How can we improve the Training of Laparoscopic Surgery thanks to the Knowledge in Robotics?

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ABSTRACT

Laparoscopic surgery becomes a standard for many surgical procedures due to its advantages over open surgery in terms of cosmetic results or patient recovery time. Unfortunately, for the surgeon and the student in medical school this surgery is imparted with many difficulties. These difficulties stem from a lack of depth perception, a poor hand-eye coordination, an alteration of haptic feedback, a reduction of the movement to four degree of freedom, a fulcrum effect and musculoskeletal pains.

Moreover, the training sessions are generally not optimal, mainly because too much information must be processed by the student at the same time. It is painful, difficult and frustrating for the student who sometimes ends up by choosing another specialty. The learning curve is too long and can be improved by more efficient training session during the first year of residency.

We expose in this article a global approach for improving laparoscopic surgery training. We proposed to enhance the set-up with the use of multi-sensory feedback, to improve the task by decomposing the difficulties, and also to take into account certain individual psychomotor skills.

Keywords: Laparoscopic surgery, training, multi-sensory-feedback, decomposition of difficulties, psychomotor skills

1. INTRODUCTION

Laparoscopic Surgery is a minimally invasive surgery (MIS) of the abdominal region. The surgeon is operating inside the body through small incisions where trocars are inserted and through which elongated instruments can be introduced. The surgery shows many advantages for the patient over open surgery in terms of cosmetic results and recovery time [1]. Unfortunately, this type of surgery comes with mechanical, ergonomic and vision problems ([2][3]). These problems impact the surgeons but also the students in medical school which have to face long, difficult and painful training. Thus, there are drop off and students often choose another specialty. There is a clear need to improve the training in laparoscopic surgery to have a less painful, faster and more efficient learning.

As for any kind of learning (music, sport or surgery) the learning of laparoscopy is divided into three main phases ([4][5]). At the beginning of the learning, students go through the *cognitive phase*. This is an observation phase during which students are following lectures or assisting surgical procedures. They study the tasks and processes in a global manner and teachers give them general explanations on how to do the task and overcome the difficulties. During this cognitive phase experts may rely on a specific cognitive task analysis (CTA) [6] made by experts who agreed on the steps and skills needed to realize a task efficiently. It has been shown that CTA can improve student training by breaking down complex task into tasks that are easier to understand and perform. It allows in-depth comprehension of the essential elements of the task.

At the end of the training and before becoming experts, students go through the so called *automatic phase*. They know all the basic gestures and they can realize whole tasks and also develop personal strategies to manage various situations they may encounter. They no longer think of the gestures but more on how they can improve them in term of comfort and accuracy. They can also teach to the students who enter the training.

Between the automatic and the cognitive phases, students have to pass by the integrative phase also called deliberate practice. After knowing all the theory and before realizing complex tasks, students repeat simple gestures or simple exercises until they perform smooth and accurate movement. They can practice the simple movements described in the CTA, the score given by the teacher is then easier to determine. This is the most important phase and it is sometimes neglected because of a lack of time from both the experts and the students.

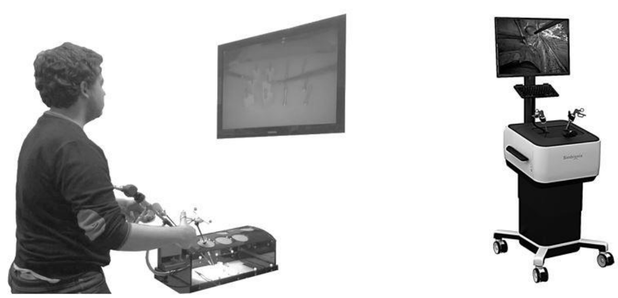

Figure 1: Training on Pelvi-Trainer or Virtual Reality Simulator

In the case of laparoscopic surgery, the integrative phase takes place outside of the operating room (OR). Indeed, practicing inside the OR is not safe for the patient because of the stressful conditions. Consequently, students must train on simulators. There are the passive ones, called pelvi-trainer [7], where the student is generally practicing the *fundamental of laparoscopic surgery* (FLS) program that regroups the required skills for the surgery [8]. In this case, students are using real laparoscopic instruments and real trocars so they can have real haptic feedbacks. The problem is that the student does not have any instantaneous score or information about his/her performance and so he/she cannot correct himself/herself in-line and take full advantage of the sessions. There are also the virtual reality simulators [9] on which the student is doing some concrete exercises as clamping a blood vessel or removing kidney stones. Blood loss, tissue damage, number of movements on each hands and total time are recorded and the student has a score at the end of each exercise which is kept in memory to see the student's improvements throughout his training. However, the virtual reality simulator is expensive and the student does not have any haptic feedbacks which make the exercise even more difficult and not fully realistic. Some studies compare the use of both simulators. In [10] it is shown that the learning with both simulators were equivalents. In [11] they found that combining 2/3 pelvi-trainer and 1/3 virtual reality simulator training gave the best results.

Whatever the type of simulator, there are problems due to the training itself. During a training session, students are tense and they adopt awkward positions especially in the upper part of the body which causes pain in back, neck and shoulders. Moreover, the cognitive load is very high and it happens that there is a bad treatment of the information and of the advices given by the teacher. For example, a student practicing a suture knot on a pelvi-trainer is required to have a good spatial representation and a mastery of the force exerted on the suture thread. At the same time he is dealing with the lack of depth perception, the reduction of the movement to four degree of freedom and the use of the instruments.

Besides, there is not enough training sessions [12]. To reach the learning plateau of a gesture. It has been shown that the student should repeat it between thirty and thirty five times through two weeks of training [13]. Some intensive training programs of two or three days on pelvi-trainer have been created [14] but it is not enough to master the gestures. Consequently, an important part of the technics acquisition takes place in the OR, in a stressful environment. In [12], it is reported that 65% of the students believe that they should have more training sessions outside of the OR. In conclusion, the current training in laparoscopic surgery during the integrative phase is not sufficient and not effective enough for different reasons:

- Students miss time to train outside the OR;
- There is no real active guidance from the teacher who can give only verbal advices;
- Students cannot apply expert's strategies due to the many problems and information that they have to deal with simultaneously;
- The set-up and the practicing conditions cause musculoskeletal pain to the students.

In this paper, after presenting a state-of-the-art, we explain our robotic-based approach to solve the above mentioned problems in the learning of laparoscopy and then some preliminary results.

2. STATE OF THE ART

Robotics in Learning

Robotics has been used in different learning as music, rehabilitation, sport and writing to guide a subject's gesture along a right path or correct his/her movement.

In rehabilitation, exoskeleton or manipulanda are used to relearn gestures [20]. The advantage of a robot over a therapist is that the robot can do the same gesture at the same speed an unlimited number of times. Different modes are implemented going from total guidance to no guidance at all from the robot, depending on the patient's need. The robot can also bring disturbing forces to enforce the patient to enter an adaptation process. He/she has to bring back the end-effector in the right trajectory and the movement is learned better [21].

In writing, a study used a PHANToM (SensAble Technologies) to teach how to write Japanese and Arabic letters [22]. First, they record expert trajectories, then the trajectories are played back by the PHANToM. There were two type of haptic guidance: 'spatial position', the robot only generates the trajectory and the subject is feeling it, and 'force generated', the robot was playing the trajectory but applied also disturbance forces. There was also a visual group that was just observing the movement. The visual group gave the worst results. The two types of haptic guidance reduced the number of pic velocity but the guidance in force showed also an improvement in the movement smoothness.

Robotics in the operating room

Today, robotics is more and more used in the OR. It intends there to help the surgeon in his gesture or in his vision. The Da Vinci system by Intuitive surgical improves the ergonomic of the procedure thanks to a comfortable sit for the surgeon, a 3D vision and 7 degree of freedom movements at the wrist of the instrument [15]. Nevertheless, a procedure with a Da Vinci system is more expensive than a classic laparoscopic surgery and it is only used for specific procedures.

Co-manipulation may also be used in laparoscopic procedures. In this case, a robotic arm holds the same laparoscopic instrument than the surgeon [16]. The surgeon is doing the procedure himself but the robotic arm brings him/her assistance when needed. For instance in [16], during a laparoscopic hepatectomy the surgeon must draw a plane bisecting the liver and cut the organ along this plane while ensuring the best accuracy and planarity of the cut. The plane is defined before the surgery and in case of deviation regarding this plane the robotic arm can bring back the tip of the instrument into it.

To improve the vision or the treatment of the information the use of multi-sensory feedback has also been studied. It can rely on the use of augmented reality on the image to show hidden information (e.g. organs, vessels…) [17], it can also rely on the use of vibration to indicate a deviation regarding a targeted plane [16] or the force exerted at the tip of the instrument [18]. The use of visual or tactile feedback improves the performance in general and tactile feedback allows a better precision [16]. Moreover, the use of vibration lightens the vision already saturated by multiple information [19].

Applying these robotic technics to the training sessions of laparoscopic surgery would in real-time allow to correct the student's gesture or inform him/her on his/her mistakes. The teacher will only have to give advices on how to do the task more easily or correct the student's posture.

Robotics in laparoscopic surgery training

Indeed, some robotics solutions have already been studied to improve the training of laparoscopic surgery.

For example in [23], they tested the haptic guidance. A robotic arm guides the student along a trajectory displayed on a graphic interface. The robot is totally active at the beginning and the student is feeling kinesthetically the movement. Then, the student reproduces the movement by himself. It is shown that the haptic guidance was efficient in time but for shape and position the vision predominates.

Augmented reality has also been used to add visual information on the endoscopic image to better understand the training scene or to indicate mistakes that the subject is making.

In [24], two training benches are used: one for the student and one for the teacher. Both were doing a suture task however the needle and the tip of the instruments of the teacher where also displayed on the screen of the student. The platform decreased the learning curve especially at the beginning of the training. In [25], students have to do a suture knot. They designed a dome where the tips of the instruments have to stay and arrows that indicate in which sense the student has to pull the suture thread. The visual information has been implemented to reflect the average performance of expert surgeons. The group with the augmented reality shows the best result. The problem with the use of augmented reality is that the vision is already saturated. Target, tips of instruments and shadows are already on the image and adding another visual information could lead to a bad treatment of the information or also disturb the gesture.

In [26], gesture analysis is also proposed as a solution to score the students during their learning of laparoscopy. The idea is to record an expert trajectory and to divide this trajectory into small gestures called surgemes. Then the student is doing the same task and they compared the surgemes of the expert and of the student. Differences between the surgemes, meaning that the student is doing something wrong, can be recorded and displayed at the end in form of a score. During the task, a robotic help or a feedback information could be added to correct the student. Nevertheless, it is difficult to define what a good trajectory is because experts have their own particular strategies.

3. OUR APPROACH

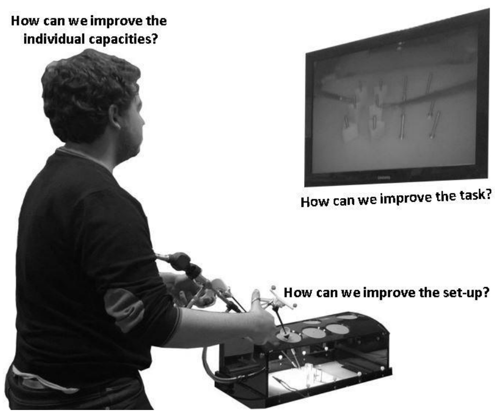

Figure 2: Laparoscopic Surgery Training Scene

A laparoscopic surgery exercise (figure 2) combines three elements: a set-up, a task and a subject, each having an important influence on the efficiency of the training. How can we improve the set-up to have an easier and less painful training? How can we design the task to make it more understandable to the student? How can we adapt the training to a particular subject? These are the three questions we try to answer in this article.

How can we improve the task?

During a practical session, the student is training on a pelvi-trainer to accomplish a task (e.g. suture knot). He has to deal with all the problems brought by the laparoscopy: 2D image, difficult hand-eye coordination, reduction of the movement to four degree of freedom, fulcrum effect and the alteration of haptic feedback [27].

An idea is to decompose the difficulties along a given session. The principle would be to ask the student to first practice a task from the FLS program in open surgery conditions (i.e.: working in an open space with a 3D and direct vision, with 15cm instruments and 6 degree of freedom movements). Then, we will add one problem at a time: the use of long instruments, the reduction of the movement to 4 degree of freedom, the 2D image and/or the loss of the coordination between hands and eyes. The student is always doing the same task, only the difficulty change each time. Compared to open surgery, the students will be alternatively confronted to:

- 40cm instruments which alter haptic feedback, change the proprioception;
- A reduction of the movement to 4 degree of freedom which prevent the translations in the horizontal plan which lead to awkward arm positions and subsequent pain in the body upper part;
- A 2D vision of the scene which causes a lack of depth perception and a loss of coordination between hands and eyes.

On the one hand, the student can work each problem individually in parallel before putting them together at the end of the training. The idea is that the student masters each difficulty independently from each other. On the other hand, we can add a difficulty on top of another to progressively, and with a lower cognitive load, master the connections between the difficulties until mastering the complete task.

Another advantage of decomposing the difficulties is to target critical areas for a specific student to improve his performance [28]. It will be also easier for the teacher to observe the student's performance which will lead to better advices.

How can we improve the set-up?

As mentioned before, a laparoscopic surgery training session is difficult and painful. The risk for the student is that he/she learns wrong gestures and bad postures. The teacher can correct the student and teach him the right way to do it but cannot evaluate the performance quantitatively and automatically. By providing instantaneous information feedbacks, we could lighten the cognitive load of the student and also the one of the teacher who could focus on the student's posture and how he/she is using his instruments.

In [16], the authors make use of visual and tactile feedbacks to guide the gesture of the subject. The tip of the instruments must go to three different points by staying in the plane defined by these points. In case of deviation from the plane, the amplitude of a bar-graph displayed on the endoscopic image is increasing or a vibror on the index finger is vibrating, both according to the amplitude of deviation. The study showed that the use of one or the other of these sensory feedbacks improved the performance in term of time and precision.

This result, among others, incited us to study the use of multi-sensory feedbacks during a training program. We have chosen to work on a cutting task from the FLS program. The goal is to cut a three centimeters radius circle on a compress in a maximum of two minutes and with a maximal deviation of 2mm from the circle line. We chose the cutting task because it is slightly less difficult than a suture knot but also sufficiently uneasy to highlight the differences between the groups. Indeed, students have to manage only the coordination between their hands whereas in a suture task students also have to manage the force at the tip of the instrument not to break the thread. Consequently, only one information is needed to the students: the deviation of the tip of the instrument regarding the circle. A visual or a tactile feedback is added to the set-up to indicate this deviation.

As a visual feedback, we chose contrary to [16] to represent the tool-tip deviation as a moving dot following the tip of the instrument (figure 3). It is green when the tip is on the circle, red when it is inside the circle and yellow when it is outside the circle. The radius of the dot is changing regarding the amplitude of deviation. We preferred this approach not to force the subject to deviate his sight from the tool tip. Moreover, student needs to know the amplitude of deviation but also where the deviation takes place.

In order to explore the potential benefit of an additional sensory feedback which doesn't increase the student's vision solicitation, we also tested, as in [16], a tactile deviation feedback. We want to see if it is still true in the case of a deviation in multiple direction. As in [16] the amplitude of deviation is indicated by the vibration amplitude of the vibrors. Then, to indicate if the deviation is inside or outside the circle we choose to use two eccentric rotating mass motor (Precision microdrivesTMPico Vibe 307-100) strapped to the inner side of the thumb and little finger of the hand holding the scissors. The one on the thumb vibrates in case of an external deviation and the one on the little finger vibrates in case of an internal deviation.

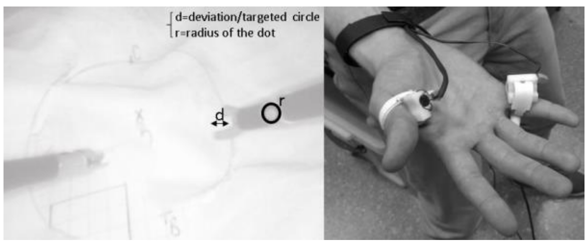

Figure 3: visual feedback (r proportional to d) and tactile feedback (2 vibrors)

How can we improve the individual capacities?

Every students do not start with the same level of dexterity and mental capacity. Moreover, some skills have been shown to be strongly correlated to laparoscopic performance as spatial representation and mental rotation [29], ambidexterity [30], finger tapping [31] and motivation [32]. This kind of correlation suggests to develop individualized training sessions during which a student practices exercises according to his own weaknesses. In our study, we want to focus on three specific psychomotor skills and evaluate their impact on the ability of a student to overcome the physical and cognitive complexity of a laparoscopic training: proprioception, dual-task management and self-efficacy.

To prove the correlation between these three skills and laparoscopic training, we will evaluate them on a group of residents of the University of Paris 6's medical school at the beginning of the laparoscopic training and re-evaluate after a semester of training. Thus, we will be able to see if there is a correlation with the performance but also with the training.

Dual-Task: In [33], it is shown that, among experienced surgeons, a correlation exists between the capacity to work on a dual-task and the performance in laparoscopic surgery. In this study, the primary task is to perform a laparoscopic exercise and the second task is to observe a screen on which squares appear randomly. When there are three vertically aligned squares on the right side of the screen, the subject clicks on a pedal with his right foot.

In our study, we want to determine if, at a novice level, a difference in dual-task capacity between subjects leads to a difference in laparoscopic surgery learning. Indeed, during a laparoscopic training session, the student is facing a multi-task problem stemming from: the two-hand coordination issue, the global task supervision requirements and the necessity to listen to the teacher. Concerning the last point indeed, it happens that some students are able to hear what the teacher says, understand his advices and then try to apply them, others do not even hear that the teacher is speaking.

To evaluate this peculiar psychomotor skill we will use the same second-task interface than in [33]. We will evaluate the laparoscopic performance on a peg transfer task. The exercise lasts 5 minutes and the final score will be the average between the peg transfer performance and the interface score.

Proprioception: Proprioception is the ability to sense one's body movements and positions based on internal stimuli. The role of proprioception in arm-eye coordination has been highlighted in [34] for example. Some studies also compared the gaze of expert surgeons and novices during a laparoscopic task [35]. They found that experts have a target-looking strategy whereas novices have a switching strategy. Indeed, during the task experts are focusing on the target and don't look at the tip position of their instruments nor at their hands whereas novices are always switching between the target and the tip of their instrument. A hypothesis is that during the training and then with professional experience surgeons significantly develop their proprioception and then tend to largely rely on it.

Our objective here is to establish to which extend the proprioception capacity is also a determinant factor among students facing a laparoscopic training session and then to design specific exercises to be implemented during the training for improving the individuals proprioception when needed.

In the field of upper-limb rehabilitation, one often relies on pointing task exercises to measure the proprioception capacity of the patients [36]. We propose here to implement the same kind of evaluation assuming that arm motion control is of primary importance for performing laparoscopy. Student will point different positions in front of them with the tip of a laparoscopic instrument alternatively with open eyes and with closed eyes. We measure the distance between the targeted point and the pointing point in closed-eyes condition.

Self-efficacy: Some studies have explored the relationship between self-efficacy and professional experience [37]. They found that experts have a higher self-efficacy than intermediate students and novices highlighting the fact that self-efficacy is increasing with professional experience.

Moreover, at a novice level, it is well known that the mental and technical difficulties imparted to the learning of laparoscopy often lead students to give up their training and even change their mind on this specialty.

Consequently, we want to evaluate the impact of self-efficacy on the performance improvement and learning curve in laparoscopy training. To do so students will answer a questionnaire on self-efficacy as the one developed in [38].

4. PRELIMINARY RESULTS ON THE IMPROVEMENT OF THE SET-UP

As explained above, we aim to use the multi-sensory feedbacks concept (visual and tactile) to improve the set-up and consequently the training.

We involved 12 novice subjects and divided them in 4 groups: a control group, a visual feedback group, a tactile feedback group and a group with the visual and tactile feedbacks. The students came every day during a week for a 20 minutes training session on a cutting task. At each session, the students started with a try without any feedback to define the baseline of the day, then continued with one or two tries with the feedback (visual or tactile or both) and finished by one try without feedback and serving for building the learning curve.

At each session, the subject responded to 2 questionnaires. One on how he/she feels during the day session (happy, tense, calm, anxious and upset). Another one on the performance with and without the feedback: did the feedback help or disturb the performance? Did it help to better understand the task? And if the last try was better than the first try of the day session. The response was given by a number between 1 (strongly disagree) and 5 (strongly agree).

Total time (t), number of movements of the scissor hand, amplitude of deviation (AD), incorrected resected area (IRS) and result of the questionnaires have been evaluated. AD (1) and IRS (2) were calculated as follows (Figure 3):

$$AD = (60 - 2\times\text{minimum radius}) + (2\times\text{maximum radius} - 60) \quad (1)$$

$$IRS = \text{Minimum Surface} + \text{Maximum Surface} \quad (2)$$

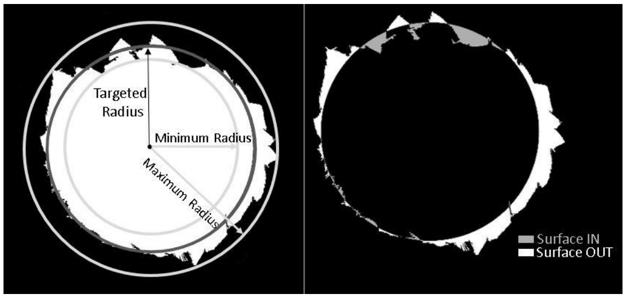

Figure 4: each compress has been post-processed to determine the minimum and maximum radius and the interior and exterior surfaces

A good subject should be fast and precise. That is why we defined a score that regroups the total time, AD and IRS (3). The average score of the first trials of all the subjects served as a reference value for normalizing all the other scores.

$$score = \frac{t\_norm + AD\_norm + IRS\_norm}{3} \quad (3)$$

There was an improvement in performance across all groups, each score decreases (figure 5). Nevertheless the differences between them were not statistically significant to see if the feedback helps during the training. Moreover, if we look at the score of the tries with feedbacks, the visual group is the less accurate. This was explained by the fact that the feedback disturbed the subject. Indeed, on average subjects answer 4 to the question "did the feedback disturb?" whereas the tactile group answered 1.8 on average.

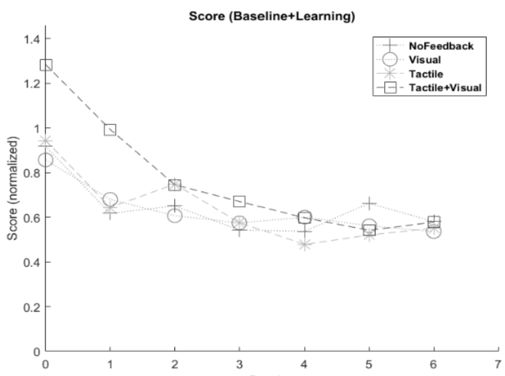

Figure 5: Score on the average of the baseline and learning tries

The results that we obtained are preliminary results. Improvements and learning plateau were observed but differences were not statistically significant to make any conclusion on the advantage or not of adding a sensory feedback to the set-up.

In the future, we want to take the same protocol but use it on an easier task, with more training sessions and a more adapted visual feedback. It may also be necessary to add a training session specifically devoted to the feedback itself. Indeed, from the cognitive point of view, it seems to be too demanding for the subject to have to understand how the feedback is working while having, at the same time, to learn a task with all the difficulties of the laparoscopic surgery.

5. CONCLUSION

Laparoscopic surgery becomes a standard for many surgical procedures but due to a painful and difficult training curriculum, students often choose another specialty. The training process seems not to be appropriate regarding all the difficulties that the student faces when practicing laparoscopic exercises: there is not enough training sessions, the student realizes a complex task under stress and the expert cannot give an objective score because there are too much information to evaluate. Consequently, there is a great need to improve the training protocols for laparoscopic surgery.

We choose a global approach to improve laparoscopic surgery training. We went to a medical school to observe how students train and what the problems are. There are three aspects that we can work on: the task, the set-up (pelvi-trainer, endoscopic image or instruments) and the individual.

The task is sometimes neglected by the student due to the many difficulties that he has to deal with. A solution would be to decompose the difficulties that is to work on one problem at a time and focus on the critical point for a given student. Advantages of such a discretization of the task may be a better performance achievement, a less painful training and easiness for the expert to correct the student.

The set-up in turn could be improved with the use of multi-sensory feedback. With a visual or a tactile feedback, the gesture can be guided along a trajectory. The student will correct in real time his gesture and understand it better. The preliminary results did not allow us to conclude on this question but a future work on an easier task and with a different visual feedback should be.

Lastly, the individual can also be taken into account through a personalized training. The idea is to evaluate psychomotor skills related to the performance in laparoscopic surgery and to adapt the training protocol according to each student's weaknesses. Interesting psychomotor skills are for example the proprioception, the self-efficacy and the dual-tack capacity. At the end of the training each students should have more or less the same performance.

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