality rates after nonelective colon cancer resection: results of a national audit. *Colorectal Disease*, *18*(6), 612-621.

Chaudhry, A., Sutton, C., Wood, J., Stone, R., & McCloy, R. (1999). Learning rate for laparoscopic surgical skills on MIST VR, a virtual reality simulator: quality of human-computer interface. *Annals of the Royal College of Surgeons of England*, **81**(4), 281.

Clark, R. E., Feldon, D., van Merriënboer, J. J., Yates, K., & Early, S. (2008). Cognitive task analysis. *Handbook of research on educational communications and technology*, **3,** 577-593.

Delaney, P. F., Reder, L. M., Staszewski, J. J., & Ritter, F. E. (1998). The strategy-specific nature of improvement: The power law applies by strategy within task. *Psychological Science*, **9**(1), 1-7.

Ericsson, K. A. (2008). Deliberate practice and acquisition of expert performance: a general overview. *Academic emergency medicine: official journal of the Society for Academic Emergency Medicine***,** **15**(11), 988-994.

Gallagher, A., et al. (2003). "PicSOr: An objective test of perceptual skill that predicts laparoscopic technical skill in three initial studies of laparoscopopic performance." *Surgical Endoscopy And Other Interventional Techniques* **17**(9): 1468-1471.

Gallagher, A. G., McClure, N., McGuigan, J., Ritchie, K., & Sheehy, N. P. (1998). An ergonomic analysis of the fulcrum effect in the acquisition of endoscopic skills. *Endoscopy*, **30**(7), 617-620.

Gallagher, A. G., Richie, K., McClure, N., & McGuigan, J. (2001). Objective psychomotor skills assessment of experienced, junior, and novice laparoscopists with virtual reality. *World journal of surgery*, **25**(11), 1478-1483.

George, D., & Mallery, P. (2003). SPSS for Windows step by step: A simple guide and reference. 11.0 update . wps. ablongman. com/wps/media/objects/385. *George 4answers. pdf*.

Goldberg, A. E., et al. (2008). "Correlation of Manual Dexterity With USMLE Scores and Medical Student Class Rank." *Journal of Surgical Research* **147**(2): 212-215.

Green, C. S., & Bavelier, D. (2006). The cognitive neuroscience of video games. *Digital media: Transformations in human communication*, 211-223.

Groenier, M., et al. (2014). "The role of cognitive abilities in laparoscopic simulator training." *Advances in health sciences education* **19**(2): 203-217.

Hamad, G. G. and M. Curet (2010). "Minimally invasive surgery." *The American Journal of Surgery* **199**(2): 263-265.

Heathcote, A., Brown, S., & Mewhort, D. J. K. (2000). The power law repealed: The case for an exponential law of practice. *Psychonomic bulletin & review*, **7**(2), 185-207.

Kramp, K. H., Det, M. J., Hoff, C., Veeger, N. J., Cate Hoedemaker, H. O., & Pierie, J. P. E. (2016). The predictive value of aptitude assessment in laparoscopic surgery: a meta-analysis. *Medical Education,* **50**(4), 409-427.

Langlois, J., Bellemare, C., Toulouse, J., & Wells, G. A. (2015). Spatial abilities and technical skills performance in health care: a systematic review. *Medical education,* **49**(11), 1065-1085.

Louridas, M., Szasz, P., Sandra de Montbrun, M. D., Harris, K. A., & Grantcharov, T. P. (2015). Can We Predict Technical Aptitude?.

Louridas, M., Quinn, L. E., & Grantcharov, T. P. (2015). Predictive value of background experiences and visual spatial ability testing on laparoscopic baseline performance among residents entering postgraduate surgical training. *Surgical endoscopy*, 1-8.

Moore, M. J. and C. L. Bennett (1995). "The learning curve for laparoscopic cholecystectomy. The Southern Surgeons Club." *American journal of surgery* **170**(1): 55-59.

Maan, Z. N., Maan, I. N., Darzi, A. W., & Aggarwal, R. (2012). Systematic review of predictors of surgical performance. *British Journal of Surgery*, **99**(12), 1610-1621.

Rahm, S., Wieser, K., Wicki, I., Holenstein, L., Fucentese, S. F., & Gerber, C. (2016). Performance of medical students on a virtual reality simulator for knee arthroscopy: an analysis of learning curves and predictors of performance. *BMC surgery,* **16**(1), 1.

Richler, J. J., et al. (2008). "Holistic processing of faces: perceptual and decisional components." *Journal of Experimental Psychology: Learning, Memory, and Cognition* **34**(2): 328.

Ritter, F. E., & Schooler, L. J. (2001). The learning curve. *International encyclopedia of the social and behavioral sciences,* **13,** 8602-8605.

Rosenberg, B. H., Landsittel, D., & Averch, T. D. (2005). Can video games be used to predict or improve laparoscopic skills?. *Journal of Endourology*, **19**(3), 372-376.

Rosser, J. C., Lynch, P. J., Cuddihy, L., Gentile, D. A., Klonsky, J., & Merrell, R. (2007). The impact of video games on training surgeons in the 21st century.*Archives of surgery*, **142**(2), 181-186.

Schlickum, M., et al. (2011). "Surgical simulation tasks challenge visual working memory and visual-spatial ability differently." *World journal of surgery* **35**(4): 710-715.

Schwarzer, G., KÜfer, I., & Wilkening, F. (1999). Learning categories by touch: On the development of holistic and analytic processing. *Memory & cognition*, *27*(5), 868-877.

Tang, C. G., Hilsinger, R. L., Cruz, R. M., Schloegel, L. J., Byl, F. M., & Rasgon, B. M. (2014). Manual dexterity aptitude testing: a soap carving study. *JAMA Otolaryngology–Head & Neck Surgery*, **140**(3), 243-249.

Rosser, J. C., Lynch, P. J., Haskamp, L. A., Yalif, A., Gentile, D. A., & Giammaria, L. (2004, January). Are video game players better at laparoscopic surgical tasks. In Newport Beach, C*A: Medicine Meets Virtual Reality Conference.*

Veenman, M. V., Wilhelm, P., & Beishuizen, J. J. (2004). The relation between intellectual and metacognitive skills from a developmental perspective. *Learning and instruction*, **14**(1), 89-109.

Walther, T., Falk, V., Metz, S., Diegeler, A., Battellini, R., Autschbach, R., & Mohr, F. W. (1999). Pain and quality of life after minimally invasive versus conventional cardiac surgery. *The Annals of thoracic surgery*, **67**(6), 1643-1647.

Appendix

1. Instructions and Coding of Strategy and Behaviour Differences

GENERAL QUESTIONS:

General Question (at the begin of the stuy):

Age:

Gender:

Nationality:

Study/Profession:

Ben je links- of rechtshandig of wisselt dit? (denk aan: schrijven, knippen, snijden, gooien)
Are you left- or righthanded or does that change? (think about: writing, using sciccors, cutting, throwing)
Bist du Links- oder Rechtshänder oder wechselt? (denke an: schreiben, schneiden, werfen)

Hoe vind jij het om met je handen te werken? (denk aan knutselen/ reperaties)
How do you feel about working with your hands? (think about crafts/repairs)
Wie findest du es mit den handwerklich zu arbeiten/ handarbeiten? (basteln/ etwas reparieren)

Beleef je frustratie momenten als jij met je handen werk?
Do you get easily frustrated while working with your hands?
Bist du schnell frustriert wenn du Handarbeiten machst?

Experience Question (directly after task):

Heb je ervaring met (afgelopen taak)? Geef eventueel voorbeelden
Do you have previous experience with (this task)? If needed, give examples
Hast du schon vorher Erfahrungen gesammelt die mit dieser Aufgabe zusammenhängen?

Questions at end of the test (pay attention to the order of the tasks the participant got during the study):

Welke taken vond je leuk? Welke taken vond je moeilijk?
Which task did you like? Which tasks were hard?
Welche Aufgabe hast du als schwierigste empfunden?

Ask about the performance (this question should be answered after every task).

How would you estimate your performance at the beginning? (on a scale from 1-7, 7 is good performance, 1 is bad performance)

Final performance

ORIGAMI (instructor)

Needed:

- 25 origami papers (special papers for our research) / 5 extra if somethings go wrong
- Pieces of tape
- Printed instruction
- Printed picture instruction of fox figure
- stopwatch

Order of events:

Introduction to task:

- Tape the picture instruction to the table in front of the participant so that the participant is not able to turn the paper
- Give a short introduction to the tasks and what needs to be accomplished
- Hand the material out to the participant
- Explain the procedure/ let the participant read the instruction
- Ask for any ambiguities or problems about the procedure
- Answer question

During task:

- Ask the participant if he is ready to start
- Then start the time
- Fill in the form during the task (see instructions for origami form)
- If the participant notifies you that he/she is finished stop the time and note it down in the form
- Start again
- Let the participant know after 10 trials the half is finished
- Let the participant know when the last 3 trials start
- Repeat this till the participant reached 20 trials

After tasks:

- Ask the participant if he had any previous experience with origami -> note the answer down in the form
- Give the participant a short break of 5 minutes till the next tasks is started

Origami form:

Performance:

- Does the fox look alike the original V/X

Strategy:

- Participant follows every step of the instructions/ participant does not look at instructions any longer
- Changes steps/ leaves steps out

Motivation:

- Motivated: M
- Frustrated: F
- Not clear: O

Comments from researcher:

- Were any questions answered
- Received the participant extra help/support

Others:

- Was there anything extra that was notified that does not fit in the other categories

Instructions for Participant

ORIGAMI

Take a piece of paper and follow the steps of the instructions below to build the fox. Try to make the fox look like the fox in the instruction, however you must do this as fast as possible. When you are ready the clock will start. And when you finish, announce this to the researcher so the time can be stopped. You are going to make 20 foxes. If you have any questions you can direct these to the examiner.

MIRROR DRAWING (instructor)

Needed:

- Mirror
- Box
- Pen
- Stopwatch
- Printed instruction
- Printed shape

Order of events:

Introduction to task:

- Tape the picture instruction to the table in front of the participant so that the participant is not able to turn the paper
- Put the mirror in position
- Give a short introduction to the tasks and what needs to be accomplished
- Hand the material out to the participant
- Explain the procedure/ let the participant read the instruction
- Ask for any ambiguities or problems about the procedure
- Answer questions

During task:

- Ask the participant if he is ready to start
- Then start the time
- Fill in the form during the task (see instructions for mirror drawing form)
- If the participant notifies you that he/she is finished stop the time and note it down in the form
- Start again
- Let the participant know after 10 trials the half is finished
- Let the participant know when the last 3 trials start
- Repeat this till the participant has reached 20 trials

After tasks:

- Ask the participant if he had any previous experience with drawing through a mirror -> note the answer down in the form
- Give the participant a short break of 5 minutes till the next tasks starts

Mirror Drawing form:

Performance:

- Did the participant draw between the lines? V/X

Strategy:

- Participant follows every step of the instructions
- Changes steps/ leaves steps out
- Participant starts at a different point.

Motivation:

- Motivated: M
- Frustrated: F
- Not clear: O

Comments from researcher:

- Were any questions answered
- Did the participant receive extra help/support

Others:

- Was there anything extra that was notified that does not fit in the other categories

Instructions for Participant

MIRROR DRAWING

In this experiment you will be tracing a shape, but instead of looking at your hands, you are going to look in a mirror. Try to stay in between the lines and to finish as fast as possible. You must start at the same point every time. If you have any questions you can direct these to the examiner.

DUNCAN LOOP (instructor)

Needed:

- Rope
- Stopwatch
- Printed instruction

Order of events:

Introduction to task:

- Tape the picture instruction to the table in front of the participant so that the participant is not able to turn the paper
- Attach the rope to something
- Give a short introduction to the tasks and what needs to be accomplished
- Hand the material out to the participant
- Explain the procedure/ let the participant read the instruction
- Ask for any ambiguities or problems about the procedure
- Answer questions

During task:

- Ask the participant if he is ready to start
- Then start the time
- Fill in the form during the task (see instructions for mirror drawing form)
- If the participant notifies you that he/she is finished stop the time and note it down in the form
- Start again
- Let the participant know after 10 trials the half is finished
- Let the participant know when the last 3 trials start
- Repeat this till the participant has reached 20 trials

After tasks:

- Ask the participant if he had any previous experience with knotting (scouting/sailing etc.) -> note the answer down in the form
- Give the participant a short break of 5 minutes till the next tasks starts

Duncan loop form:

Performance:

- Is the knot correct? V/X

Strategy:

- Participant follows every step of the instructions
- Changes steps/ leaves steps out
- Participant starts at a different point.
- Holds the rope in a different way

Motivation:

- Motivated: M
- Frustrated: F
- Not clear: O

Comments from researcher:

- Were any questions answered
- Did the participant receive extra help/support

Others:

- Was there anything extra that was notified that does not fit in the other categories

Instructions for Participant

DUNCAN LOOP

Take the rope and try to replicate the knot shown on the paper. Make sure you follow the instruction and do this as fast as possible. When you are ready the clock will start. And when you finish, announce this to the researcher so the time can be stopped. You are going to make this knot 10 times. If you have any questions you can direct these to the examiner.

BUZZ WIRE (instructor)

Needed:

- Buzz Wire
- Stopwatch
- Pen

Order of events

- Determine position of the Buzz wire
- Give a short introduction, make clear that time on task and performance are measured
- Ask for problems and answer questions

During task

- Ask the participant if he/she is ready
- If he/she agrees, the researcher answers ‘start’
- Researcher fill the form during the task (note change in strategies), monitor behaviour
- If the participant says “stop”, researcher writes down time needed to accomplish the task
- Let participant repeat the task
- Inform participant after 10 trials are completed
- Let the participant know when only 3 trials are left
- In total 20 trials needed to be completed by the participant

After tasks are completed

- Do you have previous experience with the Buzz Wire task? (when was the last time you performed this task)

Buzz Wire Form

Performance:

- Count errors

Strategy:

- Changes in holding position
- Changes in holding the wire
- Changes in mental techniques? (closing eyes before experiment?)

Motivation:

- Motivated: M
- Frustrated: F
- Not clear: O

Comments from researcher:

- Were any questions answered
- Did the participant receive extra help/support

Others:

- Was there anything extra that was notified that does not fit in the other categories

Instructions for Participant

BUZZ WIRE

In this experiment you will completing a buzz wire task (bibber spiraal/heisser Draht). Take the staff and try to follow the wire as fast as possible. Time on task and errors will be measured.

2. Syntax of the Analysis

```
DESCRIPTIVES VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /STATISTICS=MEAN STDDEV MIN MAX.

EXAMINE VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /COMPARE VARIABLE
  /PLOT=BOXPLOT
  /STATISTICS=NONE
  /NOTOTAL
  /MISSING=LISTWISE.

DATASET ACTIVATE DataSet3.
DESCRIPTIVES VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /STATISTICS=MEAN STDDEV MIN MAX.

EXAMINE VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /COMPARE VARIABLE
  /PLOT=BOXPLOT
  /STATISTICS=NONE
  /NOTOTAL
  /MISSING=LISTWISE.

DATASET ACTIVATE DataSet4.
DESCRIPTIVES VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /STATISTICS=MEAN STDDEV MIN MAX.

EXAMINE VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /COMPARE VARIABLE
  /PLOT=BOXPLOT
  /STATISTICS=NONE
  /NOTOTAL
```

```
  /MISSING=LISTWISE.

DATASET ACTIVATE DataSet1.
BOOTSTRAP
  /SAMPLING METHOD=SIMPLE
  /VARIABLES INPUT=Buzz_Wire Drawing Duncan_Loop Origami
  /CRITERIA CILEVEL=95 CITYPE=PERCENTILE  NSAMPLES=1000
  /MISSING USERMISSING=EXCLUDE.
CORRELATIONS
  /VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.

DATASET ACTIVATE DataSet3.
BOOTSTRAP
  /SAMPLING METHOD=SIMPLE
  /VARIABLES INPUT=Buzz_Wire Drawing Duncan_Loop Origami
  /CRITERIA CILEVEL=95 CITYPE=PERCENTILE  NSAMPLES=1000
  /MISSING USERMISSING=EXCLUDE.
CORRELATIONS
  /VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE.

DATASET ACTIVATE DataSet4.
BOOTSTRAP
  /SAMPLING METHOD=SIMPLE
  /VARIABLES INPUT=Buzz_Wire Drawing Duncan_Loop Origami
  /CRITERIA CILEVEL=95 CITYPE=PERCENTILE  NSAMPLES=1000
  /MISSING USERMISSING=EXCLUDE.
CORRELATIONS
```

```
/VARIABLES=Buzz_Wire Drawing Duncan_Loop Origami
/PRINT=TWOTAIL NOSIG
/MISSING=PAIRWISE.
```