

## Reference

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# Comparative Analysis of Psychophysiological Responses in Fibromyalgia Patients: Evaluating Neuromodulation Alone, Neuromodulation Combined with Virtual Reality, and Exercise Interventions

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## Products

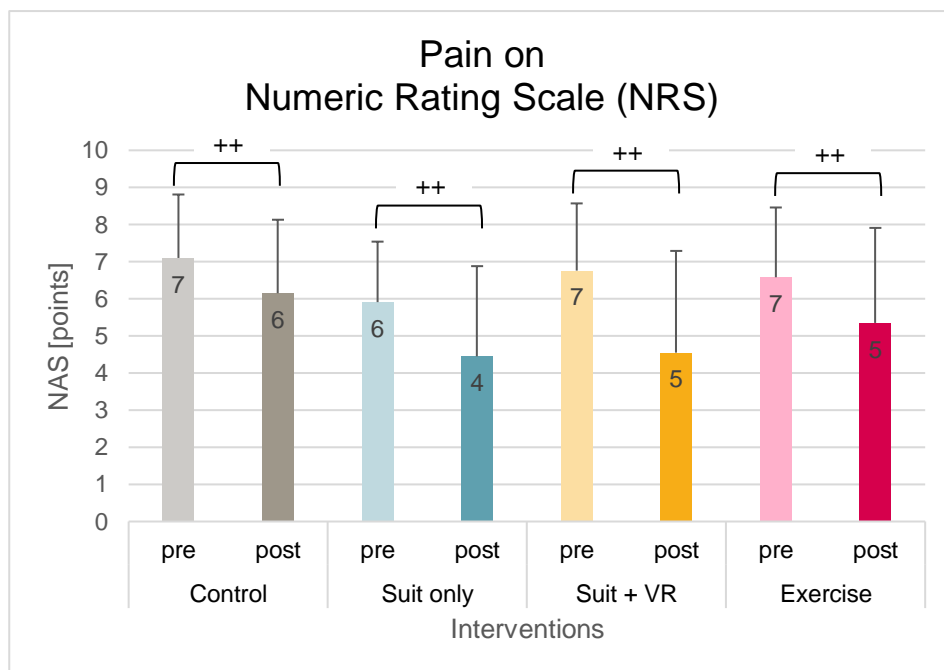
**EXOPULSE Mollii Suit vs. Suit + Virtual Reality vs. Exercise vs. Placebo (Sham)**

## Major Findings

With one hour of EXOPULSE Mollii Suit only, compared to one hour of either Suit + Virtual Reality (VR), Exercise, or Placebo treatment (control):

### → Significant reduction in subjective pain rating on NRS with all interventions

- **Suit:** decrease of 1.46 points (-24.7 %)<sup>++</sup>
- **Suit+VR:** decrease of **2.21 points** (-32.7 %)<sup>++</sup>
- **Exercise:** decrease of 1.23 points (-18.7 %)<sup>++</sup>
- **Control:** decrease of 0.95 points (-13.4 %)<sup>++</sup>



Mean values for pain on NRS ranging from 0= "no pain" to 10= "the worst pain imaginable" directly before (pre), and directly after (post) the intervention. <sup>++</sup> Significant ( $p < 0.05$ ) change.

→ **Improvements in all blood oxygenation variables with all interventions**

- **Suit & Control:** significant improvement in all variables (SmO<sub>2</sub>, THb O<sub>2</sub>Hb, and HHb)
- **Suit+VR & Exercise:** significant improvements, except for THb

→ **No significant changes in respiratory variables in any of the interventions**

→ **Improvements in functional tests**

- **Suit:** significant improvement in chair stand test and non-significant improvement in handgrip strength test
- **Suit+VR:** significant improvement 10m up and go test, one leg balance test and handgrip strength test
- **Exercise:** significant improvement in chair stand test and 10m up and go test, and non-significant improvement in one leg balance
- **Control:** significant improvement in 10m up and go test and non-significant improvement in handgrip strength test

→ **Improvements in cortical arousal**

- **Suit:** no change
- **Suit+VR:** non-significant improvement
- **Exercise & Control:** significant improvement

→ **Changes in microcirculation measured by skin temperature of hand and index finger**

- **Suit & Control:** significant and consistent temperature decrease
- **Suit+VR:** non-significant but consistent temperature decrease
- **Exercise:** non-significant but consistent temperature increase

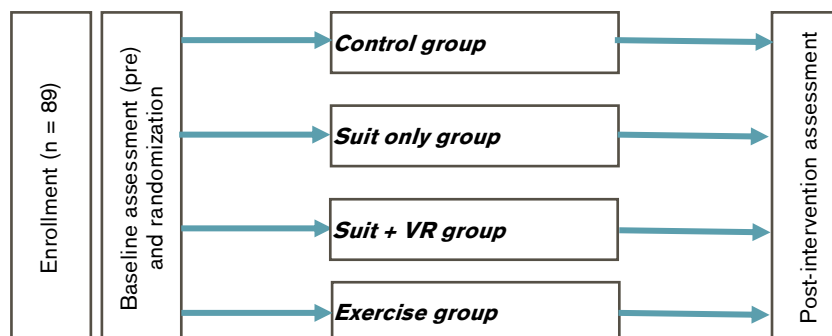
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**Population**

Subjects:	n = 89 (all female)
Etiology:	Fibromyalgia (at least three months); no neuromodulation therapy or exercise program in the last 6 months
Mean age:	Control group (n = 20): 55.1 ± 8.3 years Suit only group (n = 22): 51.8 ± 8.4 years Suit + VR group (n = 21): 51.0 ± 10.8 years Exercise group (n = 26): 51.5 ± 10.9 years

## Study Design

Randomized controlled trial (RCT) to evaluate and compare the immediate effects of different treatments on fibromyalgia patients:



Outcomes were assessed directly before and directly after the intervention.

The interventions were (1) **Control**: same protocol as the Suit only group, but the electrodes were inactive (sham stimulation); (2) **Suit only**: 60 min session with EXOPULSE Mollii Suit with all 58 electrodes active, participants lay on a massage table facing upwards; (3) **Suit + VR**: in addition to the suit with active stimulation, participants were given a virtual reality (VR) visor (Oculus Go), participants lay on a massage table facing upwards, participants could not move but mirror the movements of the avatar; (4) **Exercise**: 60 min training consisting of warm up, strength training, body weight exercises, banded exercises.

## Results

Body Functions & Structure					Activity			Participation	Environment
Pain	Spasticity	Physiological function	Psychological function	General Health	Activity	Mobility & Safety	ADLs	Preference, Satisfaction, QoL	Health Economics

**Results Table 1: Comparative statistics of post-intervention results between groups**

Category	Outcomes	Results for comparison of interventions (*Sig.)					
		Suit vs. Suit + VR	Suit vs. Exercise	Suit vs. Control	Suit + VR vs. Exercise	Suit + VR vs. Control	Exercise vs. Control
Pain	Pressure Pain Threshold (PPT) - epicondyle	0	0	+	0	0	0
	- knee	0	0	0	0	+	+
	Numeric Rating Scale (NRS)	0	0	0	0	0	0
General Health - Microcirculation	Skin Temperature measured on - palm of hand	0	+	0	+	0	+

Category	Outcomes	Results for comparison of interventions (*Sig.)					
		Suit vs. Suit + VR	Suit vs. Exercise	Suit vs. Control	Suit + VR vs. Exercise	Suit + VR vs. Control	Exercise vs. Control
	- back of hand	0	+	0	+	0	0
	- proximal index finger	0	++	0	+	0	+
	- distal index finger (fingertip)	0	+	0	+	0	+
General Health - Lung function	Forced Expiratory Volume in - 1s (FEV1),	0	0	0	0	0	0
	- 6s (FEV6), and	0	0	0	0	0	0
	- ratio (FEV1/FEV6)	0	0	0	0	0	0
	Chest Perimeter Difference	0	0	0	0	0	0
General Health - Cortical Arousal and Salivary Patterns	Critical Flicker Fusion Threshold (CFFT)	0	0	0	0	0	0
General Health - Muscle Oxygen	Muscle Oxygen Saturation (SmO <sub>2</sub> )	++	++	++	++	++	++
	Total Hemoglobin (THb)	+	++	++	0	++	++
	Deoxygenated Hemoglobin (HHb)	++	++	++	++	++	++
	Oxygenated Hemoglobin (O <sub>2</sub> Hb)	++	++	++	++	++	++
Activity	Handgrip strength test	0	0	0	0	0	0
Mobility & Safety	Chair stand test	0	0	0	0	0	0
	10 meter up-and-go test	0	0	0	0	0	0
	One-leg balance for right and left leg	0	0	0	0	0	0

\* no difference (0), trend (+ with  $p < 0.05$ ), significant (++ with  $p < 0.001$ ) difference, not applicable (n.a.)

**Results Table 2: Results for pre- and post-intervention variables for each intervention group**

<b>Category</b>	<b>Outcomes</b>	<b>Results for pre-intervention vs. post-intervention</b> <i>(expressed as means ± SD for quantitative variables)</i>		<b>Sig.*</b>
Pain	Pressure Pain Threshold (PPT) [kg] - epicondyle	<b>Control</b>	Significant increase in pressure tolerance of 0,31 kg (pre: 1.24 ±0.527 / post: 1.55 ±0.561)	<b>++</b>
		<b>Suit only</b>	Significant increase in pressure tolerance of 0,01 kg (pre: 2.04 ±1.183 / post: 2.05 ±0.665)	<b>0</b>
		<b>Suit + VR</b>	No change in pressure tolerance (pre: 1.78 ±0.683 / post: 1.78 ±0.504)	<b>0</b>
		<b>Exercise</b>	Significant increase in pressure tolerance of 0,27 kg (pre: 1.90 ±0.897 / post: 2.17 ±1.09)	<b>+</b>
	Pressure Pain Threshold (PPT) [kg] - knee	<b>Control</b>	No change in pressure tolerance (pre: 1.86 ±1.851 / post: 1.80 ±0.833)	<b>0</b>
		<b>Suit only</b>	No change in pressure tolerance (pre: 2.10 ±0.861 / post: 2.25 ±0.811)	<b>0</b>
		<b>Suit + VR</b>	Significant increase in pressure tolerance of 0,61 kg (pre: 2.02 ±0.973 / post: 2.63 ±1.250)	<b>+</b>
		<b>Exercise</b>	Significant increase in pressure tolerance of 0,42 kg (pre: 2.09 ±0.951 / post: 2.51 ±1.232)	<b>+</b>
	Numeric Rating Scale (NRS), 0 – 10 [points]	<b>Control</b>	Significant decrease of nearly 1-point on pain scale (pre: 7.1 ±1.714 / post: 6.15 ±1.981 )	<b>+</b>
		<b>Suit only</b>	Significant decrease of 1.46-point on pain scale (pre: 5.91 ±1.63 / post: 4.45 ±2.425)	<b>+</b>
		<b>Suit + VR</b>	Significant decrease of 2.21-points on pain scale (pre: 6.76 ±1.814 / post: 4.55 ±2.743)	<b>+</b>
		<b>Exercise</b>	Significant decrease of 1.23-point on pain scale (pre: 6.58 ±1.880 / post: 5.35 ±2.560 )	<b>+</b>
General Health - Microcirculation	Hand Temperature [°C] measured on - palm of hand - back of hand - proximal index finger - distal index finger	<b>Control</b>	Significant decrease of skin temperature values ( <i>Palm</i> → pre: 32.8 ±1.97 / post: 31.8 ±2.24 )	<b>+</b>
			( <i>Back</i> → pre: 32.0 ±2.00 / post: 31.2 ±2.21 )	<b>+</b>
			( <i>Proxi.</i> → pre: 31.6 ±3.13 / post: 30.3 ±3.09)	<b>+</b>
			( <i>Distal</i> → pre: 30.7 ±3.76 / post: 29.3 ±3.16)	<b>+</b>
		<b>Suit only</b>	Significant decrease of skin temperature values ( <i>Palm</i> → pre: 32.6 ±3.54 / post: 31.2 ±2.69)	<b>+</b>
			( <i>Back</i> → pre: 31.8 ±3.45 / post: 30.7 ±2.87)	<b>0</b>
			( <i>Proxi.</i> → pre: 31.0 ±4.79 / post: 29.5 ±3.42)	<b>0</b>
			( <i>Distal</i> → pre: 29.3 ±5.21 / post: 28.3 ±3.47)	<b>0</b>

Category	Outcomes	Results for pre-intervention vs. post-intervention <i>(expressed as means ± SD for quantitative variables)</i>	Sig.*
		<b>Suit + VR</b> Decrease of skin temperature values ( <i>Palm</i> → pre: 32.0 ±2.91 / post: 31.2 ±2.97) ( <i>Back</i> → pre: 31.1 ±2.58 / post: 31.1 ±2.48) ( <i>Proxi.</i> → pre: 30.5 ±3.76 / post: 29.6 ±3.73) ( <i>Distal</i> → pre: 29.1 ±4.43 / post: 27.8 ±3.89)	0 0 0 0
		<b>Exercise</b> Increase of skin temperature values ( <i>Palm</i> → pre: 33.0 ±2.29 / post: 34.2 ±2.13) ( <i>Back</i> → pre: 32.3 ±2.50 / post: 33.0 ±2.27) ( <i>Proxi.</i> → pre: 30.6 ±7.23 / post: 33.7 ±2.65) ( <i>Distal</i> → pre: 29.8 ±7.11 / post: 32.4 ±3.81)	0 0 0 0
General Health - Lung function	Forced Expiratory Volume [L / %] in - 1s (FEV1), - 6s (FEV6), and - ratio (FEV1/FEV6)	FEV1, FEV6, and FEV1/FEV6 had no significant changes prior to and after the intervention, except for FEV1/FEV6 in the Control group:	0
		<b>Control</b> Decrease of 5.25 % after the intervention (pre: 106.30 ±11.85 / post: 111.55 ±5.83)	+
	Chest Perimeter Difference [cm] <i>(between full air inspiration and expiration)</i>	<b>Control</b> No change in chest perimeter difference (pre: 7.40 ±2.55 / post: 7.48 ±1.97)	0
		<b>Suit only</b> No change in chest perimeter difference (pre: 6.65 ±2.16 / post: 7.30 ±1.72)	0
		<b>Suit + VR</b> Slight increase of 0.30 cm (pre: 6.49 ±2.79 / post: 6.79 ±2.75)	0
		<b>Exercise</b> Significant increase of 0.54 cm (pre: 6.28 ±1.94 / post: 6.82 ±2.21)	+
General Health - Cortical Arousal and Salivary Patterns	Critical Flicker Fusion Threshold (CFFT) [Hz]	<b>Control</b> Significant increase of 1.4 Hz (pre: 33.8 ±2.4 / post: 35.2 ±3.54)	+
		<b>Suit only</b> No change of CFFT (pre: 33.7 ±3.65 / post: 33.5 ±2.84)	0
		<b>Suit + VR</b> Slight increase of CFFT (pre: 33.2 ±2.28 / post: 34.0 ±2.90)	0
		<b>Exercise</b> Significant increase of 1.7 Hz (pre: 32.6 ±2.47 / post: 34.3 ±2.82)	++
General Health - Muscle Oxygen Variables	Muscle Oxygen Saturation (SmO <sub>2</sub> ) value [%]	<b>Control</b> Significant increase of 1.52% (pre: 48.63 ±11.53 / post: 50.15 ±12.25)	++
		<b>Suit only</b> Significant increase of 4.7% (pre: 53.2 ±16.12 / post: 57.94 ±15.50)	++
		<b>Suit + VR</b> Significant increase of 15.6% (pre: 45.76 ±15.05 / post: 61.34 ±12.36)	++
		<b>Exercise</b> Significant increase of 11.72% (pre: 43.91 ±14.86 / post: 55.63 ±17.62)	++
	Total Hemoglobin (THb) value [g/dL]	<b>Control</b> Significant increase of hemoglobin value (pre: 11.85 ±0.36 / post: 11.96 ±0.32)	++
		<b>Suit only</b> Significant increase of hemoglobin value (pre: 11.76 ±0.34 / post: 11.85 ±0.44)	++
		<b>Suit + VR</b> No change of hemoglobin value (pre: 12.01 ±0.39 / post: 11.81 ±0.35)	0

Category	Outcomes	Results for pre-intervention vs. post-intervention <i>(expressed as means ± SD for quantitative variables)</i>	Sig.*
	Deoxygenated Hemoglobin (HHb) value [g/dL]	<b>Exercise</b> No change of hemoglobin value (pre: 11.92 ±0.40 / post: 11.82 ±0.45)	0
		<b>Control</b> Significant decrease of HHb value (pre: 6.11 ±1.47 / post: 5.98 ±1.55)	+
		<b>Suit only</b> Significant decrease of HHb value (pre: 5.52 ±1.95 / post: 5.01 ±1.93)	++
		<b>Suit + VR</b> Significant decrease by 1.97 g/dL (pre: 6.54 ±1.87 / post: 4.57 ±1.51)	++
	Oxygenated Hemoglobin (O <sub>2</sub> Hb) value [g/dL]	<b>Exercise</b> Significant decrease by 1.43 g/dL (pre: 6.71 ±1.87 / post: 5.28 ±2.16)	++
		<b>Control</b> Significant increase of O <sub>2</sub> Hb value (pre: 5.74 ±1.27 / post: 5.97 ±1.37)	++
		<b>Suit only</b> Significant increase of O <sub>2</sub> Hb value (pre: 6.23 ±1.82 / post: 6.84 ±1.74)	++
		<b>Suit + VR</b> Significant increase by 1.77 g/dL (pre: 5.47 ±1.70 / post: 7.24 ±1.45)	++
Activity	Handgrip strength test [kg]	<b>Exercise</b> Significant increase by 1.34 g/dL (pre: 5.21 ±1.72 / post: 6.55 ±1.99)	++
		<b>Control</b> Decrease of 0.53 kg decrease (pre: 22.53 ±4.54 / post: 22.00 ±4.93)	0
		<b>Suit only</b> Better performance with 0.44 kg increase (pre: 22.57 ±5.15 / post: 23.01 ±5.77 )	0
		<b>Suit + VR</b> Better performance with 0.44 kg increase (pre: 23.14 ±5.05 / post: 24.04 ±5.39)	+
Mobility & Safety	Chair stand test [repetitions]	<b>Exercise</b> No change in handgrip strength (pre: 23.12 ±4.50 / post: 23.32 ±4.10)	0
		<b>Control</b> No change in chair stand test (pre: 11.35 ± 5.12 / post: 11.15 ± 3.63)	0
		<b>Suit only</b> Significantly better results (1.41 repetitions) (pre: 15.41 ± 6.98 / post: 16.82 ± 7.66)	+
		<b>Suit + VR</b> No change in chair stand test (pre: 12.71 ± 3.36 / post: 13.24 ± 4.85 )	0
	10 meter up-and-go test [s]	<b>Exercise</b> Significantly better results (1.58 repetitions) (pre: 13.46 ± 7.38 / post: 15.04 ± 8.07)	+
		<b>Control</b> Significant better performance (pre: 7.46 ±2.73 / post: 7.02 ±2.63 )	+
		<b>Suit only</b> No change in 10 meter up-and-go test (pre: 6.33 ±1.57 / post: 6.13 ±1.47)	0
		<b>Suit + VR</b> Significant better performance (pre: 6.17 ±0.93 / post: 5.75 ±0.99 )	++
	One-leg balance [s] for right and left leg	<b>Exercise</b> Significant better performance (pre: 6.37 ±1.29 / post: 6.08 ±1.13 )	+
		<b>Control</b> No change in balance test ( <i>right</i> → pre: 22.93 ±17.25/ post: 26.75 ±23.32) ( <i>left</i> → pre: 19.59 ±17.86 / post: 25.11 ±21.21)	0 0

Category	Outcomes	Results for pre-intervention vs. post-intervention (expressed as means ± SD for quantitative variables)	Sig.*
	<b>Suit only</b>	Decrease by 12.15 s (right → pre: 54.04 ±48.68/ post: 41.89 ±26.29) (left → pre: 43.06 ±32.58 / post: 45.57 ±37.37)	0 0
	<b>Suit + VR</b>	Significant better performance by 11.79 s increase in the right leg (right → pre: 28.51± 28./ post: 56 40.3 ±35.09) (left → pre: 33.26 ±28.63 / post: 35.62 ±33.79)	++ 0
	<b>Exercise</b>	Increase by 13.28 s in the left leg (right → pre: 43.79 ±42.62/ post: 49.97 ±49.36) (left → pre: 45.51 ±39.24 / post: 58.79 ±69.17)	0 0

\* no difference (0), positive/negative trend (+/- with  $p < 0.05$ ), significant (++)/-- with  $p < 0.001$ , not applicable (n.a.)

### Author's Conclusion

"In conclusion, our research presents compelling evidence that the EXOPULSE Mollii suit, both alone and in combination with virtual reality (VR), as well as a dedicated 1 h training session serve as effective treatment modalities for fibromyalgia (FM) patients, each yielding acute beneficial impacts. Notably, the augmented effects observed when the EXOPULSE Mollii suit is paired with VR, or when a comprehensive 1 h training session is implemented, highlight their superior efficacy over the use of the suit in isolation. This insight holds particular significance for FM patients grappling with severe pain and fatigue, showcasing the standalone suit as a viable treatment option while also suggesting enhanced benefits through its combination with other interventions. [...] Crucially, the interventions evaluated in this study demonstrated significant improvements in essential aspects such as muscle oxygenation, subjective pain perception, and activation of the parasympathetic nervous system. These outcomes highlight the comprehensive benefits of these treatments in addressing the complex symptom profile of FM, offering a multidimensional approach to management." (Rubio-Zarapuz *et al.*, 2024).

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