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Hand Sensibility, Strength, and Laxity of High-Level Musicians Compared to Non- Musicians

Susan EG Sims, MD[1], **Laura Engel, BS**[2], **Warren C Hammert, MD**[3], and **John C Elfar, MD**[3]

[1]Department of Radiology, University of Rochester, Rochester, NY

[2]University of Rochester School of Medicine and Dentistry, Rochester, NY

[3]Department of Orthopaedic Surgery, University of Rochester, Rochester, NY

Abstract

Purpose—To determine whether musicians have more sensitive, stronger, and flexible hands than non-musicians.

Methods—One hundred musicians and 100 control subjects were assessed for two-point discrimination, Semmes-Weinstein monofilament light touch, grip and pinch strength, and laxity. Musicians were included if enrolled as instrumental performance majors at a four-year accredited conservatory of music. Non-musician controls were university students who never or rarely engaged in playing an instrument. All subjects were between the ages of 18 and 28. Exclusion criteria were history of any hand condition, trauma, surgery, or diabetes. Statistical analyses were carried out using t-test, ANOVA, and correlation coefficients as appropriate.

Results—High-level musicians in our cohort showed the same handedness (dominance) as the general population. The musicians were weaker than the non-musicians Male musicians were significantly weaker in pinch and grip bilaterally than non-musicians whereas female musicians were significantly weaker only in grip on the right/dominant side. Two-point discrimination was significantly less in musicians for the left/non-dominant index, ring, and small fingers, right/ dominant small and dominant index finger. Semmes-Weinstein testing was significantly better for the right/dominant digits, including the thumb, but not the left digits with the exception of the ring and non-dominant middle and ring. There was no difference in laxity between the 2 groups.

Discussion—High-level musicians have, in general, more sensitive but weaker hands than non-musicians but the differences seem small and may not be clinically important.

Level of Evidence—Diagnostic Level III

Keywords

Laxity; Light touch threshold; Musicians; Spatial discrimination; Two point discrimination

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Corresponding author: John Elfar, MD, University of Rochester Medical Center, Department of Orthopaedics and Rehabilitation, 601 Elmwood Ave., Box 665, Rochester, NY 14642. 585-273-3157, fax 585-276-1134, openelfar@gmail.com.

Introduction

High-level instrumental musicians such as music performance majors (i.e., pre-professional) and professional musicians spend many hours daily practicing or performing. Such activity involves highly coordinated, repetitive use of the hands to master complex patterns of finger motion necessary to produce rapid musical passages. Musicians will often need to produce as many as 1400 notes per minute or 72 finger shifts per second[1], requiring a staggering amount of digital precision and velocity. Similar to elite athletes, these expert performers often become injured as a result of their craft. A better understanding of the attributes of the musicians' hand may assist in the overall goal of returning these unique individuals to pre-injury level of function.

Studies in the neuroscience literature have revealed enlarged areas of the cortical brain corresponding to hand sensorimotor control in musicians[2], leading to speculation regarding potential increased capability in these domains. However, the rare studies comparing sensorimotor skills of musicians to non-musicians are equivocal. One study[3] of sensation in the fingers of string players did not find a statistically significant difference in the two-point discrimination and light touch sensation as measured by Semmes-Weinstein monofilaments between string players and non-musicians. However, the study was limited to 10 subjects in each group. In another study[2] performed to assess the effectiveness of Hebbian stimulation (coactivation of fingertip sensory receptors in a manner designed to increase the interconnectedness of receptors and improve spatial acuity) on the fingers of pianists as opposed to non-musicians, both study groups were tested with regard to two-point discrimination of the bilateral index fingers. In that study of 14 patients per group, the authors found the pianists had a significantly lower discrimination threshold than the non-musicians.

The purpose of this study was to assess musicians and non-musicians specifically to determine potential differences in hand sensorimotor function and laxity. Our hypothesis was that high-level musicians would have improved measures of standard sensory parameters such as two-point discrimination and light touch, motor parameters such as grip and pinch strength, and measurements of laxity such as hyperextension testing.

Materials and Methods

We tested 100 musicians and 100 non-musicians for sensibility, strength, and flexibility of both hands. All testing was conducted by 2 of the authors and took place on the campuses of a high-level conservatory of music and a nearby 4-year university. Both authors took part in testing both groups, and participants were randomly assigned. Inclusion of participants in both groups was voluntary and included consecutive volunteers interested in participating until the recruitment totals were reached.

The second author was extensively trained by the first author with regard to technique prior to the start of the study. The first author observed the second author test approximately 10 subjects to ensure consistent, accurate testing. Participants were measured by either available evaluator. Testing was conducted on campus at the conservatory (musicians) and university (non-musicians), and was not blinded. Inclusion criteria for musicians were identification as an instrumental performance major at the conservatory between the ages of 18 and 28. Non-musicians at the university age 18-28 were included based on self-identification as either never or rarely having played an instrument. Exclusion criteria were any history of hand trauma, hand surgery, or diabetes mellitus. All testing was performed with verbal consent and after the approval of the institutional review board.

We measured sensibility using two-point discrimination (MacKinnon-Dellon Disk-Criminator, Neuroregen, Bel Air, MD)[4] and Semmes-Weinstein monofilament testing devices (Touch-Test Sensory Evaluators 6.65, 4.56, 4.31, 3.61, 2.83, North Coast Medical, Morgan Hill, CA and Jamar Semmes-Weinstein monofilaments, Patterson Medical Holdings, Bolingbrook, IL, 6.65, 4.56, 4.31, 3.61, 2.83, 2.44, 2.36, 1.65, Patterson Medical Holdings, Bolingbrook, IL)[5]. The same set of 8 monofilaments was used in every subject. The reliability, repeatability, normal values of these devices has been demonstrated in multiple studies[6-9]. All subjects were tested for two-point discrimination on the radial and ulnar aspects of the distal pad of all digits. The mean of the radial and ulnar measurements was used in our statistical calculations. Calluses, found largely on the fingertips of string, harp, and guitar players, were carefully avoided, as our intention was not to compare the acquired decrease in sensibility of certain areas of the digits in these subgroups of musicians. This was done despite the lack of literature on this subject but based on our observation that calluses are not innervated and may dampen the sensibility of the skin beneath them. Our objective was to compare baseline sensibility of musicians vs non-musicians. Although we could have tested sensibility over calluses, we chose to avoid these areas to focus at the area most likely to have the greatest sensibility and not test areas prone to decreased sensibility secondary to current patterns of use. Subjects were asked to place the hand palm up on a table and close their eyes. Subjects were given an example of one point and 2 points and asked if they could tell the difference. Testing then commenced beginning with the left thumb and proceeding to the index, middle, ring, and small fingers. The same order was used in the right hand. The device was pressed to each finger until the subject could feel it and the skin blanched, then it was released. The device was placed parallel to the long axis of the digit and perpendicular to the skin surface. One point was alternated randomly with 2 points of varying widths, and the narrowest, most reliable two-point discrimination was noted. Normal was considered to be any measurement ≤ 6mm[9].

We tested subjects with Semmes-Weinstein monofilaments in a similar fashion, with the hand palm up on a table and eyes closed. The monofilaments were pressed to each digit until they just bent and the subjects were asked on which digit they felt the filament. Testing began with the largest filament and proceeded with smaller filaments until the subject could no longer feel a touch. The smallest filament was recorded for each digit. Normal was considered to be .08 grams and below[5].

Strength was measured using grip and pinch gauges (Saehan (Jamar) Dynamometer 5 position grip strength gauge, Saehan hydraulic pinch gauge, Saehan Corp, Masan, Korea). Subjects were asked to firmly grip or pinch the gauge 3 times with each hand. Each of these trials was recorded. The mean of the 3 measurements was used in our statistical calculations. Normative data by age and sex are available in the literature[10-12].

Laxity was assessed by asking the subjects if they were able to comfortably touch the thumb to the forearm with flexion of the wrist or bend the small finger in extension past 90 degrees[13,14]. Prevalence of laxity is estimated to be between 3-34%[15].

Statistical analyses

The data were analyzed with regard to any statistically significant differences between musicians and non-musicians and within musicians grouped by instrument. Data were analyzed with respect to right/left and dominant/non-dominant hands to highlight any differences or lack thereof in handedness of the individual vs handedness (or asymmetry of playing position) of the instrument. Data were analyzed with respect to sensibility, strength, and laxity using standard formulas such as the t-test, ANOVA, and correlation coefficient. Statistical significance was attributed to P-values ≤ 0.05. A post-hoc power analysis was done on the two-point discrimination and Semmes-Weinstein parameters. Confidence intervals were calculated. All data analysis was done with the assistance of departmental statisticians.

Results

The age, sex, and hand dominance of test subjects are presented in Table 1. There was no significant difference in these characteristics. We also gathered data regarding instrument played, years played, hours per day spent in personal practice, and years at current practice level for the musician group (Appendix Table 1).

The two-point discrimination of the musicians was significantly (P<0.05) better than the non-musicians for the left index, ring, and small fingers and the right small finger when the data were grouped into right/left hands (Table 2). Findings were similar when grouped by hand dominance (Table 2) with the exception of the dominant index finger, which was significantly better. The musicians were subdivided into groups of like instruments consisting of woodwinds (flute/oboe/clarinet/bassoon/saxophone), strings (violin/viola/cello/bass), brass (trumpet/french horn/trombone/euphonium/tuba), percussion/piano/organ, and harp/guitar (Table 3). Two-point discrimination of right/left and dominant/non-dominant hands were compared within each instrumental group. Significant differences were found only in the harp/guitar group when dominant/non-dominant hands were compared (P=0.02).

Semmes-Weinstein testing was significantly (P<0.05) better for musicians in the left ring finger and all digits in the right hand (Table 4). Findings were similar when the data were grouped by hand dominance with the exception of the non-dominant middle finger, which was significantly more sensitive. Only in the right vs left and dominant vs non-dominant ring fingers was there a difference that crossed over to the next larger monofilament (the 2.44 monofilament). When musicians were divided into groups of like instruments for comparison of right vs left and dominant vs non-dominant hands (Appendix Table 2), no significant difference was found between the hands. The sensibility data were analyzed for subjects with identical sensibility (Appendix Table 3). When the sensibility data were controlled for age and sex, only the Semmes-Weinstein left index finger data attained statistical significance (P=0.07 unmatched, P=0.05 matched). No tests lost significance.

The non-musicians were significantly stronger (*P*<0.02) bilaterally in the male group (*P*<0.03) and the right/dominant grip of females (*P*<0.04) Appendix Table 4) When the data were grouped by hand dominance, this did not change. All measurements were at the low to below normal (greater than one standard deviation below the mean) range of published normative data for sex and age[10,12]. Only woodwind and percussion/piano/organ players had a significantly different (*P*<0.05) grip strength when comparing right vs left and dominant vs non-dominant hands (with the addition of the harp/guitar players) within groups of musicians (Appendix Tables 5 and 6).

Since the musicians were, in general, significantly more sensitive but weaker than non-musicians, we performed a correlation coefficient analysis of sensibility and strength within the musician group (Appendix Table 7). Two-point discrimination was significantly inversely related to pinch on the left. Semmes-Weinstein monofilament testing was significantly related to grip on the left. However, the r-values for both of these relationships were low and represent weak correlation.

Lastly, we examined laxity of the wrist and small finger using 2 elements of the Beighton laxity scoring system[14] (Table 5). There was a 13-42% prevalence of laxity without a significant difference between musicians and non-musicians.

Discussion

Musicians in this study were, in general, more sensitive but weaker than age-matched non-musicians, and similar for laxity. Our hypothesis was thus partially accepted, as we proposed musicians would be more sensitive, stronger, and more flexible than non-musicians. The differences noted, although statistically significant, would not likely be clinically important. Two-point discrimination was always within 1 mm between the groups, which is the smallest increment for which the device tests. The Semmes-Weinstein results were similar in that the average differences, with very few exceptions, did not cross over from one size filament to the next. All subjects were able to sense monofilaments in the normal or better range between 2.83 and 1.65. Nevertheless, we did find differences that were statistically significant.

Our speculation is musicians' hands are weaker than non-musicians because of the protection musicians provide for their upper extremities. Although data were not collected regarding sports played or other physical activities for the musicians tested, anecdotally these individuals likely had less opportunity than the non-musicians to participate in sports while enrolled full time at a conservatory of music where intercollegiate sports programs were not as readily available. It may be that strength is always inversely related to sensibility, particularly at extremes of performance of any kind. If true, then perhaps testing should be done to further delineate the extent to which this relationship exists with respect to performance level or type of activity.

Two-point discrimination and detection threshold were significantly, albeit weakly, related to some strength measurements in musicians. In addition, the clinical importance, if any, is yet to be determined. Given the potential sensibility and strength differences between musicians and non-musicians, the issue of a causal relationship between the 2 is intriguing but beyond the scope of our study. It is possible that better spatial discrimination is found in musicians who grip their instruments less strongly, although this does not explain the opposite correlation between detection threshold and strength. It is also possible this finding is, although statistically significant, not clinically important or relevant to performance. More study is required with regard to this question.

Many musical instruments are played asymmetrically, for example the violin is fingered with the left hand and bowed with the right regardless of hand dominance. However, with the exception of two-point discrimination between the dominant and non-dominant hands of harpists and guitarists and right/left grip strength of woodwind and percussion/piano/organ players and dominant/non-dominant hands of harp/guitar players, there were no significant differences between the hands of musicians. Harpists have calluses on all fingers of both hands except the small, and guitarists have calluses on the fingers of their left hand (the majority of guitarists play with the instrument in the left hand position). It is possible some callus formation was not visible and could have skewed the results. With regard to woodwind instruments, the right hand is always in the distal position on the instrument and perhaps gains greater grip strength over time secondary to this configuration. This does not, however, explain the differences found in percussion/piano/guitar players and harp/guitar players with respect to grip strength.

Laxity was not found to be statistically significantly different between the musicians and non-musicians we tested, although increased right wrist laxity in musicians approached significance (P=0.07). It may be that excess laxity is not an advantage with respect to musical technique and thus is not found in this population either as a natural or developed characteristic. Anecdotally, some of the musicians tested in this study with seemingly excessive laxity expressed awareness of this trait and related they found it to be a hindrance in the handling of their instrument. Given the 3-34% prevalence[15] of laxity in the population, the 13-42% prevalence seen in our study was somewhat high.

Strengths of this study include the large sample size and small number of individuals performing testing, thus limiting variability in measurement. Limitations of this study primarily involve the inherent tendency of two-point discrimination and Semmes-Weinstein testing devices to be subjective. Every effort was made to standardize the testing methods using these devices as described above. Although attempts were made to vary the two-point discrimination test, it is possible the subjects were able to accurately guess on some occasions. In addition, although effort was made to apply a consistent pressure throughout threshold testing, it is likely there was some uncontrollable variability in this. Although it would have been ideal for all subjects to be tested by the same examiner, this was not logistically possible. However, testing was limited to 2 of the authors with extensive training and side-by-side testing. An additional weakness was the lack of controlling for sex, which may have been a potential source of bias. Laxity was based on subjects reporting whether they could comfortably perform the tasks. They may have underreported discomfort in order to simply finish the extensive testing.

Many questions remain unanswered. This study shows that there are small statistically significant differences in the sensorimotor function of musicians. These differences may not be functionally relevant. Do musicians have more sensitive hands because they are musicians or are they musicians because they have more sensitive hands? With such small differences, are there any functional benefits to these differences? These questions were beyond the scope of the current study. In addition, although most instruments are played differently with the right hand as opposed to the left, there were not right vs left differences in the musician group. Further study is needed to ascertain the cause of the strength differences observed and to understand any cause-effect relationships in. high-level musicians who use the hands in ways that are quite different than non-musicians and who have detectable differences in sensory and motor function.

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Appendix Table 1

Characteristics of musician subjects

Instrument	
Flute	5
Oboe	8
Clarinet	5
Bassoon	5
Saxophone	2
Violin	10
Viola	9
Cello	5
Bass	7
Trumpet	1
French horn	1
Trombone	6
Euphonium	2
Tuba	1
Percussion	8
Harp	5
Guitar	2
Piano	17

Instrument	
Organ	1
Years played, average (range, SD)	11.1 (4-22, 3.37)
Hours per day practicing, average (range, SD)	3.26 (0.5-7, 1.27)
Years at current level of practice, average (range, SD)	4.11 (1-20, 2.76)

SD = standard deviation

Appendix Table 2

Semmes-Weinstein comparison within instrumental groups left vs right hands and Semmes-Weinstein comparison within instrumental groups non-dominant vs dominant hands

Semmes-Weinstein comparison within instrumental groups left vs right hands			
	Average (SD) left hand Semmes-Weinstein	**Average (SD) right hand Semmes-Weinstein**	
Woodwinds	2.44 (0.30)	2.46 (0.35)	$P = 0.85$
Strings	2.52 (0.25)	2.50 (0.24)	$P = 0.47$
Brass	2.65 (0.23)	2.59 (0.33)	$P = 0.74$
Percussion/piano/organ	2.51 (0.20)	2.43 (0.27)	$P = 0.18$
Harp/guitar	2.42 (0.14)	2.40 (0.22)	$P = 0.70$
Left: ANOVA, 5 groups, p = 0.35 Right: ANOVA, 5 groups, p = 0.58			
Semmes-Weinstein comparison within instrumental groups non-dominant vs dominant hands			
	Average (SD) non-dominant hand Semmes-Weinstein	**Average (SD) dominant hand Semmes-Weinstein**	
Woodwinds	2.42 (0.30)	2.41 (0.29)	$P = 0.85$
Strings	2.51 (0.25)	2.51 (0.24)	$P = 0.81$
Brass	2.56 (0.23)	2.48 (0.34)	$P = 0.74$
Percussion/piano/organ	2.52 (0.21)	2.50 (0.29)	$P = 0.71$
Harp/guitar	2.42 (0.14)	2.40 (0.22)	$P = 0.70$
Non-dominant: ANOVA, 5 groups, p = 0.45 Dominant: ANOVA, 5 groups, p = 0.48			

SD = standard deviation

Appendix Table 3

Number of subjects with identical sensibility

Sensibility test	**Number of repeated patterns**	**Number of subjects with identical patterns among the number of repeated patterns**
2 point discrimination, radial and ulnar left hand (10 measurements)	6	12

Sensibility test	Number of repeated patterns	Number of subjects with identical patterns among the number of repeated patterns
2 point discrimination, radial and ulnar right hand (10 measurements)	6	13
Semmes-Weinstein, left hand (5 measurements)	23	93
Semmes-Weinstein, right hand (5 measurements)	26	103

Appendix Table 4

Grip and pinch data

	Musicians	**Non-musicians**	
Average grip/pinch, female, kg	Average (range, SD, CI)	Average (range, SD, CI)	
Grip left	22.4 (12-42, 5.9, ± 1.2)	24.4 (10-40, 5.1, ± 1.0)	*P* = 0.06
Grip right	24.0 (12-46, 6.5, ± 1.3)	26.5 (12-38, 5.1, ± 1.0)	*P* = **0.03**
Pinch left	5.7 (2.5-8.5, 1.1, ± 0.2)	6.0 (2-10, 1.4, ± 0.3)	*P* = 0.25
Pinch right	6.1 (2-9, 1.3, ± 0.3)	6.4 (2-11.5, 1.5, ± 0.3)	*P* = 0.26
Average grip/pinch, male, kg (range, SD, CI)			
Grip left	35.8 (12-66, 8.3, ± 1.6)	40.1 (20-65, 8.8, ± 1.7)	*P* = **0.02**
Grip right	38.4 (18-65, 9.4, ± 1.8)	43.6 (22-64, 8.8, ± 1.7)	*P* = **0.01**
Pinch left	8.2 (3-12, 1.8, ± 0.4)	9.2 (5.5-15, 1.8, ± 0.4)	*P* = **0.01**
Pinch right	8.0 (4-13.5, 1.5, ± 0.3)	9.7 (6-12.5, 1.7, ± 0.3)	*P* <**0.01**
Average grip/pinch, female, kg (range, SD, CI)			
Grip non-dominant	22.4 (12-42, 5.9, ± 1.2)	24.4 (10-40, 5.1, ± 1.0)	*P* = 0.06
Grip dominant	24.1 (12-46, 6.5, ± 1.3)	26.5 (18-38, 5.1, ± 1.0)	*P* = **0.03**
Pinch non-dominant	5.7 (2.5-8.5, 1.1, ± 0.2)	5.9 (2-10, 1.4, ± 0.3)	*P* = 0.30
Pinch dominant	6.1 (2-9, 1.3, ± 0.3)	6.4 (2-11.5, 1.5, ± 0.3)	*P* = 0.22
Average grip/pinch, male, kg (range, SD, CI)			
Grip non-dominant	35.8 (16-66, 8.2, ± 1.6)	40.5 (20-65, 9.7, ± 1.9)	*P* = **0.02**
Grip dominant	38.4 (18-65, 9.5, ± 1.9)	43.2 (24-61, 8.0, ± 1.6)	*P* = **0.01**
Pinch non-dominant	8.2 (3-12, 1.8, ± 0.4)	9.3 (5.5-15, 1.8, ± 0.4)	*P* < **0.01**
Pinch dominant	7.9 (4-13.5, 1.6, ± 0.3)	9.6 (5.5-14.5, 1.7, ± 0.3)	*P* <**0.01**

SD = standard deviation, CI = confidence interval

Appendix Table 5

Grip comparison within instrumental groups left vs right hands and pinch comparison within instrumental groups left vs right hands

Grip comparison within instrumental groups left vs right hands			
	Average (SD) left hand grip, kg	**Average (SD) right hand grip, kg**	
Woodwinds	27.0 (9.6)	31.1 (12.4)	*P* < **0.01**
Strings	30.8 (10.1)	30.9 (10.2)	*P* = 0.87
Brass	31.5 (8.6)	31.7 (9.7)	*P* = 0.90
Percussion/piano/organ	27.8 (10.6)	31.0 (11.3)	*P* < **0.01**
Harp/guitar	26.5 (9.3)	29.2 (9.2)	*P* = 0.16
Left: ANOVA, 5 groups, p = 0.47 Right: ANOVA, 5 groups, p = 0.99			
Pinch comparison within instrumental groups left vs right hands			
	Average (SD) left hand pinch, kg	**Average (SD) right hand pinch, kg**	
Woodwinds	6.7 (1.9)	7.0 (2.3)	*P* = 0.28
Strings	7.0 (1.9)	7.0 (1.8)	*P* = 0.83
Brass	7.1 (2.0)	7.2 (1.6)	*P* = 0.81
Percussion/piano/organ	7.1 (2.3)	7.1 (1.7)	*P* = 0.98
Harp/guitar	6.0 (1.3)	6.5 (1.5)	*P* = 0.28
Left: ANOVA, 5 groups, p = 0.73 Right: ANOVA, 5 groups, p = 0.93			

SD = standard deviation

Appendix Table 6

Grip comparison within instrumental groups non-dominant vs dominant hands and pinch comparison within instrumental groups non-dominant vs dominant hands

Grip comparison within instrumental groups non-dominant vs dominant hands			
	Average (SD) non-dominant hand grip, kg	**Average (SD) dominant hand grip, kg**	
Woodwinds	27.0 (9.6)	31.1 (12.0)	*P* < **0.01**
Strings	30.7 (10.2)	31.0 (10.2)	*P* = 0.69
Brass	31.5 (8.6)	31.7 (9.7)	*P* = 0.90
Percussion/piano/organ	27.9 (10.5)	30.8 (12.0)	*P* = **0.02**
Harp/guitar	26.1 (9.1)	29.7 (9.2)	*P* = **0.04**
Non-dominant: ANOVA, 5 groups, p = 0.47 Dominant: ANOVA, 5 groups, p = 1.00			
Pinch comparison within instrumental groups non-dominant vs dominant hands			

Grip comparison within instrumental groups non-dominant vs dominant hands			
	Average (SD) non-dominant hand grip, kg	**Average (SD) dominant hand grip, kg**	
	Average (SD) non-dominant hand pinch, kg	**Average (SD) dominant hand pinch, kg**	
Woodwinds	6.7 (1.9)	7.0 (1.9)	*P* = 0.28
Strings	7.0 (1.9)	7.0 (1.8)	*P* = 0.91
Brass	7.1 (2.2)	7.2 (1.6)	*P* = 0.81
Percussion/piano/organ	7.1 (2.3)	7.0 (1.8)	*P* = 0.65
Harp/guitar	6.2 (1.5)	6.3 (1.3)	*P* = 0.67
Non-dominant: ANOVA, 5 groups, p = 0.75 Dominant: ANOVA, 5 groups, p = 0.89			

SD = standard deviation

Appendix Table 7

Correlation between measurements of sensitivity and strength

	Pinch, left	***P* value**	**Grip, left**	***P* value**
Two-point discrimination, left	Correlation coefficient = -0.15	**0.03**	Correlation coefficient = -0.12	0.08
	Pinch, right	***P* value**	**Grip, right**	***P* value**
Two-point discrimination, right	Correlation coefficient = -0.023	0.74	Correlation coefficient = -0.096	0.18
	Pinch, left	***P* value**	**Grip, left**	***P* value**
Semmes-Weinstein, left	Correlation coefficient = 0.12	0.13	Correlation coefficient = 0.21	**0.01**
	Pinch, right	***P* value**	**Grip, right**	***P* value**
Semmes-Weinstein, right	Correlation coefficient = 0.071	0.39	Correlation coefficient = 0.052	0.53

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Table 1

Subject characteristics

	Musicians	Non-musicians	
Total subjects	100	100	
Age, average (range)	20.1 (18-28)	20.2 (18-27)	$P = 0.50$
Female	52	61	$P = 0.20$
Male	48	39	
Right handed	93	91	$P = 0.60$
Left handed	7	9	

Table 2

Two-point discrimination data

	Musicians	**Non-musicians**	
2 point discrimination, mm (range 2-6 for musicians, 2-9 for non-musicians)	**Average (SD, CI)**	**Average (SD, CI)**	
Left thumb	3.1 (0.9, ± 0.2)	3.0 (0.7, ± 0.1)	*P* = 0.50
Left index	2.6 (0.7, ± 0.1)	2.8 (0.6, ± 0.1)	*P* < **0.01**
Left middle	2.9 (0.7, ± 0.1)	3.0 (0.8, ± 0.2)	*P* = 0.08
Left ring	3.0 (0.8, ± 0.2)	3.2 (0.9, ± 0.2)	*P* < **0.01**
Left small	3.3 (0.9, ± 0.2)	3.6 (0.9, ± 0.2)	*P* < **0.01**
Right thumb	2.9 (0.7, ± 0.1)	2.9 (0.8, ± 0.2)	*P* = 0.69
Right index	2.5 (0.6, ± 0.1)	2.7 (0.7, ± 0.1)	*P* = 0.06
Right middle	2.8 (0.7, ± 0.1)	2.9 (0.9, ± 0.2)	*P* = 0.09
Right ring	3.0 (0.8, ± 0.2)	3.2 (1.0, ± 0.2)	*P* = 0.1
Right small	3.2 (0.9, ± 0.2)	3.5 (1.0, ± 0.2)	*P* < **0.01**
Non-dominant thumb	3.1 (0.8, ± 0.2)	3.0 (0.7, ± 0.1)	*P* = 0.40
Non-dominant index	2.6 (0.7, ± 0.1)	2.8 (0.6, ± 0.1)	*P* = **0.02**
Non-dominant middle	2.9 (0.7, ± 0.1)	3.0 (0.8, ± 0.2)	*P* = 0.05
Non-dominant ring	3.0 (0.8, ± 0.2)	3.3 (1.0, ± 0.2)	*P* < **0.01**
Non-dominant small	3.3 (1.0, ± 0.2)	3.6 (1.0, ± 0.2)	*P* < **0.01**
Dominant thumb	2.9 (0.8, ± 0.2)	2.9 (0.8, ± 0.2)	*P* = 0.58
Dominant index	2.5 (0.6, ± 0.1)	2.7 (0.7. ± 0.1)	*P* < **0.01**
Dominant middle	2.8 (0.7, ± 0.1)	2.9 (0.8, ± 0.2)	*P* = 0.14
Dominant ring	3.0 (0.8, ± 0.2)	3.2 (0.9, ± 0.2)	*P* = 0.17
Dominant small	3.2 (0.9, ± 0.2)	3.5 (1.0, ± 0.2)	*P* < **0.01**

SD = standard deviation, CI = confidence interval
P

Table 3

Two-point discrimination comparison within instrumental groups left vs right hands and two-point discrimination comparison within instrumental groups non-dominant vs dominant hands

	Musicians	**Non-musicians**	
Total subjects	100	100	
Age, average (range)	20.06 (18-28)	20.25 (18-27)	*P* = 0.50
Female	52	61	*P* = 0.20
Male	48	39	
Right handed	93	91	*P* = 0.60
Left handed	7	9	
Two-point discrimination comparison within instrumental groups left vs right hands			
	Average (SD) left hand two-point discrimination, mm	**Average (SD) right hand two-point discrimination, mm**	
Woodwinds	3.0 (0.8)	2.9 (0.8)	*P* = 0.39
Strings	2.9 (0.8)	2.9 (0.8)	*P* = 0.76
Brass	3.4 (0.8)	3.2 (0.8)	*P* = 0.42
Percussion/piano/organ	2.9 (0.9)	2.8 (0.8)	*P* = 0.29
Harp/guitar	2.9 (0.9)	2.7 (0.7)	*P* = 0.09
Left: ANOVA, 5 groups, p = 0.11 Right: ANOVA, 5 groups, p = 0.076			
Two-point discrimination comparison within instrumental groups non-dominant vs dominant hands			
	Average (SD) non-dominant hand two-point discrimination, mm	**Average (SD) dominant hand two-point discrimination, mm**	
Woodwinds	3.0 (0.8)	2.9 (0.8)	*P* = 0.39
Strings	2.9 (0.8)	2.9 (0.8)	*P* = 0.70
Brass	3.4 (0.8)	3.2 (0.8)	*P* = 0.42
Percussion/piano/organ	2.9 (0.9)	2.8 (0.8)	*P* = 0.66
Harp/guitar	3.0 (0.8)	2.6 (0.7)	*P* = **0.02**
Non-dominant: ANOVA, 5 groups, p = 0.093 Dominant: ANOVA, 5 groups, p = 0.085			

SD = standard deviation

Table 4

Semmes-Weinstein data

	Musicians	**Non-musicians**	
Semmes-Weinstein, common log of force measured in tenths of a milligram (range 1.65-2.83 for both groups)	**Average (SD, CI)**	**Average (SD, CI)**	
Left thumb	2.57 (0.25, ± 0.07)	2.59 (0.27, ± 0.05)	$P = 0.71$
Left index	2.48 (0.26, ± 0.07)	2.56 (0.24, ± 0.05)	$P = 0.07$
Left middle	2.47 (0.26, ± 0.08)	2.55 (0.25, ± 0.05)	$P = 0.08$
Left ring	2.43 (0.26, ± 0.08)	2.53 (0.28, ± 0.05)	$P = \mathbf{0.04}$
Left small	2.49 (0.23, ± 0.07)	2.54 (0.25, ± 0.05)	$P = 0.23$
Right thumb	2.51 (0.33, ± 0.09)	2.67 (0.24, ± 0.05)	$P < \mathbf{0.01}$
Right index	2.46 (0.31, ± 0.09)	2.61 (0.25, ± 0.05)	$P < \mathbf{0.01}$
Right middle	2.50 (0.18, ± 0.05)	2.60 (0.27, ± 0.05)	$P < \mathbf{0.01}$
Right ring	2.40 (0.24, ± 0.07)	2.58 (0.23, ± 0.05)	$P < \mathbf{0.01}$
Right small	2.44 (0.22, ± 0.06)	2.59 (0.24, ± 0.05)	$P < \mathbf{0.01}$
Non-dominant thumb	2.57 (0.25, ± 0.07)	2.59 (0.27, ± 0.05)	$P = 0.71$
Non-dominant index	2.48 (0.26, ± 0.07)	2.56 (0.24, ± 0.05)	$P = 0.10$
Non-dominant middle	2.45 (0.25, ± 0.07)	2.55 (0.26, ± 0.05)	$P = \mathbf{0.04}$
Non-dominant ring	2.41 (0.25, ± 0.07)	2.53 (0.27, ± 0.05)	$P = \mathbf{0.01}$
Non-dominant small	2.49 (0.23, ± 0.07)	2.54 (0.25, ± 0.05)	$P = 0.22$
Dominant thumb	2.51 (0.33, ± 0.09)	2.67 (0.24, ± 0.05)	$P < \mathbf{0.01}$
Dominant index	2.46 (0.31, ± 0.09)	2.61 (0.25, ± 0.05)	$P < \mathbf{0.01}$
Dominant middle	2.51 (0.19, ± 0.06)	2.60 (0.25, ± 0.05)	$P = \mathbf{0.02}$
Dominant ring	2.42 (0.26, ± 0.07)	2.58 (0.23, ± 0.05)	$P < \mathbf{0.01}$
Dominant small	2.44 (0.22, ± 0.06)	2.59 (0.23, ± 0.05)	$\mathbf{P < 0.01}$

SD = standard deviation, CI = confidence interval

Table 5

Laxity data

	Musicians	Non-musicians	
Total subjects	100	100	
Age, average (range)	20.06 (18-28)	20.25 (18-27)	*P* = 0.50
Female	52	61	*P* = 0.20
Male	48	39	
Right handed	93	91	*P* = 0.60
Left handed	7	9	
Laxity, can touch thumb to wrist/bend small finger >90°, percent positive	**Musicians**	**Non-musicians**	
Left wrist	33	42	*P* = 0.19
Left small	15	21	*P* = 0.27
Right wrist	27	39	*P* = 0.07
Right small	12	18	*P* = 0.24