Hylonome

Effects of short term water immersion on peripheral reflex excitability in hemiplegic and healthy individuals: A preliminary study

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Abstract

Background: Reflex excitability is increased in hemiplegic patients compared to healthy controls. One challenge of stroke rehabilitation is to decrease the effects of hyperreflexia, which may be possible with water immersion. **Methods/Aims:** The present study examined the effects of acute water immersion on electrically-evoked $H_{max}:M_{max}$ ratios (a measure of reflex excitability) in 7 hyperreflexive hemiplegic patients and 7 age-matched healthy people. $H_{max}:M_{max}$ ratios were measured from soleus on dry land (L1), immediately after (W1) and 5 minutes after immersion (W5), and again after five minutes on land (L5). **Results:** Water immersion led to an acute increase in $H_{max}:M_{max}$ ratio in both groups. However, after returning to dry land, there was a non-significant decrease in the $H_{max}:M_{max}$ ratio of 8% in the hemiplegic group and 10% in healthy controls compared to pre-immersion values. **Interpretation:** A short period of water immersion can decrease peripheral reflex excitability after returning to dry land in both healthy controls and post-stroke patients, although longer immersion periods may be required for sustainable effects. Water immersion may offer promise as a low-risk, non-invasive and non-pharmaceutical method of decreasing hyperreflexivity, and could thus support aquatic rehabilitation following stroke.

Keywords: H/M-ratio, Reflex Excitability, Hemiplegia, Water Immersion, Stroke Rehabilitation

Introduction

Stroke is one of the leading causes of death and disability, and with prevalence of stroke set to increase over the next 20 years, the financial burden of stroke is also set to escalate globally[1,2]. Irrespective of the type of stroke, loss of functional capacity is one of the major problems, and a main focus of rehabilitation is the restoration of function using a wide range of methods[3]. Following an upper motor neuron lesion such as stroke, the performance of activities of daily living is affected by the development of spasticity and the consequences of decreased physical activity, e.g. muscle weakness, impaired motor control and soft tissue contracture[4]. Prevalence of spasticity after stroke ranges from 19-92% and is a common factor restricting restoration of function[5,6]. Spasticity is characterised by an exaggerated response of the stretch reflex, or hyperreflexia, to a velocity-dependent stretch of a muscle at rest[7]. One challenge of rehabilitation paradigms for stroke patients is to decrease the impact of spasticity on active and passive movement, thereby improving rehabilitation participation and completion of activities of daily living (ADL).

Abbreviations

L1	Measurements performed on dry land before immersion.
W1	Measurements performed immediately after immersion in water.
W5	Measurements performed five minutes after being immersed in water.
L5	Measurements performed on dry land five minutes after the water measurements.

	Patients	Controls
Sex	3 female, 4 male	3 female, 4 male
Age	49±10	50±9
Height (cm)	171±11	171±10
Body mass (kg)	83±23	73±13
Reason for hemiplegia	4 infarction, 3 haemorrhage	-
Years since stroke	7±8 (range: 3-26)	-
Achilles tendon reflex	3.0±0	-
Active ankle dorsiflexion	2.1±1.2	-
Active ankle plantar flexion	2.3±1.3	-
Passive ankle dorsiflexion	3.6±1.5	-
Passive ankle plantar flexion	1.9±1.9	-

Values are mean ± SD. Achilles tendon reflex scores are based on the NINDS scale[23], 1=hyporeflexia, 4=clonus. Active ankle dorsi/plantar flexion scores are based on the modified MRC scale for testing strength[24], 0=plegic, 5=strong movement. Passive scores are based on the modified modified Ashworth scale[25], 1=normal, 5=rigid.

Table 1. Subject characteristics for the patient and control groups.

Aquatic therapy is one rehabilitation modality that has strong evidence to show that it is effective at improving muscle strength of the paretic leg following stroke[3], and is one that holds therapeutic promise. The specific properties of water, such as pressure and relative weightlessness, could be exploited to reduce abnormal side-effects of hemiplegia such as altered muscle tone and weakness, which are magnified by the effects of gravity[8]. There is evidence that water immersion alters normal neuromuscular function[9,10]. Electromyographic (EMG) recordings underwater have generally demonstrated decreased lower limb muscle EMG amplitudes and EMG/force-ratios for maximal and submaximal contractions when compared to measurements on dry land[9-11] (but see also [12]). In particular, in healthy people seated underwater, H-reflexes tend to decrease[10]. As the H-reflex is an electrical test of reflex excitability that involves the same pathway as the stretch reflex but bypasses muscle spindles[13], a decrease in H-reflex size indicates a decrease in reflex excitability. If this finding could be replicated in situations where reflex excitability is abnormally high, water immersion could be a valuable tool for clinical rehabilitation.

Neurophysiological responses to water immersion have been largely unexplored in pathological conditions. Therefore, the present study was designed to examine the effects of acute underwater immersion on neuromuscular function in hemiplegic patients and age-matched healthy people. It was hypothesised that water immersion would lead to a decrease in reflex excitability in hemiplegic post-stroke patients.

Materials and methods

Subjects

Seven hemiplegic patients and seven healthy age and gender matched control subjects volunteered to participate in this study

(Table 1). The study received approval from the Ethical Committee of the Kymenlaakso Central Hospital, and subjects gave written informed consent. Inclusion criteria for the hemiplegic patients were: (1) stable hemiplegic symptoms caused by hemorrhage or cerebral infarction, (2) hyperreflexia, (3) ability to walk with or without assistive device, (4) ability to manage activities of daily living independently. Exclusion criteria were: (1) cognitive problems, (2) cardio-pulmonary disease, (3) dementia.

Measurements

After shaving, abrading and cleaning the skin with alcohol, surface EMG electrodes (Medicotest N-OO-S, Denmark) were positioned bilaterally over soleus below the distal heads of the gastrocnemius muscles. Inter-electrode distance was 2 cm. After determining the optimal stimulating location, a cathode electrode (1 cm²) was placed over the tibial nerve in the popliteal fossa, and the anode (5 x 8 cm) was positioned superior to the patella. Single 1 ms square pulses were delivered by a constant current stimulation unit (Grass Telefactor, Model S48K, Astromed Inc, USA). Stimulation intensity was adjusted in small increments (4-5 mA) to produce full H-reflex and M-wave recruitment curves, which were sampled by the EMG equipment (ME6000, Mega Electronics Ltd, Kuopio, Finland) at a frequency of 1000 Hz and recorded using MegaWin software (Mega Electronics Ltd). Approximately twenty stimuli were collected at each measurement interval, using a randomised inter-stimulus interval of at least 10 seconds. The highest H-reflex and M-wave values were used for further analysis.

Protocol

All data were collected in a single session, which included identical measurements performed on land (L1), immediately after water immersion (W1) and after five minutes of immersion (W5) with the water at the level of the mid-sternum and the lower limb approximately 60 cm below this point. Finally, the measurements were repeated after five minutes on land (L5). The room and water temperatures were 26ºC and 33ºC, respectively. Throughout the measurements, subjects were seated in a poolside elevator chair with hip angle at 110°, knee angle at 160° and ankle angle at 90° (180°=full extension). In order to guarantee identical position throughout the measurement session, the ankles and thighs were stabilized with straps, and subjects were instructed to keep the head still, eyes open, and look forwards at all times. To protect the recording equipment and to guarantee patient safety, each subject wore thin waterproof trousers (Vision Flyfishing, Finland). At each measurement interval, H-reflexes and M-waves were evoked from the affected hemiplegic leg in the patient group and the dominant leg in controls. At L1, the non-affected leg of the patient group was also measured as a reference.

Statistical analysis

Means and standard deviations were calculated for the peak-to-peak amplitudes of maximal H- and M-responses and $H_{max}:M_{max}$ ratios for all subjects and conditions. Of these parameters, statistics were only performed on the $H_{max}:M_{max}$ ratio be-

	Hemiplegic group			Control group		
	H-reflex (mV)	M-wave (mV)	$H_{max}:M_{max}$	H-reflex (mV)	M-wave (mV)	$H_{max}:M_{max}$
L1						
Non-affected	3.46 (1.53)	5.70 (1.39)	0.60 (0.21)	3.65 (1.67)	7.23 (2.30)	0.52 (0.16)
Affected	4.83 (2.24)	7.46 (2.49)	0.64 (0.21)			
W1	5.70 (2.56)	7.75 (2.29)	0.73 (0.24)	4.32 (2.41)	7.80 (3.78)	0.58 (0.17)
W5	5.11 (2.67)	7.56 (2.17)	0.66 (0.28)	4.16 (2.72)	7.28 (3.72)	0.58 (0.20)
L5	4.31 (2.26)	7.06 (1.95)	0.59 (0.26)	3.36 (1.81)	7.16 (2.45)	0.47 (0.14)

Table 2. Absolute values for H-reflex, M-wave and $H_{max}:M_{max}$ ratios on dry land (L1), immediately after water immersion (W1), after 5 minutes of immersion (W5) and after 5 minutes on land (L5). Values represent group mean (SD).

cause this is a normalized value that allows group comparisons. Subject characteristics were compared between groups using independent samples t-tests where appropriate. A mixed ANOVA (group x time) was used to examine differences between groups (between-subjects factor) and experimental time points (within-subjects factor), and bonferroni post hoc tests were used as appropriate. Within-group differences in maximal M-wave amplitude across time points were assessed using repeated measures ANOVA. For all ANOVAs, Mauchly's sphericity test was performed, and where this assumption was violated, Greenhouse-Geisser adjustments were used. Healthy and affected limbs were compared at baseline using dependent samples t-tests in the patient group. Significance was accepted for $p < 0.05$.

Results

There were no statistical differences between groups in terms of age (t=-0.086, p=0.933), height (t=-0.051, p=0.960) or body mass (t=1.001, p=0.337). The values of maximal H-reflexes, M-waves and $H_{max}:M_{max}$ ratios are shown in Table 2. At L1, independent samples t-tests revealed no statistical difference between the $H_{max}:M_{max}$ ratio of the control group and the affected patient limb (t=1.194, p=0.257) or the non-affected limb (t=0.817, p=0.431). A mixed ANOVA revealed a significant main effect of time (F=9.166, p<0.001) but not group (F=1.174, p=0.302) on the $H_{max}:M_{max}$ ratio. The group x time interaction was also not significant (F=0.686, p=0.567). Pairwise comparisons based on the significant effect of time revealed that the $H_{max}:M_{max}$ ratio increased between L1 and W1 (p<0.05; Mean Difference: 0.074, 95% CI: 0.013-0.135). Between W5 and L5, there was a significant decrease in the $H_{max}:M_{max}$ ratio (p<0.05; Mean Difference: 0.096, 95% CI: 0.004-0.189). When comparing the pre- and post-immersion values on land (L1 and L5), there was no significant difference in the $H_{max}:M_{max}$ ratio (p=0.449). To explore the effects of water immersion further, relative changes in $H_{max}:M_{max}$ ratio relative to the values at L1 are shown in Figure 1. Changes in H/M ratios were largely due to changes in H-reflex amplitude, as M-wave amplitudes did not differ across time points in the patient group (F=0.344, p=0.794) or the controls (Greenhouse-Geisser adjusted F=0.715, p=0.475; see also Table 2).

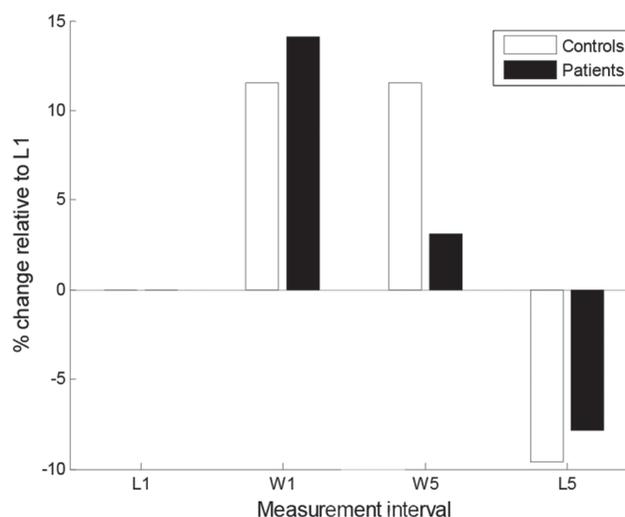Within the hemiplegic group, the affected and non-affected

Figure 1. Group mean changes in the $H_{max}:M_{max}$ ratio across all time points. Values are expressed as percentage change relative to the respective values at L1.

limbs were compared using the value recorded at L1 for the non-affected limb, and the values from each measurement interval for the affected limb. The $H_{max}:M_{max}$ ratio did not differ significantly between the affected and non-affected limbs at L1 (t=-1.307, p=0.261), W1 (t=-2.062, p=0.108) or W5 (t=-1.392, p=0.236). Similarly, at L5, after the subjects had been on dry land for 5 minutes, there was no significant difference between limbs (t=-0.688, p=0.529).

Discussion

The present study was among the first to examine reflex responses both in and out of water, and this technique may open new possibilities for aquatic research. The results revealed that immediately after immersion in water, the $H_{max}:M_{max}$ ratio increased in the affected limb of hemiplegic stroke patients and healthy controls. This is in contrast to the results of a previ-

ous study that reported an approximately 30% reduction in the $H_{max}:M_{max}$ ratio during water immersion[10]. This apparent difference may be due to the fact that waterproof trousers were worn in the present study but not in the previous study. Previous research using compressive joint supports and taping suggests a modulation of proprioception following their application[14,15], which may be mediated by pressure and/or cutaneous pathways. Alternatively, it has been suggested that water immersion leads to a rapid decrease in afferent firing of some pathways[16], and this may be briefly over-compensated by other pathways. In addition to the use of waterproof trousers, the period of immersion was also longer in the study of Pöyhönen and Avela (>10 minutes versus 5 minutes), which may also have contributed to the observed differences between studies. This suggestion is somewhat supported by the finding that the $H_{max}:M_{max}$ ratio almost returned to pre-immersion levels after just 5 minutes of immersion in the patient group, and may thus have continued to decrease with a longer immersion period. The longer-term effects of immersion are of clinical relevance as it is currently unknown how long these effects last and how they impact function in activities of daily living.

Although not reflected in the group level statistics, after returning to dry land, reflex excitability was generally lower at L5 compared to L1 in both groups (Figure 1). This is in agreement with the results of Pöyhönen and Avela[10]. It is also noteworthy that while the control group showed no change in $H_{max}:M_{max}$ ratio during immersion (i.e. between W1 and W5), the ratio dramatically decreased in the patient group. Conversely, there was a large decrease in $H_{max}:M_{max}$ ratio between W5 and L5 in controls, and this difference was much smaller in the patient group. Interestingly, both groups showed similar relative decreases at L5, although the mechanisms of these changes may be different between groups, a topic that warrants further research. For example, stroke may lead to changes in numerous neural pathways, and it cannot be determined from our data whether and how such changes affect reflex responses during and after immersion.

The finding that water immersion can alter reflex excitability over a short timescale may have important clinical implications. From our data it is not possible to determine whether functionally relevant decreases in reflex excitability would best be elicited by performing rehabilitation during water immersion, or whether to perform immersion followed by rehabilitation on land. Both of these rehabilitation methods have shown promise for restoration of function post-stroke (e.g. [3]; see also [17] regarding dry immersion), but it remains to be determined which of these modalities is more effective and under which conditions.

Certain limitations should be considered when interpreting these results. For example, in our design, subjects were strapped into a chair and their feet did not contact the pool floor. Although necessary to enable posture to be matched between test conditions, this differs from standard underwater rehabilitation protocols, where subjects stand or walk on the pool floor. This may be clinically relevant, since cutaneous receptors in the foot sole, as well as muscle spindles and Golgi tendon organs, likely respond differently to weight bearing compared to our study design. The small sample size may limit generalizability of the results, since reflex response amplitudes are highly vari-able between trials and individuals[18], and may be influenced by subtle changes in numerous peripheral, spinal and supraspinal pathways[19]. Moreover, although H-reflex inter-session repeatability is good on land[20], we currently do not have repeatability data concerning underwater measurements. Finally, the stroke patients in this study were independently mobile and capable of performing ADL's, and it remains to be seen how immersion would influence reflex responses in patients with more severe spasticity and functional impairments. Previous research has shown that on land, the $H_{max}:M_{max}$ ratio is positively correlated with spasticity scores[21]. This suggests that immersion-induced decreases in $H_{max}:M_{max}$ ratio may be smaller in more severely spastic patients, although this remains to be tested, especially as the correlation between $H_{max}:M_{max}$ ratio and spasticity is not necessarily seen in all individuals[22].

In conclusion, a short period of water immersion generally led to a reduction in peripheral reflex excitability after returning to dry land in both healthy controls and post-stroke patients. However, the data highlight the need for research into the immediate and long-term effects of immersion for longer periods of time, i.e. reproducing clinically used immersion durations. This method, when combined with appropriate rehabilitation techniques, may offer promise as a low-risk, non-invasive, non-pharmaceutical training environment.

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