Assessing the "Rule of 10" in Orthopedic Robot-Aided Rehabilitation for Tailoring Exercise Dose

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Abstract

Robot-aided rehabilitation has gained attention for its ability to deliver standardized, repeatable therapeutic interventions. A key but underexplored aspect of these protocols is determining the optimal therapy dose, often defined by the number of repetitions. This study examines the "Rule of 10," a guideline used by physiotherapists to adjust exercise intensity based on patient-reported pain and exertion, recommending that the Cumulative Perceived Strain (CPS) should not exceed 10 to avoid overstrain.

Eight orthopedic patients participated in a robot-aided rehabilitation session using a KUKA Lightweight Robot 4+ controlled by a tunable interaction controller. The relationship between the number of repetitions performed and clinical scales was examined across different CPS values.

The results demonstrated that CPS = 11 returned strong statistically significant correlations ($\rho = 0.79$ and $\rho = -0.75$ for CMS and DASH, respectively). This indicates that 11 may be a more suitable threshold for customising therapy intensity. Future research should endeavour to refine therapy protocols by integrating real-time assessments of strain and clinical conditions.

Keywords

Robot-aided rehabilitation, Physical rehabilitation, Rule of 10, Cumulative Perceived Strain

1. Introduction

Robot-aided rehabilitation protocols have gained significant attention in recent years due to their potential to enhance the effectiveness and efficiency of rehabilitation interventions [1], including applications for upper limb rehabilitation in the context of musculoskeletal conditions [2, 3]. By incorporating robotic devices into therapy sessions, these protocols offer standardized methods for delivering therapeutic exercises and monitoring patients' progress and state [4]. However, a critical aspect that appears to be overlooked in many of these protocols is determining the optimal therapy dose. Several studies have emphasized that the dose of rehabilitation therapy, defined by the duration, intensity, and frequency of exercises, is a key determinant of treatment effectiveness. An appropriately tailored dose can accelerate recovery, improve functional outcomes, and enhance patient adherence to rehabilitation programs [5]. In the context of robot-aided rehabilitation, in which sessions can be

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highly standardized and repeatable, determining the optimal dose is particularly important, as too low an intensity may yield insufficient benefits, while excessive intensity can lead to overexertion and increased risk of injury [6]. This dose-response relationship is well established in the broader rehabilitation literature [7, 8], yet remains underexplored in robot-assisted therapy settings.

An emerging concept in clinical practice, though not yet scientifically validated, is the so-called "Rule of 10"[1]. This empirical guideline is often used by physiotherapists to modulate the intensity of rehabilitation exercises based on the patient perception of pain and physical workload. According to this rule, the sum of Pain Level (PL) [9] and Rate of Perceived Exertion (RPE) [10] scores, here defined as Cumulative Perceived Strain (CPS), should ideally not exceed 10, to avoid overstrain and potential harm. However, the validity of this rule in robot-aided rehabilitation has never been thoroughly validated.

Thus, the objective of this study is to investigate the "Rule of 10" validity in a real robot-aided rehabilitative scenario by assessing if the number of exercises performed under a CPS equal to 10 is justified by the specific clinical condition expressed in terms of Constant-Murley Score (CMS) and Disability of the Arm, Shoulder and Hand (DASH) clinical scales. Eight patients with outcomes of orthopedic surgery of the upper limb, along with their physiotherapists, were enrolled in the study to achieve this goal. Each patient participated in a robot-aided rehabilitation session using an end-effector robotic device implementing a tunable interaction control, which allowed the robot to adjust the level of assistance provided to the patient. By integrating subjective perception with clinical assessments, this study aims to improve the personalization of robot-aided rehabilitation protocols. A deeper understanding of these factors will help advance more evidence-based, patient-centered approaches in rehabilitation treatments, ensuring that interventions are tailored more precisely to individual needs.

2. Materials and Methods

2.1. Experimental setup

The main components of the experimental setup used in this study are reported in Figure 1.

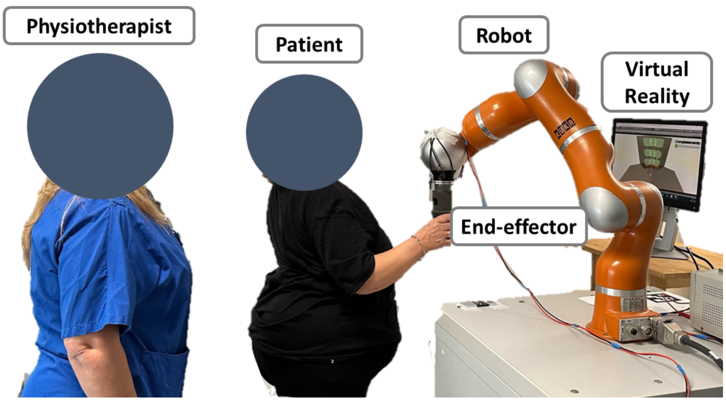

Figure 1: Experimental setup.

More in detail it is composed of:

- a KUKA Lightweight Robot 4+, a 7-DoFs anthropomorphic robotic arm controlled with a tunable interaction control implemented [11]. The control system allows the robot to assist patients in two ways: first, by keeping the robot end-effector close to the desired path, compensating for deviations; and second, by advancing the patient tangentially along the trajectory to ensure the task is completed within a set timeframe.

[1]"Exercise dosing for pain is NOT the same as exercise dosing for fitness!", by Ben Cormack, available at https://cor-kinetic.com/exercise-dosing-for-pain-is-not-the-same-as-exercise-dosing-for-fitness/

The interaction control adjusts assistance based on the patient's condition, providing minimal support during autonomous movement and increasing help as needed. This flexibility ensures the robotic arm delivers appropriate support, promoting engagement and preventing overstrain [3];
- an ergonomic flange that represents the human-robot physical interface;
- a virtual reality game displaying both the desired trajectory and the actual position of the robot end-effector.

2.2. Experimental protocol

Eight patients with outcomes of orthopedic surgery of the upper limb (1 M, 7 F; mean age 69.8 ± 6.3 y.o.; which underwent surgical interventions of cuff-rotator suture or inverse prosthesis) were enrolled in the study. The details of the patients' characteristics are reported in Table 1.

Table 1
Characteristics of the enrolled patients.

	P1	P2	P3	P4	P5	P6	P7	P8
Gender	F	F	F	F	M	F	F	F
Age	64	77	65	72	66	80	63	71
Impaired Limb	L	R	R	L	R	R	R	R
DASH	55	56	67	74	47	28	68	29
CMS	45	54	39	29	45	59	29	51

At the beginning of the session, clinical therapists administered the CMS and DASH clinical scales to quantify the clinical condition of the patients. The CMS is a widely used assessment tool that measures shoulder functionality, particularly evaluating pain, daily activities, range of motion, and strength. It provides a comprehensive understanding of upper limb function and the patient's physical limitations. The DASH score complements CMS by assessing the impact of musculoskeletal conditions on a patient's ability to perform daily tasks, offering insights into the patient's functional recovery over time. On average, the patients scored 43.88 ± 11.03 on the CMS and 53.00 ± 17.37 on the DASH scale, reflecting a diverse range of impairment severity across the cohort.

Each patient underwent a rehabilitation session under the physiotherapist's supervision, who followed they/them during the conventional therapy treatment. Moreover, they were instructed to perform nine cycles of three-dimensional point-to-point trajectories with the assistance of the robot. These trajectories originate from an initial position and extend towards nine separate targets positioned at three different heights. During the patient-robot interaction, each physiotherapist asked the patient to declare any changes in perceived RPE and PL, to compute the CPS.

The study was conducted under Ethical Committee approval (Ethical Approval N. 03/19 PAR ComEt CBM) and in accordance with the Declaration of Helsinki. All patients have been adequately informed about the purpose of the study and gave their written informed consent.

2.3. Data Analysis

To investigate the potential relationships between the recommended dose of exercises and the clinical scales, and to evaluate the "Rule of 10" effectiveness, Spearman correlation coefficients ρ were computed for each possible value of CPS $\in \{1, 12\}$. The analysis considered not only the predefined threshold of CPS = 10, following the "Rule of 10", but also explored a broader range of CPS. By examining CPS values in the range $[1 - 12]$, we aimed to identify potential patterns that could indicate relationships between the CPS and their clinical scales. The correlation was computed between the number of repetitions after which the CPS exceeded the predefined threshold and the individual clinical scales (i.e., CMS and DASH). The derived correlations have been considered *very weak* if $|\rho| \leq 0.19$, *weak* if $0.20 \leq |\rho| \leq 0.39$, *moderate* if $0.40 \leq |\rho| \leq 0.59$, *strong* if $0.60 \leq |\rho| \leq 0.79$ and *very strong* if $0.80 \leq |\rho| \leq 1.00$.

3. Results and Discussion

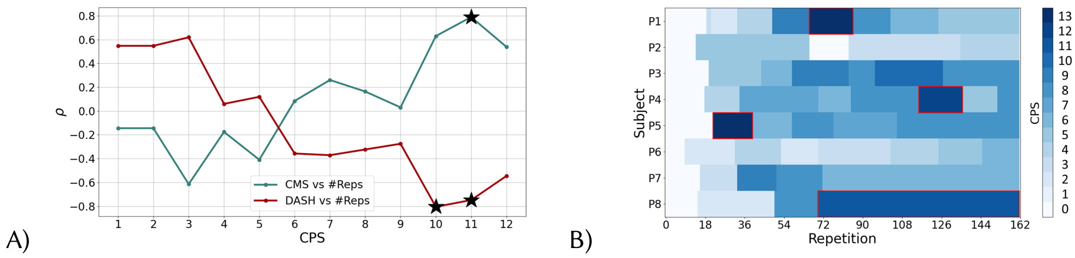

Figure 2: A) Correlation strength between the number of repetitions after which the CPS exceeds the threshold (i.e. CPS $\in \{1, 12\}$) and the clinical scales (i.e. CMS and DASH). Black stars indicate significant values ($p \leq 0.05$). **B**) Heatmap of CPS values perceived by each patient (P) during the robot-aided rehabilitation session. The blocks of movements where CPS ≥11 are highlighted in red.

The correlation strength computed between the number of movements and the disability at each CPS is presented in Fig. 2A. For CPS $\leq$ 5 the correlations with both CMS and DASH are not statistically significant. This weak correlation suggests that, at these lower CPS levels, the disability or functionality, as assessed by CMS and DASH, has little influence on the number of repetitions a patient can perform. This could imply that other factors are affecting performance at these lower strain levels, or that CMS and DASH may not be sensitive enough to detect changes in strain within this range.

However, as CPS values rise above 5, a clearer pattern begins to emerge. Specifically, the DASH score shows a predominantly negative correlation with the number of repetitions performed. This aligns with expectations, as the DASH score is designed to measure the degree of disability in individuals with upper limb disorders. Lower DASH scores reflect less disability, which should theoretically enable patients to perform more repetitions. Therefore, the negative correlation suggests that individuals with fewer functional limitations (as indicated by lower DASH scores) can perform more repetitions, consistent with the notion that they experience fewer challenges during therapy.

Conversely, the CMS score exhibits a primarily positive correlation with the number of repetitions. This is expected, as a higher CMS score represents better shoulder functionality. Patients with higher CMS scores are anticipated to handle more repetitions, indicating greater tolerance for the exercises. The positive correlation implies that as shoulder functionality improves, the number of repetitions a patient can perform increases accordingly.

It is evident that the correlation strength between disability and the number of repetitions increases with CPS, with particularly strong correlations observed at CPS = 10 ($|\rho| = -0.81$ and $p = 0.01$ for DASH). This suggests that as the strain level rises, the relationship between disability assessments (DASH and CMS) and the number of repetitions performed becomes more pronounced. Notably, at CPS = 11, both DASH and CMS demonstrate a significant and robust correlation with the number of repetitions ($|\rho| = -0.75$ and $p = 0.03$ for DASH, $|\rho| = 0.79$ and $p = 0.02$ for CMS). This indicates that CPS = 11 may serve as an optimal threshold for tailoring exercise intensity based on the patients' clinical conditions.

However, while CPS = 11 appears to provide a useful benchmark for regulating exercise levels, it is important to recognize that this conclusion is based on preliminary analysis. The optimal CPS value was not known a priori, and the therapy protocol initially included a fixed total of 162 movements for all participants. Consequently, the perceived CPS values recorded by participants over time, as illustrated in Fig. 2B, reflect the variability in perceived strain throughout the session.

This variability underscores a potential limitation: the fixed number of movements might not have been ideally matched to individual tolerances, which could have influenced the observed correlations. Furthermore, it is worth noting that 7 out of the 8 participants were female, which raises the possibility that the analysis could be influenced by gender-related factors.

4. Conclusion

This paper proposed an analysis aimed at investigating whether the ”Rule of 10” could have a clinical basis. Eight orthopedic patients and their respective physiotherapists were enrolled in an experimental robot-aided rehabilitative session during which RPE and PL were collected. A correlation analysis was carried out, revealing that a CPS value of 11 should be considered to determine when to stop the rehabilitation therapy.

Future studies should focus on incorporating dynamic adjustments based on real-time assessments of strain and disability to refine exercise prescriptions. Additionally, further exploration of CPS values is necessary to establish more precise thresholds for optimizing therapy intensity. Increasing the sample size and ensuring a more diverse representation in terms of age groups and gender will also be crucial to achieve more robust and generalizable findings. Furthermore, future plans include the integration of an Artificial Intelligence module capable of analyzing clinical scale values and CPS data to accurately predict the optimal number of repetitions a patient can perform without reaching overstrain.

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