

Danish multicentre study on reference values for nerve conduction studies

Birger Johnsen, Birgit Andersen, Martin Fabricius and Torben Smith

Introduction

Three neurophysiological centers in Denmark examined a total of 86 patients in a multicentre study in order to obtain reference values for sensory and motor nerve conduction studies.

Methods

Sensory nerve conduction studies were performed bilaterally on the radial nerve, the lateral cutaneous nerve of forearm and the sural nerve. Motor nerve conduction studies were performed unilaterally on the peroneal nerve and the tibial nerve.

Stimulation and recording sites were cleaned with spirit and grinded. The stimulation electrode was a bar stimulator (Dantec 13L36) with a distance of 23 mm between the cathode and the anode. Recording electrodes were Blue Sensor NF10 electrodes. For sensory studies recording electrodes were placed longitudinally: the cathode was placed with its longest axis transversely to the course of the nerve, the anode was placed distally along the axis of the nerve so the white borders of the two electrodes just touched each other resulting in an inter-electrode distance of 22 mm. For motor studies the recording electrodes were placed according to the "belly-tendon" principle, i.e. the cathode was placed above the bulk of the muscle and the anode electrode above the tendon. An earth strap was placed between the stimulation and recording electrodes. The limb was warmed to at least 35 degree with a heating lamp and/or a heating pad. The bar electrode was moved around during stimulation in order to obtain the largest response and to minimize artefacts. Stimulation strength was supramaximal. Stimulation duration was 0.2 msec, however, in case it was not possible to obtain supramaximal stimulation, the stimulation duration was increased to 0.3 or 0.5 msec. Stimulation was performed with a monophasic pulse, but in case of large artefacts biphasic pulse could be tried. Stimulation frequency was 1 Hz for motor studies and 2 Hz for sensory studies. F-wave studies were carried out by applying 20 supramaximal stimulations at 1 Hz. F-wave studies were performed twice with the cathode distal and with the anode distal. Filter settings were 20 Hz lower cut off and 10 kHz upper cut off.

For sensory studies averaging was used until a stable response was obtained. Latency was measured to first positive peak. Amplitude was measured from negative peak to maximal positive peak. Duration was measured from first positive peak to second positive peak.

For motor studies latency was measured as the first negative deflection from the baseline at an amplification of 1 mV/division and a time-base of 2 msec/division. Amplitude was measured from negative peak to positive peak. Area was measured as the area of the first negative deflection. Duration was measured from the first negative deflection to the first baseline crossing.

Radial nerve sensory. Recording site: Proximal in the tabatière between the tendons of m. extensor pollicis longus and extensor pollicis brevis above the 1st carpo-metacarpal joint. Stimulation site: 10 cm proximal to the recording electrode over the radial bone.

Lateral cutaneous nerve of forearm sensory. Recording site: 12 cm distal to stimulation electrode on a line between the stimulation electrode and the radial artery at wrist. Stimulation site: At the elbow just laterally to the biceps tendon.

Sural nerve sensory. Recording site: Behind lateral malleolus at the most prominent point of the malleolus, which approximately corresponds to 1 cm proximal to the end of the fibular bone. Stimulation site: 13 cm proximal to the recording electrode just lateral to the edge of the achilles tendon.

Peroneal nerve motor. Recording site: Above the most prominent bulk of the extensor digitorum brevis muscle. Stimulation sites: Over the deep peroneal nerve 1) 9 cm proximal to the recording electrode, 2) 2 cm distal to capitulum fibulae, 3) 10 cm proximal to stimulation site 2 in the popliteal fossa, the distance measured on extended knee.

Tibial nerve motor. Recording site: From the abductor hallucis muscle 1 cm under the tuberositas of os naviculare. Stimulation sites: Over the tibial nerve 1) 9 cm proximal to the recording electrode behind the medial malleolus, 2) in the groove of the popliteal fossa.

Material

Centre	1	2	3	Total
All subjects	&29	28	29	86
Radial right	29	28	29	86
Radial left	29	28	29	86
Cut. ant. lat. right	29	28	29	86
Cut. ant. lat. left	29	*27	29	85
Sural right	29	%27	29	85
Sural left	∕28	%#26	29	83
Peroneal	§28	∇26	29	83
Tibial	29	28	29	86

&: One subject aged 79 excluded due to suspicion of a neuropathy

*: Not performed (scar on arm)

?: Not performed bilaterally

∕: Sural data on left side not registered due to technical problems

#: No sural response on left side (age 81)

§: Not performed

∇: Two subjects both aged 79 had no response

There were no inter-laboratory differences in age, height or weight (ANOVA, $p \geq 0.05$).

Results

Regression analyses and confidence intervals for side differences

Regression analyses were performed on conduction velocities, amplitudes and duration with the independent factors age, squared age and height. Significant ($p < 0.05$) relations are included in the tables, however, if there were significant relations both for age and squared age, usually only the strongest relation was shown. R^2 can be interpreted as the amount of variation that can be explained by the independent parameter. In the tables it is illustrated how the standard deviation is reduced by the use of the regression equation.

Sensory nerve conduction

Side differences

There were no side-differences on nerve conduction velocity of the radial nerve and the lateral cutaneous nerve of forearm. The nerve conduction velocity of the sural nerve was lower on left side (mean right 55.0 m/s, left 53.5 m/s, $t = 4.7$, $p < 0.001$). There were no side differences on amplitudes or duration for any of the three nerves.

Further analyses were arbitrarily performed on left side values.

Distribution

For all three nerves, conduction velocities, amplitudes and duration fitted reasonably well a normal distribution, however, after logarithmic transformation the fit was slightly better for amplitudes.

Intercentre differences

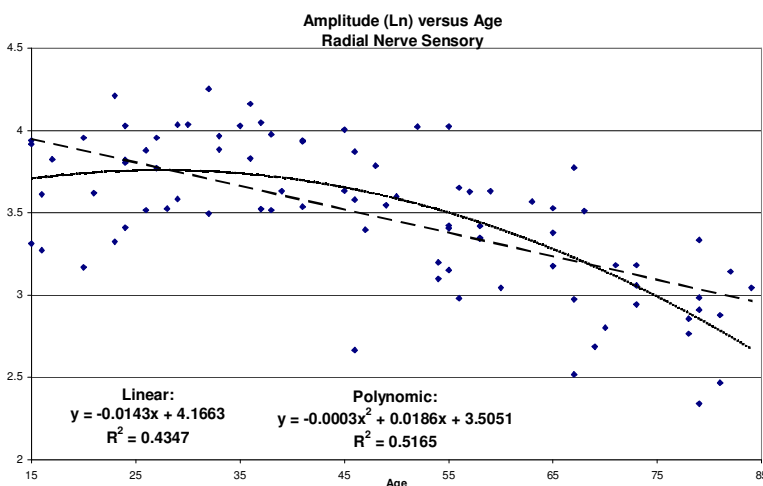
There were no inter-centre differences on conduction velocity, amplitude or duration for any of the three nerves (ANOVA, $p \geq 0.05$).

Radial nerve.

Recording site: Tabatière. Stimulation site: 10 cm proximal to recording site.

Radial nerve							
Regression analyses of conduction velocity, amplitude and duration							
Conduction velocity	N	R ² (%)	Constant (m/sec)	SD (m/sec)	Age (years)	Age*Age (years*years)	Height (cm)
	86		64.2	5.0			
	86	8.5	66.2	4.8		-0.000737**	
	86	12.6	94.9	4.7			-0.179***
	86	22.9	99.4	4.5		-0.000816**	-0.193***
Amplitude (Ln)	N	R ² (%)	Constant exp(μV)	SD exp(μV)	Age (years)	Age*Age (years*years)	Height (cm)
	86		3.49	0.44			
	86	49.1	3.90	0.31		-0.000154***	
	86	53.5	5.48	0.30		-0.000158***	-0.0092**
§	86	55.6	5.05	0.30	0.0172*	-0.000329**	-0.0088**
Duration	N	R ² (%)	Constant (msec)	SD (msec)	Age (years)	Age*Age (years*years)	Height (cm)
	86		1.08	0.13			
	86	14.3	1.02	0.12		0.0000246***	

N, number of subjects; R², R²; SD, standard deviation; Age, age-coefficient; Age*Age, squared age-coefficient; Height, height-coefficient; *, p<0.05, **, p<0.01, ***, p<0.001; §, visual inspection showed a better fit for a second order polynomial function (se figure below).



Confidence intervals for side differences

Radial nerve					
Absolute side differences					
	N	Unit	Median	95%	99%
Conduction velocity	86	m/sec	2.3	6.9	8.2
Amplitude	86	microV	3.4	13.3	17.4
Duration	86	Msec	0.1	0.3	0.4

Radial nerve					
Percent side differences					
	N	Unit	Median	5%	1%
Amplitude %	86	%	89	70	62

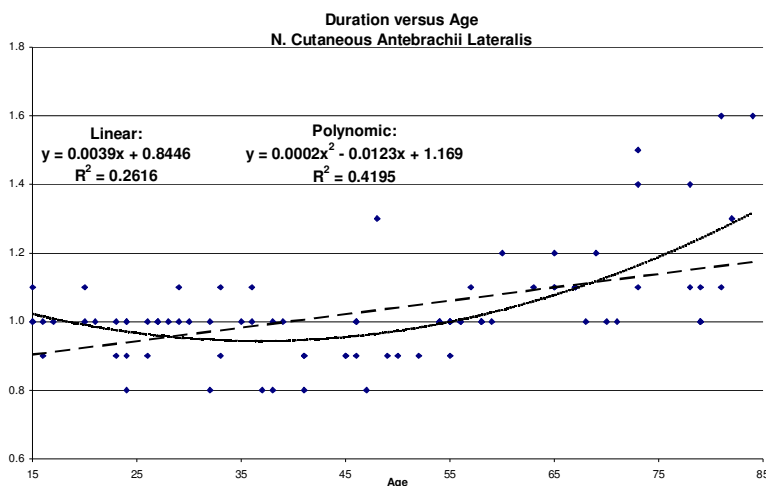
Side differences on amplitudes in percent calculated as the lowest value divided by the highest value multiplied by 100.

Lateral cutaneous nerve of forearm.

Recording site: 12 cm distal to stimulation site. Stimulation site: Elbow just laterally to the biceps tendon.

Lateral cutaneous nerve of forearm						
Regression analyses of conduction velocity, amplitude and duration						
Conduction velocity	N	R ² (%)	Constant (m/sec)	SD (m/sec)	Age (years)	Age*Age (years*years)
	85		66.5	4.8		
	85	13.0	68.8	4.5		-0.000861***
Amplitude (Ln)	N	R ² (%)	Constant exp(μV)	SD exp(μV)	Age (years)	Age*Age (years*years)
	85		2.76	0.47		
	85	19.5	3.04	0.42		-0.000103***
Duration	N	R ² (%)	Constant (msec)	SD (msec)	Age (years)	Age*Age (years*years)
	85		1.03	0.16		
	85	26.2	0.85	0.13	0.00393***	
	85	33.2	0.91	0.13		0.0000449***
§	85	42.0	1.17	0.12	-0.0123***	0.000167***

N, number of subjects; R², R²; SD, standard deviation; Age, age-coefficient; Age*Age, squared age-coefficient; *, p<0.05, **, p<0.01,***, p<0.001; §, visual inspection showed a better fit for a second order polynomial function (see figure below).



Lateral cutaneous nerve of forearm					
Absolute side differences					
	N	Unit	Median	95%	99%
Conduction velocity	85	m/sec	2.6	7.3	10.6
Amplitude	85	microV	3.0	12.4	26.9
Duration	85	msec	0.1	0.3	0.6

Lateral cutaneous nerve of forearm					
Percent side differences					
	N	Unit	Median	5%	1%
Amplitude %	85	%	84	37	26

Side differences on amplitudes in percent calculated as the lowest value divided by the highest value multiplied by 100.

Sural nerve.

Recording site: Behind lateral malleolus at most prominent point. Stimulation site: 13 cm proximal to recording site

Sural nerve							
Regression analyses of conduction velocity, amplitude and duration							
Conduction velocity	N	R ² (%)	Constant (m/sec)	SD (m/sec)	Age (years)	Age*Age (years*years)	Height (cm)
	83		53.5	4.9			
	83	16.9	87.4	4.5			-0.198***
Amplitude (Ln)	N	R ² (%)	Constant exp(μV)	SD exp(μV)	Age (years)	Age*Age (years*years)	Height (cm)
	83		2.34	0.62			
	83	52.6	2.94	0.43		-0.000228***	
	83	61.8	6.14	0.39		-0.000237***	-0.0185***
Duration	N	R ² (%)	Constant (msec)	SD (msec)	Age (years)	Age*Age (years*years)	Height (cm)
	83		1.42	0.21			
	83	14.3	1.32	0.20		0.0000412***	
	83	26.1	0.06	0.19		0.0000448***	0.00729***

N, number of subjects; R², R²; SD, standard deviation; Age, age-coefficient; Age*Age, squared age-coefficient; Height, height-coefficient; *, p<0.05, **, p<0.01, ***, p<0.001.

Sural nerve					
Absolute side differences					
	N	Unit	Median	95%	99%
Conduction velocity	83	m/sec	2.0	7.6	7.9
Amplitude	83	microV	1.6	7.8	20.9
Duration	83	msec	0.1	0.4	0.6

Sural nerve				
Percent side differences				
	N	Unit	Median	5% 1%
Amplitude %	83	%	88	42 36

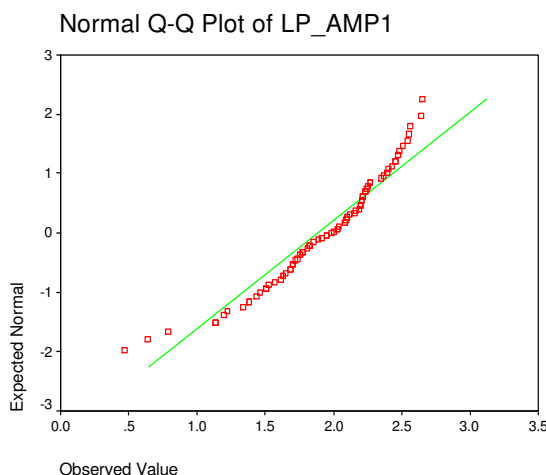
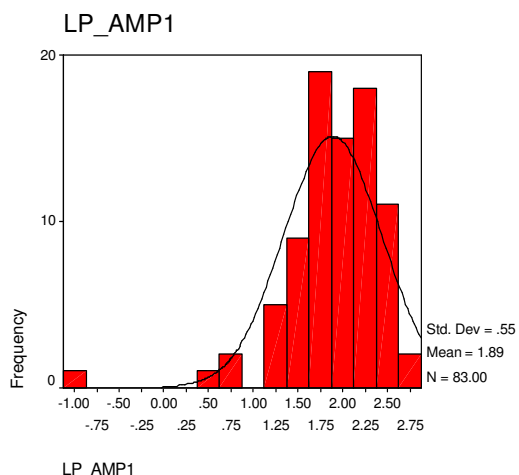
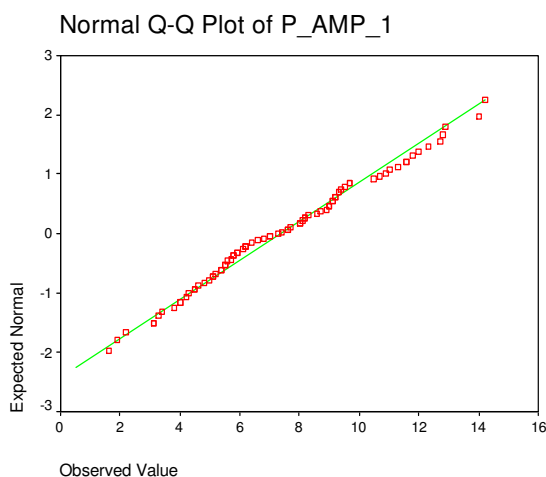
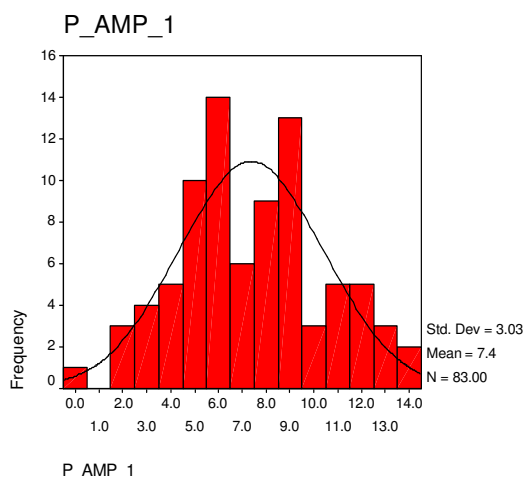
Side differences on amplitudes in percent calculated as the lowest value divided by the highest value multiplied by 100.

Motor nerve conduction

Distribution

Both for peroneal and tibial nerve distal latencies, conduction velocities, amplitudes, area, duration, F-wave minimal latency fitted reasonably well a normal distribution. F-wave frequency for peroneal nerve did also follow a normal distribution, but F-wave frequency for tibial nerve did not.

For amplitudes and area the fit to a normal distribution was poorer after logarithmic transformation (shown for peroneal amplitude in the figures below).



F-wave study proximal versus distal stimulation

There were no differences on F-wave minimal latency or F-wave frequency obtained from distal and proximal cathode stimulator position. This was true for both peroneal and tibial nerves.

F-wave parameters obtained with distal cathode stimulator position are used for calculations.

Intercentre differences

Peroneal nerve

There were no intercentre differences on distal latency, conduction velocities, amplitudes, area, duration or F-wave latency. There was a minor inter-centre difference on F-wave frequency (ANOVA, N=82, F=4.3, p=0.02).

Tibial nerve

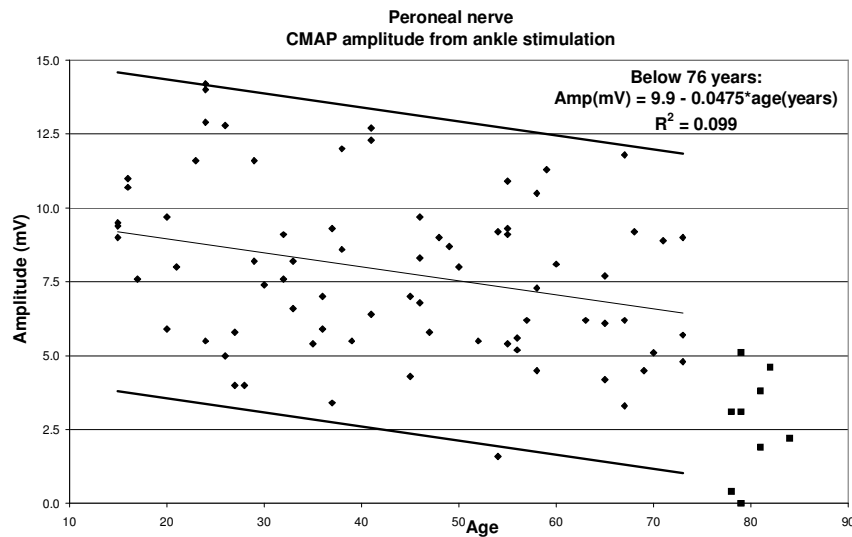
There were no inter-centre differences on distal latency, amplitudes, area, duration or F-wave latency. There was a significant inter-centre difference on conduction velocity (ANOVA, N=86, F=4.8, p=0.01). The inter-centre difference was still present after correction for age and height. Separate regression equations are calculated for each centre.

Peroneal nerve.

Recording site: M. ext. dig. brevis. Stimulation sites: 1) Ankle 9 cm proximal to recording site, 2) 2 cm distal to capitulum fibulae, 3) 10 cm proximal (distance measured on extended knee).

Peroneal nerve							
Regression analyses of distal latency, conduction velocity, amplitude, area and duration							
Distal latency Segment	N	R ² (%)	Constant (m/sec)	SD (m/sec)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle – m. ext. dig. brevis	83		4.15	0.68			
	83	6.0	3.93	0.66		0.000086*	
	83	9.0	0.65	0.65			0.0205**
	83	17.2	-0.05	0.63		0.000101**	0.0230**
Conduction velocity Segment	N	R ² (%)	Constant (m/sec)	SD (m/sec)	Age (years)	Age*Age (years*years)	Height (cm)
Below knee - ankle	83		47.8	4.0			
	83	6.9	50.3	3.9	-0.0535**		
	83	26.0	83.0	3.5			-0.206***
	83	37.0	89.2	3.2	-0.0682***		-0.224***
Above knee – below knee	83		52.8	7.9			
	83	10.4	58.8	7.5	-0.128**		
	83	11.2	56.3	7.4		-0.00136**	
	83	16.6	88.1	7.3		-0.00148***	-0.184*
Amplitude (age < 76 years)§ Stimulation site	N	R ² (%)	Constant (mV)	SD (mV)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle	75		7.8	2.8			
	75	8.9	9.9	2.7	-0.0475**		
Below knee	75		7.0	2.5			
	75	10.3	9.0	2.4	-0.0457**		
Above knee	75		6.8	2.4			
	75	10.7	8.8	2.3	-0.0455**		
Area (age < 76 years) Stimulation site	N	R ² (%)	Constant (mV*msec)	SD (mV*msec)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle	75		12.7	4.4			
	75	8.7	16.0	4.3	-0.0752*		
Below knee	75		11.9	4.1			
	75	9.5	15.1	3.9	-0.0726**		
Above knee	75		11.8	4.1			
	75	9.0	14.8	3.9	-0.0704**		
Duration Stimulation Site	N	R ² (%)	Constant (msec)	SD (msec)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle	83		5.3	0.69			
	83	5.9	2.4	0.68			0.01683*
Below knee	83		5.6	0.77			
	83	6.8	1.9	0.74			0.02175**
Above knee	83		5.7	0.80			
	83	7.8	1.8	0.78			0.02255*

N, number of subjects; R², R²; SD, standard deviation; Age, age-coefficient; Age*Age, squared age-coefficient; Height, height-coefficient; *, p<0.05, **, p<0.01, ***, p<0.001; §, see figure next page.



The regression line of the lower limit of normal for amplitude obtained from ankle stimulation calculated for all 83 subjects crossed the x-axis at 75 years (not shown). Because of this, and also due to the fact that it was not possible to obtain a response in two subjects aged 79, the regression equations in the table above is only calculated for subjects below 76 years.

Peroneal nerve.

Recording site: M. ext. dig. brevis. Stimulation sites: 1) Ankle 9 cm proximal to recording site, 2) 2 cm distal to capitulum fibulae, 3) 10 cm proximal (distance measured on extended knee).

Peroneal nerve							
Regression analyses of F-wave minimal latency, amplitude change, area change and dispersion							
F-wave minimal latency	N	R ²	Constant	SD	Age	Age*Age	Height
Stimulation Site		(%)	(msec)	(msec)	(years)	(years*years)	(cm)
Ankle	81		47.5	5.0			
	81	10.0	43.6	5.0	0.0840**		
	81	10.2	45.3	5.0		0.000871**	
	81	55.1	-16.2	3.4			0.373***
	81	67.7	-25.0	2.9	0.09212***		0.400***
	81	71.4	-25.2	2.8		0.001184***	0.408***
Amplitude change	N	R ²	Constant	SD	Age	Age*Age	Height
Segment		(%)	(%)	(%)	(years)	(years*years)	(cm)
Below knee - ankle	83		-10.9	6.5			
Above knee - below knee	83		-2.5	5.0			
Area change	N	R ²	Constant	SD	Age	Age*Age	Height
Segment		(%)	(%)	(%)	(years)	(years*years)	(cm)
Below knee - ankle	83		-5.7	6.8			
Above knee - below knee	83		-1.3	6.1			
Dispersion	N	R ²	Constant	SD	Age	Age*Age	Height
Segment		(%)	(%)	(%)	(years)	(years*years)	(cm)
Above knee - ankle	83		5.3	6.1			
	83	9.6	0.818	5.8	0.0950**		
Above knee - below knee	83		1.7	4.9			

N, number of subjects; R², R²; SD, standard deviation; Age, age-coefficient; Age*Age, squared age-coefficient; Height, height-coefficient; *, p<0.05, **, p<0.01, ***, p<0.001.

Peroneal nerve					
F-wave frequency					
	N	Unit	Median	5%	1%
F-wave frequency	83	%	50	15	0

Tibial nerve.

Recording site: M. abd. hall. Stimulation sites: 1) Ankle 9 cm proximal to recording site, 2) popliteal fossa.

Tibial nerve							
Regression analyses of distal latency, conduction velocity, amplitude, area and duration							
Distal latency Segment	N	R ² (%)	Constant (m/sec)	SD (m/sec)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle – m. abd. hallucis	86		3.9	0.56			
	86	10.6	3.6			0.0000917**	
	86	12.5	0.44	0.53			0.020***
	86	25.1	-0.11	0.49		0.000100***	0.022***
Conduction velocity§ Popliteal fossa - ankle	N	R ² (%)	Constant (m/sec)	SD (m/sec)	Age (years)	Age*Age (years*years)	Height (cm)
Centre 1	29		48.1	4.5			
Centre 2	28		46.7	4.3			
Centre 3	29		50.5	5.1			
Centre 1	29	20.0	50.7	4.1		-0.000952*	
Centre 2	28	15.2	49.0	4.1		-0.000806*	
Centre 3	29	17.9	53.4	4.7		-0.00117*	
Centre 3	29	36.7	102.3	4.1			-0.307***
Centre 1	29	44.7	90.7	3.5		-0.00127***	-0.226**
Centre 3	29	52.9	104.0	3.6		-0.00112**	-0.300***
Amplitude Stimulation site	N	R ² (%)	Constant (mV)	SD (mV)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle	86		17.2	6.3			
	86	7.3	46.3	6.1			-0.170*
	86	27.9	21.6	5.4		-0.00167***	
	86	37.8	55.8	5.0		-0.00175***	-0.199***
Popliteal fossa	86		13.5	5.2			
	86	7.7	38.4	5.1			-0.145**
	86	38.1	17.8	4.1		-0.00162***	
	86	48.9	47.6	3.8		-0.00169***	-0.173***
Area Stimulation site	N	R ² (%)	Constant (mV*msec)	SD (mV*msec)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle	86		22.5	8.2			
	86	36.3	29.1	6.6		-0.00248***	
	86	39.9	56.3	6.4		-0.00254***	-0.158*
Popliteal fossa	86		20.2	8.1			
	86	42.2	27.3	6.2		-0.00264***	
	86	44.8	50.1	6.1		-0.00269***	-0.133*
Duration Stimulation Site	N	R ² (%)	Constant (msec)	SD (msec)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle	86		5.6	0.81			
	86	5.9	2.4	0.79			0.0197*
Popliteal fossa	86		6.4	0.92			
	86	13.8	0.6	0.86			0.0343***

N, number of subjects; R², R²; SD, standard deviation; Age, age-coefficient; Age*Age, squared age-coefficient; Height, height-coefficient; *, p<0.05, **, p<0.01, ***, p<0.001; §, inter-centre difference.

Tibial nerve.

Recording site: M. abd. hall. Stimulation sites: 1) Ankle 9 cm proximal to recording site, 2) popliteal fossa.

Tibial nerve							
Regression analyses of F-wave minimal latency, amplitude change, area change and dispersion							
F-wave minimal latency Stimulation Site	N	R ² (%)	Constant (msec)	SD (msec)	Age (years)	Age*Age (years*years)	Height (cm)
Ankle	86		49.2	5.6			
	86	12.8	44.5	5.2	0.0986 ***		
	86	14.1	46.4	5.2		0.00105***	
	86	60.9	-25.7	3.5			0.437***
	86	79.5	-35.1	2.6	0.119***		0.459 ***
	86	80.3	-32.4	2.5		0.00123***	0.457***
Amplitude change Segment	N	R ² (%)	Constant (%)	SD (%)	Age (years)	Age*Age (years*years)	Height (cm)
Popliteal fossa - ankle	86		-21.3	13.0			
	86	10.5	-15.7	12.4		-0.00212**	
Area change Segment	N	R ² (%)	Constant (%)	SD (%)	Age (years)	Age*Age (years*years)	Height (cm)
Popliteal fossa - ankle	86		-11.1	12.2			
	86	17.6	-4.3	11.2		-0.00257***	
Dispersion Segment	N	R ² (%)	Constant (%)	SD (%)	Age (years)	Age*Age (years*years)	Height (cm)
Popliteal fossa - ankle	86		11.6	10.2			
	86	5.1	-27.7	10.0			0.230*

N, number of subjects; R², R²; SD, standard deviation; Age, age-coefficient; Age*Age, squared age-coefficient; Height, height-coefficient; *, p<0.05, **, p<0.01, ***, p<0.001.

Tibial nerve					
F-wave frequency					
	N	Unit	Median	5%	1%
F-wave frequency	86	%	100	87	40