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Research article

Surgical experience and different glove wearing conditions affect tactile sensibility

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ABSTRACT

Background: The fingers' tactile sensibility is essential in surgery, especially in microsurgery. Therefore, surgeons seeking to improve their performance often prefer certain glove brands and wearing habits. There is the need of objectively testing these glove wearing conditions and determine the effect of surgical experience with regard to tactile sensibility by comparing surgeons with non-surgeons.

Methods: This cross-sectional single-center pilot-study was conducted between June and August 2021. Two groups of 27 surgeons and 27 non-surgeons underwent two-point-discrimination (2PD) and Semmes-Weinstein monofilament testing (SWMT) of both index fingers with bare hands and with wearing six different brands of surgical gloves. Different wearing conditions, such as single-gloving, double-gloving, well-fitted, under- and oversized gloves, were evaluated within and between the groups.

Results: Most glove types decreased tactile sensibility (2PD and SWMT) of surgeons and non-surgeons. Interestingly, the thinnest gloves showed similar 2PD values to bare hands in both groups. Double-gloving negatively impacted SWMT, without influencing 2PD. Undersized gloves showed better 2PD and SWMT than well-fitted gloves, while oversized gloves showed no tactile drawbacks. With bare hands and certain glove conditions, the surgeons' 2PD and SWMT was significantly better than the non-surgeons', indicating a positive effect of surgical experience on tactile sensibility.

Conclusion: Our study demonstrated the positive impact of surgical experience on tactile sensibility, as demonstrated by the surgeons. The sensibility of the gloved hand varies on the surgical glove type, but favors thinner gloves, single gloving (rather than double gloving) and undersized or well-fitted gloves.

1. Introduction

Tactile exploration plays a crucial role for surgeons as it allows the identification of abnormalities and areas of interest in different tissues [1]. Particularly in microsurgery, it is of utmost importance to grip the tissue atraumatically, to cut and dissect it with appropriate force and to apply adequate tension, when a knot is tied. The finger's interaction with a surface is physiologically detected by mechanoreceptors located at different levels in the skin [2]. Wearing gloves reduces the effectiveness of fine touch discrimination [3], although it is an indispensable protective barrier against bloodborne pathogens while performing surgery [4].

Previous studies that evaluated the effect of medical gloves using standardized sensibility tests, i.e., Semmes-Weinstein monofilament and two-point discrimination, have shown that wearing gloves reduces significantly touch sensitivity [3, 5, 6]. To alleviate the impediment to surgical performance caused by gloves, surgeons have different glove wearing habits and preferences, i.e., personal choice of glove brand, glove thickness, single-gloving, double-gloving, well-fitted, undersized or oversized gloves [7]. Those glove conditions have been examined in

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several studies with regard to tactile sensibility, however, much of the research is insufficiently comprehensive and not scientifically rigorous: Either glove comparison was conducted with only two glove brands [5] or sensibility was evaluated in a subjective manner based on interviews [4]. Other studies compared non-sterile gloves with participants allowed to choose the glove size which fitted subjectively the best [6, 8, 9].

Double gloving is widely considered as a means to further reduce blood exposure to the hands and bloodborne infections due to breeches of the glove barrier, e.g., through sharp instruments or material fatigue during long surgical procedures [10, 11]. In this aspect, the sensibility performance of double gloving is commonly discussed in the literature and led to controversial results: Some studies proved a deficit of sensibility when wearing a double layer [6, 11] and others noticed no difference compared to single gloving [3, 10].

Additionally, the issue of wrong glove fit was the subject of other studies which evaluated predominantly the risk of perforation and the effect on manual dexterity [12, 13]. Under- and oversized gloves were reported to be critical in these terms, especially when well-fitted gloves are institutionally unavailable or different anatomical hand dimensions were present [13]. Besides these circumstances, individuals may also prefer wearing oversized gloves due to subjective comfort [12]. Regarding sensibility performance of wrong glove fit, there is only data of non-healthcare workers and non-surgical gloves with bigger range of glove sizes (XS, S, M, L, XL): Both studies favored well-fitted gloves when comparing to oversized gloves [3, 6].

To our knowledge, no study has been conducted to investigate the effect of surgical experience on tactile sensibility. In contrast to non-surgeons, surgeons are used to wearing gloves regularly during surgical procedures for their own protection and in order to maintain a sterile environment. There is reason to believe that surgeons develop better fingertip sensibility by training repeatedly throughout their career [2, 14]. Therefore, this study aims to determine whether there is an objective difference in cutaneous sensibility of two-point discrimination and pressure threshold when comparing surgeons, who also practice microsurgery, with non-surgical individuals. Furthermore, we comprehensively analyzed the effect of six competing glove brands and different wearing conditions (single-, double-gloving, regular sized, oversized, undersized gloves) on tactile sensibility, evaluating a preference of wearing gloves in the clinical field.

2. Methods

2.1. Ethical approval

The study was conducted in accordance with the Declaration of Helsinki, and approved by the ethics committee of the Technical University Munich, Germany (reference number: 299/21S-SR; date of approval: 12.08.2021). Only participants who provided their written consent were included. None refused to participate. The work has been reported to be in line with the CONSORT guidelines [15].

2.2. Study collective

In this single-center study, surgeons and non-surgeons were recruited between June and August 2021 at our institution. After screening for exclusion criteria, a total of 54 individuals (27 surgeons and 27 non-surgeons) were included. Surgeons work in the department of Plastic (n = 14), Vascular (n = 9) and Orthopedic and Traumatology surgery (n = 4) and needed to have at least six months of experience in the microsurgical field to be included. Non-surgeons included nurses and medical students at our clinic. The participants' age was limited to 25–55 years in order to increase comparability due to deterioration of tactile sensibility with age [16, 17, 18]. Exclusion criteria involved neurological disorders, peripheral vascular disease of the upper extremities, rheumatoid arthritis or other collagen disorders affecting the peripheral nerves. For demographics, see Table 1.

Table 1. Demographic data.

	Non-surgeons	Surgeons
Total number	27	27
Women	15 (56%)	8 (30%)
Men	12 (44%)	19 (70%)
Age*	29.6 ± 6.4	33.4 ± 8.7
Dominant hand (right/left)	27/0	27/0
Surgical experience (years)*	-	6.7 ± 8.8
Microsurgical experience (years)*	-	3.0 ± 2.8

* Mean ± standard deviation.

2.3. Tactility tests

2.3.1. Semmes-Weinstein monofilament test (SWMT)

The Semmes-Weinstein monofilament test (SWMT) was applied to measure pressure thresholds for cutaneous sensitivity of the index finger of both hands. The SWMT is an objective method of assessing the tactile perception and is widely used by clinicians to evaluate sensory disturbances [19]. One set of filaments (size 1.65–6.65) consists of 20 monofilaments labelled from 1.65 to 6.65 relating to the logarithm of 10 times the force needed to bow the filament. Each nylon monofilament was precisely calibrated and of equal length (38 mm). The more the labeled number increases, the thicker the filament becomes. The thinnest monofilament to elicit a response by the study participant was determined by serial testing with target forces from 0.008 g to 300 g.

2.3.2. Static two-point discrimination (2PD)

The Arex Discriminator (F - Palaiseau Cedex; 2–8 mm) was used to assess the static two-point discrimination (2PD) by applying one or two prongs onto the pulp of the index finger [20]. The distance between two prongs ranges from 2 mm to 8 mm and the smallest distance which could be distinguished by the study participant was recorded.

2.4. Glove assignment

The individual glove size was assigned using the Arhimedean principle of water immersion [21], as applied in our previous pilot-study [3]. The individual hand volume was measured depending on the volume of the displaced water and assigned to a glove size as following: Size 6 = 174–218 ml; size 6.5 = 201–285 ml; size 7 = 222–304 ml; size 7.5 = 288–365 ml; size 8 = 327–381 ml. The glove size was checked whether the glove fit well on the stretched fingers, without restriction of movement or wrinkling. We tested a total of six sterile medical glove types (Braun Vasco OP sensitive®; Cardinal Health Protexis Neoprene®; Semper med supreme®; Semper med syntegra®; Biogel Surgeons®; Gammex Latex sensitive®, see Table 2). Semper Med Supreme® gloves are the standard gloves at our institution and were used to determine the effects of double-, under- and oversized gloving. Wearing over- or undersized gloves was defined as one glove size above or lower from the regular, well-fitted size.

Table 2. Glove types (taken from product sheets).

Glove type	Manufacturer	Glove thickness (fingertip)	Glove price
Biogel Surgeons®	Mölnlycke®	0.21mm–0.27 mm	1.53 Euro
Vasco OP sensitive®	Braun®	0.17mm–0.21 mm	0.59 Euro
Protexis Neoprene® (latex-free)	Cardinal Health®	0.17 mm	1.03 Euro
Gammex Latex sensitive®	Ansell®	0.14mm–0.17 mm	1.70 Euro
Supreme®	Sempermed®	0.19mm–0.23 mm	1.20 Euro
Syntegra® (latex-free; hypoallergenic)	Sempermed®	0.19mm–0.24 mm	1.69 Euro

2.5. Experimental procedure

Testing was performed by one examiner in a quiet examination room. Study participants were investigated in a seated position with their hands placed comfortably on a table in front of them. Before each individual was examined, the investigator explained the procedure and demonstrated the testing devices. First, both bare hands were evaluated. Then, different glove types (Table 2) and wearing conditions (single-, double-gloving, regular sized, oversized, undersized gloves) were tested in random orders, to reduce a learning effect as a bias, with the patients blindfolded throughout the examination. We assessed the combined sensibility of fingertip, i.e., the radial and ulnar digital nerve of the index finger (N3/4) of both hands. The arithmetic mean of both hands was then calculated.

2.6. Statistical analysis

For statistical analysis we used the GraphPad Prism 9 Software. Data sets were analyzed by repeated measures two-way analysis of variance (ANOVA), with subsequent comparisons using Tukey's post-hoc analysis. All values are expressed as means ± standard error of the mean (SEM). A value of $p < 0.05$ was considered statistically significant (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$).

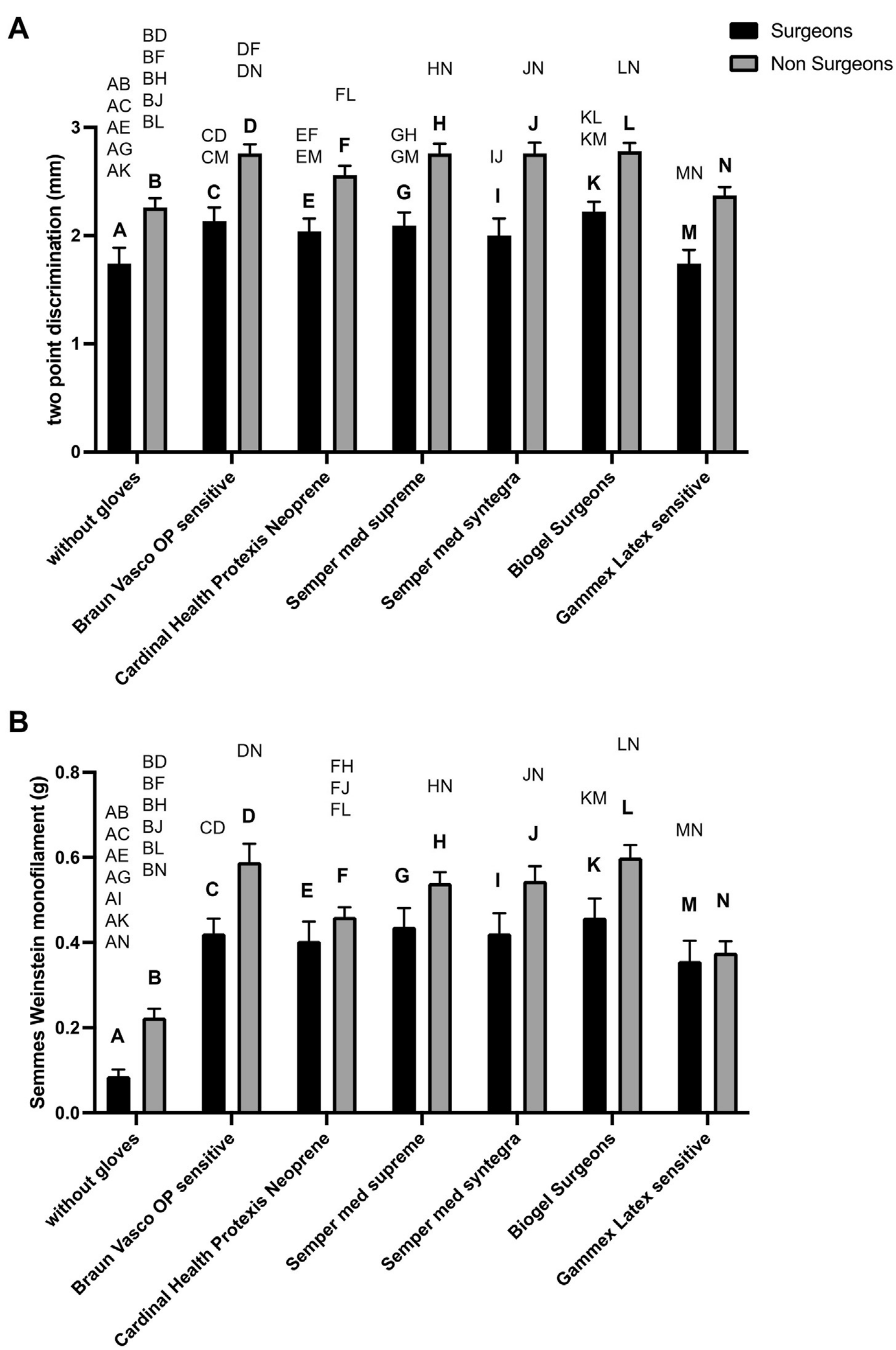

Figure 1. The effects of surgical profession and glove types on tactility. (A) Two-point-discrimination and (B) Semmes-Weinstein monofilament test of surgeons (black; n = 27) and non-surgeons (gray; n = 27) wearing six types of gloves compared to without gloves. Data are means ± SEM. Two-way repeated measures ANOVA with Tukey's post-hoc test. Data points are means ± SEM. Capital letter pairs over plots indicate statistical comparison of corresponding data points. For all pair comparisons, $p < 0.05$.

3. Results

3.1. The effects of surgical profession and glove types on tactility

Firstly, we investigated the possible influence of handedness (dominant vs. non-dominant hand) of surgeons and non-surgeons with regards to two-point discrimination (2PD) and pressure threshold sensitivity by Semmes-Weinstein monofilament testing (SWMT). There were no significant differences of the dominant and non-dominant hand detected with bare hands and with wearing six different gloves in both profession cohorts ($p > 0.05$; data not shown). For the following measurements, we therefore used the mean 2PD- and SWMT-values of both hands for each individual.

We started to examine the effects of (micro-)surgical profession and glove types on tactility. The surgeons had a mean of 6.7 years of profession and 3.0 years of microsurgical experience (Table 1). Non-surgeons were nurses and medical students. We tested tactility using two-point discrimination (2PD) and pressure threshold sensitivity by Semmes-Weinstein monofilament testing (SWMT) with bare hands and with wearing a single-layer of six different gloves in both profession cohorts (Table 2).

For 2PD-testing, a two-way ANOVA showed a statistically significant difference between professions (surgeons and non-surgeons) ($F (1, 52) = 20.48$, $p < 0.0001$) and between glove types ($F (4.817, 250.5) = 22.47$, $p < 0.0001$), with no interaction between these factors ($F (6, 312) = 1.11$; $p = 0.36$) (Figure 1A, Table 5). A post-hoc analysis with the non-surgeons' group revealed a deterioration of 2PD with wearing most of the gloves compared to bare hands ($p < 0.05–0.0001$), except with Gammex Latex sensitive® (Figure 1A, Table 3). Gammex Latex sensitive® yielded nearly the same 2PD results as bare hands (2.259 ± 0.086 mm vs 2.370 ± 0.078 mm, $p = 0.82$) (Figure 1A). In the surgeons' group, the effect of wearing gloves on tactile sensibility was similar to the non-surgeons group: 2PD was reduced while wearing most of the gloves, except Gammex Latex sensitive ®, which showed the same mean values as bare hands (1.741 ± 0.147 mm vs 1.741 ± 0.126 mm, $p < 0.99$) (Figure 1A, Table 3). A post-hoc analysis between professions showed better 2PD results in surgeons than in non-surgeons across all conditions with bare hands and with all types of gloves (Figure 1A, Table 3, $p < 0.05–0.001$).

For SWMT-testing, a two-way ANOVA reported a significant interaction of profession and glove type ($F (6, 312) = 2.33$, $p = 0.03$), with a statistically significant difference between professions (surgeons and non-surgeons) ($F (1, 52) = 7.19$, $p = 0.01$) and between glove types ($F (4.579, 238.1) = 58.22$, $p < 0.0001$) (Figure 1B, Table 6). A post-hoc analysis with the non-surgeons' group revealed a considerable deterioration of pressure threshold sensitivity with all types of gloves in comparison to bare hands ($p < 0.0001$) (Figure 1B, Table 4). In this aspect, Cardinal Health® showed better results than its competitors ($p < 0.05–0.001$) which in turn demonstrated no significant difference among each other (Figure 1B). In the surgeons' group, all types of gloves deteriorated the pressure threshold sensitivity compared to bare hands ($p < 0.0001$) (Figure 1B, Table 4). Here, Gammex Latex sensitive® showed better mean SWMT results than its competitors and was significantly better than Biogel Surgeons® (0.357 ± 0.048 g vs 0.459 ± 0.045 g) ($p = 0.02$). In a post-hoc analysis between professions, SWMT exhibited better results in surgeons compared to non-surgeons only with bare hands (0.086 ± 0.021 g vs 0.224 ± 0.016 g, $p < 0.0001$) and with Braun Vasco OP sensitive® (0.422 ± 0.034 g vs 0.589 ± 0.043 g, $p = 0.03$) (Figure 1B). SWMT of other glove types showed no significant differences between surgeons and non-surgeons.

Table 3. Descriptive statistics of two-point discrimination of non-surgeons (n = 27) and surgeons (n = 27): Without gloves, with wearing 6 different glove brands and testing of Gammex Latex sensitive in double, under- and oversized gloving.

Two point discrimination	Non-surgeons		Surgeons	
	Mean in mm	SEM	Mean in mm	SEM
without gloves	2.259	0.086	1.741	0.147
Braun Vasco OP sensitive	2.759	0.086	2.130	0.130
Cardinal Health Protexis Neoprene	2.556	0.090	2.037	0.119
Semper med supreme	2.759	0.090	2.093	0.122
Semper med syntegra	2.759	0.098	2.000	0.158
Biogel Surgeons	2.778	0.077	2.222	0.090
Gammex Latex sensitive	2.370	0.078	1.741	0.126
Semper med supreme double	2.815	0.061	2.204	0.085
Semper med supreme undersized	2.704	0.077	1.778	0.114
Semper med supreme oversized	2.796	0.108	1.963	0.131

SEM = Standard error of the mean.

Table 4. Descriptive statistics of Semnes-Weinstein monofilament test of non-surgeons (n = 27) and surgeons (n = 27): Without gloves, with wearing 6 different glove brands and testing of Gammex Latex sensitive in double, under- and oversized gloving.

Semnes-Weinstein monofilament test	Non-surgeons		Surgeons	
	Mean in g	SEM	Mean in g	SEM
without gloves	0.224	0.021	0.086	0.016
Braun Vasco OP sensitive	0.589	0.043	0.422	0.034
Cardinal Health Protexis Neoprene	0.460	0.023	0.404	0.045
Semper med supreme	0.540	0.026	0.438	0.043
Semper med syntegra	0.545	0.035	0.422	0.047
Biogel Surgeons	0.600	0.030	0.459	0.045
Gammex Latex sensitive	0.600	0.030	0.357	0.048
Semper med supreme double	0.685	0.041	0.589	0.060
Semper med supreme undersized	0.307	0.024	0.386	0.037
Semper med supreme oversized	0.585	0.031	0.547	0.047

SEM = Standard error of the mean.

Table 5. ANOVA Table of Glove type x Profession on two-point discrimination.

Source	SS	DF	MS	F (DFn, DFd)	P value
Glove type x Profession	0.6204	6	0.1034	F (6, 312) = 1.109	P = 0.3569
Glove type	12.57	6	2.095	F (4.817, 250.5) = 22.47	P < 0.0001
Profession	35.29	1	35.29	F (1, 52) = 20.48	P < 0.0001
Subject	89.59	52	1.723	F (52, 312) = 18.48	P < 0.0001
Residual	29.09	312	0.09325		

SS = sum of squares, DF = degress of freedom, MS = mean squares, F = F-ratio.

Table 6. ANOVA Table of Glove type x Profession on Semnes-Weinstein monofilament test.

Source	SS	DF	MS	F (DFn, DFd)	P value
Glove type x Profession	0.2187	6	0.03646	F (6, 312) = 2.333	P = 0.0322
Glove type	5.457	6	0.9096	F (4.579, 238.1) = 58.22	P < 0.0001
Profession	1.079	1	1.079	F (1, 52) = 7.190	P = 0.0098
Subject	7.804	52	0.1501	F (52, 312) = 9.606	P < 0.0001
Residual	4.874	312	0.01562		

SS = sum of squares, DF = degress of freedom, MS = mean squares, F = F-ratio.

3.2. The effects of surgical profession and glove layer on tactility

For tactile investigation of glove layer, i.e., single and double gloving, on surgeons and non-surgeons, we used Semper med supreme® gloves, which are the standard gloves at our institution and compared them to bare hands.

For 2PD-testing, a two-way ANOVA showed a statistically significant difference between professions (surgeons and non-surgeons) ($F (1, 52) = 23.36$, $p < 0.0001$) and between glove layer ($F (1.783, 92.71) = 35.05$, $p < 0.0001$), and no interaction between these factors ($F (2, 104) = 0.6577$, $p = 0.52$) (Figure 2A, Table 7). Post-hoc analysis showed a significant decrease of 2PD of single-gloving ($p < 0.003$) and double-gloving ($p < 0.0001$) compared to bare hands in both profession groups, however, there was no impact of double-gloving compared to single-gloving detectable in surgeons and non-surgeons (Figure 2A, p = 0.58 and p = 0.69 respectively). When comparing double gloving between surgeons and non-surgeons, 2PD of surgeons performed better (2.204 ± 0.085 mm vs 2.815 ± 0.061 mm, $p < 0.0001$).

For SWMT-testing, a two-way ANOVA showed a statistically significant difference between professions (surgeons and non-surgeons) ($F (1, 52) = 7.74$, $p = 0.008$) and between glove layer ($F (1.631, 84.82) = 133.3$, $p < 0.0001$), and no interaction between these factors ($F (2, 104) = 0.28$, $p = 0.76$) (Figure 2B, Table 8). Interestingly, post-hoc analysis showed a significant reduction of pressure threshold sensibility with double gloving compared to single gloving in surgeons and non-surgeons (Figure 2B, $p = 0.0004$ and p = 0.003 respectively). When wearing double gloves, there is no statistically difference of SWMT between surgeons and non-surgeons (Figure 2B, $p = 0.48$).

These results suggest a deterioration of sensibility only with regard to pressure threshold sensibility with double gloving. Furthermore, surgeons performed only better in 2PD when wearing different glove layers, but not in SWMT.

3.3. The effects of surgical profession and glove fit on tactility

Finally, we investigated the tactile effect of glove fit, i.e., fitted, under- and oversized gloves using Semper med supreme® gloves on surgeons and non-surgeons and compared them to bare hands.

Table 7. ANOVA Table of Glove layer x Profession on two-point discrimination.

Source	SS	DF	MS	F (DFn, DFd)	P value
Glove layer x Profession	0.1512	2	0.07562	F (2, 104) = 0.6577	P = 0.5202
Glove layer	8.059	2	4.029	F (1.783, 92.71) = 35.05	P < 0.0001
Profession	14.52	1	14.52	F (1, 52) = 23.36	P < 0.0001
Subject	32.32	52	0.6216	F (52, 104) = 5.406	P < 0.0001
Residual	11.96	104	0.1150		

SS = sum of squares, DF = degress of freedom, MS = mean squares, F = F-ratio.

Table 8. ANOVA Table of Glove layer x Profession on Semnes-Weinstein monofilament test.

Source	SS	DF	MS	F (DFn, DFd)	P value
Glove layer x Profession	0.01376	2	0.006878	F (2, 104) = 0.2787	P = 0.7574
Glove layer	6.581	2	3.291	F (1.631, 84.82) = 133.3	P < 0.0001
Profession	0.5063	1	0.5063	F (1, 52) = 7.744	P = 0.0075
Subject	3.400	52	0.06538	F (52, 104) = 2.649	P < 0.0001
Residual	2.567	104	0.02468		

SS = sum of squares, DF = degress of freedom, MS = mean squares, F = F-ratio.

For 2PD-testing, a two-way ANOVA showed a statistically significant interaction between profession and glove fit ($F (3, 156) = 4.08$, $p = 0.0081$), as well as a significant difference between professions (surgeons and non-surgeons) ($F (1, 52) = 28.63$, $p < 0.0001$) and between glove fit ($F (2.815, 146.4) = 18.34$, $p < 0.0001$) (Figure 3A, Table 9). In a post-hoc analysis, 2PD of non-surgeons did not change with under- and oversized gloves compared to the fitted size, while in surgeons, undersized gloves showed significantly better 2PD values than well-fitted ones (1.778 ±

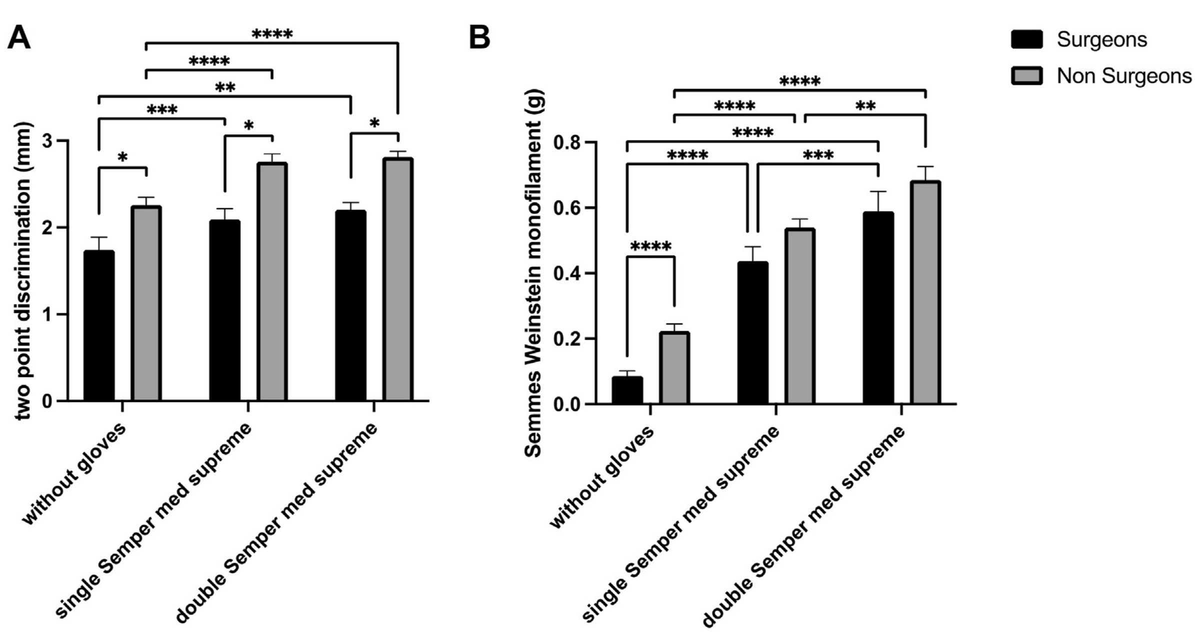

Figure 2. The effects of surgical profession and glove layer on tactility. (A) Two-point discrimination and (B) Semmes-Weinstein monofilament test of surgeons (black; n = 27) and non-surgeons (gray; n = 27) wearing single and double layer of Semper med supreme® gloves compared to without gloves. Data are means ± SEM. Two-way repeated measures ANOVA with Tukey's post-hoc test. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$.

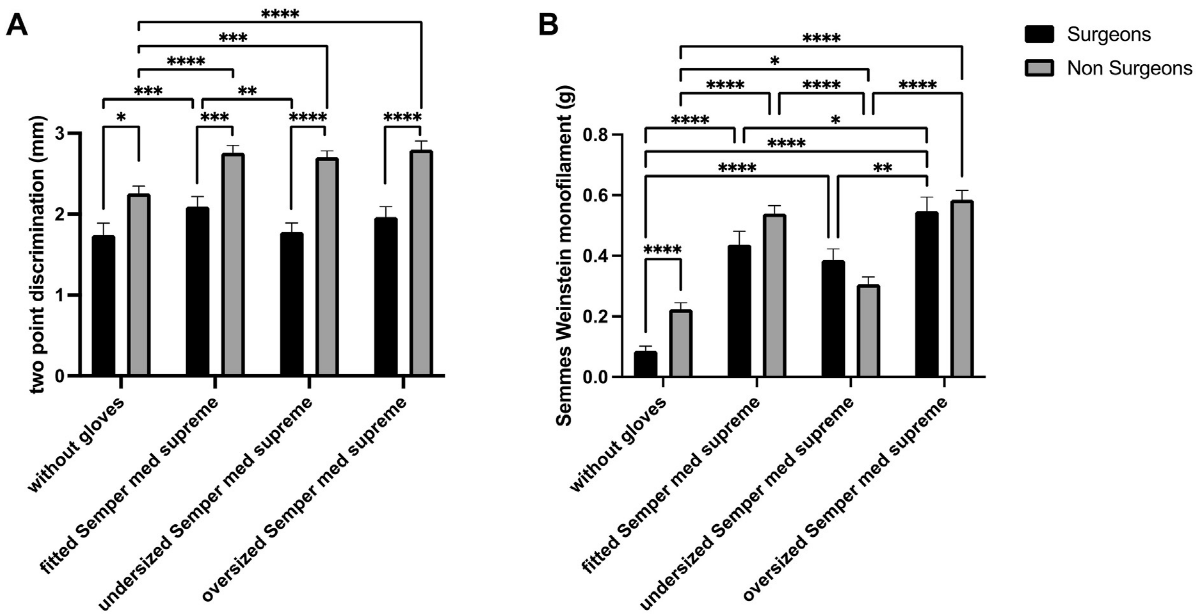

Figure 3. The effects of surgical profession and glove fit on tactility. A) Two-point discrimination and (B) Semmes-Weinstein monofilament test of surgeons (black; n = 27) and non-surgeons (gray; n = 27) wearing different glove fit (fitted, under- and oversized gloves) of Semper med supreme® gloves compared to without gloves. Data are means ± SEM. Two-way repeated measures ANOVA with Tukey's post-hoc test. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$.

Table 9. ANOVA Table of Glove fit x Profession on two-point discrimination.

Source	SS	DF	MS	F (DFn, DFd)	P value
Glove fit x Profession	1.318	3	0.4394	F (3, 156) = 4.077	P = 0.0081
Glove fit	5.929	3	1.976	F (2.815, 146.4) = 18.34	P < 0.0001
Profession	29.26	1	29.26	F (1, 52) = 28.63	P < 0.0001
Subject	53.15	52	1.022	F (52, 156) = 9.482	P < 0.0001
Residual	16.81	156	0.1078		

SS = sum of squares, DF = degress of freedom, MS = mean squares, F = F-ratio.

0.114 mm vs 2.093 ± 0.122 mm, $p = 0.002$) and nearly reversed the effect of glove wearing, setting the 2PD value at a similar level as with bare hands (1.778 mm vs 1.741 mm, Figure 3A). Comparing surgeons and non-surgeons in a post-hoc analysis, surgeons showed better 2PD values with under- and oversized gloves (Figure 3A, both $p < 0.0001$).

For SWMT-testing, a two-way ANOVA reported a significant interaction of profession and glove fit (F (3, 156) = 7.25, $p = 0.0001$), as well as a significant difference between glove fit (F (2.465, 128.2) = 103.8, $p < 0.0001$), but no difference between professions (surgeons and non-surgeons) (F (1, 52) = 2.13, $p = 0.15$) (Figure 3B, Table 10). For non-surgeons, SWMT showed in a post-hoc analysis significantly better results when wearing undersized gloves compared to the well-fitted size (0.307 ± 0.024 g vs 0.540 ± 0.026 g, $p < 0.0001$, Figure 3B). In the surgeons' group, however, undersized gloves showed better mean values than the well-fitted glove size, though this was not significant (0.386 ± 0.037 g vs 0.438 ± 0.043 g, $p = 0.41$). Oversized gloves in surgeons seemed to have a deterioration of SWMT compared to well-fitted (0.547 ± 0.047 g vs 0.438 ± 0.043 g, $p = 0.02$) and undersized gloves (0.547 ± 0.047 g vs 0.386 ± 0.037 g, $p = 0.0014$). In non-surgeons, oversized gloves were significantly worse than undersized gloves (0.585 ± 0.031 vs 0.307 ± 0.024, $p < 0.0001$), but was not significantly inferior to fitted gloves (0.585 ± 0.031 vs 0.540 ± 0.024, $p = 0.37$).

Table 10. ANOVA Table of Glove fit x Profession on Semnes-Weinstein monofilament test.

Source	SS	DF	MS	F (DFn, DFd)	P value
Glove fit x Profession	0.3691	3	0.1230	F (3, 156) = 7.250	P = 0.0001
Glove fit	5.286	3	1.762	F (2.465, 128.2) = 103.8	P < 0.0001
Profession	0.1327	1	0.1327	F (1, 52) = 2.134	P = 0.1501
Subject	3.233	52	0.06218	F (52, 156) = 3.664	P < 0.0001
Residual	2.648	156	0.01697		

SS = sum-of-squares, DF = degress of freedom, MS = mean squares, F = F-ratio.

Overall, different glove sizes have a significant impact in both surgeons and non-surgeons regarding 2PD and SWMT, favoring the undersized gloves and secondly the well-fitted gloves in terms of sensibility performance. Furthermore, surgeons performed only better in 2PD compared to non-surgeons with different glove fit, but not in SWMT.

4. Discussion

We can describe the human hand as an "extension of our brain", as active touch with our hands leads to cortical synaptic changes, which analyze the quality of the sensation [2]. Wearing gloves puts an additional layer onto the sensory receptors located in our fingers, which inhibits natural touch sensibility. We could confirm in this study, as previously demonstrated [3, 5, 9], that wearing gloves reduces fine touch discrimination in non-surgeons and as well as in surgeons (Figure 1). Interestingly, we found that Gammex Latex sensitive® (with the thinnest material: 0,14 mm) have nearly the same two-point-discrimination (2PD) as bare hands, therefore approaching the performance levels of direct skin sensibility (Figure 1). In this context, other studies confirmed as well that thinner gloves outperform gloves made of thicker material in tactile sensibility [3, 8, 22]. Pressure threshold performance by Semmes-Weinstein monofilament testing (SWMT) was significantly reduced while wearing gloves, yet, the mean values of Gammex Latex sensitive® gloves were better once again than its competitors. Nevertheless, the superior performance of thinner gloves (Gammex Latex sensitive®) comes with higher financial expenses, which has to be taken into consideration, since the annual expenses caused by surgical gloves in German hospitals has been increasing to 47 million Euros in 2020 [23]. In this regard, the value-for-money topic is very debated: An US-American survey conducted on 500 plastic surgery medical practitioners showed that 36.5% consider gloves as a price-wise investment and would pay increased costs (10–25%) for better gloves [24]. Altogether, the clinical correlation of our findings would recommend an adjustment of the choice of the glove type to the clinical task, e.g., thinner gloves in the field of microsurgery.

Additionally, we confirmed a positive impact of (micro-) surgical experience on tactile sensibility: Surgeons exhibited superior 2PD with both bare and gloved hands compared to non-surgeons (Figure 1, Tables 5 and 6). For SWMT, a benefit of surgical experience was dependent on the glove type, and was only significant with bare hands and with Braun Vasco OP sensitive® in the post-hoc analysis, although mean values of the surgeons' SWMT were better with all other glove types. These results are in accordance to Schmauss et al., who demonstrated that long-term tactile training could reduce the known age-dependent decline of the sensibility of the hand [14]. In this regard, the age between both groups in this study was comparable (Table 1; $p = 0.07$), thus decreasing any age-related bias. It has to be noted that we included surgeons with a mean microsurgical experience of 3 years, which may have a compound effect on the superior tactile sensibility in the surgeons' group.

Double-gloving during surgery can protect the surgeon from infections, e.g., needlestick injuries, and the patient from contamination through the surgeon and has become a common practice [11, 25]. However, presumed disadvantages, such as reduced tactile sensibility or diminished manual dexterity oppose these safety advantages [10]. Many surgeons do not care for double gloves, due to hand tingling/numbness/pain and decreased hand dexterity/sensibility [11], although glove perforation was reported in a recent systematic review as high as 14.4%, with 68.6% cases not identified by the practitioners [7]. Regarding sensibility testing, we can confirm in this study that double-gloving had a negative impact on SWMT, both for surgeons and non-surgeons, though no influence on 2PD was found (Figure 2). This is in accordance to previous studies which found the reason of decreased pressure threshold sensibility in the additional layer which causes increased material thickness and the possibility of movement of the layers against each other [3, 6, 10, 11]. A comparison between surgeons and non-surgeons showed that surgeons yielded better 2PD-values than non-surgeons when wearing double gloves, which supports the beneficial effect of surgical experience on tactile sensibility mentioned earlier. Regarding SWMT, double gloving was found to have no significant difference between both profession groups, although mean values of the surgeons' SWMT were better.

Interestingly, our study showed improved tactile performance with undersized gloves in both surgeons and non-surgeons compared to the well-fitted glove size (Figure 3). Furthermore, 2PD of undersized gloves in surgeons and SWMT in non-surgeons approached similar values as with bare hands. The reason may lie in the effect that the glove material is stretched out over the fingertip, leading to a more direct contact of the glove and also thinning out the glove material, which supports the beneficial effect of a thinner glove mentioned earlier. However, both groups noted subjective discomfort, when wearing undersized gloves. Similar studies reported that undersized gloves can limit the hand motion and cause pain and numbness of the hands [3, 12]. Oversized gloves, in contrast, are reported to be more comfortable [12], and had no clear negative impact on 2PD and SWMT compared to well-fitted gloves in our study. Indeed, an incorrect glove finger length and fingertip fit are according to a US-American study as high as 41.6% and are mostly derived from hand anatomy variations [24]. Moreover, non-fitting glove sizes were tested elsewhere to be less safe, with a higher perforation risk compared to well-fitted gloves [13]. Given those results, the best choice of the glove size is recommended to be well-fitted, but with regard to tactile sensibility rather favors an undersized glove – at the expense of comfort/mobility and the risk of perforation. In this point, we acknowledge that the ideal glove type is dependent not only on the sensibility performance but also on other various factors which have been described in the literature with dexterity, grip strength, fitting, reliability and hand hygiene [26]. Upon examination of an impact of surgical experience, surgeons were found to yield better 2PD-values than non-surgeons with under- and oversized gloves, but there was no significant differences in SWMT in both gloved conditions.

The various degress of sensibility have been described with spatiality, intensity, temporality and modality [27]. In this study, the overall results of the glove-wearing conditions demonstrated better fingertip sensibility of surgeons mainly in 2PD which can be interpreted as increased spatial precision of sensibility. It has been discovered that elevated 2PD is related to the innervation density of the finger pulp, in which each axon represent a sensory field [27]. In this context, sensory training has been found to generate a substantial improvement in stimulus discrimination, cortical sensory skills and motor performance [2, 14, 28]. Thus, the positive impact of surgical experience on tactile sensibility can be hereby explained. Upon examination of pressure threshold sensibility, which represents the quality of intensity, only the bare hand condition and one single-gloved condition (Braun Vasco OP sensitive®) demonstrated a significant positive impact of surgical experience. In contrast to 2PD, pressure sensibility is encoded by neural impulses per time of the same axon, instead of recruitment of adjacent axons [27]. Apparently, wearing a layer of glove material results in a disturbance of pressure intensity detection and natural axon stimulation, regardless of the benefit of a higher number of axons developed under surgical training. From another perspective, the impact of surgical experience on a possible change in the (somato-)sensory cortex represents another dimension of analysis and remains to be evaluated.

Possible limitations of this study may be the low number of participants of 27 non-surgeons and 27 surgeons in a single center and that there was no matching performed regarding gender and age. Furthermore, there is reason to belief, that - besides gender and age - ethnicity has also a different impact on tactile sensation, as shown in previous studies [14, 18, 29]. However, the evaluation of surgical experience and different glove wearing conditions on tactile sensibility was conducted as an explorative pilot study which aimed at the general comparison of surgeons and non-surgeons as cohorts and resulted in the above-mentioned significant findings, approving the conducted study design. In addition, the participants were tested blind-folded, which would suggest an enhancement of tactile sensibility. Studies previously demonstrated that blind subjects may develop higher sensitivity of the median nerve which can enhance the tactile sensibility of the index finger through compensatory brain plasticity [30, 31]. However, neuroplasticity is a lengthy ongoing process [32], which would have a minor impact on our study design by eliminating the visual sense only for a short period of time.

5. Conclusion

Our study found a significant beneficial effect of surgical experience on the cutaneous sensibility measurements of two-point discrimination and pressure threshold sensibility. Surgeons practicing microsurgery showed an improved tactile spatial acuity, which may be due to long-time fine-motoric practice. Among six different glove types and wearing conditions, the best tactile performance was reached by wearing: thinner gloves, single gloving (rather than double gloving) and undersized/fitted gloves. Surgeons and microsurgeons should feel encouraged to try different glove types and wearing conditions to increase their surgical performance through better tactile sensibility, favorably in procedures which require higher fingertip sensibility and accuracy. Therefore, unproper choice (oversized gloves, double gloving) may lead to inappropriate use of force and reduce precision/accuracy in maneuvering tissues or applying sutures, particularly in microsurgery.

Declarations

Author contribution statement

Tanita Man: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Jun Jiang: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Manuela Schulz: Conceived and designed the experiments; Analyzed and interpreted the data.

aydar Kükrek and Julia Betzl: Analyzed and interpreted the data; Wrote the paper.

Hans-Günther Machens and Holger C. Erne: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Philipp Moog: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Analyzed and interpreted the data;

Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no competing interests.

Additional information

No additional information is available for this paper.

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