Clinical Neurophysiology Practice 5 (2020) 23–29

Contents lists available at ScienceDirect

Clinical Neurophysiology Practice

journal homepage: www.elsevier.com/locate/cnp

Research paper

Impact of technical variations on the ring-finger test for carpal tunnel syndrome

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ARTICLE INFO

Article history:
Received 4 February 2019
Received in revised form 19 November 2019
Accepted 23 November 2019
Available online 11 December 2019

Keywords:
Nerve conduction study
Ring finger test
Median-ulnar nerves comparison tests

ABSTRACT

Objective: To assess if recording the sensory latencies of the median and ulnar nerves one-by-one (consecutive) or at the same time (simultaneous) in the ring-finger test for carpal tunnel syndrome (CTS) will show equivalent results or if it will lead to a different clinical classification of patients.
Methods: We assessed the limits of agreement between the simultaneous and the consecutive method based on the median- ulnar sensory latency difference derived by both methods in 80 subjects and compared the number of minimal CTS cases identified by the two methods.
Results: Limits of agreement ranged from −0.23 to 0.29 ms. A significantly higher proportion of subjects with minimal CTS (only detectable by using the comparison test) was found using the simultaneous method (n = 8 and 2, respectively; p = 0.03).
Conclusion: The two methods have a poor to moderate agreement as indicated by the range of the limits of agreement (0.5 ms).
Significance: Even small methodological changes to the ring-finger test can lead to results with different clinical meaning in the same individual and one should be aware of which method was used when interpreting results.

1. Introduction

In patients with clinically suspected carpal tunnel syndrome (CTS), nerve conduction studies (NCS) can demonstrate reduced median nerve conduction velocity (Bland, 2007; Werner and Andary, 2011; Deniz et al., 2012). However, in a considerable proportion of patients with clinically suspected CTS the sensory nerve conduction velocity in the median nerve is within the normal range, but reduced function of the median nerve can be demonstrated if the median and the ulnar nerve are directly compared and a latency difference above a defined cut-off value is found (Padua et al., 1997). A frequently used test to compare the ulnar and the median nerve in these patients is the ring finger test (Uncini et al., 1989), which compares directly the sensory latencies of the ulnar and the median nerve from the 4th finger. This test has the advantage that the patient serves as their own control and it is therefore less dependent on age, sex and hand temperature than tests which compare conduction velocities to normal values. The test s diagnostic precision varies considerably (Wang and Yan, 2013; Kouyoumdjian et al., 2002; Capone et al., 1998). Different practical approaches to the test are in use, and this might partly explain the varying diagnostic precision. The orthodromic ring finger test may be performed in a consecutive manner where one nerve is recorded first, then the setup is rearranged and the other nerve recorded. The test can also be performed by recording the sensory potential of the median and the ulnar nerves simultaneously, thus saving time and potentially making the examination less unpleasant for the patient. It is unclear, if these two methods can be used interchangeably.

Abbreviations: CTS, carpal tunnel syndrome; EMG, electromyography; HAVS, hand arm vibration syndrome; NCS, nerve conduction study.

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https://doi.org/10.1016/j.cnp.2019.11.005
2467-981X/

We thus aimed to assess if the two methods showed acceptable agreement and hypothesized that the number of correctly identified minimal carpal tunnel syndrome cases (defined as clinical symptoms and NCS findings indicative of median nerve entrapment present) would not differ between the methods.

2. Methods

2.1. Subjects

The study population is that of a Norwegian health survey of rock drillers and road workers in a Norwegian construction company. The NCS were performed between November 2015 and June 2016. The data were collected with the purpose of assessing peripheral nerve damage in road workers and rock drillers with exposure to hand-arm vibration. The study was approved by the Regional Ethics Committee (REK 2013/1031). All participants provided a written consent. Data were collected assuming that the simultaneous and the consecutive method would produce equivalent results. We performed both methods as a quality check.

2.2. Nerve conduction studies

All NCS were performed using Focus Keypoint.Net EMG equipment (Natus medical incorporated, Pleasanton, USA). Skin temperature was measured with an Exergen dermaTemp handheld infrared thermographic scanner (Exergen corporation, Watertown, MA, USA) and maintained at over 30 degrees C in all cases. If skin temperature was below 30 degrees, the participants held their hands in warm water for 2–5 min and temperature was measured again. We used the same type of electrodes for the consecutive and the simultaneous recording. For recording, we used pre- gelled disposable surface electrodes (Alpine biomed, Skovlunde, Denmark). For stimulation, we used a hand-held stimulation bar with fixed inter-electrode distances. The stimulation electrodes consist of felt tips which had a diameter of 7.5 mm and were soaked in saline solution. When being placed on the proximal phalanx and using supramaximal stimulation, they allow simultaneous stimulation of the median and ulnar nerves. In addition, an E0 "ground electrode" was placed on the hand being tested. We performed the following protocol: We started with the motor study of the ulnar and median nerves. Then we performed sensory study of ulnar nerve (palm, 4th and 5th finger, starting with the 4th) and then sensory study of the median nerve (palm, 2nd, 3rd, 4th finger, starting with the 4th). The measurements we hereby obtained from the 4th finger constitute the consecutive method. We then performed the simultaneous method by adding a pair of electrodes for the ulnar nerve and placed these at the previously marked and used recording spot. The extra pair of electrodes used for recording the ulnar nerve in the simultaneous method was connected to a separate amplifier. In summary, the simultaneous method consists of simply adding a pair of recording electrodes for the ulnar nerve after having performed the consecutive median nerve sensory testing, so that we ended up with one pair for the median and one pair for the ulnar nerve (Fig. 1).

2.3. Procedures common to both methods

We performed both methods orthodromically. A fixed distance of 14 cm was used from the stimulation point (cathode position) at the proximal phalanx of the ring finger to the active registration electrode over the median nerve and the ulnar nerve at the wrist. We measured the distances, marked all points for electrode placement and used the same recording and stimulation points for both methods. We used the same type of recording and stimulation

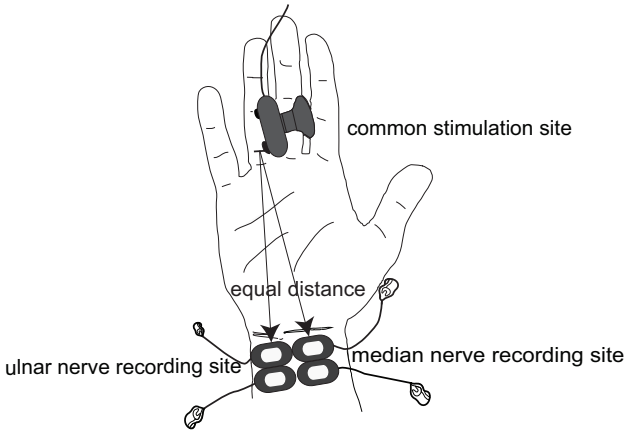

Fig. 1. Recording set-up for the simultaneous method.

electrodes for both nerves and in both methods. Recording electrodes were placed with an inter-electrode distance of 3 cm. We achieved supramaximal stimulation by increasing stimulus intensity by 20% after the amplitude reached its maximum. We then gave a series of 10 stimuli with pulse duration of 0.1 ms each. Motor amplitudes were automatically measured from baseline to peak. Sensory amplitudes were measured from the negative peak to the intersection of a line drawn from the first to the last positive peak. Latencies were calculated based on the peak of the negative deflection (see Fig. 2a and b for examples of the simultaneous recording). Conduction velocities were measured based on the onset of the response. Low (at 20 Hz) and high frequency filter (at 10 kHz) settings were employed.

2.4. Description of the two methods

We always performed the consecutive method first: we placed the recording electrodes at the measured distance for the ulnar

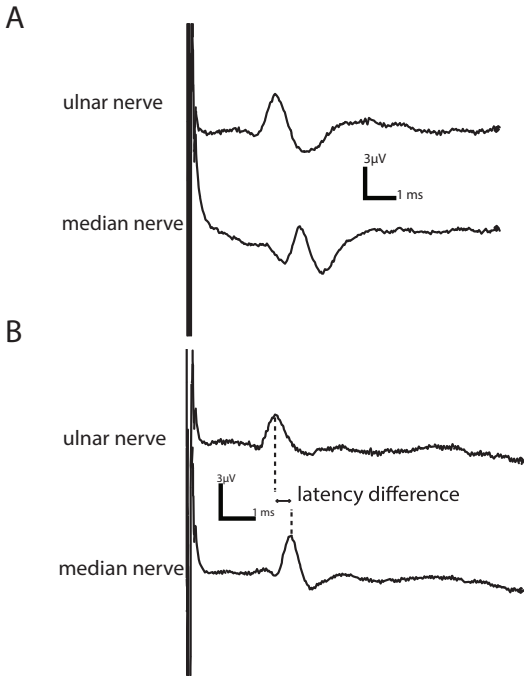

Fig. 2. Examples of recordings with the simultaneous method in two different patients (a, b).

nerve, and performed the sensory ulnar nerve stimulation and registration. We then removed the recording electrodes, and repeated the procedure for the sensory median nerve. For the simultaneous method, we placed the recording electrodes at the given distances for both nerves at the wrist. We then stimulated at the phalanx of the ring finger and recorded the sensory responses of the median and the ulnar nerves simultaneously.

2.5. Analysis of the NCS data

For each subject, the ulnar and median nerve sensory latencies, amplitudes and conduction velocities were extracted using both methods. We graded the NCS findings according to Padua et al. (Padua et al., 1997) as either normal, minimal median nerve entrapment, mild median nerve entrapment, moderate median nerve entrapment or severe median nerve entrapment. Minimal median nerve entrapment was defined as a sensory latency difference $\geq$0.5 ms between the median and the ulnar nerve in the absence of other findings; mild median nerve entrapment was defined as reduced sensory conduction velocity in the median nerve, moderate median nerve entrapment as additional increased motor distal latency, severe median nerve entrapment as the absence of sensory responses. For the minimal grade, we used the absolute latency difference, for the other grades (mild, moderate and severe), results were considered abnormal according to normal values for the laboratory. These normal values are derived from an unpublished northern joint-effort and are integrated into the software. They are adjusted for age, sex and height.

3. CTS diagnosis

Clinical criteria for the diagnosis of CTS were based on the presence of at least two of the following symptoms: nocturnal episodes of paresthesia in the median nerve distribution, numbness in the fingers innervated by the median nerve, alleviation of symptoms by shaking of the limb. Positive family history of CTS (parents or siblings) and weakness in the hand as supportive criteria could replace one of the criteria above if only one of the obligatory criteria were met. Subjects were diagnosed with CTS if the clinical criteria were met and if at the same time NCS findings indicative of at least minimal median nerve entrapment were present.

4. Statistical analysis

For all participating subjects, a one sample Student's *t*-test was used to test whether the difference between the two methods is equal to zero. The normality assumption was tested by means of visual inspection using a histogram and Q-Q plots and was found to be satisfied. We used a Bland Altman plot to compare the two recording methods. Using the difference between latency of the ulnar and of the median nerve, we calculated both the difference between the simultaneous recording and the consecutive recording and the mean of the simultaneous and the consecutive method for each subject. We then plotted these two values against one another. The limits of agreement were calculated as 1.96 * standard deviation of the measurement differences on either side of the mean. The mean and the upper and lower limit of agreement were included as horizontal lines in the figures (Figs. 3 and 4). P-values < 0.05 were considered statistically significant.

When assessing the ability of the two methods to identify cases with minimal CTS, we used the clinical criteria for CTS as a gold standard. We used a McNemar test to compare the number of subjects with a minimal CTS diagnosis (defined as both clinical criteria met and median-ulnar latency difference $\geq$0.5 ms) derived by the two methods. All analyses were performed using IBM SPSS v 24 software.

5. Results

5.1. Sample description

We examined the left and right hands of 80 subjects aged 22 to 68 years (median 43 years). All subjects were men. 72 subjects had technically satisfying NCS data on at least one hand.

5.2. Nerve conduction findings

The results of the nerve conduction studies are summed up in Tables 1 and 2. The number of subjects with minimal median nerve entrapment (defined as median- ulnar sensory latency differences >0.5 ms without further NCS findings) was significantly different between the two methods in the right hand (11 and 4, respectively, p = 0.01) and borderline statistically different in the left hand (11 and 6, respectively, p = 0.06). A minimal median nerve entrapment was found in 16 subjects with at least one method in at least one hand (Table 3).

In the right hand, the mean median-ulnar latency difference was borderline statistically different between the two methods (p = 0.06; latency difference of 0.36 ms and 0.32 ms respectively); in the left hand, no statistically significant difference was found (p = 0.14; latency difference of 0.32 ms and and 0.31 ms, respectively). See Fig. 5. We have not received negative feedback from the patients regarding unpleasantness of the simultaneous stimulation.

5.3. CTS cases

The ability of the two methods to identify cases with minimal CTS is given in Tables 3–5. The number of subjects diagnosed with minimal CTS (defined as median-ulnar sensory latency >0.5 ms as the only NCS finding and clinical criteria for CTS fulfilled) was significantly different (8 and 2, respectively, p = 0.03) for the two methods in both hands combined (n = 16) and in the right hand alone (n = 11). In the left hand (n = 11), the simultaneous method identified 2, the consecutive 1 subject with minimal CTS. All subjects with minimal CTS in the left hand had bilateral CTS with more pronounced symptoms in the right hand.

5.4. Bland Altman analysis

In the right hand, the mean difference in latency between the median and the ulnar nerve with the consecutive method was 0.32 ms (SD 0.34 ms), and the mean difference between the two methods was 0.03 ms with a standard deviation of 0.13 ms. Ninety-five percent of measurements were within the limits of agreement from −0.23 ms to 0.29 ms (Fig. 3).

In the left hand the mean difference between the two methods was 0.023 ms, the mean latency difference with the consecutive method was 0.31 ms (SD 0.51 ms). Ninety-five percent of measurements were within the limits of agreement from −0.23 ms to 0.27 ms (Fig. 4).

6. Discussion

Our data reveal that the agreement between the simultaneous and the consecutive method of conducting the ring-finger test is clinically not acceptable and that the two methods produce results with different clinical implications.

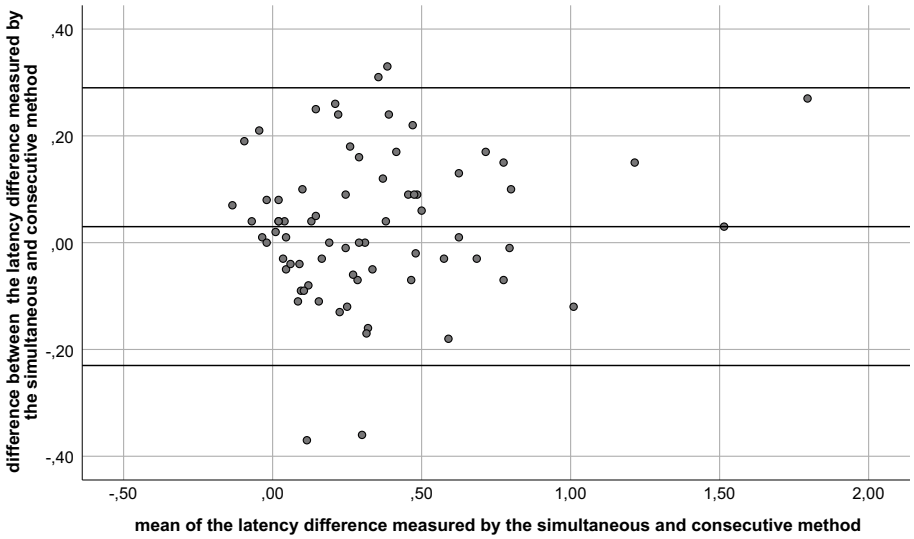

Fig. 3. Bland Altman plot for the right hand showing on the x-axis the mean of the simultaneous and the consecutive measurement, and on the y-axis the difference between the simultaneous and consecutive measurement. The average difference is indicated as a horizontal line at 0.03. The upper and the lower limits of agreement are indicated as horizontal lines at 0.29 ms and −0.23 ms, respectively.

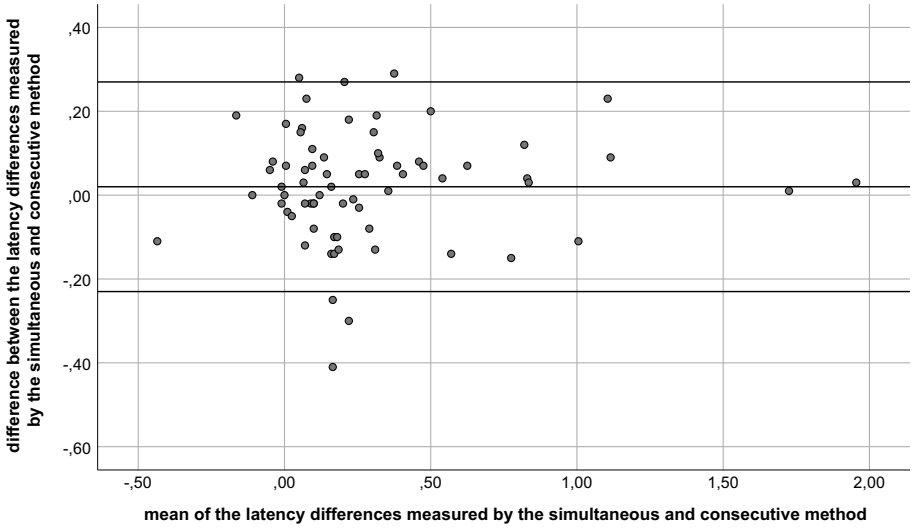

Fig. 4. Bland Altman plot for the left hand showing on the x-axis the mean of the simultaneous and the consecutive measurement, and on the y-axis the difference between the simultaneous and consecutive measurement. The average difference is indicated as a horizontal line at 0.02. The upper and the lower limits of agreement are indicated as horizontal lines at 0.27 ms and −0.23 ms, respectively.

We assessed agreement based on the limits of agreement and the mean difference between the two methods. The limits of agreement were relatively wide. These ranged from −0.23 ms to 0.29 ms in the right hand and from −0.23 ms to 0.27 ms in the left hand. Assessing the limits of agreement between the two methods is the recommended approach when comparing two instruments which measure the same quantitative value and is regarded as superior to a straight forward computation of a correlation coefficient (Bland and Altman, 1986; Watson and Petrie, 2010). Limits of agreement show to which degree measurements of the same quantitative value differ between two different instruments in the same individual. The limits of agreement illustrate the difference between the methods as a range in the same unit as the measured quality, and allow to judge if this difference is clinically acceptable, or if it will lead to a different diagnosis simply because a different instrument was chosen. The limits of agreement indicate that a measurement from one method might differ by −0.23 ms to 0.29 ms from the measurement obtained by the other method (for the right hand; and between −0.23 ms and 0.27 ms for the left hand). To put these values into clinical perspective, the most often used cut-off value to demonstrate a minimal median nerve entrapment and thus a CTS diagnosis with the ring-finger test is 0.5 ms (Uncini et al., 1989). We argue that the cut-off value is so close to the limits of agreement, that patients might receive a CTS diagnosis with one method but not the other. The cut-off value has been a subject of discussion before (Logigian et al., 2014; Nodera et al., 2003; Preston et al., 1994; Wang and Yan, 2013; Kouyoumdjian et al., 2002; Capone et al., 1998), especially in patients with diabetes or with ambiguous clinical symptoms (Salerno et al., 1998; Rivner et al., 2001). The mean difference between the two methods was small (0.03 ms) considering the clear difference in how many CTS cases (defined as NCS findings and clinical symptoms present) the two methods identified. In a population like the present, increased sensory latencies of the median nerve, as high as the cut-off value are more prevalent than in the general population (Armstrong et al., 2008; Salerno et al.,

Table 1
Summary of nerve conduction study data (NCS).

Latency parameter	Hand	Recording method	
		Simultaneous	Consecutive
Median nerve latency mean in ms (SD)	Right hand	3.35 (0.42)	3.32(0.40)
	Left hand	3.27 (0.45)	3.30 (0.51)
Ulnar nerve latency mean in ms (SD)	Right hand	3.00 (0.28)	3.00 (0.28)
	Left hand	2.97 (0.27)	2.98 (0.27)
Median- ulnar nerve latency difference mean in ms (SD)	Right hand	0.35 (0.36)	0.32 (0.34)
	Left hand	0.31 (0.47)	0.31 (0.51)
Median-ulnar nerve latency difference range in ms (minimum-maximum)	Right hand	2.03 (−0.10–1.93)	1.85 (0.19– 1.66)
	Left hand	2.46 (−0.49–1.97)	2.32 (−0.38–1.94)

Table 2
Distribution of nerve conduction studies severity grades (N = 72).

NCS severity grade	Left hand simultaneous	Left hand consecutive	Right hand simultaneous	Right hand consecutive
0	50	53	45	49
1	11	6	11	4
2–4	11	13	16	19

Table 3
Agreement between the consecutive and simultaneous methods in identifying minimal carpal tunnel syndrome (CTS) cases in both hands.

		Consecutive		
		No CTS	CTS	Total
Simultaneous	No CTS	8	0	8
	CTS	6	2	8
Total		14	2	16

P = 0.03

1998). It can be argued that in this population already a small mean difference between the methods is enough to produce the different sensitivities of the methods. In addition, one must consider that individual differences of up to +0.29 ms (or −0.23 ms) are to be expected. This probably explains why we found a higher number of individuals with a latency difference of ≥0.5 ms with the simultaneous method, and at the same time a small, not significant average difference between the methods. However, this difference trended towards being significant (p = 0.06). In the left hand, we did not find a significant difference regarding the number of CTS cases identified by the two methods. We assume that this is due to the low number of cases with CTS in the left hand in this group and that the analysis thus lacked the power necessary to demonstrate a significant difference. We rationalize this assumption by the limits of agreement, which are very similar to the right hand, especially considering the range (0.5 ms). Further, the number of measurements ≥0.5 ms was borderline statistically significantly different between the methods (p = 0.06).

We found good specificity for both methods (Table 5), which is surprising in the light of previous reports (Redmond and Rivner, 1988). A reason might be the higher prevalence of CTS in our population compared to the general population (Franklin and Friedman, 2015; Barcenilla et al., 2012), which simply gives a false impression of high specificity.

There are several technical factors that might have influenced our measurements. We cannot rule out that the variation between the methods is due to error in measurement of the distances and placement of the electrodes. We tried to minimize measurement error as we measured and marked the stimulation and registration sites before testing, used the same measurements for both methods and kept the recording electrodes for the median nerve in place when switching over to the simultaneous method. It can be argued that the simultaneous method might be less prone to measurement and placement errors, as placement of stimulation electrodes is only performed once and not twice as in the consecutive method. Another possible explanation for the difference between the methods is that the simultaneous method might be more self-controlling than the consecutive, as it measures both nerves with the hand in the same posture and with the same stimulus intensity and background noise level and thus potentially reducing measurement errors. Not stimulating the ulnar and median nerves in the 4th finger directly one after another might have led to a certain

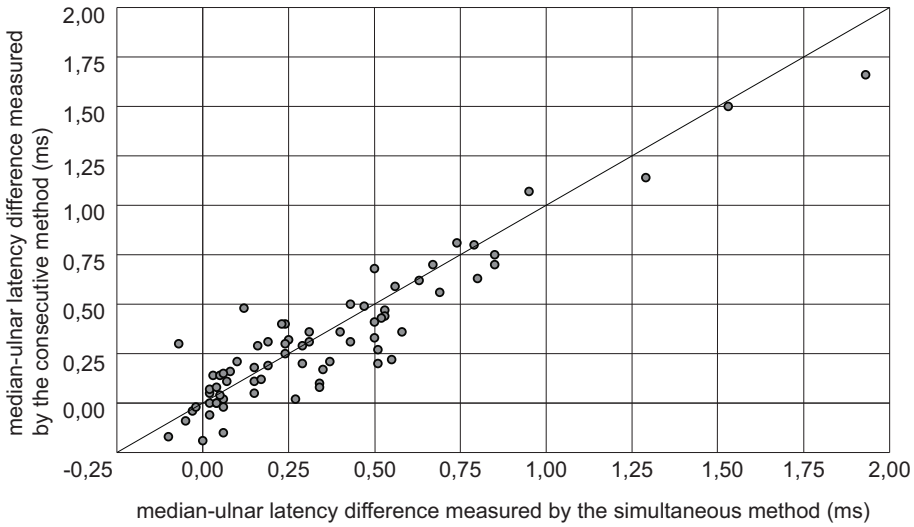

Fig. 5. Raw median-ulnar sensory latency differences for both methods. The x-axis shows the latency difference between the median and ulnar nerves as measured by the simultaneous method. The y-axis shows the latency difference between the median and ulnar nerves as measured by the consecutive method. The diagonal line represents equal values for x and y (y = 1x + 0).

Table 4
Relationship between the clinical criteria for carpal tunnel syndrome (CTS) and the consecutive and simultaneous methods in the minimal median entrapment subgroup (N = 16).

		Clinical criteria for CTS met	Clinical criteria for CTS not met
Consecutive method	≥0.5 ms median-ulnar latency difference	2	2
	≤0.5 ms median-ulnar latency difference	6	6
Simultaneous method	≥0.5 ms median-ulnar latency difference	8	3
	≤0.5 ms median-ulnar latency difference	0	5

Table 5
Relationship between the clinical criteria for carpal tunnel syndrome (CTS) and the consecutive and simultaneous methods in the whole population (N = 72).

		Clinical criteria for CTS met	Clinical criteria for CTS not met
Consecutive method	≥0.5 ms median-ulnar latency difference	9	7
	≤0.5 ms median-ulnar latency difference	12	44
Simultaneous method	≥0.5 ms median-ulnar latency difference	16	8
	≤0.5 ms median-ulnar latency difference	5	43

The consecutive method has a sensitivity of 42% and a specificity of 86%, the simultaneous method a sensitivity of 76% and a specificity of 84%.

bias. This was due to a change in our clinical standard protocol by the additional testing of the remaining median and ulnar fingers with the objective of assessing peripheral nerve damage in the study population. However, we were aware of this limitation and made an effort to keep the hand in the exact same position during both measurements. Placing an extra pair of electrodes at the median nerve while stimulating the ulnar nerve might reduce measurement error. However, to achieve a realistic comparison between the two methods, it is necessary to reposition the recording electrodes in the consecutive approach, as one uses only one pair of electrodes in this method. This is due to economic factors, as the comparison test is not needed in patients with reduced conduction velocity in the median nerve and the routine use of two sets of electrodes in all patients with suspected CTS would produce a lot of wasted electrodes. Also, we cannot exclude an order effect in which the investigator was biased by the result of the first method when performing the second, as we have not randomized the order of the two methods. However, we consider it unlikely that the order in which the methods were performed was a source of bias in the present study, as the average latencies and the difference between the latencies were not different between the methods. Furthermore, we did not measure the skin temperature continuously, and thus it cannot be ruled out that sweating or cooling after warming might have influenced the measurements. However, we measured temperature again if we found significantly reduced conduction velocities.

Even though we tried to minimize the impact of each of these factors, we cannot rule out that they influenced the measurements and we argue that our study illustrates how important standardization of methods is.

Further limitations need to be addressed. On a global basis, stimulation with a hand-held bar is less common than with ring electrodes. However, at least in northern Europe, the orthodromic method is more commonly performed with a stimulation bar. Since the normative values used in our lab were collected in this manner, we used this approach also in this study. We find our approach less time consuming, as we can use the stimulation bar for both motoric NCS and sensory NCS and find the repositioning of the bar more time efficient. In this study, we did not see a far-field potential from the median or ulnar nerves when recording the respective other nerve. This might be due to that we tried to place the electrodes as precisely as possible over the nerves. Further, this sample population had relatively large hands and wrists and thus possibly a wide distance between the median and ulnar nerves. This, in addition to that all subjects were men, might reduce the external validity of our findings. Further, all subjects were exposed to risk factors for carpal tunnel syndrome such as heavy manual work and use of vibrating tools (Kozak et al., 2015; Barcenilla et al., 2012), which explains the higher prevalence of CTS in our study as compared to the general population. The same is true for other conditions associated with high exposure to vibrating tools such as hand-arm-vibration syndrome (HAVS) which have a higher prevalence in populations such as the present. In patients with HAVS, nerve damage, especially to the median nerve has been found (Rolke et al., 2013). However, we do not believe this can have affected our findings, as this should not cause a higher proportion of median entrapment cases in the simultaneous method alone. We did not systematically rule out other musculoskeletal conditions in the hands or forearms. Likewise, we did not perform clinical provocation methods such as Tinels maneuver or Phalens test. However, these tests may be misleading as they may have a higher specificity and sensitivity for tenosynovitis in the hand than for carpal tunnel syndrome (El Miedany et al., 2008). This could introduce a bias when performing the tests in our study population with its high manual workload. As this study was part of a health survey, we did not perform a priori calculations of sample size. This might have influenced the significance level of the mean difference and it can be conceived that a larger sample size might show a significant difference between the methods. Moreover, we had no information on the inherent measurement error of the orthodromic ring finger test. We could not use ROC analysis to compare how precise the two methods are when measuring the latency, as this would require knowledge of the true latency, which is not known. Likewise, the number of carpal tunnel cases in the material was too small to use receiver operating curves with the clinical definition as a gold standard in order to determine cut-off values. We used a clinical definition of CTS as the reference standard. This might be problematic, as previous studies have demonstrated a varying degree of correlation between clinical symptoms and NCS (Gomes et al., 2006) and different clinical symptoms have different degrees of correlation to NCS findings (Schrijver et al., 2005). NCS has a false positive rate (Redmond and Rivner, 1988). Further, the clinical presentation of CTS varies to a significant degree (Nora et al., 2004). We performed every measurement only once in the same individual. In order to compare test-retest reliability and thus measurement error between and within the methods, it would have been necessary to perform measurements twice in random order in the same individual. We can therefore not quantify to which degree the simultaneous test is "self-controlling".

Our results suggest that technical variations in the way the ring-finger comparison test is performed might lead to changes in the diagnostic accuracy of this test.

Neurophysiologic labs should be aware of how easily the results of ring-finger can be influenced by methodological variations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Armstrong, T., Dale, A.M., Franzblau, A., Evanoff, B.A., 2008. Risk factors for carpal tunnel syndrome and median neuropathy in a working population. J. Occup. Environ. Med. 50, 1355–1364.

Barcenilla, A., March, L.M., Chen, J.S., Sambrook, P.N., 2012. Carpal tunnel syndrome and its relationship to occupation: A meta-analysis. Rheumatology (Oxford) 51, 250–261.

Bland, J.D., 2007. Carpal tunnel syndrome. BMJ 335, 343–346.

Bland, J.M., Altman, D.G., 1986. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1, 307–310.

Capone, L., Pentore, R., Lunazzi, C., Schonhuber, R., 1998. Pitfalls in using the ring finger test alone for the diagnosis of carpal tunnel syndrome. Ital. J. Neurol. Sci. 19, 387–390.

Deniz, F.E., Oksuz, E., Sarikaya, B., Kurt, S., Erkorkmaz, U., Ulusoy, H., Arslan, S., 2012. Comparison of the diagnostic utility of electromyography, ultrasonography, computed tomography, and magnetic resonance imaging in idiopathic carpal tunnel syndrome determined by clinical findings. Neurosurgery 70, 610–616.

El Miedany, Y., Ashour, S., Youssef, S., Mehanna, A., Meky, F.A., 2008. Clinical diagnosis of carpal tunnel syndrome: Old tests-new concepts. Joint Bone Spine 75, 451–457.

Franklin, G.M., Friedman, A.S., 2015. Work-related carpal tunnel syndrome: Diagnosis and treatment guideline. Phys. Med. Rehabil. Clin. N. Am. 26, 523-+.

Gomes, I., Becker, J., Ehlers, J.A., Nora, D.B., 2006. Prediction of the neurophysiological diagnosis of carpal tunnel syndrome from the demographic and clinical data. Clin. Neurophysiol. 117, 964–971.

Kouyoumdjian, J.A., Morita, M.P., Molina, A.F., 2002. Usefulness of additional nerve conduction techniques in mild carpal tunnel syndrome. Arq. Neuropsiquiatr. 60, 923–927.

Kozak, A., Schedlbauer, G., Wirth, T., Euler, U., Westermann, C., Nienhaus, A., 2015. Association between work-related biomechanical risk factors and the occurrence of carpal tunnel syndrome: An overview of systematic reviews and a meta-analysis of current research. BMC Musculoskelet Disord. 16, 231.

Logigian, E.L., Villanueva, R., Twydell, P.T., Myers, B., Downs, M., Preston, D.C., Kothari, M.J., Herrmann, D.N., 2014. Electrodiagnosis of ulnar neuropathy at the elbow (une): A bayesian approach. Muscle Nerve 49, 337–344.

Nodera, H., Herrmann, D.N., Holloway, R.G., Logigian, E.L., 2003. A bayesian argument against rigid cut-offs in electrodiagnosis of median neuropathy at the wrist. Neurology 60, 458–464.

Nora, D.B., Becker, J., Ehlers, J.A., Gomes, I., 2004. Clinical features of 1039 patients with neurophysiological diagnosis of carpal tunnel syndrome. Clin. Neurol. Neurosurg. 107, 64–69.

Padua, L., Lomonaco, M., Gregori, B., Valente, E.M., Padua, R., Tonali, P., 1997. Neurophysiological classification and sensitivity in 500 carpal tunnel syndrome hands. Acta Neurol. Scand. 96, 211–217.

Preston, D.C., Ross, M.H., Kothari, M.J., Plotkin, G.M., Venkatesh, S., Logigian, E.L., 1994. The median–ulnar latency difference studies are comparable in mild carpal tunnel syndrome. Muscle Nerve 17, 1469–1471.

Redmond, M. David, Rivner, Michael H., 1988. False positive electrodiagnostic tests in carpal tunnel syndrome. Muscle Nerve 11, 511–518.

Rivner, Michael H., Swift, Thomas R., Malik, Khalid, 2001. Influence of age and height on nerve conduction. Muscle Nerve 24, 1134–1141.

Rolke, R., Rolke, S., Vogt, T., Birklein, F., Geber, C., Treede, R.D., Letzel, S., Voelter-Mahlknecht, S., 2013. Hand-arm vibration syndrome: Clinical characteristics, conventional electrophysiology and quantitative sensory testing. Clin. Neurophysiol. 124, 1680–1688.

Salerno, D.F., Franzblau, A., Werner, R.A., Bromberg, M.B., Armstrong, T.J., Albers, J. W., 1998. Median and ulnar nerve conduction studies among workers: Normative values. Muscle Nerve 21, 999–1005.

Schrijver, H.M., Gerritsen, A.A., Strijers, R.L., Uitdehaag, B.M., Scholten, R.J., De Vet, H. C., Bouter, L.M., 2005. Correlating nerve conduction studies and clinical outcome measures on carpal tunnel syndrome: Lessons from a randomized controlled trial. J. Clin. Neurophysiol. 22, 216–221.

Uncini, A., Lange, D.J., Solomon, M., Soliven, B., Meer, J., Lovelace, R.E., 1989. Ring finger testing in carpal tunnel syndrome: A comparative study of diagnostic utility. Muscle Nerve 12, 735–741.

Wang, Y.J., Yan, S.H., 2013. Improvement of diagnostic rate of carpal tunnel syndrome with additional median-to-ulnar comparative nerve conduction studies. Acta Neurol. Taiwan 22, 152–157.

Watson, P.F., Petrie, A., 2010. Method agreement analysis: A review of correct methodology. Theriogenology 73, 1167–1179.

Werner, R.A., Andary, M., 2011. Electrodiagnostic evaluation of carpal tunnel syndrome. Muscle Nerve 44, 597–607.