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Original article

Virtual reality simulator improves the acquisition of basic arthroscopy skills in first-year orthopedic surgery residents

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ABSTRACT

Introduction: Arthroscopy training using a virtual reality (VR) simulator is said to improve the training of orthopedic surgery residents, although it has never been evaluated in a large representative population of first-year residents.
Hypothesis: We hypothesized that first-year residents who train on a VR simulator would improve their basic arthroscopy skills more than residents who use other training methods. The primary aim was to compare various arthroscopy-learning techniques after 6 months of training.
Population and methods: The study population consisted of 107 first-year residents who were tested twice on a VR arthroscopy simulator (December 2017 and June 2018). The residents were divided into three groups: no specific arthroscopy training (A), non-specific and one-off arthroscopy training (B), 6 months of VR arthroscopy simulator training (C). During the testing, they had to perform the Periscoping exercise (orientation of angled scope) and the Catch the Stars Glenohumeral exercise (extraction of loose bodies). The parameters analyzed were time (s), camera alignment relative to horizontal (%), camera path length (cm) and grasper path length (cm).
Results: After 6 months, there was a significant difference between groups during the Periscoping exercise in the time (A: 137.8 s; B: 126.7 s; C: 92.2 s) ($p < 0.0001$), camera alignment (A: 93%; B: 98%; C: 97%) ($p = 0.0028$), camera path length (A: 116.9 cm; B: 112.5 cm; C: 67.3 cm) ($p < 0.0001$) and during the Catch the Stars Glenohumeral exercise in the time (A: 112.2 s; B: 103 s; C: 61.4 s) ($p < 0.0001$), camera path length (A: 46.3 cm; B: 40.9 cm; C: 32.9 cm) ($p < 0.0153$) and grasper path length (A: 146.4 cm; B: 142.2 cm; C: 95.8 cm) ($p < 0.0001$).
Discussion: The residents who participated in the VR arthroscopy simulator training program for 6 months had better results when performing practical exercises and standard arthroscopy tasks than those who did not receive any training or only received only one-off training. Their final performance indicated technical mastery that the other residents had not achieved.
Level of Evidence: II, Prospective, comparative, non-randomized study.

1. Introduction

The conditions under which medical residents practices have changed recently in France. The duration of the workweek is limited to 48 h and safety breaks are now mandatory under the impetus of European regulations [1]. Paradoxically, the residency reform that went into effect on 1 November 2017 aims to make the residents functional more quickly, at the end of their 4th year instead of the 5th year. Thus, the training program for first-year residents needs to be modified to make it more efficient. This is where simulation comes in, such as the use of plastic models to simulate bone fixation [2] and the use of virtual reality (VR) arthroscopy simulators. Various studies have demonstrated the benefits of arthroscopy simulator training in various countries [3–6], including France [7,8] (Table 1). The conclusions are based on comparisons in time parameters (i.e. time needed to complete an exercise) and instrument paths (i.e. distance over which an instrument is moved during an exercise) that are measured by the simulator. These two parameters

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Table 1
Key studies showing a benefit of VR simulator training in surgery residents.

Author	Journal	Type of study	Study population	VR simulation program	Control group	Outcomes	Tool	Main findings
Howells et al. (2008)	*J Bone Joint Surg Br*	Prospective randomized blinded, single center	Junior residents (*n* = 20)	3 sessions with 6 arthroscopy procedures over 1 week	Traditional training	Supervised knee arthroscopy in the operating room	Orthopaedic Competence Assessment Project and global rating scale	Skills improved with training and significant improvement in OR performance
Jackson et al. (2012)	*J Bone Joint Surg Am*	Prospective randomized, multicenter	Advanced residents (*n* = 19)	Meniscal repair over 6 months: 1/month, 1 only, 0	Traditional training	VR meniscus repair	Simulator data	Skills improved and maintained after 6 months without training
Henn et al. (2013)	*Arthroscopy*	Prospective randomized blinded	1st year residents (*n* = 17)	6 sessions over 3 months	Traditional training	Shoulder arthroscopy on cadaver: joint exploration	Modified GOALS scale	Trained residents improve more and were 30% faster than the others. No difference on the GOALS scale
Cannon et al. (2014)	*J Bone Joint Surg Am*	Prospective randomized blinded, multicenter	3rd year residents (*n* = 48)	Knee diagnostic arthroscopy program (average of 11 h)	Traditional training	Supervised knee arthroscopy in the operating room	Global Performance Rating Scale	Better results (instrument use) but no difference in speed
Dunn et al. (2015)	*Journal of Surgical Education*	Prospective randomized blinded, single center with 1-year follow-up	Residents of all levels (*n* = 17)	4 sessions of 15 min over 3 months	Traditional training	Supervised shoulder arthroscopy in the operating room	ASSET	Better results (ASSET and speed) in the simulation group, but not maintained at 1 year
Rebolledo et al. (2015)	*American Journal of Sports Medicine*	Prospective randomized blinded, single center	1st and 2nd year residents (*n* = 14)	2.5 h on knee and shoulder simulator	Education	Shoulder and knee arthroscopy on cadaver: joint exploration	Injury Grading Index	Residents (simulation group) were faster and caused less damage
Waterman et al. (2016)	*Orthopedics*	Prospective randomized blinded, single center	Residents of all levels (*n* = 22)	4 sessions of 15 min over 3 months	Traditional training	VR and supervised shoulder arthroscopy in the operating room	ASSET	Better in vivo results (ASSET safety score) in simulation group
Martin et al. (2016)	*Arthroscopy*	Prospective observation, multicenter	Residents of all levels (*n* = 48)	3 sessions of 4 days each	No	Shoulder arthroscopy: joint exploration	Simulator data	All residents improved on the time, camera path length and instrument path length variables
Marcheix et al. (2017)	*Orthopaedics and Traumatology: Surgery and Research*	Prospective, controlled, single center	Residents of all levels (*n* = 9)	1 hour per week for 3 months	Senior surgeons	Shoulder arthroscopy: glenohumeral and subacromial exploration	Simulator data	After 3 months of regular training, there were no longer differences between the residents and senior surgeons
Rahm et al. (2018)	*BMC Musculoskeletal Disorders*	Prospective controlled	Residents of all levels (*n* = 20)	VR shoulder and knee simulator: 3 to 5 h	Senior surgeons	Knee VR: diagnosis, extraction of loose bodies, meniscectomy/Shoulder VR: diagnosis, joint exploration	Simulator data and ASSET	All the residents improved after the training, more in the knee than the shoulder. Difference between residents and expert surgeons persisted
Ledermann et al. (2020)	*Journal of American Academy of Orthopaedics Surgeons*	Prospective, controlled blinded	Junior residents (*n* = 11)	10 sessions of 30 min weekly	Senior surgeons	Supervised knee arthroscopy in the operating room	ASSET	Residents improved after their training program and transferred their skills to the OR

GOALS: Global Operative Assessment of Laparoscopic Skills; ASSET: Arthroscopic Surgery Skill Evaluation Tool.

are well-known measures of skill acquisition [9]. As of now, seven prospective studies have sought to demonstrate the effectiveness of arthroscopy training on a VR simulator. Five of them have demonstrated skill transfer directly to the operating room through an in vivo arthroscopy assessment [4,6,10–12]. Two other studies have validated the improvement in skills based on a cadaver model assessment [13,14]. The effectiveness of the VirtaMed AG (Zurich) ArthroS™ simulator has already been established [15,16]. However, while a resident's performance on the ArthroS™ knee and shoulder simulator is correlated with the number of arthroscopy procedures a resident has done, this correlation has not been determined [17] for the FAST module of the ArthroS™ simulator since it is mainly targeted at beginners.

Because this is a new teaching approach in France, a large-scale study was conducted at the request of the Teacher Academy (*Collège des enseignants d'orthopédie*) and the Francophone Society of Arthroscopy (SFA) [18]. At the time of the residency reforms, mandatory national training with arthroscopy triangulation was implemented for all residents within the same school. A network of sites all over the country who already had VR arthroscopy simulators and various ArthroS™ modules was used to train first-year residents in orthopedic surgery and evaluate their arthroscopy skills, based on the training method, at the start and end of their first 6 months of residency. We hypothesized that first-year residents who train regularly on a VR simulator would improve their basic arthroscopy skills more than residents who use other training methods.

The primary aim of this study was to compare various arthroscopy-learning techniques in a population of first-year residents after 6 months of training. The secondary aims were to inventory the arthroscopy training during the first year of orthopedic surgery residency in France and to determine the initial abilities that each resident has at the start of the program.

2. Population and methods

2.1. Population

All the first-year residents in orthopedic surgery in metropolitan France were required to attend to two testing sessions, scheduled 6 months apart (December 2017 then June 2018): 117 residents were evaluated during the first session and 111 during the second session. Their usual course of studies was not altered for this study, and all residents continued their training at the respective university hospitals. Those who attended both testing sessions were included in the study in a prospective manner.

2.2. Group make-up

The 107 residents who attended both testing sessions (3 absent during 1st session, 5 absent during 2nd session, 2 changed specialty during study period) were divided into three groups according to the type of training they received over the 6-month period. Group A consisted of residents who did not receive any additional specific arthroscopy training between the two sessions. Group B consisted of residents who received additional and one-off non-specific arthroscopy training for less than 10 h (arthroscopy training on cadavers, box trainer, laparoscopy or arthroscopy simulator). Group C consisted of residents who received additional training on the ArthroS™ VR simulator during 6 months between the two sessions, with a minimum of 10 h of independent practice on the simulator, and who performed the exercise sequence in the FAST and Shoulder modules.

2.3. F.A.S.T. (Fundamentals of Arthroscopic Surgery Training) module (ArthroS™ VirtaMed AG, Zurich)

The testing session started on the FAST module through a hands-on session with the Image Centering and Telescoping exercises, which helps the user understand how the simulator works. The goals were to control the centering of 10 successive targets to an image for 3 s and then to control the scope's depth relative to these targets. Next, the testing was done using the *Periscoping* exercise, where the aim is to become familiar with how the 30° angled lens rotates around the scope's axis by using both hands in a coordinated manner. The resident had to orient the camera toward a three-dimensional target, so that the 30° scope gives it a face-on view, which is signalled by a flashing marker around the target. This exercise also evaluates centering ability and depth perception. Ten successive targets are presented that requires the resident to move the camera and angled scope together. A single examiner gave each participant the same instructions.

2.4. Shoulder module (ArthroS™, VirtaMed AG, Zurich)

Next, on the Shoulder module in lateral decubitus, the Diagnostic I exercise allows the resident to become familiar with the glenohumeral space for about 10 min by examining a healthy, right shoulder joint and identify five anatomical structures: long biceps tendon in its groove, subscapularis tendon, inferior labrum, infraspinatus insertion, supraspinatus insertion. Next, residents were evaluated on the Catch the Stars Glenohumeral exercise during which they had to remove five successive stars in the glenohumeral joint using the arthroscopy grasper through an anterior portal with the specimen in lateral decubitus. Since the stars were mobile, the resident was required to move the grasper's tip between the glenoid and humeral head, down to the inferior labrum. The scope was inserted in the posterior portal. A single examiner followed the participants during the warm-up phase, helping them to orient themselves.

2.5. Assessment methods

The residents were tested twice: during the first session, all residents started by watching a 5-minute online video that explained the system. This provided an overview of the simulator, showing the residents how the interface worked and how to specifically handle the scope. On the day they were required to attend, they filled out a questionnaire and then were evaluated using the FAST and Shoulder modules. During the second session, they repeated the same exercises on the FAST and Shoulder modules and filled out a questionnaire at the end. During each of the two sessions, the Periscoping and Catch the Stars Glenohumeral exercises were repeated three times in a row.

2.6. Outcomes

The outcomes evaluated during the Periscoping exercise on the FAST module consisted of time (s), camera path length (cm) and camera alignment relative to horizontal (%). During the Catch the Stars exercise in the Shoulder module, time (s), camera path length (cm) and grasper path length (cm) were evaluated. The main parameters were the change in the performance between the first and second test session and between each group.

2.7. Analysis

The exercises were done three times during the two sessions; the first and third trial in each session was analyzed to capture the instantaneous improvement during the session, then the

Table 2
Features of the entire study population and three groups before the first testing session and 6 months later. Groups compared with the Fisher test.

		Total $n = 107$			A $n = 76$ (71.0%)			B $n = 17$ (15.9%)			C $n = 14$ (13.1%)			
		n	%/mean	SD[a]	*n*	%/mean	SD[a]	*n*	%/mean	SD[a]	*n*	%/mean	SD[a]	*p*[*]
Before first session														
Age														0.3483
		107	25.4	1.3	76	25.4	1.4	17	25.6	1.2	14	25.3	1.4	
Sex														0.8917
	Female	31	29		23	30.3		5	29.4		3	21.4		
	Male	76	71		53	69.7		12	70.6		11	78.6		
Handedness														1
	Ambidextrous	1	0.9		1	1.3		0	0		0	0		
	Right-handed	95	88.8		67	88.2		15	88.2		13	92.9		
	Left-handed	11	10.3		8	10.5		2	11.8		1	7.1		
Assistant during arthroscopy														0.1825
	1 to 5	52	48.6		39	51.3		9	52.9		4	28.6		
	5 to 10	22	20.6		15	19.7		4	23.5		3	21.4		
	> 10	17	15.9		13	17.1		3	17.6		1	7.1		
	> 50	3	2.8		1	1.3		0	0		2	14.3		
	None	13	12.1		8	10.5		1	5.9		4	28.6		
Primary surgeon during arthroscopy														0.3257
	1 to 5	15	14		12	15.8		3	17.6		0	0		
	No	92	86		64	84.2		14	82.4		14	100		
Assistant during laparoscopy														0.1639
	1 to 5	40	37.4		27	35.5		6	35.3		7	50		
	5 to 10	17	15.9		13	17.1		3	17.6		1	7.1		
	> 10	9	8.4		4	5.3		1	5.9		4	28.6		
	> 50	6	5.6		4	5.3		2	11.8		0	0		
	None	35	32.7		28	36.8		5	29.4		2	14.3		
Primary surgeon during laparoscopy														0.0294
	1 to 5	12	11.2		7	9.2		5	29.4		0	0		
	No	95	88.8		69	90.8		12	70.6		14	100		
Number of hours wanted on VR simulator	106	19	13	76	17	12	17	21	17	14	25	12		0.036
Second session: 6 months later														
Assistant during arthroscopy														0.6453
	1 to 5	22	20.6		17	22.4		2	11.8		3	21.4		
	5 to 10	24	22.4		19	25		4	23.5		1	7.1		
	> 10	49	45.8		33	43.4		8	47.1		8	57.1		
	> 50	12	11.2		7	9.2		3	17.6		2	14.3		
Primary surgeon during arthroscopy														0.4847
	1 to 5	46	43		35	46.1		5	29.4		6	42.9		
	None	61	57		41	53.9		12	70.6		8	57.1		
Number of hours wanted on VR simulator	107	19	11	76	17	10	17	18	8	14	29	14		0.0133

[a] Standard deviation.
[*] Fisher exact test for qualitative variables, Kruskal–Wallis test for quantitative variables.

improvement from one session to the other. Thus the 1st and 3rd trials came from the first session and the 4th and 6th trials came from the second session. The homogeneity of the three groups was verified using the Fisher test for qualitative variables and the Kruskal–Wallis for quantitative variables. The statistical analysis was carried out with SAS® 9.4 software and a *p* value less than 0.05 was considered significant.

All residents provided written consent for anonymous use of their data from the questionnaires and simulator. Approval from the local research ethics committee was not required for this study.

3. Results

Among the 107 residents included in the study, the mean age was 25.4 years (±1.3), with no differences between groups (Table 2). The gender distribution was similar between groups (40% women, 60% men) as was the share of right-handed individuals (mean of 89%). There was no significant difference between groups in their prior arthroscopy experience, at the enrolment or after 6 months. None of the residents in group C reported having performed laparoscopy as the primary surgeon ($p = 0.0294$). For the question: "If arthroscopy VR simulation was mandatory during the first semester, how many hours of training would you like to have?", there was a significant difference in group C, at enrolment ($p = 0.036$) and after 6 months ($p = 0.0133$).

Residents in group B received various kinds of training: VR arthroscopy simulation on different joints (3–6 h) or knee only (1 h), cadaver training sessions (4–5 h), laparoscopy VR simulator (2 h), box trainer (1.5 h) and laparoscopy on pigs (2 h). The residents in group C did an average of 14 h of training and a minimum of 10.

For the Periscoping exercise, there was a significant difference between groups after 6 months in the time (A: 138; B: 127; C: 92; $p < 0.0001$), camera alignment (A: 93; B: 98; C: 97; $p = 0.0028$), and camera path length (A: 117; B: 113; C: 67; $p < 0.0001$) (Fig. 1).

For the Catch the Stars Glenohumeral exercise, there was a significant difference between groups after 6 months in the time (A: 112; B: 103; C: 61; $p < 0.0001$), camera path length (A: 46; B: 41;

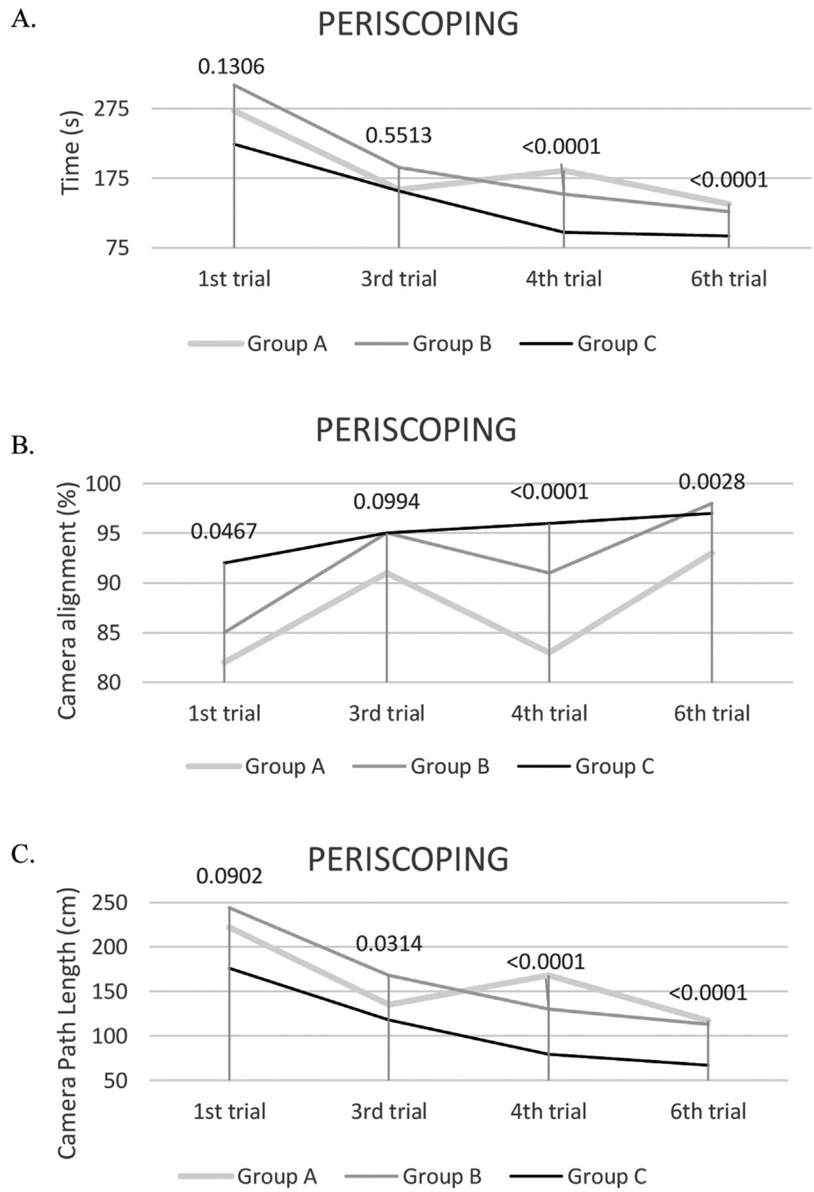

Fig. 1. Results on the Periscoping exercise with mean values for each group: time (A), camera alignment (B) and camera path length (C). 1st and 3rd trials were done during the first testing session in December 2017, then the 4th and 6th trials were done 6 months later in June 2018 during the second testing session.

C: 33; $p = 0.0153$) and grasper path length (A: 146; B: 142; C: 96; $p < 0.0001$) (Fig. 2).

4. Discussion

4.1. Improvement after 6 months

The main finding of this study is the observation that consistent training for 6 months on a VR simulator results in more improvement than any type of one-off training (Fig. 1). Indeed, the skills acquired during the first testing session had been lost by the start of the second session. This phenomenon was particularly true for the Catch the Stars Glenohumeral exercise that involves all the three-dimensional skills required for true arthroscopy practice (Fig. 2). These findings support the statement by Jackson et al. [19] that there is no given number of repetitions for each resident before they reach a level of expertise, since this number depends first and foremost on the specificity of the task that is being acquired. When evaluating advanced residents on an arthroscopy simulator who were performing meniscal suture repair during a 6-month training course, these authors remarked that the skills acquired were maintained in those who had not trained for 6 months. Thus, the exercise that consists in removing a glenohumeral loose body through an anterior portal in lateral decubitus may be a more specific and demanding task than a meniscectomy, which could explain why the acquired skills were lost in 6 months without regular training.

Currently, arthroscopy training is organized differently at each French university hospital, from traditional mentoring in the operating room, to cadaver training and simulator sessions. The time and grasper path length results in the 6th trial during the Catch the Stars Glenohumeral exercise (Fig. 2) were clearly better in group C, who trained regularly on the simulator, than in the other residents who either trained with other methods or with the simulator for only a few hours (1 to 6 h). Moreover, after 6 months, all the residents had already assisted during arthroscopy surgery (57% more than 10 times), and 43% had already participated in arthroscopic surgery as the primary surgeon (Table 2).

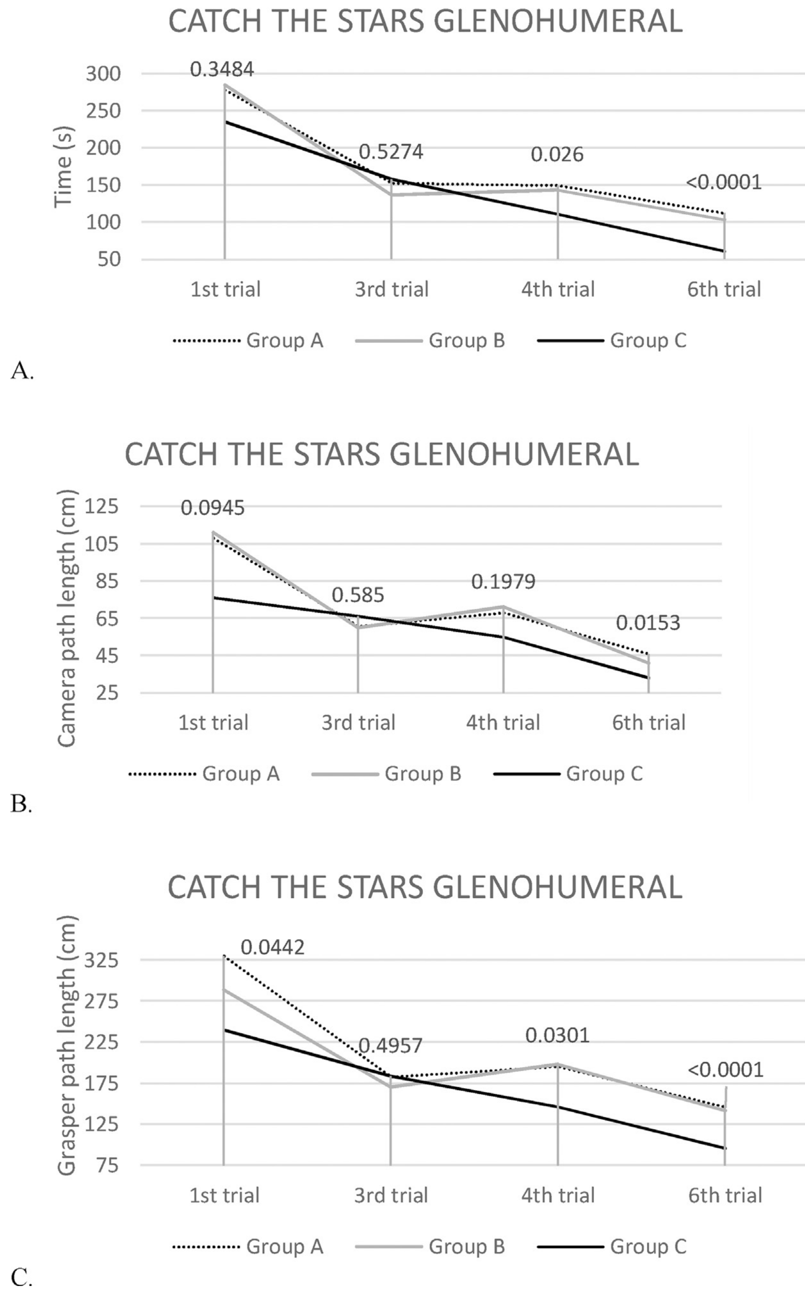

Fig. 2. Results on the Catch the Stars Glenohumeral Exercise with mean values for each group: time (A), camera path length (B) and grasper path length (C). 1st and 3rd trials were done during the first testing session in December 2017, then the 4th and 6th trials were done 6 months later in June 2018 during the second testing session.

4.2. Resident motivation and target population

All the residents in this study chose to become orthopedic surgeons, thus they were arthroscopy beginners at the start of their orthopedic training. The correlation between arthroscopy skills on a simulator and experience level or residency stage has been reported in multiple studies [20,21]. For example, in the study by Martin et al. [22] of 27 residents over 3 years, the residency stage and the number of shoulder arthroscopy procedures before the evaluation appeared to be correlated with good base performance during triangulation ($r = 0.60$ and $r = 0.55$, respectively). Thus, our study provides initial average values in a large homogenous population of first-year residents, along with their improvement over a 6-month period.

In fact, our study population consisted of residents who are motivated to learn and practice new skills. These were not simply medical students [23], volunteers or paid [14], like in the Schijven et al. study [24], who showed that among four improvement profiles, innate aptitudes could be more or less well applied to the acquisition of skills, including a group who did not improve. In the literature on VR arthroscopy, several profiles of innate aptitude have been described, in particular two extreme groups: those who are very good as they have scores greatly above average, making up 7% [25] to 17% of the sample [24], and those who are very bad as they have scores clearly below the average, making up 12% [25] to 20% of the sample [24]. Unlike the Schijven et al. study, our findings suggest that significant improvement is possible as long as residents have regular training over 6 months, although every resident improved, no matter their initial skill level. We assess the motivation of these surgery residents by asking them twice: “If arthroscopy VR simulation was mandatory during the first semester, how many hours of training would you like to have?”

While the answers in group A did not change over the 6-month period (17 h) and the residents in group B answered less after 6 months (21 h to 18 h), only the residents in group C stated they would like more training (25 h to 29 h) (Table 1), which leads us to conclude that they were still motivated after their training. This is also evidence that this type of training is acceptable to young residents. However, a wide window of testing times was provided for both sessions (8 am to 7 pm) that did not interfere with their program of study. It is possible that their skills and their motivation would not have been as high if they had been evaluated at the end of the day instead of the start.

4.3. Limitations

The primary bias in this study is that measurement tool was used as a training tool for 6 months. Thus, the residents in group C could have achieved better results because they were better prepared for the final testing session. However, their training program did not include the two specific exercises used for the testing. They used all the other exercises available in the Shoulder and FAST modules of ArthroS™. To get around this bias, various studies have used grading scales (Global Rating Scales) that typically require two blinded tests to limit subjectivity [4,6,12]. However, these scales do not provide a metric evaluation, nor do they capture the progression after *x* repetitions in an impartial manner like measurements done on a simulator. Use of the ArthroS™ simulator is correlated between the residency year and the measured performance [17]. Thus, it was relevant to use it as a measurement tool in the same population on a large scale.

Another bias is the lack of randomization. The residents who trained for 6 months on a VR simulator were the ones who worked at hospitals that already had these VR simulators available. It is possible that residents interested in arthroscopy specifically chose to go to these teaching hospitals because they knew they would have access to a simulator. However, this study was devised only after the residents had been assigned to the various sites in metropolitan France. Also, some of the hospitals did not yet have a VR simulator at the time this study was set up. In other hospitals, while the simulators were available, the feedback from previous residency classes was that access was limited and very few residents used them when no specific training program was in place.

For this study, the use of video games by residents was not analyzed, since the literature is inconsistent about its impact. To take this factor into account, it would have been necessary to create different subgroups of residents, those who do not play video games, those who play them every week and those who play them every day over a 6-month period, while also taking into account the kinds of games (First-Person Shooter, 3D sports games, 2D games) [26]. This was not the goal of our study. Similarly, since the resident's course of study was not interrupted, they could attend the testing session any time between 8 am and 7 pm, sometimes the day after being on-call and in a random manner. We felt this was not a limiting factor since we were measuring basic skills during their formal training period.

5. Conclusion

This study found that 6 months of regular training on an arthroscopy VR simulator yields better results that one-off training sessions for first-year orthopedic surgery residents. These findings suggest that investments made by a training center are more beneficial to arthroscopy beginners than occasional one-off training sessions, which allows them to have regular training and maintain the acquired skills over time. In the coming years, it would be interesting to retest these residents after their orthopedic residency to assess their future performance and how it changes with time.

Disclosure of interest

F. Sirveaux is a consultant for Tornier Wright Medical. The other authors declare that they have no competing interest.

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Contributions

P. Walbron: primary author.
H. Common: critical review of article.
H. Thomazeau: critical review, President of Teachers' College.
K. Hosseini: statistics.
L. Peduzzi: critical review of article.
Y. Bulaid: critical review of article.
F. Sirveaux: Thesis supervisor, President of SFA.

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