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Original Article

The effect of Jendrassik maneuver on the persistence of the peroneal nerve F-wave

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ABSTRACT

Objectives: This study investigated whether peroneal nerve F-wave persistence increased when the Jendrassik maneuver (JM) was performed, aiming to obtain information about the physiology of F-waves and JM.

Patients and methods: Thirty healthy individuals (HIs; 17 females, 13 males; mean age: 33.6±8.2 years; range, 23-50 years) were included in the prospective experimental study conducted between June 15, 2021, and December 15, 2021. Nerve conduction studies of peroneal, superficial peroneal, posterior tibial, and sural nerves were performed in one extremity of each HI. The peroneal nerve F-wave study was performed at rest (Study 1), during JM (Study 2), and after JM (Study 3). F-wave persistence of the peroneal nerve, maximum F-wave amplitude (ampF-wave$_{max}$), mean F-wave amplitude (ampF-wave$_{mean}$), minimum F-wave latency, and the ratio of ampF-wave$_{mean}$ to maximum M amplitude (F/M ratio) were analyzed.

Results: The mean peroneal nerve F-wave persistence in Study 1, Study 2, and Study 3 was 28.7±23.9%, 52.3±32.1%, and 34.7±29.0%, respectively. F-wave persistence in Study 2 was higher compared to Studies 1 and 3 ($p<0.001$ and $p<0.001$, respectively). Moreover, ampF-wave$_{max}$, ampF-wave$_{mean}$, and F/M ratio in Study 2 were higher than Studies 1 and 3 ($p=0.026$ and $p=0.021$ for ampF-wave$_{mean}$; $p=0.015$ and $p=0.003$ for ampF-wave$_{max}$; $p=0.033$ and $p=0.015$ for F/M ratio, respectively). F-wave persistence in Study 2 was positively correlated with ampF-wave$_{max}$ and ampF-wave$_{mean}$ ($p<0.001$, $r= 0.717$; $p<0.001$, $r=0.786$, respectively).

Conclusion: This study demonstrated that JM increased F-wave persistence and amplitude. Jendrassik maneuver may show its effect through motor neuron excitability.

Keywords: F-wave persistence, F-wave, motor neuron excitability, Jendrassik maneuver, peroneal nerve.

F-waves are potentials generated by antidromic activation of motor neurons. By analyzing F-waves, information about the physiology of the motor neuron and its axon can be obtained, thus providing important clues for the diagnosis of polyneuropathies such as Guillain-Barré syndrome.[1-3] F-waves have many parameters, such as minimum F-wave latency (latF-wave$_{min}$), mean F-wave latency, F-wave chronodispersion, maximum F-wave amplitude (ampF-wave$_{max}$), and F-wave persistence.[1,4-6] F-wave parameters such as persistence and amplitude provide important information about the physiology of the motor neuron pool and its excitability.[7-10] The number of F-waves that can be obtained with a certain number of stimuli is known as F-wave persistence.[5-11] The persistence of F-waves differs between nerves, possibly depending on the muscle from which the F-waves are derived.[6,7,12,13] It has been reported that voluntary

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contraction increases the persistence or amplitude of F-waves.[8,9,14,15] The Jendrassik maneuver (JM) facilitates the H-reflex, yet the mechanism of JM is still unclear.[16-18] Just as JM affects the H-reflex, it can also have an effect on the F-wave. Moreover, the existence of such a possibility may indicate that JM may exert its effect through the motor neuron pool. Therefore, whether JM has an effect on peroneal nerve F-wave persistence was investigated.

PATIENTS AND METHODS

This prospective experimental study was conducted in the clinical neurophysiology laboratory of the Adana City Training and Research Hospital between June 15, 2021, and December 15, 2021. Thirty healthy individuals (HIs; 17 females, 13 males; mean age: 33.6±8.2 years; range, 23-50 years) were included in the study. They were required to have the following characteristics: *(i)* a normal neurological examination; *(ii)* normal nerve conduction study findings, according to previously recommended reference values;[19] *(iii)* absence of clinical findings suggestive of lumbosacral radiculopathy, lumbosacral plexopathy, or mononeuropathy (e.g., peroneal or sciatic neuropathy); *(iv)* absence of a disease that may cause neuropathy (e.g., diabetes mellitus).

Nerve conduction studies

Nerve conduction studies were performed using the Cadwell Sierra Summit electromyography unit (Cadwell Laboratories, Kennewick, WA, USA). High-low filters for motor and sensory nerve conduction studies were 20 Hz-10 kHz and 20 Hz-2 kHz, respectively. Stimulation and recording were performed with surface electrodes. Nerves were stimulated supramaximally. The stimulation frequency and duration were 1 Hz and 0.1 msec, respectively. Electrodiagnostic tests were performed if the temperature of the lower extremity was above 31°C. Cold extremities were warmed. Sensitivity for sensory and motor nerve conduction studies were set at 10 μV/division and 2 mV/division, respectively. The sweep speed for sensory and motor nerve conduction studies were 1 msec/division and 5 msec/division, respectively.

Peroneal, posterior tibial, sural, and superficial peroneal nerve conduction studies were performed on one of the lower extremities. Peroneal nerve compound muscle action potential (CMAP) and posterior tibial nerve CMAP were recorded from the extensor digitorum brevis (EDB)/tibialis anterior and abductor hallucis muscles, respectively. The distance between the stimulation point at the ankle and the recording electrode was 8 cm for both peroneal and posterior tibial motor nerve conduction studies. Stimulation points of the posterior tibial nerve were the ankle and popliteal fossa. The peroneal nerve was stimulated at the ankle, below the fibular head, and at the popliteal fossa. To obtain sural and superficial peroneal compound nerve action potentials (CNAPs), the distance between the stimulation points and the recording electrode was set to 10-14 cm. Compound muscle action potential and CNAP amplitudes were calculated by measuring peak to peak. Sural sensory nerve conduction velocity was calculated using both onset and peak latency, and superficial peroneal nerve conduction velocity was calculated using onset latency.

Peroneal nerve F-wave study and the Jendrassik maneuver

High pass and low pass filters for F-wave operation were 20 Hz and 10 kHz, respectively. Sensitivity and sweep speed were 200-500 μV/division and 10 msec/division, respectively. To obtain peroneal and posterior tibial nerve F-waves, recording electrodes were placed on the EDB and abductor hallucis muscles, respectively. The peroneal and posterior tibial nerves were supramaximally stimulated at 25% more than the intensity of stimulation that produced the highest amplitude M-wave.[1] The stimulation frequency and duration was 0.5 Hz and 0.1 msec, respectively. F-waves were obtained with 10 stimuli.[4,7,11,20] The time interval between stimulations was 2 sec. The amplitude of the F-wave was measured from peak to peak. It was considered an F-wave if the potential was >40 μV.[1,21] A-waves were carefully distinguished from F-waves by considering their characteristics.[5,22]

The analysis included lat$F\text{-}wave_{min}$, the number of F-waves (F-waveN), $ampF\text{-}wave_{max}$, and the presence of A-waves. The mean of the F-wave amplitudes ($ampF\text{-}wave_{mean}$) was calculated if at least five F-waves were obtained.[7] In addition, the ratio of $ampF\text{-}wave_{mean}$ to maximum M-response amplitude (F/M ratio) was recorded.

The JM and the F-wave studies were performed while HIs were lying in a relaxed position. Participants rested for 5 min before performing the peroneal nerve F-wave studies. The JM was performed as HIs attempted to pull their hands apart while their hands and fingers were clamped together. Additionally, HIs clenched their teeth during this time.[23] Three studies were performed: Study 1, a peroneal nerve F-wave study performed while the HI was in a relaxed

position; Study 2, an F-wave study performed while HIs were performing the JM; Study 3, an F-wave study performed after Study 2 while HIs were in a relaxed position. Between the studies, the HIs waited in a relaxed position for 60 sec.

Statistical analysis

The G*Power software version 3.1.9.2 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) was used to estimate the sample size. With type 1 error (α)=0.05 and type 2 error (β)=0.10, it was decided that at least 12 to 15 participants should be included in the study.[15]

Data were analyzed using IBM SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequency and percentage. For numerical data, mean ± standard deviation (minimum-maximum) were used. Cochran's Q test was used to compare categorical variables between groups. Pairwise comparison of categorical variables was performed using McNemar's test. Bonferroni correction was used for post hoc analysis. The Mann-Whitney U test was used to compare F-wave parameters between male and female HIs and between the extremity sides on which the nerve conduction study was performed. The dependent numerical data were compared between groups with the Friedman test and the Wilcoxon signed-rank test. Eta squared was calculated to determine the effect size (eta squared <0.06, minor effects; 0.060<eta squared<0.140, moderate effects; eta squared>0.140, large effects).[24] The Spearman correlation test was used for correlation analysis. Based on the previously suggested values, the strength of the correlation was classified according to the correlation coefficient (r) as follows:[24,25] r ≥0.9/ r ≤-0.9, perfect; 0.7≤ r <0.9/-0.9< r ≤-0.7, strong; 0.5≤ r <0.7/-0.7< r ≤-0.5, moderate; 0.3< r ≤0.5/-0.5≤ r <-0.3, weak; r <0.3/r >-0.3, poor. A *p*-value <0.05 was considered statistically significant.

RESULTS

The mean height, weight, and body mass index of the participants were 167.9±8.1 (range, 150 to 183) cm, 72.8±14.5 (range, 53 to 109) kg, and 25.7±3.8 (range, 19.8 to 32.7) kg/m^2, respectively.

The findings of the posterior tibial, peroneal, sural, and superficial peroneal nerve conduction studies are shown in Table 1. A nerve conduction study was performed on the right lower extremity of 16 HIs and the left lower extremity of 14 HIs. The peroneal F-wave parameters obtained from Studies 1, 2, and 3

TABLE 1
Nerve conduction study findings of the HIs

Nerve conduction study	Mean±SD	Median	Min-Max
Posterior tibial nerve			
CMAP Terminal latency (m/sec)	3.7±0.7	3.4	2.9-5.6
CMAP Amplitude (mV)	13.8±7.0	13.5	4.2-32.0
Velocity ankle-popliteal fossa (m/sec)	49.3±5.1	48.0	41-64
MinlatF-wave (m/sec)	45.2±3.6	44.5	40.5-56.0
F-waveN	9.9±2.5	10	9-10
Peroneal nerve (recorded from EDB)			
CMAP Terminal latency (m/sec)	3.7±0.6	3.8	2.7-4.5
CMAP Amplitude (mV)	8.7±3.1	8.4	3.8-16.6
Velocity ankle-below the fibular head (m/sec)	53.2±4.6	53	45-65
Velocity below the fibular head-popliteal fossa (m/sec)	60.1±5.9	61	45-71
Peroneal nerve (recorded from TA)			
CMAP Amplitude (mV)	8.9±2.0	9.2	3.9-12.5
Velocity ankle-below the fibular head (m/sec)	58.1±8.6	59	43-75
Sural nerve			
CNAP Amplitude (μV)	18.4±8.2	16.9	5.9-44.8
Velocity (onset)	55.8±7.0	55	43-71
Velocity (peak)	43.9±4.9	44	35-54
Superficial peroneal nerve			
CNAP Amplitude (μV)	15.2±6.9	13.2	7.1-35.1
Velocity (onset)	55.0±6.3	54.0	42-71

HIs: Healthy individuals; SD: Standard deviation; CMAP: Compound muscle action potential; EDB: Extensor digitorum brevis; TA: Tibialis anterior; CNAP: Compound nerve action potential.

TABLE 2
Comparison of F-wave parameters between Studies 1, 2, and 3

F-wave parameter	Study 1				Study 2				Study 3				*p*
	n	Mean±SD	Median	Min-Max	n	Mean±SD	Median	Min-Max	n	Mean±SD	Median	Min-Max	
F-waveN	30	2.87±2.39	3	0-8	30	5.23±3.21	5	0-10	30	3.47±2.90	3	0-10	**<0.001**
F-wave persistence (%)	30	28.7±23.9	30	0-80	30	52.3±32.1	50	0-100	30	34.7±29.0	30	0-100	**<0.001**
latF-wave$_{Min}$ (msec)	21	43.9±4.0	43.8	37.9-54.8	27	43.2±3.8	42.4	38.0-53.6	24	43.4±3.5	43.1	38.0-53.9	0.691
ampF-wave$_{Max}$ (μV)	21	232.4.5±144.5	183	54-659	27	300.9±205.3	205	108-946	24	175.3±94.6	171	54-442	**0.010**
ampF-wave$_{Mean}$ (μV)	11	154.8±65.0	154	79-296	18	201.8±93.8	174	99-416	10	151.3±49.9	136	78-210	**0.012**
F/M ratio (%)	11	1.78±0.71	1.46	1.05-3.33	18	2.33±1.08	2.26	0.79-5.32	10	1.44±0.37	1.35	0.96-2.02	**0.012**

SD: Standard deviation; F-waveN: F-wave number; ampF-wave$_{Max}$: Maximum amplitude of F-waves; ampF-wave$_{Mean}$: Mean amplitude of F-waves; latF-wave$_{Min}$: Minimum latency of F-waves; F/M ratio: Ratio of ampF-wave$_{Mean}$ to M wave with maximum amplitude. The Friedman test was used. F-wave persistence/F-waveN, ampF-wave$_{mean}$, AmpF-wavemax, F/M ratio were higher in Study 2 than in Studies 1 and 3 (Wilcoxon test; p<0.001 and p<0.001 for F-wave persistence/F-waveN; p=0.026 and p=0.021 for ampF-wave$_{mean}$; p=0.015 and p=0.003 for ampF-wave$_{Max}$; p=0.033 and p=0.015 for F/M ratio). Eta squared values for F-wave persistence, ampF-wave$_{Mean}$, ampF-wave$_{Max}$, and F/M ratio were 0.114 (p<0.001), 0.095 (p=0.012), 0.105 (p=0.010), and 0.081 (p=0.012), respectively. F-wave parameters were not different between Studies 1 and 3 (p>0.05).

Figure 1. An example of peroneal nerve F-waves obtained from Studies 1, 2, and 3.

Figure 2. Comparison of the number of participants with at least one F-wave achieved between Studies 1, 2, and 3.

The presence of F-waves was compared between groups with Cochran's Q test (p=0.050).

TABLE 3
Correlation between F-wave number and demographic characteristics/F-wave parameters

Demographic and peroneal nerve F-wave parameters	Study 1 F-waveN			Study 2 F-waveN			Study 3 F-waveN		
	n	r	*p*	n	r	*p*	n	r	*p*
Age (years)	30	0.299	0.108	30	-0.228	0.226	30	-0.030	0.873
Height (cm)	30	0.127	0.505	30	0.084	0.660	30	0.209	0.268
Weight (kg)	30	0.118	0.533	30	0.175	0.356	30	0.094	0.621
BMI (kg/m^2)	30	0.051	0.788	30	0.183	0.332	30	0.015	0.939
latF-wave$_{Min}$ (msec)	21	-0.201	0.383	27	-0.079	0.696	24	-0.203	0.573
ampF-wave$_{Max}$ (μV)	21	0.383	0.087	27	0.717	<0.001	24	0.635	0.001
ampF-wave$_{Mean}$ (μV)	11	0.302	0.367	18	0.786	<0.001	10	0.204	0.573
F/M ratio (%)	11	-0.284	0.397	18	0.441	0.90	10	-0.064	0.862

BMI: Body mass index; F-waveN: F-wave number; AmpF-wavemax: Maximum amplitude of F-waves; AmpF-wavemean: Mean amplitude of F-waves; latF-wavemin: Minimum latency of F-waves; F/M ratio: Ratio of AmpF-wavemean to M wave with maximum amplitude; r: Correlation coefficient; The Spearman correlation test was used.

are compared in Table 2. There were no differences in the peroneal nerve F-wave parameters between sex and between the sides of the extremities in which the nerve conduction study was performed (p>0.05). Figure 1 exemplifies the peroneal nerve F-waves obtained from Studies 1, 2, and 3. The number of HIs with A-waves in Studies 1, 2, and 3 was eight (27%), six (20%), and five (17%), respectively; the difference was not significant (p>0.05).

Peroneal nerve F-waves could not be obtained from nine HIs in Study 1, whereas F-waves could be obtained in six of these nine HIs in Study 2. One of the three HIs who did not have peroneal nerve F-waves in Studies 1 and 2 had F-waves in Study 3. In the remaining two HIs, F-waves of the peroneal nerve could not be obtained. In Figure 2, the number of HIs in whom F-wave was achieved through at least one of the 10 stimuli was compared between Studies 1, 2, and 3. Table 3 shows the correlation of the demographic data/F-wave parameters and F-waveN for the HIs. Figure 3 shows the positive correlation between ampF-wave$_{max}$ and the F-waveN in Study 2.

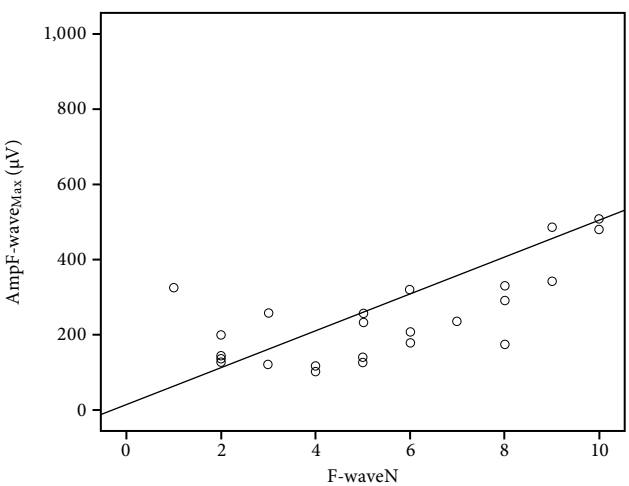

Figure 3. Positive correlation between ampF-wave$_{max}$ and the F-waveN in Study 2.

F-waveN: F-wave number; AmpF-wave$_{max}$: Maximum amplitude of F-waves.

DISCUSSION

The main objective of this study was to determine the effect of JM on the peroneal nerve F-wave. The obtained results demonstrate that JM affected F-wave persistence, ampF-wave$_{mean}$, ampF-wave$_{max}$, and F/M ratio. These findings may indicate that the effect of JM may be related to motor neuron excitability.

It has been reported that peroneal nerve F-wave persistence is lower than the F-wave persistence of the tibial, median, and ulnar nerves.[6,7,12,13] This may be related to the muscle in which the F-wave was recorded.[7] It has also been reported that the persistence of F-waves recorded from antigravity muscles was higher than the persistence of F-waves recorded from antigravity antagonist muscles, such as EDB.[7] Another explanation may be related to the fact that F-wave persistence provides information about the number of motor units of the muscle in which the recording was made. The deep peroneal nerve branches only to the EDB muscle in the foot, but the tibial nerve branches to more than one muscle in the foot, including the abductor hallucis.[22] Therefore, the F-wave persistence

obtained by recording the EDB muscle may be lower than the F-wave persistence obtained by recording the abductor hallucis muscle. Consistent with this information, there are studies showing that the tibial nerve F-wave persistence was close to 100%, similar to the present study.[6,7,12]

Peroneal nerve F-wave persistence has been reported as approximately 50 to 60% in some studies,[6,12] while others report it as approximately 30 to 40%.[7,13] These peroneal nerve F-wave persistence differences may be due to methodological differences. In the present study, an F-wave was considered to have a potential >40 μV;[1,21] however, other studies consider the potential to be >20 μV.[4,12] Another reason might be that Studies 1 and 3 were performed while the HIs were in the relaxed position. Previous research has shown that the persistence and amplitude of the F-wave decreases in the resting position.[8] Moreover, Nakazumi and Watanabe[15] reported that voluntary contractions increased the F-wave amplitudes in contrast to the resting state. They reported that ampF-wave$_{max}$ increased with mild voluntary contraction in controls. Furthermore, they found that ampF-wave$_{max}$ increased with mild voluntary contraction compared to the ampF-wave$_{max}$ at rest in patients with lower motor neuron disease, similar to controls. However, this amplitude increase was not found in patients with upper motor neuron disease.[15] This can be explained by the fact that the structures proximal to the motor neuron affect the motor neuron, and as a result, the ampF-wave$_{max}$ increases. However, it would be useful to confirm this hypothesis with other studies. Similarly, another study demonstrated that F-wave persistence and amplitudes decreased on the side of paresis in acute upper motor neuron lesions.[26] In that study, it was found that these F-wave abnormalities improved when compared to the healthy sides in the chronic phase of this upper motor neuron lesion. In yet another study, it was reported that F-wave persistence was low on the paretic side in patients with stroke and that motor imagery could increase F-wave persistence and amplitude.[27]

Research has shown that mild voluntary contraction increases F-wave persistence.[28] In addition, facilitation of F-waves was reported when muscle activation was greater than 50% of maximal voluntary contraction.[14] However, it should be kept in mind that F-wave size has also been shown to change with strong contraction of the contralateral extremity or with sensory stimuli.[9] In the present study, JM was used rather than mild voluntary contraction, and it was shown that ampF-wave$_{mean}$ and F/M ratio increased, in addition to ampF-wave$_{max}$ and F-wave persistence. Jendrassik maneuver is known to facilitate the H-reflex and the tendon tap reflex.[16-18] Comparison of the F-wave and H-reflex pathways show that both are obtained through backfiring through the motor neuron. Unlike the F-wave, afferent Ia nerve fibers have an important role in the H-reflex pathway.[5,11] Considering this information and the findings obtained from the present study, JM does not act on Ia nerve fibers. The fact that H-reflex facilitation was reported in a previous study despite blocking of afferent Ia nerve fibers may support this.[16] This fact, as well as the absence of muscle activity in the soleus muscle while the H-reflex is facilitated during JM, may indicate that the fusimotor system activation, which is believed to be predominant in the JM mechanism, does not have an effect on the JM mechanism alone.[18] Similarly, some have reported that the fusimotor system, acting through gamma motor neurons, does not have a predominant effect on the facilitation of the H-reflex and tendon tap reflex,[17,29,30] but some reported that the fusimotor system was important in the JM mechanism.[31,32] Although mechanisms such as intrinsic spinal mechanisms and presynaptic disinhibition in addition to fusimotor activation are thought to be the cause of facilitation in JM, the mechanism of JM has yet to be clarified.[18,23,30] The JM mechanism may not be explained by a single mechanism such as fusimotor system activation or presynaptic inhibition. Jendrassik maneuver may act through an intrinsic spinal mechanism or upper motor neurons or the interaction of the previously mentioned mechanisms with each other. Considering reports such as increased F-wave persistence and amplitude on the spastic side, F-wave amplitudes not increased as a result of voluntary contraction in patients with upper motor neuron disease compared to controls and those with lower motor neuron disease, lower motor neuron membrane excitability may be affected by stroke[15,33,34] and may show that F-wave persistence and amplitude can be modified by structures proximal to motor neurons in the anterior horn, as previously mentioned. Similarly, the effect of JM on F-wave persistence and amplitude may be regulated by mechanisms such as the cortical motor drive. As a result of upper motor neuron discharges with voluntary contraction, motor neuron excitability, which decreases with rest, may increase.[8] Further studies on F-wave and JM, including transcranial magnetic stimulation, are necessary to provide an understanding of the mechanism of F-wave and JM.

The fact that there was a strong positive correlation between F-wave persistence and F-wave amplitude in Study 2 may mean that more motor neurons are fired with JM. Interestingly, F-wave persistence and ampF-wave$_{max}$ were found to be correlated in Study 3. Although not significant, the persistence of F-waves in Study 3 was higher than in Study 1. F-wave amplitudes may have increased as the F-wave persistence increased. It is difficult to explain the findings of Study 3, but as previously mentioned, the 60-sec rest break between studies may be an explanation. It may mean that the effect of JM persists, albeit for a short time. However, this hypothesis needs to be confirmed.

In this current study, it was also found that F-wave latencies did not change during JM. The lack of change in F-wave latencies during JM can be attributed to the firing of large motor neurons with antidromic stimulus and the lack of opportunity for activation of other fast axons during voluntary contraction.[28,35]

There were some limitations in this research. Performing the F-wave study with 10 stimuli may be one of these. However, it should be kept in mind that this study was on F-wave persistence rather than F-wave latency, and there are other F-wave studies with 10 stimuli.[4,7,11,20] It was stated in the method section that at least five F-waves should be obtained for the calculation of ampF-wave$_{mean}$. Another limitation may be the fact that in Studies 1 and 3, in which JM was not utilized, the number of ampF-wave$_{mean}$ was lower than in Study 2. It should be noted that the eta square values (effect size) for F-wave persistence, ampF-wave$_{mean}$, ampF-wave$_{max}$, and F/M ratio comparisons between studies were between 0.060 and 0.140 (moderate effect).

In conclusion, this study showed that F-wave persistence, F-wave amplitudes, and F/M ratio increase during JM. Thus, it can be concluded that the JM mechanism might be related to the excitability of the motor neuron pool.

Ethics Committee Approval: The study protocol was approved by the University of Health Sciences Adana City Training and Research Hospital Clinical Research Ethics Committee (date: 12.02.2020, no: 50/723). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea concept: H.F., Ş.B., Z.A.; Design: H.F., Ş.B.; Supervision, resources, materials, data collection, processing, writing manuscript, critical review: H.F., İ.Ö., Ş.B., M.Y., Z.A.; Analysis: H.F., İ.Ö., Z.A.; Literature research: H.F., İ.Ö., Ş.B., M.Y.

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