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Optimal Rest Interval between Sets in Robot-Based Upper-Arm Rehabilitation

Virgil Miranda, Gissele Mosqueda, Pablo Delgado, Yimesker Yihun

Abstract—Muscular fatigue affects the muscle activation that is needed for producing the desired clinical outcome. Integrating optimal muscle relaxation periods into a variety of health care rehabilitation protocols is important to maximize the efficiency of the therapy. In this study, four muscle relaxation periods (30, 60, 90 and 120 seconds) and their effectiveness in producing consistent muscle activation of the muscle biceps brachii between sets of an elbow flexion and extension task were investigated among a sample of 10 subjects with no disabilities. The same resting periods were then utilized in a controlled exoskeleton-based exercise for a sample size of 5 subjects and have shown similar results. On average, the muscle activity of the biceps brachii decreased by 0.3% when rested for 30 seconds, and it increased by 1.25%, 0.76% and 0.82% when using muscle relaxation periods of 60, 90 and 120 seconds, respectively. The preliminary results suggest that a muscle relaxation period of about 60 seconds is needed for optimal continuous muscle activation within rehabilitation regimens. Robot-based rehabilitation is good to produce repetitive tasks with the right intensity and knowing the optimal resting period will make the automation more effective.

Keywords—Rest intervals, muscle biceps brachii, robot rehabilitation, muscle fatigue.

I. Introduction

SKELETAL muscle is an important part of the human system as it allows for movement and conduction of activities of daily living (ADL). Skeletal muscle makes up approximately 40% of a human's total body weight, ultimately converting the body's chemical energy into mechanical energy [1]. Mechanical energy is shown in the form of walking, grasping, maintaining posture, and other activities of daily living. However, with undergoing activities of daily living comes the possibility of muscles experiencing fatigue. Muscular fatigue can be defined as a decrease in a muscle's force capacity, which can be noted by electromyography (EMG) signals [2], feelings of discomfort, or even a motor deficit [3].

In clinical settings, rehabilitation exercises are designed to support muscle activation and maximize the use of the affected muscles [4]. However, the effectiveness of the muscle activation process is also affected by muscular fatigue [5]. In order to address the inconsistencies caused by muscle fatigue, muscle relaxation periods have been considered in a variety of health protocols, including athletic training [6] and rehabilitation exercises [7]. However, muscle relaxation periods vary in their purpose and duration depending on the application and desired outcome.

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Strength training protocols utilize muscle relaxation periods to aid the production of the desired physical outcome [6]. A study conducted by Maia et al. [8] focused on the antagonist and agonist muscle pairs of recreationally trained men and examined the effects of different rest intervals upon repetition performance and muscle activation. This study found that longer resting periods of 3-minutes and 5-minutes negatively affected repetition performance and muscle activation. For these individuals, a muscle relaxation period that was shorter in time (i.e. less than 3-minutes) was deemed optimal as it ensured effective physical performance and muscle activation. In another study [6], resting periods of 3- to 5-minutes were deemed ideal only for certain strength training goals such as muscular strength, muscular power, and for overall physiological safety. However, this study also found that shorter resting periods (i.e. 30 to 60 seconds) were optimal for improving muscular strength and muscular hypertrophy as they allowed for sufficient muscular recovery.

Robotic devices such as exoskeletons have been used to provide upper limb rehabilitation therapy [9], [10]. Although, the exoskeletons contribute towards the rehabilitation of the affected part, its quantitative effect on the respective muscle is unknown. Moreover, inadequate knowledge of muscular fatigue has caused mild to severe deformations of the muscle or bone in the users and this stays true to exoskeletons as well [11], [12].

Higher intensity physiotherapy tasks could cause muscle fatigue and lower intensity exercises could make it challenging for the patients to achieve desired results [11], [13]. Finding the ideal muscle relaxation period for such applications helps in making targeted exercise prescriptions and provides desired training outcome. Optimal resting periods are also vital to control robot-based rehabilitation processes accordingly.

This study aims to determine the ideal resting time for biceps brachii muscles to avoid fatigue and re-stabilize. For the purpose of this study, two different experimental setups were performed to investigate the resting time between rehabilitation tasks without and with the use of a 5 degree-of-freedom (DOF) upper-arm exoskeleton.

II. Methodology

The experiment was designed to find the optimal resting period for muscle relaxation during the elbow flexion and extension rehabilitation task. As it is indicated in the background literature reviews, different resting periods have been utilized mostly in training exercise protocols. In this study, we have considered resting periods of 30, 60, 90, and 120 seconds. For the study, 10 participants (seven men and three women) between the ages of 18 and 30, with no disabilities were recruited. The subjects have fulfilled several screening criteria such as (1) having dominant right-hand capabilities, (2) could lift objects of at least 5 pounds, (3) had no injuries that prevented successful and painless weightlifting, and (4) did not consistently participate in any intense weightlifting activities.

The use of robots to automate therapeutic exercises is becoming a common practice in most healthcare centers. Thus, the elbow flexion and extension exercise was replicated with five subjects while wearing an upper-arm exoskeleton. This will help us to verify whether the same resting period or a new one is needed when subjects execute the same task and interact with an exoskeleton.

III. Experimental Setup

Upon arrival, the participants were briefed about the study and signed the necessary consent forms. The experimenters then demonstrated the motion of an elbow flexion and extension task, and allowed the participant to practice the motion with a 2-kg weight loaded on the weight-holding apparatus. Once comfortable with the motions, the Delsys Trigno EMG sensors were placed on the muscle biceps brachii. The maximum voluntary contraction (MVC) of the muscle was then recorded. In order to control the number and frequency of the task across the subjects, the participants were asked to follow the displayed video of the elbow flexion and extension movements as shown in Fig. 1.

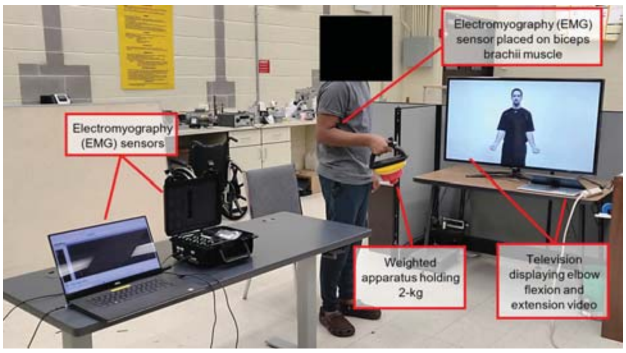


Fig. 1 Experimental setup

The experimental tasks then consisted of four different stages: (1) performing the task, (2) briefly resting the muscle, (3) performing the same task, and (4) fully resting the muscle. The participant was first asked to perform nine repetitions of elbow flexion and extension task, similar to the one shown in [14]. The participant was then given a relaxation period of 30 seconds and later the participant was asked to complete nine more repetitions of elbow flexion and extension movements. Lastly, a 5-minute break was given to allow the muscle to reset and re-stabilize as per the literature shown in [6]. This process was then repeated, with the brief muscle relaxation periods of 60, 90 and 120 seconds. A video with these corresponding times and elbow flexion and extension movements was played in order to allow for consistency and direction of each participants.

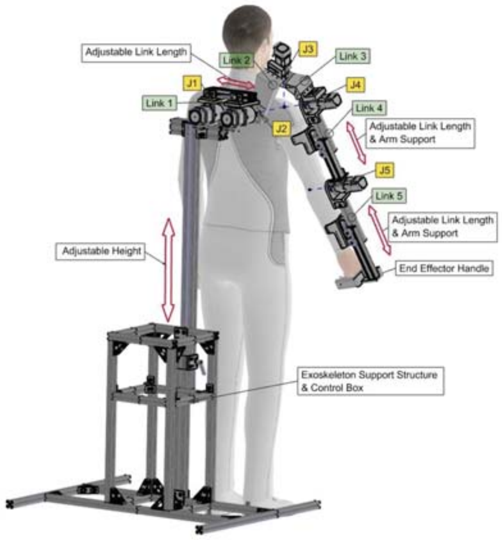


Fig. 2 The 5-dof upper-arm exoskeleton

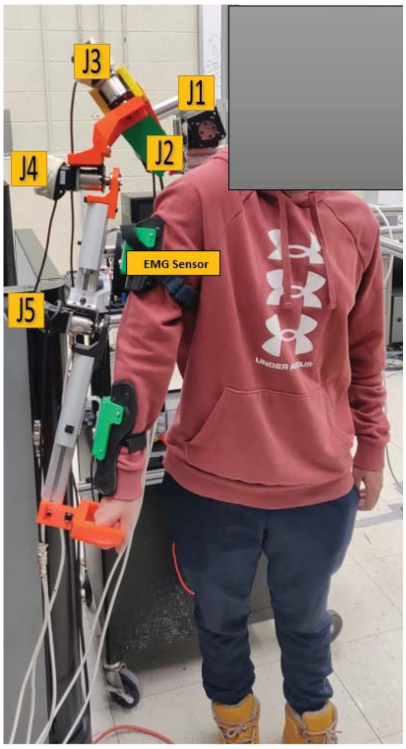


Fig. 3 Experimental setup with exoskeleton

For the second portion of the study, a 5-DOF exoskeleton, [15], was used to perform the elbow flexion and extension task. The exoskeleton consisted of 5 active revolution joints. The first joint (J1) is located at the base and aligned the exoskeleton shoulder joint (3 revolute joints with their axes of rotation intercepting one another, J2, J3, and J4), followed by the elbow joint, J5. The exoskeleton had two arm holders to rigidly attach to the upper arm and the forearm of the subject. The upper and lower arm part of the exoskeleton are adjustable to align and fit different sized users as shown in Fig. 2.

The participants were briefed about the functionality of the exoskeleton and the task at hand. Just as in the first portion of the study, an EMG sensor was placed on the muscle of interest, the bicep brachii, to record the surface EMG of each subject during the elbow flexion and extension task (Fig. 3). The four different stages implemented in the first part of the experiment were emulated with the exoskeleton. The robotic device was programmed to perform nine repetitions of the elbow flexion and extension task with a range of motion between 0° to 120°, closely imitating that of a human arm.

IV. Results and Discussion

The EMG data were normalized with respect to the maximum voluntary contraction (MVC) collected. The data were filtered using band pass filter for the range of 10-180 Hz. It was then analyzed for the peak amplitudes using the root mean square method. The EMG data were plotted for each subject along with the respective bar plots to visualize the percentage of muscle activity during the respective trials. The mean average of all the four different time intervals were plotted. The bar plot analysis provided visual representation of the amplitudes both before and after the resting period, which further helped to compare the level of percentage change.

Root mean square of the muscle activity of a subject while performing nine repetitions of the elbow movement for various time intervals without the exoskeleton is shown in Fig. 4. The y-axis represents the percentage of the muscle activity of biceps brachii normalized to the maximum value obtained by the voluntary contraction. The EMG data plot also confirmed that the subject(s) followed the tasks consistently throughout the study.

Peak amplitudes of the muscle activity for the 10 subjects during different resting intervals, while performing the tasks without the exoskeleton, are shown in Fig. 6. It was found that 40% of the subjects showed increased muscle activity after resting for 30 seconds, 90 seconds and 120 seconds, whereas 60% of the subjects showed increased muscle activity after resting for 60 seconds. In every different trials, there were 10% to 20% of the subjects who showed approximately similar peak percentages of the muscle activity.

Average peak amplitude for the 4 different time intervals for all 10 subjects is shown in Fig. 5. On an average the muscle activity of biceps brachii was 0.6% lesser when performing the same intensity and repetitive task after resting for 30 seconds. The trials performed after resting for 60 seconds showed an increase in the muscle activity by 1.6%. Similarly, the resting period of 90 seconds yielded in an average increase of 0.62% and the resting period of 120 seconds showed an average increase of 0.75% in the amplitude of muscle activity.

For the trials involving the exoskeleton similar analyses were performed. Fig. 7 shows the muscle activity of a subject while performing the elbow flexion extension task with the exoskeleton. It can be seen from the plots that the tasks performed with the exoskeleton adapted well with the methodology. The exoskeleton provided consistent assistance throughout the experiment as it is evident from the amplitude analysis.

The peak amplitudes of the muscle activity for the different resting intervals performed with the exoskeleton for 5 different

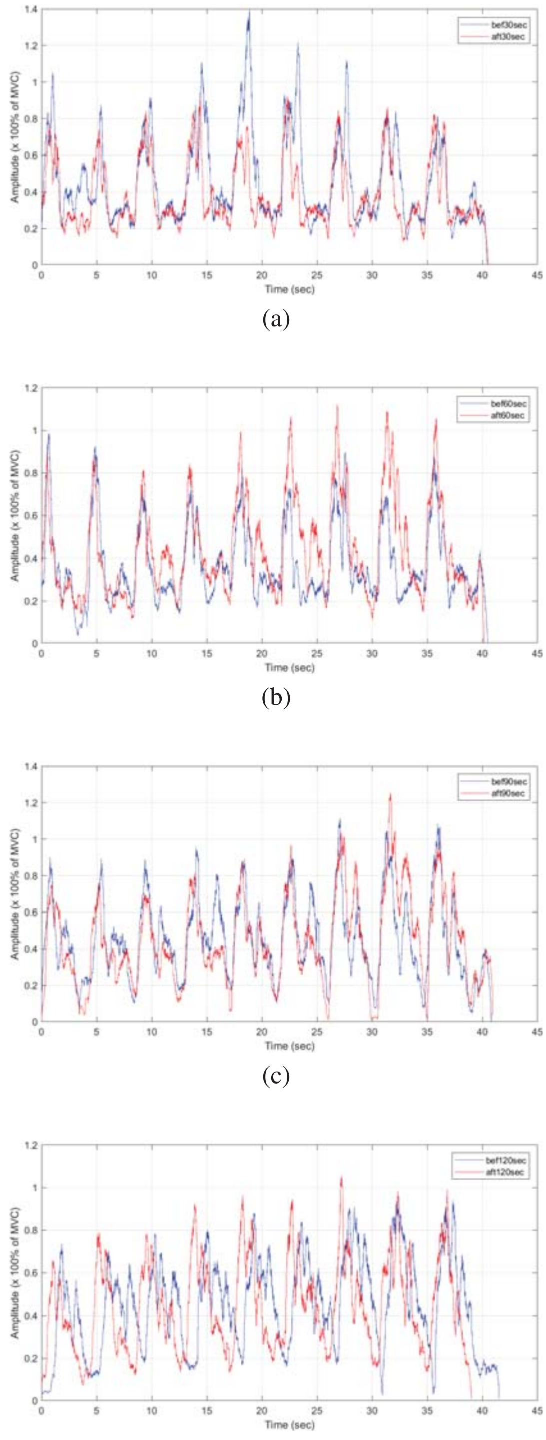


Fig. 4 EMG data of a subject while performing 9 repetitions of elbow flexion and extension task without exoskeleton, for the time intervals of (a) 30 seconds (b) 60 seconds (c) 90 seconds and (d) 120 seconds

subjects can be seen in Fig. 8. It was seen that 40% of the subjects who performed the tasks with the exoskeleton showed increased muscle activity after resting for 30 seconds and 120 seconds whereas, the muscle activity was evidently higher in 60% of the subjects who rested for 60 seconds while

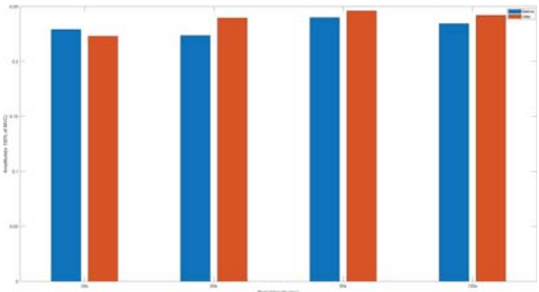


Fig. 5 Average peak amplitude for 10 subjects for the 4 different time intervals

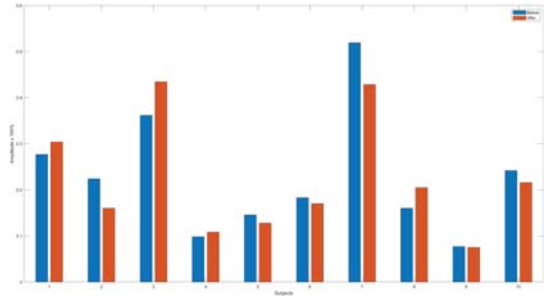
performing this task; 80% of the subjects showed decreased muscle activity after resting for 90 seconds during the trial.

The average peak amplitudes for the five subjects tested with the exoskeleton for the four different resting intervals can be seen in Fig. 9. The biceps brachii muscle activity was found to be approximately about 0.9% higher after resting for 60 seconds, 90 seconds and 120 seconds. However, it decreased about 0.018% when performing the elbow flexion-extension task with 30 seconds of rest.

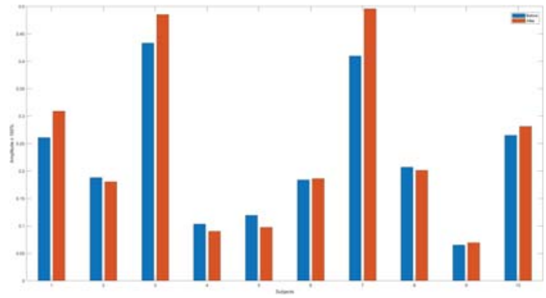
From the results, it can be inferred that by allowing the subjects to rest for approximately 60 seconds, the successive task could be more efficient and productive. Although, the percentage of increment of the muscle activity is seen to be only about 1%, it can affect the muscle to a considerable extent when the task is performed repetitively. This can be applied to exoskeletons, but by taking care of the intensity and speed of the performance in a single trial.

V. Conclusion and Recommendation

The effects of different resting periods or time intervals on the muscle biceps brachii were studied. The results have suggested that by resting the biceps brachii muscle for approximately 60 seconds during an upper-arm rehabilitation exercise, will give a better muscle excitation in a followup gradually increased intensities. The tests on the exoskeleton further solidified the findings, which could also strengthen the current physiotherapy regimens practised along with the robotic exoskeletons. Conducting the experiment with more subjects of a wider range of age group and testing it on stroke patients would further solidify the study.



(a)



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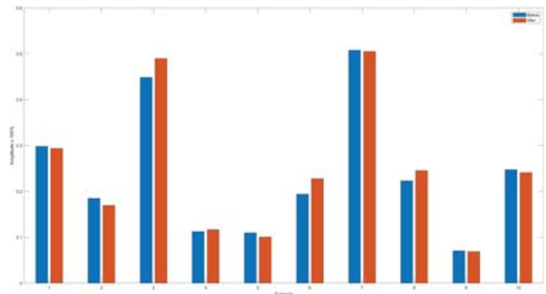

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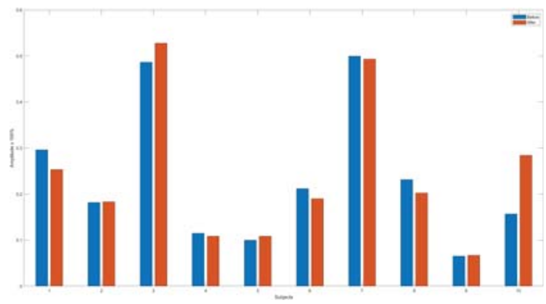
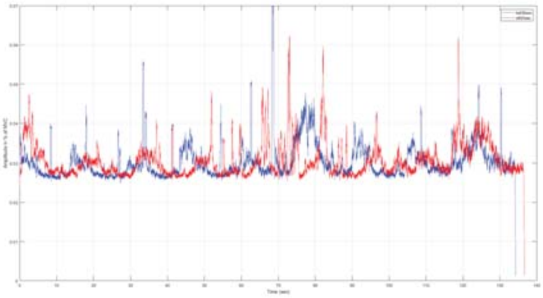
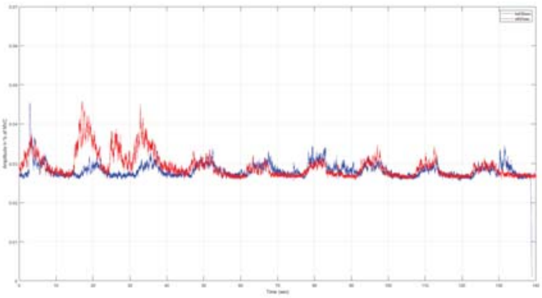


(d)

Fig. 6 Peak amplitudes for 10 subjects during the resting intervals of (a) 30 seconds (b) 60 seconds (c) 90 seconds and (d) 120 seconds, performed without the exoskeleton



(a)



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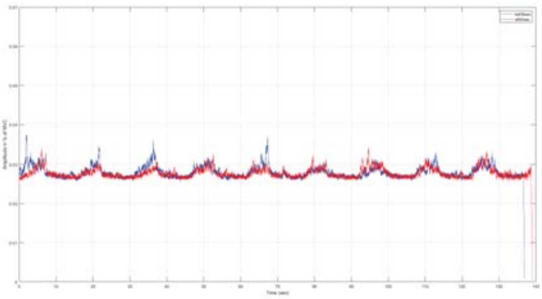

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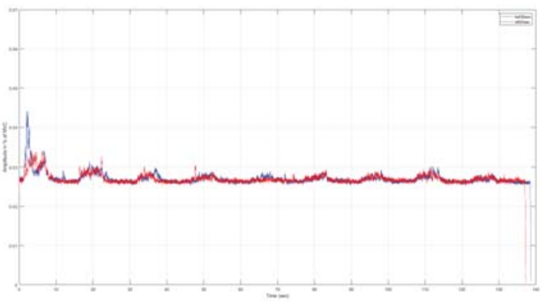
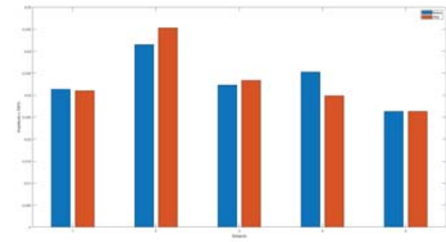
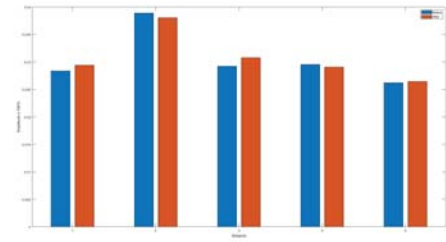


(d)

Fig. 7 EMG data of a subject while performing 9 repetitions of elbow flexion and extension task with the exoskeleton, for the time intervals of (a) 30 seconds (b) 60 seconds (c) 90 seconds and (d) 120 seconds



(a)



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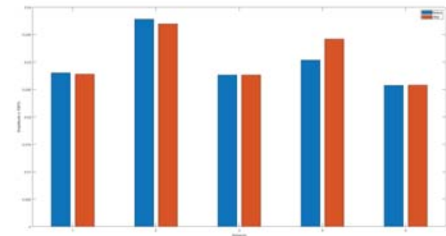

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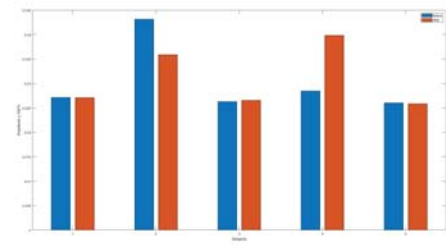

(d)

Fig. 8 Peak amplitudes for 5 subjects during the resting intervals of (a) 30 seconds (b) 60 seconds (c) 90 seconds and (d) 120 seconds, performed with the exoskeleton

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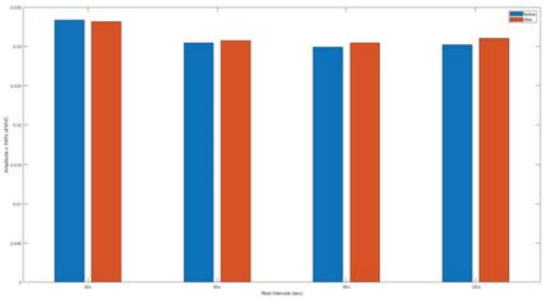

Fig. 9 Average peak amplitude for 5 subjects for the 4 different time intervals with the exoskeleton

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