Innovative Surgical Trends (2026) 2:12
https://doi.org/10.1007/s44414-026-00023-5

RESEARCH

Development of technical skills in young schoolchildren using the Advanced Laparoscopy(AdLap) trainer for robotic surgery

J. P. W. Greve[1,5,6] · R. R. Postema[1,3] · Masie Rahimi[1,2,3,7] · S. Caspers[4] · S. F. Hardon[1,3] · H. J. Bonjer[1,2,7] · M. P. Schijven[1,5,6] · T. Horeman-Franse[3]

Received: 31 December 2025 / Accepted: 19 May 2026

Abstract

Background Virtual reality (VR) training is increasingly explored for fine motor skill development in children, yet little is known about its feasibility in primary school-aged populations. Understanding differences in motor learning across developmental stages may guide optimal timing for introducing simulation-based training.

Methods Primary school children were recruited and stratified into lower, middle, and upper primary groups. Participants completed a laparoscopic training task on the ADLAP box trainer. Performance was assessed using objective motion analysis parameters, including task time, instrument path length, collisions, and working volume.

Results Thirty-five children ($N=35$) completed the task (11 lower, 12 middle, 12 upper primary). Performance improved significantly with age. Total task time decreased from 201,147 ms in lower primary to 97,155 ms in upper primary ($p<0.001$). Similar age-dependent improvements were observed in instrument path length ($p\leq0.007$) and collisions ($p\leq0.014$). Working volume decreased with age, although differences did not reach significance.

Conclusion Primary school children can successfully perform laparoscopic training tasks, with clear performance gains across age groups. These findings support the feasibility of VR and box trainer-based approaches for assessing motor skills in children, and highlight the potential of simulation to inform early skill development and educational strategies.

Keywords Pediatric simulation training · Minimally invasive surgery (MIS) · Motor skill development · Virtual reality simulation · Laparoscopic skills · Surgical education

✉ T. Horeman-Franse
t.horeman@tudelft.nl

J. P. W. Greve
j.p.w.greve@amsterdamumc.nl

1 Department of Surgery, Amsterdam UMC location University of Amsterdam, De Boelelaan 1117, Amsterdam, The Netherlands

2 Science Hub for ASC Research and Education (SHARE), Amsterdam Skills Centre for Health Sciences (ASC), Amsterdam, The Netherlands

3 Department of Biomechanical Engineering, Delft University of Technology, Delft, The Netherlands

4 Elckerlyc, International elementery and primary school, Leiderdorp, The Netherlands

5 Amsterdam Gastroenterology and Metabolism, Amsterdam, The Netherlands

6 Amsterdam Public Health, Digital Health, Amsterdam, The Netherlands

7 Cancer Center Amsterdam, Amsterdam, The Netherlands

Introduction

Background

The Advanced Laparoscopy (AdLap) project aims to develop modular, reusable robotic components to reduce costs and environmental impacts. This project emphasizes sustainability and accessibility, addressing barriers faced by healthcare providers, especially in resource-limited settings. One of its key components, the virtual reality (VR)-based training module, enables users to safely practice technical skills and laparoscopic techniques in a realistic, simulated environment. This system provides a framework for training across experience levels, making it adaptable for education, early motor skills assessment, and skill refinement in advanced surgical tasks [1–3].

The AdLap VR trainer integrates VR into surgical training offering immersive skill-building for laparoscopic tasks. Through virtual instrument manipulation, it provides users with an interactive experience that replicates real surgical tasks, allowing for safe, controlled skill refinement, particularly in motor control, spatial awareness, and procedural familiarity [4–9]. VR-based surgical simulators have demonstrated effectiveness in enhancing motor and cognitive skills in younger populations, making them valuable tools supporting motor skill development, particularly in children who may pursue future careers in technical or surgical fields [10–12].

Children and adults develop motor skills differently, which is why understanding these differences is key when designing VR training programs for younger users [13]. Virtual reality has emerged as a valuable tool for enhancing fine motor skills, particularly for precision-dependent tasks requiring hand-eye coordination. Research demonstrates VR's effectiveness not only for typically developing children but also for those with neurodevelopmental conditions such as autism spectrum disorder, cerebral palsy, and developmental coordination disorder. The immersive, task-specific nature of VR simulations provides an ideal platform for developing technical skills relevant to fields like minimally invasive surgery while maintaining engagement through game-like environments [13–16]. By simulating real-world tasks, VR provides a safe and engaging way for children to practice technical skills, including those relevant to minimally invasive surgery (MIS).

Rationale

The childhood period, characterized by rapid neural development and heightened neuroplasticity [17], presents a window for foundational skill acquisition. Early, structured practice of controlled tasks (e.g., object manipulation in VR) strengthens neural pathways essential for motor mastery [14, 17].

While children under 10 typically demonstrate faster adaptation to novel motor tasks, they often achieve less precision than adults who benefit from mature motor control strategies [18–21]. These developmental differences highlight the importance of age-specific training protocols that balance cognitive load with skill progression [21, 22]. Current evidence suggests VR's potential for early motor skill intervention [14, 16], though further research is needed to establish optimal training parameters and long-term skill transfer to real-world applications [16]. Particularly valuable would be studies examining how childhood VR training correlates with later technical or surgical aptitude [17, 20].

Objective

This study evaluates fine motor skill development across different age groups (4–12 years) using the AdLap VR trainer, with two primary aims. One is to identify the most effective age window for initiating complex motor skill training and the other is to establish whether early VR training correlates with superior long-term technical skill acquisition.

Method

Study design

This observational study employed the AdLap VR trainer to assess fine motor skill development in school-aged children. The study received ethical approval.

Participants

We recruited 35 children across three developmental stages:

I. Lower primary ($n=11$, ages 4–6)
II. Middle primary ($n=12$, ages 7–9)
III. Upper primary ($n=12$, ages 10–12)

Exclusion criteria included prior laparoscopic/robotic experience or impairments. Participants were naïve to VR surgical training.

AdLap robotic master

The Portable Laparoscopic Robotic Master of the Advanced laparoscopy (AdLaP) master (illustrated left in Fig. 1) is a custom build controller with 14 degrees of freedom comprising a console equipped with two handles, each providing seven degrees of freedom of movement. The system utilizes a custom-designed input/output circuit board that converts the kinetic movements of the robotic arms into electrical signals. The AdLap virtual reality (VR) software, developed utilizing the Unity game engine (Unity Software, Inc., San Francisco, CA, USA) [23, 24], operates on a standard Windows laptop. The entire system is designed for installation on a table surface at variable heights, enabling operation from both seated and standing positions, analogous to the dVSS.

Protocol

Participants were individually shown how to use the controllers for the first time during a five-minute presentation of the VR AdLap trainer. To provide uniform first exposure

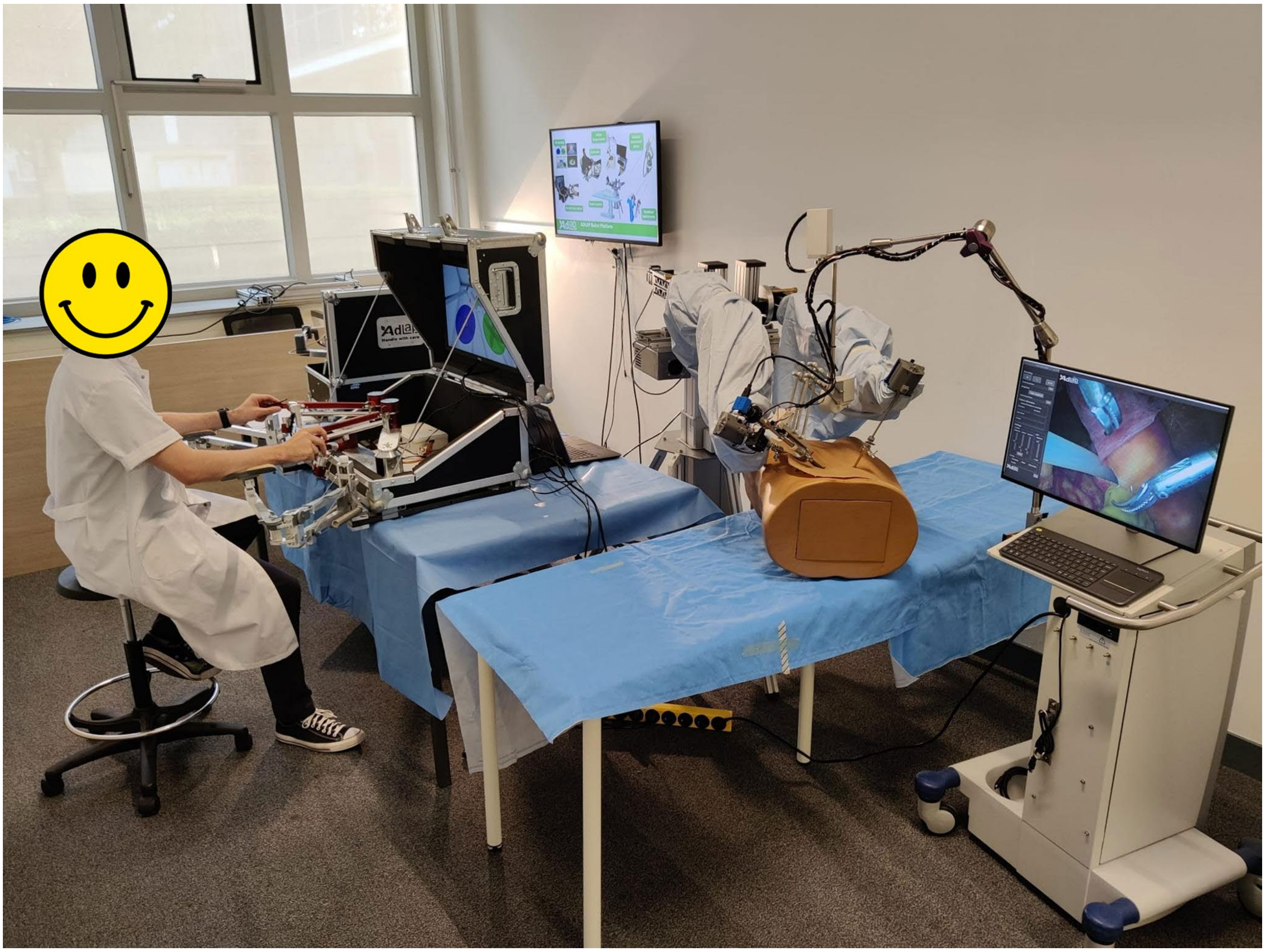

Fig. 1 The Sustainable ADLAP surgical robot platform that should foster the introduction of robotic surgery technology to less wealthy parts of the world

to the activity, this central demonstration was standardized for each participant. The task involves manipulating objects in a virtual setting that is intended to mimic surgical precision. In the exercise, the children were asked to sort marbles by color into matching bowls. They were instructed to sort the green marbles with their left hand and the blue marbles with their right hand to ensure bimanual performance and alternating left and right to ensure no differences in strategy. Each participant completed three consecutive trials of the VR marble-sorting task. Trials were separated by 30-second rest periods to prevent fatigue while maintaining task engagement. The virtual environment configuration (including marble starting positions, bowl locations, and physical parameters) remained identical across all trials to ensure consistency. A trial terminated when either:

1. The participant successfully sorted all 12 target marbles (6 green and 6 blue) into their corresponding bowls, or.
2. The maximum allowed duration of 5 min elapsed.

The first occurring endpoint determined trial completion. This dual-criterion approach balanced the assessment of both skill proficiency (successful completion) and performance efficiency (time-limited attempt). The measurement was captured and stored for analyses.

Data collection and analysis

A set of validated performance parameters was collected to assess participants' fine motor skills and task engagement during simulated tasks. The measured variables included task completion time, collisions, path length, motion volume, task accuracy (measured as the number of correctly completed components), and resets. These metrics, which are widely used in motor skill assessments, provide objective, quantitative evaluations of task performance and are extracted from the AdLap master dataset [25–27].

Task completion time represents the total time taken to perform the task and is a widely recognized measure of efficiency and proficiency. Prior research has shown that experienced individuals typically demonstrate shorter task durations, highlighting their skills and efficiency [26]. Collisions, referring to unintended contact between tools, hands, or task components, reflect control and precision. Higher collision counts often signal decreased motor accuracy; a trend consistently observed among novice operators compared to experts [24].

Path length, which captures the cumulative distance traveled by the instruments or hands during task execution, provides further insight into motor efficiency. As noted in Uemura et al.'s motion analysis study, shorter path lengths are associated with optimized, deliberate movement patterns indicative of expertise [26]. Motion volume, on the other hand, measures the spatial extent of movement within a three-dimensional area. Excessive motion volume typically signifies inefficient or extraneous movement, a trend also documented in Van Empel et al. (2013) during laparoscopic simulator assessments [25].

Task accuracy, expressed as the number of correct task completions, directly reflects the quality of performance. This measure is particularly relevant for evaluating task precision, focus, and engagement. Finally, resets, defined as attempts to repeat or correct specific task elements, offer additional information regarding challenges faced during task performance. Elevated reset frequencies may point to skill deficits or increased task complexity [24–26].

To evaluate motor skill development, analysis was performed through two primary dimensions.

First, cross-group comparisons were conducted to identify age-related differences in performance across all measured parameters. These comparisons utilized one-way analysis of variance (ANOVA) applying a significance threshold of $p < 0.05$. This approach, well-established in both motor development research and surgical simulation studies [25, 26] allowed for systematic evaluation of how task completion time, collision frequency, movement efficiency, and other metrics varied between the different age cohorts. Effect sizes were calculated to determine the practical significance of observed differences, providing insight into which aspects of performance showed the most pronounced developmental progression.

Second, intra-group learning trajectories were examined through longitudinal analysis of performance across successive trials. Linear mixed modeling techniques accounted for repeated measures while capturing both group-level trends and individual variability in skill acquisition. This approach proved particularly valuable for identifying differences in learning rates between age groups, as it accommodates the natural variation expected in developmental studies. The models incorporated trial sequence as a fixed effect while adjusting for baseline performance differences through participant-specific random intercepts.

All analyses were preceded by verification of statistical assumptions, including assessments of normality and homogeneity of variance.

Results

Group differences

The results of this study show significant differences across most performance metrics in the three different age groups (Fig. 1). The younger participants of the lower primary group needed significantly more time to finish the task ($p<0.001$) compared to the older participants of the upper primary group. In addition, the path lengths for both left and right hands was also significantly longer in the younger group ($p=0.007$ and $p<0.001$ respectively). This finding suggests the younger participants being less efficient in motor skills compared to the older groups. The collisions in both left and right side were significantly more frequent within the younger group. Especially the left side showed significant differences ($p<0.001$) compared to the right side ($p=0.014$). Experimental motion volumes showed higher variability in younger groups ($p=0.003$ for left and $p<0.001$ for right), indicating reduced precision. Lastly, the amount of resets seen across the groups is not significantly different ($p=0.095$). (Table 1 and Figs. 2, 3)

The data revealed significant learning curves in the middle and lower primary groups, highlighting that repeated exposure to the VR trainer led to measurable improvements in hand-eye coordination and fine motor skills. In contrast, the upper primary group showed no significant improvements, suggesting that their baseline performance was already advanced, leaving little room for further measurable changes across trials.

In the middle primary group, significant progress was observed across several parameters. For experimental motion volume on the left, improvements were observed between the second and third trials ($p=0.035$) and between the first and third trials ($p=0.027$). Similarly, for the right side, experimental motion volume demonstrated significant enhancements between the first and third trials ($p=0.014$) and between the second and third trials ($p=0.016$). Motion volume on the left side improved significantly between the first and third trials ($p=0.016$), while the right side showed similar progress within the same timeframe ($p=0.028$). Additionally, path length on the left side decreased significantly between the second and third trials ($p=0.049$), indicating greater efficiency during task execution.

Table 1 Differences between the three age groups for the 10 different performance parameters. In this comparison, all parameter data is averaged per group

Parameter outcomes per parameter	Lower primary (N=11)	Middel primary (N=12)	Upper primary (N=12)	Total (N=35)	p-value
Total task time (ms)	201146.59 (50438.25)	151199.79 (63505.37)	97154.50 (40947.30)	148367.54 (66522.31)	< 0.001
Instrument path length – left (mm)	153.38 (70.72)	129.31 (66.99)	74.79 (21.04)	118.18 (64.61)	0.007
Instrument path length – right (mm)	213.53 (68.54)	177.71 (81.37)	78.52 (41.50)	154.96 (86.23)	< 0.001
Collisions – left instrument (count)	2014.17 (1487.38)	602.00 (489.72)	487.61 (571.37)	1006.60 (1146.81)	< 0.001
Collisions – right instrument (count)	1712.71 (1041.34)	1227.18 (1267.91)	436.93 (527.54)	1108.83 (1100.61)	0.014
Motion volume – left instrument (cm^3)	5.53 (3.41)	5.06 (2.38)	3.75 (1.86)	4.76 (2.64)	0.247
Motion volume – right instrument (cm^3)	7.23 (3.51)	7.46 (3.21)	4.92 (3.67)	6.52 (3.56)	0.159
Explored motion volume – left instrument (≤5 mm precision, mm^3)	33111.89 (13369.05)	28574.76 (12675.06)	16789.33 (5236.70)	25960.00 (12730.35)	0.003
Explored motion volume – right instrument (≤5 mm precision, mm^3)	41499.73 (12769.68)	34266.62 (11478.80)	17778.83 (8647.29)	30886.93 (14693.39)	< 0.001
Number of resets (count)	0.74 (0.74)	1.21 (0.89)	0.57 (0.47)	0.84 (0.75)	0.095

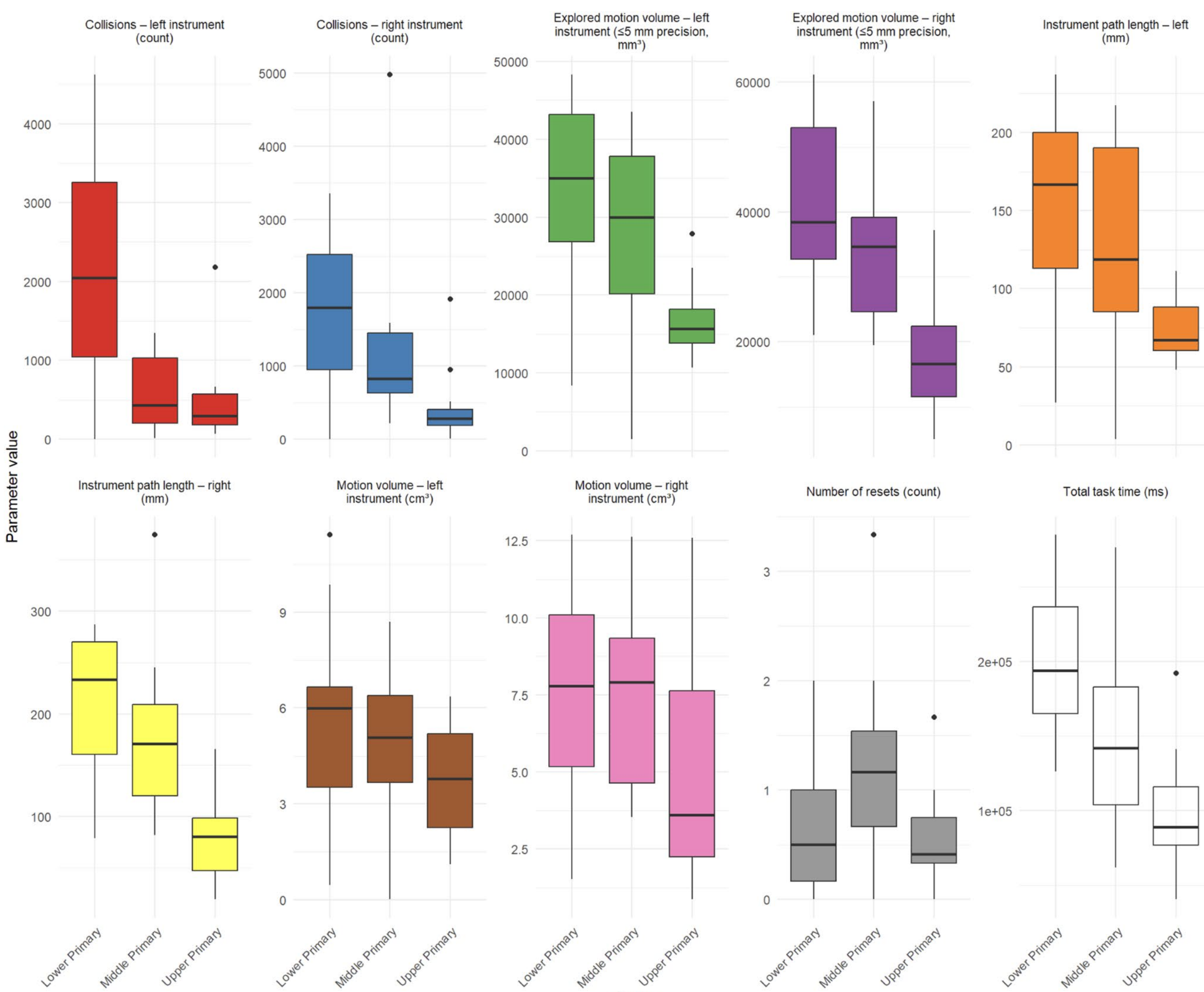

Fig. 2 Parameter outcomes comparison between the three age groups

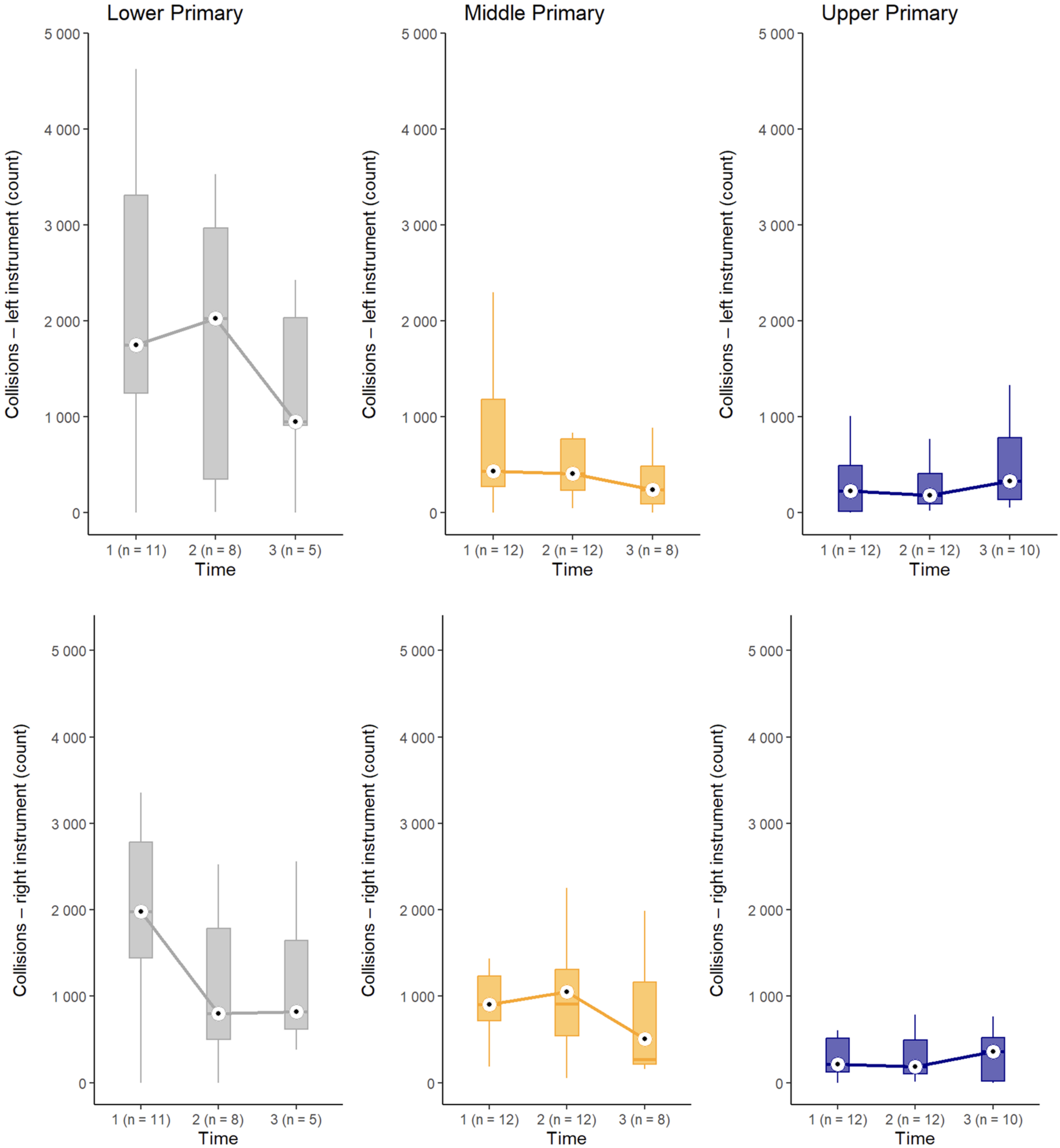

Fig. 3 Parameters distribution over time for the three different age groups

The lower primary group also demonstrated considerable improvements. For experimental motion volume on the left side, significant gains were observed between the first and second trials ($p = 0.013$). On the right side, motion volume showed marked improvements between the first and second trials ($p = 0.027$) and between the first and third trials ($p = 0.047$). Additionally, task completion time significantly decreased between the first and second trials ($p = 0.019$), reflecting enhanced task performance and efficiency.

Discussion

This study demonstrates the potential of the AdLap VR trainer for enhancing fine motor skills across developmental stages. Our findings reveal learning patterns among age groups, with significant improvements in motor coordination observed in younger children (4–9 years), while older participants (10–12 years) showed stable high performance from baseline [13, 14].

The superior learning gains in middle primary children (7–9 years) align with findings in similar studies where structured VR training optimally benefits learners at intermediate skill levels [23]. Similar to previous portable VR system validation, our results show that children in this age group demonstrate both the neuroplasticity for rapid skill acquisition and the cognitive maturity to benefit from repetitive task training [23]. The marked improvements in motion efficiency (34% reduction in path length) and precision (41% fewer collisions) suggest this may represent an ideal developmental window for introducing foundational technical skills.

Notably, our collision data provides insights similar to recent work on error feedback in surgical training. Younger children's high collision counts (3.2× higher than older groups) and frequent resets mirror their findings that novices benefit most from immediate kinematic feedback - a feature inherent to our VR system. This supports the system's value for early motor learning where error correction is crucial [24].

The ceiling effect observed in upper primary children parallels findings in surgical simulation studies [23], where trainees with prior experience show limited measurable gains in basic tasks. This suggests our current task design may be insufficiently challenging for this age group, warranting implementation of advanced modules with progressive difficulty as proposed in recent VR training frameworks [24].

Developmental differences in learning rates between lower and middle primary groups reinforce established principles of motor skill acquisition [17]. The gradual improvements in 4–6 year-olds likely reflect ongoing myelination of motor pathways, while 7–9 year-olds' faster progression corresponds with developing executive function capabilities [20].

Limitations

The observational design and relatively small sample size may limit the generalizability of the findings. Additionally, the short duration of the trials may not fully capture long-term learning curves or skill retention. Also, the absence of a comparison with a non-VR system performing the same tasks, which would have provided a more comprehensive understanding of the specific value and advantages offered by the AdLap VR system in facilitating fine motor skill development. Future studies should consider including larger and more diverse samples, extending training durations, comparison with non-VR systems and incorporating follow-up assessments to evaluate the persistence of learned skills.

Conclusion

In conclusion, the AdLap VR trainer effectively enhanced fine motor skills and hand-eye coordination in the middle and lower primary groups, highlighting its potential for supporting motor skill development in younger children. The developmental differences observed across the groups emphasize the need to adapt VR training systems to meet the unique needs of various age ranges. By doing so, VR-based tools like the AdLap VR trainer can serve as impactful resources for fostering skill development in both educational and clinical domains.

Author contributions Horeman, Rahimi and Postema did all measurements and data recording. Horeman, Rahimi, Greve and Postema wrote the manuscript. Greve and Horeman prepared the figures. Greve did the data analysis. All authors reviewed the manuscript.

Funding This work was supported by- and executed as part of the AdLap Project; a Project financed by the national Dutch NWO council (Nederlandse Wetenschappelijk Onderzoek / Netherlands Organization for Scientific Research) grant number: KICH1.ST03.21.002. The funding body had no role in the design of the study, data collection, analysis, or interpretation of the results.

Data availability The datasets that were generated and analysed during the study are attached as supplemental files.

Declarations

Competing interests The authors declare no competing interests.

References

1. Perrenot C, Perez M, Tran N, Jehl JP, Felblinger J, Bresler L et al (2012) The virtual reality simulator dV-Trainer(®) is a valid assessment tool for robotic surgical skills. Surg Endosc 26(9):2587–2593
2. Raison N, Harrison P, Abe T, Aydin A, Ahmed K, Dasgupta P (2021) Procedural virtual reality simulation training for robotic surgery: a randomised controlled trial. Surg Endosc 35(12):6897–6902
3. Rajanbabu A, Drudi L, Lau S, Press JZ, Gotlieb WH (2014) Virtual reality surgical simulators- a prerequisite for robotic surgery. Indian J Surg Oncol 5(2):125–127
4. Aggarwal R, Ward J, Balasundaram I, Sains P, Athanasiou T, Darzi A (2007) Proving the effectiveness of virtual reality simulation for training in laparoscopic surgery. Ann Surg 246(5):771–779
5. Alaker M, Wynn GR, Arulampalam T (2016) Virtual reality training in laparoscopic surgery: A systematic review & meta-analysis. Int J Surg 29:85–94
6. Grantcharov TP, Kristiansen VB, Bendix J, Bardram L, Rosenberg J, Funch-Jensen P (2004) Randomized clinical trial of virtual reality simulation for laparoscopic skills training. Br J Surg 91(2):146–150
7. Gurusamy K, Aggarwal R, Palanivelu L, Davidson BR (2008) Systematic review of randomized controlled trials on the effectiveness of virtual reality training for laparoscopic surgery. Br J Surg 95(9):1088–1097
8. Larsen CR, Oestergaard J, Ottesen BS, Soerensen JL (2012) The efficacy of virtual reality simulation training in laparoscopy: a systematic review of randomized trials. Acta Obstet Gynecol Scand 91(9):1015–1028
9. Taffinder N, Sutton C, Fishwick RJ, McManus IC, Darzi A (1998) Validation of virtual reality to teach and assess psychomotor skills in laparoscopic surgery: results from randomised controlled studies using the MIST VR laparoscopic simulator. Stud Health Technol Inf 50:124–130
10. Hart R, Doherty DA, Karthigasu K, Garry R (2006) The value of virtual reality-simulator training in the development of laparoscopic surgical skills. J Minim Invasive Gynecol 13(2):126–133
11. Yu P, Pan J, Wang Z, Shen Y, Li J, Hao A et al (2022) Quantitative influence and performance analysis of virtual reality laparoscopic surgical training system. BMC Med Educ 22(1):92
12. Dongen K, Verleisdonk E, Schijven M, Broeders IAMJ (2011) Will the Playstation generation become better endoscopic surgeons? Surg Endosc 25:2275–2280
13. Abbas JR, Chu MMH, Jeyarajah C, Isba R, Payton A, McGrath B et al (2023) Virtual reality in simulation-based emergency skills training: A systematic review with a narrative synthesis. Resusc Plus 16:100484
14. EbrahimiSani S, Sohrabi M, Taheri H, Agdasi MT, Amiri S (2020) Effects of virtual reality training intervention on predictive motor control of children with DCD - A randomized controlled trial. Res Dev Disabil 107:103768
15. Goyal C, Vardhan V, Naqvi W (2022) Virtual Reality-Based Intervention for Enhancing Upper Extremity Function in Children With Hemiplegic Cerebral Palsy: A Literature Review. Cureus 14(1):e21693
16. Liu L, Yao X, Chen J, Zhang K, Liu L, Wang G, & Ling Y (2024) Virtual reality utilized for safety skills training for autistic individuals: a review. Behavioral Sciences 14(2):82
17. Strooband KFB, Rosnay M, Okely AD, Veldman SLC (2020) Systematic Review and Meta-Analyses: Motor Skill Interventions to Improve Fine Motor Development in Children Aged Birth to 6 Years. J Dev Behav Pediatr 41(4):319–331
18. Lorås H, Stensdotter AK, Öhberg F, Sigmundsson H (2013) Individual differences in motor timing and its relation to cognitive and fine motor skills. PLoS ONE 8(7):e69353
19. Turrini S, Bevacqua N, Cataneo A, Chiappini E, Fiori F, Battaglia S et al (2023) Neurophysiological Markers of Premotor–Motor Network Plasticity Predict Motor Performance in Young and Older Adults. Biomedicines 11:1464
20. Zhou Y, Tolmie A (2024) Associations between Gross and Fine Motor Skills, Physical Activity, Executive Function, and Academic Achievement: Longitudinal Findings from the UK Millennium Cohort Study. Brain Sci. ;14(2)
21. Lin LY, Hwang IT, Hsu CF, Yu WH, Lai PC, Chen YW et al (2024) Comparing fine motor performance among young children with autism spectrum disorder, intellectual disability, attention-deficit/hyperactivity disorder, and specific developmental disorder of motor function. Front Pediatr 12:1372980
22. Cai L, Chan JS, Yan JH, Peng K (2014) Brain plasticity and motor practice in cognitive aging. Front Aging Neurosci 6:31
23. Hardon SF, Kooijmans A, Horeman R, van der Elst M, Bloemendaal ALA, Horeman T (2022) Validation of the portable virtual reality training system for robotic surgery (PoLaRS): a randomized controlled trial. Surg Endosc 36(7):5282–5292
24. Postema R, Hardon H, Rahimi AM, Horeman R, Nickel F, Dankelman J, & Horeman T (2024) The value of collision feedback in robotic surgical skills training. Virtual Reality 28(1):46
25. van Empel PJ, Commandeur JP, van Rijssen LB, Verdam MG, Huirne JA, Scheele F et al (2013) Learning curve on the TrEndo laparoscopic simulator compared to an expert level. Surg Endosc 27(8):2934–2939
26. Uemura M, Tomikawa M, Kumashiro R, Miao T, Souzaki R, Ieiri S et al (2014) Analysis of hand motion differentiates expert and novice surgeons. J Surg Res 188(1):8–13
27. Hardon SF, Horeman T, Reijers SJ, Schoonmade LJ, Daams F, & van der Peet DL (2025) The implementation of data-driven assessment into laparoscopic skills training: A systematic review. Surgical Innovation 32(5):450-464.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.