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Monitoring manual dexterity in dental students — a quasi-longitudinal study and insights from a natural pandemic experiment

Elżbieta Zarzecka-Francica[1], Andrzej Gala[1], Paweł Myciński[2], Małgorzata Pihut[1]

[1] Department of Prosthodontics and Orthodontics, Institute of Dentistry, Jagiellonian University Medical College, Kraków, Poland
[2] Department of Conservative Dentistry with Endodontics, Institute of Dentistry, Jagiellonian University Medical College, Kraków, Poland

Corresponding author: Elżbieta Zarzecka-Francica, D.D.S.
Department of Prosthodontics and Orthodontics, Institute of Dentistry
Jagiellonian University Medical College
ul. Montelupich 4, 31-155 Kraków, Poland
Phone: +48 12 424 54 41; E-mail: elzbieta.zarzecka@uj.edu.pl

Abstract: Clinical classes for dental students in Poland start at the beginning of the third year and continue until the end of the fifth year. The implementation of theoretical knowledge tests and trains their manual skills and makes visible the complexity and variability of clinical cases. The COVID-19 pandemic forced a clinical lockdown, interrupting students' ability to train for six months.

The aim of the study was to compare manual dexterity scores measured by the Purdue Pegboard Test (PPT) before and after clinical lockdown among third- and fifth-year dental students and to assess the role of clinical placement. We investigated whether the initial female manual dexterity advantage has changed and whether the subjective assessment of dexterity correlates with objective measurement. The study consisted of students performing PPT subtests, tallying the score and answering additional questions. The cross-sectional (quasi-longitudinal) study included 175 students; 96 before the outbreak of the pandemic and 79 who took a six-month break from full-time classes. Measurements were taken each time for Year III at the very beginning of the start of practical classes, and for Year V at the end.

Analysis comparing cohorts studied before and after the clinical lockdown revealed no significant differences in PPT scores within the same year of study. However, fifth-year students achieved higher scores than third-year students on selected PPT subtest. The t-Welch test showed that year V scores significantly higher on most subtests compared to year III. In a two-factor ANOVA analysis, women scored higher than men on all subtests. Spearman's correlation analysis revealed a lack of correlation between self-esteem and objective PPT scores among third- and fifth-year students.

The findings may suggest a relative stability of the assessed aspects of manual dexterity during a break lasting up to six months, and clinical seniority was associated with higher PPT score. The gender effect persisted, while self-assessment did not coincide with objective measurement supporting the need for objective monitoring of teaching needs.

Keywords: manual dexterity, dental students, Purdue Pegboard Test, fine motor skills, clinical training, COVID-19 pandemic, clinical lockdown.

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Introduction

Dentistry is a field of medicine that requires not only theoretical knowledge, but also precise manual skills, visuomotor coordination and well-developed perception. [1, 2, 3] From the third year of study onwards, dental students begin to apply the theoretical knowledge they have acquired in clinical practice, and the achievement of the intended learning outcomes is also contingent upon adequate manual dexterity.

Manual dexterity is the ability to perform rapid, precise, and coordinated movements of the upper limbs, with particular involvement of the hands and fingers, under visual control and with spatial orientation. [4] Manual dexterity may be classified into gross motor skills, involving the shoulders and elbows, and fine motor skills encompassing precise movements of the fingers and wrists. [5] Dental practice performed in mirror view and with the use of a microscope or magnifying loupes increases the complexity of clinical procedures and requires the operator to fully utilise fine motor skills. [5, 3] Extensive theoretical knowledge does not guarantee nor corresponds to proficiency in clinical procedures; therefore, dexterity tests should be more widely used for the early identification of students' educational needs. [5, 6]

Manual dexterity tests, such as the Purdue Pegboard Test (PPT), the O'Connor Tweezer Test, and the Grooved Pegboard Test, may be used during the admission process for dental studies. They serve as a screening tool used to identify candidates with poor psychomotor skills and to reduce attrition rates during the course of study. [6] In a study conducted in Tel Aviv, two simple tests—the Purdue Pegboard Test (PPT) and the O'Connor Tweezer Test—used to assess manual dexterity under indirect vision predicted, with 80% accuracy, whether a student would pass the preclinical phantom course, highlighting the strength of objective measurement. [4] Due to its ease of administration and proven validation, the Grooved Pegboard Test remains the most widely used tool, and its scores correlate well with the fine motor skills required in clinical practice. [7]

The first lockdown triggered by COVID-19 created the conditions for a natural experiment; an unplanned, simultaneous "intervention" affecting the entire student population. It has caused a surge in stressors among dental students worldwide. [8, 9, 10] Preventive measures reduced the level of psychological burden; however, it did not return to pre-pandemic levels for a prolonged period. [8, 10, 11, 12, 13]

The abrupt transition to online teaching completely precluded the opportunity for clinical practice and for the refinement of manual dexterity through work with patients. [11] The psychomotor domain posed the greatest challenge in remote education, as it requires multisensory feedback, movement coordination, and progressive motor consolidation. [14] It is this domain that remains the least well-documented area of clinical education during the COVID-19 pandemic, and Eroglu *et al.*, in reporting their findings, called for the implementation of objective assessment tools to monitor it. [15] Despite studies evaluating the quality of online education and findings documenting a gradual improvement in dental students' perceptions of e-learning, the majority of pandemic-related articles rely on students' self-assessment of competencies rather than on objective manual tests, thereby creating a research gap. [16, 17, 18]

In our study, through manual dexterity measurements conducted shortly after the resumption of classes, we sought to capture the potential effect of the interruption in clinical training. A study designed in this manner allowed us to determine whether students' subjective discomfort related to the interruption in clinical practice translated into objectively measured manual dexterity. [10]

The study we conducted employed a cohort comparison design (quasi-longitudinal in nature) and included groups of dental students examined before the outbreak of the pandemic and after the interruption enforced by the lockdown. The aim of the study was to answer the questions:

1. whether manual dexterity scores measured using the Purdue Pegboard Test (PPT) differed between cohorts of third- and fifth-year students assessed before the outbreak of the pandemic and cohorts affected by the clinical lockdown (March–September 2020);
2. whether a longer duration of clinical training translates into higher Purdue Pegboard Test scores;
3. whether the female advantage in manual dexterity observed during the initial stage of clinical education persists until the completion of their studies;
4. whether students' subjective assessment of manual dexterity correlates with its objective measurement.

Materials and Methods

The study was a cohort comparison conducted before and after the lockdown-related interruption, with the lockdown treated as an external intervention.

It utilised four measurements performed in two groups of students. Group one (A) consisted of students assessed before the outbreak of the pandemic, whereas group two (B) comprised students who experienced a six-month interruption of in-person classes (from March 2020 to September 2020).

Subgroups were formed within each group:

III A — third-year students (assessed before the pandemic in October 2019, at the beginning of clinical education);

V A — fifth-year students (assessed before the pandemic in June 2019, at the completion of clinical education);

III B — third-year students (assessed after the resumption of clinical classes in October 2020, at the beginning of clinical education);

V B — fifth-year students (assessed in June 2021, at the completion of clinical education).

Owing to this study schedule, third-year students were assessed at the beginning, and fifth-year students at the end of the three-year period of clinical education. This approach allowed for a comparison of results before and after the COVID-19-related lockdown.

Participants first provided information regarding their gender, dominant hand, and subjective assessment of their manual dexterity on a scale from 1 to 5. Self-rated manual dexterity was defined as follows: 1 — poor; 2 — below average; 3 — average; 4 — above average; and 5 — very good. The students then performed the Purdue Pegboard Test. All measurements were collected by one trained examiner according to a standardised protocol, eliminating differences between examiners.

The Purdue Pegboard Test (PPT; model 32020A, Lafayette Instrument Company, Lafayette, IN, USA) consists of a board with four compartments holding pins, washers, and collars, and two parallel rows of holes. The student, seated in a comfortable position with their elbows resting on the table, performs the tasks (subtests) previously explained and presented in a standardised manner. The objective is to place as many individual components or specified assemblies as possible into the holes within a defined time limit. Performance is assessed across four subtests:

subtest 1 — right hand;
subtest 2 — left hand;
subtest 3 — simultaneous use of the right and left hands;
subtest 4 — the sum of the scores obtained in subtests 1. 2. and 3;
subtest 5 — assembly dexterity involving the simultaneous use of both hands (assembly sequence).

The first three subtests each last 30 seconds, whereas the assembly sequence lasts 60 seconds (P, T, I).

For the statistical analysis addressing the first study objective, namely the comparison of cohorts from the same year of study before and after the clinical lockdown, each group was treated separately, maintaining the division into four subgroups: III A, III B, V A, and V B. In contrast, to achieve the second, third, and fourth objectives, differences were analysed between two groups formed from third-year students (subgroups III A and III B) and fifth-year students (subgroups V A and V B).

Statistical analyses were performed in R, version 4.5 (R Core Team, 2025), using the following packages: rio (1.2.1), report (0.5.8), epiR (2.0.75), readxl (1.4.3), dplyr (1.1.4), and tidyr (1.3.1). In addition, analyses were performed using IBM SPSS Statistics, version 29.0 (IBM Corp., Armonk, NY, USA). Distributional assumptions were assessed with the Shapiro-Wilk test, and homogeneity of variance was evaluated using Levene's test. Categorical variables were compared using the chi-square test, with reporting of Cramér's V/φ. For continuous variables, a two-way ANOVA (measurement: pre-COVID vs post-COVID; year of study: third vs fifth) and Welch's t-test for independent samples were applied, in accordance with the analytical plan and as presented in the tables. In the ANOVA, partial η^2 was reported; in the t-tests, Cohen's d was reported; in all cases, 95% confidence intervals were provided. The relationship between self-assessed manual dexterity and PPT subtest scores was analysed using Spearman's rho with 95% confidence intervals. All tests were two-sided, and the significance level was set at $\alpha = 0.05$; unless otherwise specified, p-values were not adjusted for multiple comparisons, and interpretations were based on effect sizes and 95% confidence intervals.

Participants provided informed consent to take part in the study, and the study (approval no. 1072.6120.124.2019) was approved by the Bioethics Committee.

Results

Characteristics of the study population

The study included 175 students (n = 175), of whom 96 were assessed before the outbreak and 79 after the outbreak of the COVID-19 pandemic. Third-year students comprised a group of 84 participants, and fifth-year students 91. Women accounted for 76%, and over 97% of participants reported right-hand dominance. The proportions of gender and dominant hand did not differ significantly between the groups. Detailed characteristics of the study groups are presented in Table 1.

PPT subtest scores before the COVID-19 outbreak and after the clinical lockdown

Detailed PPT subtest scores obtained by female and male students in the third and fifth years of study, assessed before the COVID-19 outbreak and after the clinical lockdown, are presented in Table 2.

Table 1. Characteristics of the study groups before the COVID-19 pandemic (A and B), after the pandemic outbreak and in the 3rd and 5th year study groups in terms of gender and dominant hand (right or left) (*p-value of the χ^2 test, χ^2 — value of the χ2 test statistic, φ/V — effect size for the χ^2 test*).

	Before COVID (III A)		Pre-COVID (V A)				
Respondents: n 96	n 51	%	n 45	%	χ^2	p	φ/V
Gender							
Women	40	78.4	35	77.8	0.006	0.938	0.008
Men	11	21.6	10	22.2			
Dominant hand							
Right	48	94.1	44	97.8	0.802	0.370	0.091
Left	3	5.9	1	2.2			
	Post-COVID (III B)		Post-COVID (V B)				
Participants: n 79	n 33	%	n = 46	%	χ^2	p	φ/V
Gender							
Women	24	72.7	34	73.9	0.14	0.906	0.013
Men	9	27.3	12	26.1			
Dominant hand							
Right	33	100.0	44	95.7	1.472	0.225	0.137
Left	0	0	2	4.3			

	Pre-COVID (III A)		Post-COVID (III B)				
Participants: n 84	n 51	%	n 33	%	χ2	p	φ/V
Gender							
Women	40	78.4	24	72.7	0.36	0.549	0.06
Men	11	21.6	9	27.3			
Dominant hand							
Right	48	94.1	33	100.0		0.276	0.15
Left	3	5.9	0	0			
	Pre-COVID (V A)		Post-COVID (V B)				
Participants: n 91	n 45	%	n 46	%	χ2	p	φ/V
Gender							
Women	35	77.8	34	73.9	0.19	0.667	0.05
Men	10	22.2	12	26.1			
Dominant hand							
Right	44	97.8	44	95.7		1.000	0.06
Left	1	2.2	2	4.3			

Table 2. Purdue Pegboard Test subtest values in third- and fifth-year student subgroups assessed before the COVID-19 outbreak (III A, V A) and after the clinical lockdown (III B, V B) (*M — mean, Mdm — median, Q1–Q3 — interquartile range, t — t-test statistic comparing women vs. men, df — degrees of freedom, p — p-value of the t-test, 95% CI — confidence interval for the mean difference, LL — lower limit of the interval, UL — upper limit of the interval, Cohen's d — effect size indicating the strength of differences between groups*).

	women			men						95% *CI*		
Dependent variable	M	Mdn	Q1–Q3	M	Mdn	Q1–Q3	t	df	p	LL	UL	Cohen's d
III A												
Right_hand	16.40	17	15.25–17	14.27	14	14–5	6.42[a]	30.95	<0.001	1.45	2.80	1.57
Left_hand	15.00	15	14–16.75	13.45	13	12–15	2.72	49	0.009	0.40	2.69	0.93
Both_hands	12.80	13	11.25–14	11.91	12	11–13	1.51	49	0.138	−0.30	2.08	0.51
Right+left+both	44.25	44	42–47	39.64	40	37–42	3.50	49	0.001	1.96	7.27	1.19
Assembly	41.40	45	38.25–45	36.45	37	33–40	2.80	49	0.007	1.39	8.50	0.95
V A												
Right_hand	16.97	17	16–18	16.70	17	15–17.25	0.51	43	0.610	−0.79	1.34	0.18
Left_hand	15.83	16	14–17	15.70	15.5	15–16.25	0.23	43	0.818	−0.99	1.25	0.08
Both_hands	13.06	13	12–14	12.70	13	12–13.25	0.73	43	0.469	−0.63	1.34	0.26
Right+left+both	45.86	46	43–48	45.10	45	43–47.25	0.64	43	0.526	−1.63	3.15	0.23
Assembly	39.17	40	35–44	38.80	38.5	37–41	0.18	43	0.859	−3.82	4.56	0.06
III B												
Right_hand	16.92	17	16–17.75	15.22	15	13.5–17.5	2.09[a]	9.47	0.065	−0.13	3.52	1.10
Left_hand	14.71	15	13.25–16	14.44	15	11.5–16.5	0.31	31	0.762	−1.50	2.02	0.12
Both_hands	13.38	13	12–14	12.22	12	11.5–13	2.21	31	0.035	0.09	2.22	0.86
Right+left+both	44.75	45	42–47	41.89	41	38–47.5	1.87	31	0.072	−0.27	5.99	0.73
assembly	41.75	43	37.5–44.75	40.89	43	34.5–45.5	0.39	31	0.696	−3.59	5.31	0.15
V B												
Right_hand	17.24	17	16–18.25	15.75	15.5	14–17.75	1.93	44	0.060	−0.06	3.03	0.65
Left_hand	15.38	15	14–17	14.33	14	13–16	1.69	44	0.098	−0.20	2.30	0.57
Both_hands	13.79	14	13–15	12.92	13	11.25–14.75	1.43	44	0.159	−0.36	2.11	0.48
Right+left+both	45.82	45.5	43–49.25	43.00	43.5	38.25–46	1.53	44	0.133	−0.89	6.54	0.51
Assembly	42.00	41.5	38–44.5	39.08	40.5	33–45.25	1.06[a]	13.72	0.307	−2.99	8.82	0.46

The two-way ANOVA (variables analysed: manual dexterity pre-COVID-19 vs. post-COVID-19 across the third and fifth years of study) did not reveal differences in manual dexterity in any of the five PPT subtests among either third- or fifth-year students. Detailed results are presented in Table 3.

Table 3. Comparison of subtest performance between groups III A (third year before the pandemic), III B (third year after the clinical lockdown), V A (fifth year before the pandemic), and V B (fifth year after the clinical lockdown) (*t — t-test statistic, df — degrees of freedom, p — p-value, mean difference — difference of means, std. error difference — standard error of the difference, 95% Confidence Interval of the Difference — confidence interval for the mean difference, lower — lower limit, upper — upper limit*).

Comparison III A with III B	Subtest	t	df	p	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
	Right_hand	−1.4	82	0.165	−0.513	0.367	−1.243	0.216
	Left_hand	0.07	82	0.944	0.03	0.434	−0.832	0.893
	Both_hands	−1.243	82	0.217	−0.453	0.364	−1.177	0.272
	Right+Left+Both	−0.761	82	0.449	−0.715	0.94	−2.584	1.154
	Assembly	−0.957	82	0.341	−1.182	1.234	−3.638	1.274

Comparison V A with V B	Subtest	t	df	p	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
	Right_hand	0.154	89	0.878	0.063	0.412	−0.755	0.882
	Left_hand	1.916	89	0.059	0.691	0.361	−0.026	1.408
	Both_hands	−1.727	89	0.088	−0.587	0.34	−1.263	0.088
	Right+Left+Both	0.626	89	0.533	0.602	0.961	−1.307	2.511
	Assembly	−1.681	89	0.096	−2.15	1.279	−4.692	0.392

The role of clinical experience in the development of manual dexterity and the effect of gender

Welch's t-test showed that fifth-year students achieved significantly higher PPT scores in three of the five subtests compared with third-year students: Right hand ($p = 0.008$), Left hand ($p = 0.005$), and Right + Left + Both ($p = 0.006$). A detailed analysis of the Purdue Pegboard Test subtests for the third and fifth years is presented in Table 4.

In the two-way ANOVA (gender, year of study), women achieved higher scores than men in all five PPT subtests, and fifth-year students achieved higher scores than third-year students. In the initial stage of clinical practice, the difference between women and men was statistically significant; however, among fifth-year students, the observed female advantage decreased. Statistics in this respect are presented in Table 5.

Table 4. Comparison of manual skills of third- and fifth-year students in Purdue Pegboard Test subtests (*M — mean, SD — standard deviation, t — t-test statistic comparing third- vs. fifth-year students, df — degrees of freedom, p — p-value, 95% CI — confidence interval for the mean difference, LL — lower limit, UL — upper limit, Cohen's d — effect size for the mean difference*).

	Third year (n = 84)		Fifth year (n = 91)					95% CI		
Dependent variable	**M**	**SD**	**M**	**SD**	**t**	**df**	**p**	**LL**	**UL**	**Cohen's d**
Right_hand	16.14	1.65	16.88	1.95	−2.70	171.69	0.008	−1.27	−0.20	0.41
Left_hand	14.65	1.93	15.45	1.75	−2.85	167.61	0.005	−1.35	−0.24	0.43
Both_hands	12.79	1.64	13.27	1.64	−1.97	171.96	0.050	−0.98	0.00	0.30
Right+Left+Both	43.54	4.20	45.38	4.57	−2.79	173.00	0.006	−3.16	−0.54	0.42
Assembly	40.80	5.52	40.18	6.16	0.70	172.85	0.483	−1.12	2.37	0.11

Table 5. Gender dimorphism in Purdue Pegboard Test scores (ANOVA analysis: sex × year of study) (*F — ANOVA test statistic, df — degrees of freedom, p — p-value, η2 — effect size measure*).

	Effect	F	df	p	η2
Right hand	Year of study	10.75	1; 171	**0.001**	0.06
	Sex	21.51	1; 171	**<0.001**	0.11
	Year of study* sex	2.58	1; 171	0.110	0.02
Left hand	Year of study	7.62	1; 171	**0.006**	0.04
	Sex	6.56	1; 171	**0.011**	0.04
	Year of study* sex	0.28	1; 171	0.601	<0.01
Both hands	Year of study	4.22	1; 171	**0.042**	0.02
	Sex	7.54	1; 171	**0.007**	0.04
	Year of study* sex	0.41	1; 171	0.525	<0.01
Right+left+both	Year of study	9.86	1; 171	**0.002**	0.06
	Sex	14.32	1; 171	**<0.001**	0.08
	Year of study* sex	1.61	1; 171	0.206	0.01
Assembly	Year of study	0.05	1; 171	0.823	<0.01
	Sex	5.20	1; 171	**0.024**	0.03
	Year of study* sex	0.51	1; 171	0.476	<0.01

Self-assessment and objective measurement of manual dexterity

Spearman's correlation analysis revealed that subjective self-assessment of manual dexterity did not reflect the actual test results. Both among third- and fifth-year students, no correlation was observed between self-assessment and objectively measured manual dexterity scores. Detailed results are presented in Table 6.

Table 6. Comparison of self-assessed manual skills of third- and fifth-year students with objective subtest measurements of the Purdue Pegboard Test (*rs — correlation coefficient between objective manual skill measurement and self-assessment, p — p-value, 95% CI — confidence interval for the correlation coefficient rs*).

Test	Self-assessment of skills					
	Third year (n = 84)			Fifth year (n = 91)		
	rs	p	95% CI	rs	p	95% CI
Right_hand	−0.01	0.922	−0.23; 0.21	−0.07	0.498	−0.28; 0.14
Left_hand	0.02	0.885	−0.20; 0.24	0.02	0.869	−0.20; 0.23
Both_hands	0.02	0.850	−0.20; 0.24	0.14	0.189	−0.08; 0.34
Right+left+both	0.01	0.954	−0.21; 0.23	0.02	0.832	−0.19; 0.23
Assembly	−0.07	0.526	−0.29; 0.15	0.05	0.614	−0.16; 0.26

Discussion

During the pandemic, the majority of students expressed uncertainty and concerns regarding the forms of education proposed by universities. [16] There were proposals to develop simulators, haptic technologies based on virtual reality (VR)/augmented reality (AR), and tele-dentistry as future solutions in similar crises. [11] The absence of clinical training increased students' concerns about a decline in the manual dexterity required for professional practice. Many students rated both clinical and theoretical classes as worse throughout the entire pandemic period. [19] Even if the lockdown enforced a suspension of patient care, it is important to have objective assessment tools that allow for a reliable evaluation of current manual dexterity levels, the early detection of any regression caused by the interruption in clinical training, and the planning of targeted activities to compensate for identified deficits.

Psychomotor abilities of students at two measurement points: before and after the clinical lockdown

Our proposed study model, based on objective assessment of manual dexterity conducted shortly after the clinical lockdown, may effectively fill the diagnostic gap by facilitating universities' adaptation of curricula in similar situations in the future. It is worth noting that there are reports indicating a regression in clinical skills following a suspension of patient care, and consequently a lack of practice of manual skills. [20] In our quasi-longitudinal study, when comparing pre-pandemic and post-clinical lockdown cohorts, we did not observe statistically significant differences in manual dexterity, which may confirm the stability of psychomotor competences during a break lasting up to six months. Despite this, our other questionnaire-based studies conducted among the same group of students during the pandemic showed that concerns about insufficient practical preparation were among the major stressors. [10, 13] Longer lockdowns would require separate measurements.

Such findings should not constitute a conclusion for universities that there is no necessity to fill the clinical training gap in similar situations. Seymour-Walsh *et al.* demonstrate that, if a transition to remote teaching is necessary, universities are able to develop students' psychomotor skills remotely, provided that online activities (video, distributed practice) are well designed. The authors criticise condensed courses intended to compensate for missed training and emphasise the necessity of distributing practice over time in order to consolidate the motor trace. Intensive training following a break does not provide time for the consolidation of motor memory. [14] The observational learning strategy (video-based) is consistent with this trend. It appears that even observation of a virtual procedure alone activates motor circuits and supports the maintenance of the memory trace. LeBel *et al.* demonstrated the effectiveness of this strategy in their study. [21] Many conclusions from other studies, including those conducted at Harvard University, favour a hybrid teaching model in the future, comprising 25–50% online content, while manual skill development should definitively be conducted on site in the form of clinical training. [16, 22]

Role of clinical experience in the development of manual dexterity

Compared with third-year students, fifth-year achieved higher Purdue Pegboard Test score, suggesting that tree years of clinical training may contribute to the development of manual dexterity. Fifth-year students achieved significantly higher PPT scores in three of the five subtest compared with third-year students, whereas the both-hands subtest was borderline and the assembly subtest did not differ significantly. This supports the assumption that clinical training and patient contact accelerate motor consolidation. The results of Saeed *et al.* indicate that systematic preclinical training can significantly improve third-year dental students' manual dexterity, as measured, among others methods, by the Purdue PegBoard Test. [23] However, our data did not reveal significant differences between the third-year cohorts studied before and after the pandemic, sugest that the impact of the pandemic break on PPT scores in this group was not confirmed in our studies.

It is also worth citing the assertion that experience shapes resilience. The manual dexterity of fifth-year students at the Catholic University of Rome did not regress despite a six-month interruption, confirming the resilience, stability, and plasticity of manual competencies developed during the course of students' education. [24]

Numerous pre-pandemic studies confirm that senior students outperform junior students in terms of manual skills. [4] The six-month interruption in practising their skills did not eliminate this advantage, as fifth-year students maintained significantly higher PPT scores compared with third-year students. This suggests that clinical experience enhances manual skills and that competencies remain stable provided that practice is maintained. The implementation of tele-dentistry and VR exercises could help maintain competencies during extended lockdowns by improving students' manual skills, supporting future university programs, and providing a buffer for clinical interruptions. [25]

Gender effect independent of clinical experience

There is a common belief that women have greater manual dexterity than men. In our study of third-year students, women achieved higher PPT scores compared with men, confirming this social stereotype. In the overall analysis, women achieved higher mean PPT scores than men; however, in the fifth-year subgroups, these differences were less clear. Because the sex x year-of-study interaction was not significant, the results should not be interpreted as unequivocal evidence of a persisting female advantage until the end of clinical education. Previous evidence indicates that both manual and spatial abilities contribute to the acquisition of dental skills; [3] therefore, the present findings should be interpreted in this broader educational context rather than confimation of a persistent sex-related advantage. This advantage of women can be explained by smaller hand and finger size, which facilitates grasping small objects, and by women more frequently engaging in daily tasks that require greater precision. Intensive clinical practice for students, both women and men, led to higher scores in most of those assessed. Such results support the concept that clinical training and exposure to stimuli promote neuroplastic compensation, enabling students to achieve better competencies.

A study conducted by Frank *et al.* confirms that dexterity is amenable to training. Moreover, he reported no differences in the quality of scaling performed by students between genders, but only after prior intensive training. [26] From a neurobiological perspective, this can be explained by the presence of mechanisms of long-term motor memory consolidation. Repetition of clinical procedures activates the motor cortex and the mirror system, leading to the remodeling of motor maps.

Intensive, systematic practice distributed over time benefited all students in our study; however, we did not observe a reduction in gender-related differences. Results from Lugassy *et al.* show that even preclinical exposure to complex tasks can improve manual skills, particularly in students who were initially less manually dexterous. [4] Comparative analysis in our study showed that both genders systematically develop manual skills over time and with practice.

Dexterity tests such as the PPT are used at various stages of education and for different purposes. Our results suggest that such tests should serve a diagnostic function rather than a selective one. They allow for early identification of students experiencing regression in manual skills, those with lower manual dexterity, and those requiring additional support.

Discrepancy between self-assessment and objective measurement of manual dexterity

In our analyses, there was no significant correlation between subjective self-assessment of manual dexterity and PPT subtest scores. This self-assessment of manual skills may result from limited experience, insufficient knowledge, lack of comparison with others, or absence of exposure to clinical conditions without supervisor support. These results indicate that self-assessment does not reliably reflect psychomotor competencies, and objective measurements serve as a tool for accurate evaluation in this context. In educational practice, this finding justifies the use of objective tests to monitor progress and quickly identify needs.

If the academic environment rarely evaluates actual skills, for example through practical exams, and does not provide feedback, the illusion of competence may persist, and students themselves may show less motivation to improve their skills. Interestingly, there are publications suggesting that individuals with high manual skills often tend to underestimate their own self-assessment. [27, 28] This may result from awareness of the existing criteria. Clinical experience, and the expertise acquired through it, improves the accuracy of the self-assessment. [29] Despite students expressing anxiety about a decline in manual skills, PPT results did not confirm this. However, in their subjective self-assessment, students rated their skills higher than indicated by objective measurements. This shows a large discrepancy between students' perception and the objective results. At the same time, this highlights the diagnostic limitations of questionnaires alone and points to the usefulness of employing objective and reliable tests.

PPT, due to its relatively low cost, reliability, objectivity, and short completion time, is a suitable test for periodic monitoring of students' manual skills. It allows verification of competency levels in a relatively short time, both in relation to subjective variables (self-assessment) and objective factors (disruptions in education, clinical interruptions, or program reorganization). Its simple protocol allows evaluation of the effectiveness of alternative training methods (VR/AR simulations), providing data on whether the implemented innovations actually improve manual dexterity. PPT can serve as part of a quality assurance system in education that universities should use, combining its diagnostic value with the possibility of prompt educational intervention.

It is worth emphasizing that our study was based on measurements taken during a unique period of a natural experiment, namely the COVID-19 pandemic. A limitation of our work is the quasi-longitudinal nature of the study, in which we compare different groups across successive manual measurements.

Conclusions

1. In this quasi-longitudinal study, no significant differences in PPT scores were found between students assessed before the pandemic and those assessed after the clinical lockdown.
   The finding may suggest a relative stability of the assessed aspects of manual dexterity in the face of an external factor such as the clinical lockdown. From a practical perspective, in the event of similar interruptions, objective monitoring and staggered clinical training appear more justified than the automatic implementation of catch-up-courses.
2. Clinical experience influences manual skills
   Higher PPT scores among fifth-year students compared with third-year students indicate an relationship between the level of clinical education and better performance of selected manual tasks. However, the study does not allow the mechanism underlying this relationship to be clearly determined. Study programmes should therefore minimize gaps and disruptions in students' real clinical contact, fully utilizing this potential.
3. Gender differences in PPT scores without a significant gender x year of study interaction
   From the perspective of the curriculum, this means that universities should focus on individually monitoring initial results and providing well-targeted support (additional exercises, observational learning, peer-assisted learning).
4. Limited value of self-assessment and the need for objective measurements of manual skills
   The low concordance between students' self-assessment and PPT results highlights the limited value of questionnaires as a diagnostic tool. Universities should therefore systematically monitor progress through objective tests such as the PPT, rather than relying solely on students' self-reported competencies.
5. PPT provides diagnostic value as a tool for monitoring the quality of education
   Thanks to its low cost, high reliability and short completion time, the PPT test proves itself as a diagnostic tool for periodic manual dexterity testing. It enables early detection of regression following interruptions in practical training, objective assessment of alternative forms of training (VR/AR, simulations) and rapid identification of students requiring targeted support without using the test as an exclusionary screening tool.
6. Objective measurements can reduce unnecessary emotional burden on students and correct the illusion of declining manual skills during periodic breaks in clinical practice, while also allowing students to objectively assess their own competencies.

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Conflict of interest

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Author contribution statements

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