Automated objective robot-assisted assessment of wrist passive ranges of motion

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Word count: 1692

Abstract

The measurement of wrist passive ranges of motion (ROMs) can provide insight into improvements and allow for effective monitoring during a rehabilitation program. Compared with conventional methods, this study proposed a new robotic assessment technique for measuring passive ROMs of the wrist. The robotic system has a reconfigurable handle structure that allows for multi-dimensional applications of wrist motions. The assessment reliability of this robotic system was analysed on 11 subjects for measuring wrist extension/flexion and radial/ulnar deviation. Preliminary data demonstrated its potential with intraclass correlation coefficient ($ICC_{2,1}$) all greater than 0.857 and standard error of measurement (SEM) less than 3.38°. Future work will focus on the standardization of the assessment protocol of this robotic system for assessment purposes, paving the way for its clinical application.

Keywords: Robotic, assessment technique, wrist, passive range of motion

1. Introduction

Although the human wrist is a biomechanical marvel when it is intact and functioning, orthopedic or neurological impairments inevitably cause dysfunction to its motion (Skirven et al., 2011). Over the past few decades, a variety of robot-assisted rehabilitation techniques have been developed to restore wrist/hand motor function. Krebs et al. (2007) integrated a wrist robotic device into the shoulder-and-elbow MIT-MANUS. Initial clinical results demonstrated the efficacy of this robot in providing continuous passive motion, strength, sensory, and sensorimotor training for the wrist. Squeri et al. (2014) developed a haptic robot to quantify motor impairment and assist wrist articular movements. The proposed adaptive control strategy showed great potential in maximizing the recovery of the wrist ranges of motion (ROMs). An important feature of robot-assisted therapy is that exercises should be tailored to specific impairments (Sanguineti et al., 2009). Passive ROM is of high clinical importance in therapy and assessment of musculoskeletal disorders. Typically in robot rehabilitation an initial active ROM target is set so that subjects can easily achieve the goal, and that ROM is progressively modified over the course of the entire protocol. However, these existing rehabilitation systems have not been implemented with assessment of passive wrist ROMs, nor has any method been validated to reliability assess passive ROMs.

This study proposes a new robot-assisted assessment technique for measuring passive ROMs of the human wrist. The reliability of this method for measuring wrist extension/flexion (E/F) and radial/ulnar deviation (RD/UD) is analysed. To the best of the authors' knowledge, this is the first example of robot-assisted automation of assessing passive wrist ROMs based on predefined joint torque values. The reconfigurable robotic design is also a novel device which allows continuous posture adjustment of the handle.

2. Methods

2.1 Participants

Eleven healthy subjects *(six males: Age 26.17±4.22 years, Height 173.83±7.28 cm, Weight 79.83±10.03 kg, and five females: Age 26.40±5.98 years, Height 164.20±3.49 cm, Weight 55.30±5.72 kg)* volunteered to participate in this study. The study was approved by the University of Auckland, Human Participants Ethics Committee (019707) and consents were obtained from all participants.

2.2 Instrumentation

The proposed assessment technique is implemented using a reconfigurable wrist rehabilitation robot and an adaptive passive assessment strategy, as in Figure 1. The robot mechanically consists of a handle, a handle holder, the base, and the forearm holder with straps. The handle can be rotated along the handle holder for arbitrary posture adjustment. To follow convention

(Horger, 1990), the motion measurement of wrist E/F is achieved by setting 0˚ of the handle (horizontal), and that of RD/UD by adjusting the handle to 90˚ (vertical).

Its electronic control system consists of a flat brushless motor (EC 90, Maxon), a magnetic rotary sensor (AS5048A, AMS), and a static torque sensor (JNNT-1, Zhongwan), which allows the implementation of adaptive passive assessment technique. The robot reverses when real-time human-robot interaction torque triggers a predefined value of wrist passive torque. Data of the angular position of the human wrist are collected from the built-in magnetic rotary sensor.

Figure 1. A reconfigurable wrist rehabilitation robot. (IT: Interaction torque; WPT: Wrist passive torque; E/F: Extension/flexion; RD/UD: Radial/ulnar deviation)

2.3 Procedures

Subjects sat on a height-adjustable chair with the forearm strapped and hand grasping the handle. The wrist joint was visually adjusted to approximate the rotational axis of the wrist robot, with fingers holding the handle for assessment exercises. The device was set with two configurations: 0˚ for wrist E/F and 90˚ for wrist RD/UD. The predefined wrist passive torque was set with two grades: 2.5/3.5 Nm for males and 2/2.5 Nm for females. These values were set using experience from pilot trials, and in clinical practice can be predefined by therapist based on a specific subject and his/her pathology. Thus there are a total of four measures (APA-0-L, APA-0-H, APA-90-L, and APA-90-H), where APA means adaptive passive assessment, 0 or 90 is the position of the handle, L or H refers to the level of torque limit (Low level: 2 Nm for females and 2.5 Nm for males, High level: 2.5 Nm for females and 3.5 Nm for males). For each measure, each participant was required to repeat 12 cycles of the passive assessment movement. This device was driven to work in a constant low-velocity environment (5°/s) to mimic clinical wrist rehabilitation exercises.

2.4 Statistics

Intraclass correlation coefficient (ICC) was used to examine the test-retest reliability of the four measures. Absolute reliability was determined by calculating the standard error of measurement (SEM) and smallest real difference (SRD) with 95% confidence interval, as in Eqs (1) and (2) (Weir, 2005), where standard deviation (SD) is the mean SDs of all measurements. SEM % and SRD % were also calculated to facilitate the comparability with other studies. In this study, $ICC_{2,1}$ was selected for data analysis with two-way random, absolute agreement, 95% confidence interval.

$$SEM = SD\sqrt{(1-ICC)} \quad (1)$$

$$SRD = SEM * 1.96 * \sqrt{2} \quad (2)$$

3. Results

Each participant conducted 12 cycles of passive assessment movement for each measure. The maximum and minimum joint angle values can be extracted for each cycle. To minimize the effects from random factors, such as active engagement with the robot from human users, each data set finally includes 10 elements by removing the maximum and minimum values. To facilitate data analysis in SPSS, Table 1 presents the mean and SD of measurements over all participants for each measure and each cycle, where wrist ROM values do not vary in a predictable way with the measurement cycle. It is assumed that exercises with 12 cycles of measurements are not enough for an increase of wrist ROM, and the influence of removing maximum and minimum values is negligible.

Table 1. Means and SDs of measurements over all participants.

Table 2 summarizes the statistical results of the test-retest reliability of the selected four measures, where all $ICC_{2,1}$ values are greater than 0.857 and SEM values are less than 3.38°. Munro's correlation description (Munro, 2004) is used to interpret ICC values as high reliability of APA-0-H-F and APA-90-H-UD. The reliability of all others is excellent with $ICC_{2,1}$ no less than 0.9.

Table 2. Statistical results of the test-retest reliability of the selected four measures.

4. Discussion and conclusion

To achieve adaptive robotic protocols, assessment is normally required to tune controllers based on training performance or joint capacity. Squeri et al. (2014) explored an adaptation law by increasing task difficulty as a subject succeeds in completing a task, and assessed wrist ROMs by the use of the Fugl-Meyer assessment technique (Gladstone et al., 2002). While this robotic system showed promise in increasing wrist ROMs and decreasing its spasticity, it did not allow for automatic detection of the joint ROMs. In contrast, the proposed robot-assisted technique in this study can conduct automatic assessment of human wrist ROMs. Even though its reliability is satisfactory as in Table 2, the clinical efficacy and applications have not been clear yet when comparing with standard assessment tools, such as Fugl-Meyer Assessment (Gladstone et al., 2002) and Modified Ashworth Scale (Gregson et al., 1999).

With respect to conventional assessment methods of wrist passive ROMs, the proposed robotic technique has the following features. First, it does not depend on manual operation by raters. This means that the influences of subjective factors from raters can be greatly eliminated. Second, this proposed technique depends on multiple measurements to minimize the influences of objective factors from participants. For passive ROM assessment of the wrist, participants are theoretically required to be fully relaxed and avoid active contribution that may significantly affect the accuracy. Third, the proposed technique has comparable assessment accuracy to manual methods. An example is a manual device developed by Zhang et al. (2015) for measuring ROMs of ankle dorsiflexion and plantarflexion with all $ICC_{2,1}$ values no less than 0.846. The intrarater reliability of goniometric measurements of passive wrist motions was evaluated on 48 subjects (Horger, 1990), with $ICC_{2,1}$ values no less than 0.908 and SEM values no greater than 3.537°. These are in line with the proposed robot-assisted assessment results. Last but most unique, the proposed robotic assessment technique can be reconfigured for continuous adjustments. The most basic two configurations are 0° of the handle for wrist E/F, and 90° for wrist RD/UD.

The relevance of the proposed robot-assisted assessment method to therapy is manifested in two aspects. One is to allow robot-assisted assessment of the wrist passive ROM during the training, facilitating intelligent control of the rehabilitation protocol. The participant does not have to get off the device for progress evaluation during robot-assisted therapy. The proposed method, in the other hand, provides a more objective assessment method compared to goniometric measures. Traditional goniometric measures are subject to different raters (Horger, 1990), while this technique requires only the determination of an appropriate torque limit.

While the proposed assessment technique has many advantages, three limitations exist and should be further investigated. One is the determination of the predefined wrist passive torque. Potential values can be set by physiotherapists based on their clinical experiences or a preliminary examination. Second is the determination of the number of assessment cycles. Both statistical and clinical requirements should be considered to derive the optimal cycle number to trade off assessment accuracy with time. Thirdly, measures should be taken to minimize active contribution from participants. The next prototype will be also implemented with a harmonic reducer to minimize gear clearance for improved assessment accuracy, and with a load-dependent forearm holder to allow for consistent anatomical motion for comfort and safety.

This is the first attempt, in the field of robot-assisted rehabilitation to automate the assessment of passive joint ROMs, wherein the wrist robot can be reconfigured to achieve continuous postures of the handle. Preliminary data from 11 healthy subjects demonstrated its potential with $ICC_{2,1}$ all greater than 0.857 and SEM less than 3.38°. Future work will mainly aim to standardise the protocol of the proposed robotic system for measuring passive ROMs of the human wrist. Its clinical efficacy in contrast with standard clinical assessment tools should be also investigated.

Conflict of interest statement

The authors declare that there is no conflict of interest.

Acknowledgement

This material was based on work supported by the University of Auckland, Faculty of Engineering Research Development Fund-3625057 (Physical Robot-Human Interaction for Performance-Based Progressive Robot-Assisted Therapy).

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