A Validation of an automated version of The Modified Jepsen Taylor Hand Function Test

Author: Ida Falk Nielsen;

Abstract

Introduction Most stroke patients suffer from neurological or musculoskeletal conditions involving hand disabilities. Post stroke rehabilitation is an important part of restoring lost abilities in the hand function and testing for progress and performance on an ongoing basis is performed ongoing manually by a therapist. For this purpose a validated and reliable objective test is used. Most of these tests involve measuring the time it takes to complete a set of activities, which is crafted to match a set of common daily activities. The testing is costly to the health care system, and makes the patient reliant on therapist assistance and more inexpensive methods of testing are needed. **Methods** The trial included eleven healthy subjects, 4 women, 7 men, 20 -30 years of age. All subjects completed the 3 subtests of the Modified Jepson Taylor Hand Function Test, and time was measured during all tests, by a therapist and by a Microsoft kinect camera. **Result** The measurements in subtest 2 showed no indication of any overall systematic discrepancies between the manual assessments and the automatic assessments. For the measurements in subtest 4 there was an indication of a systematic difference, between the two measurement methods. For the measurements in subtest 5 there was an indication of systematic difference between the two measurements methods The duration of the time in seconds, which it took for the 11 participants, to perform the subtests of the MJT was recorded automatically and manually and compared with a Bland Altman plot fir each subtest.

Conclusion This study managed to show that the automated MJT works, and that it was possible to retrieve useful measurements and pictures from the Kinect Camera. Some differences were found between the two measuring methods and the automated measurement in subtest 4,that showed shorter times than the manual measurement, while the opposite was found in the measurement for subtest 5. All time differences between the methods were within 1.1 sec however and if put in perspective of the average time, it took to perform each of the three subtests subtest 2 (0.50 sec), subtest 4(1.1 sec.) and subtest 5 (0.60 sec.) it is considered an acceptable error. Therefore this study concludes that the automated test is as useful, as the manual test, and that the automated MJT test, can measure time just as well as the manual MJT.

Key words: *Stroke, hemi paretic, hand function test, The Jebsen Taylor hand function test (JTHFT), The Modified Jebsen Hand Function Test (MJT) Microsoft kinect, rehabilitation, automated home based testing,*

Introduction

The World Health Organization (WHO) estimates that 17.5 million people (31%) globally died in 2012 from cardiovascular disease, among them 6.7 million people died due to stroke (1).Motor function disability is the most common symptoms after stroke, and most rehabilitation efforts are based on motor learning, to induce neural plasticity to aid the ability of the brain to develop new neurons interconnections and to attain new functions and to compensate for the motor function disabilities (4).

Access to appropriate health care and assistive devices that can help patients to become independent of others and to restore some of their lost motor control skills, is basic to the overall wellbeing and to community integration (2). In most high to middle income countries, adults with neurological or musculoskeletal conditions involving hand disabilities as a result of stroke attend a rehabilitation program after discharge form the hospital(3).

However WHO report, that many of the consequences of stroke, stems from the lack of adequate medical care. In low to middle income countries, only 5 to 15 % of people receive the healthcare and assistive devices they need. This leaves these patients dependent on others and unable to perform common daily activities (3). On a worldly scale, this presents a real challenge that concerns all stroke patients with upper limb impairment, as is makes these patients dependent on others(5).

Most stroke patients suffer from neurological or musculoskeletal conditions involving hand disabilities (4). Some of the technologies that have proven to be effective in restoring hand and arm function include functional electrical stimulation (FES) that is used to assist the arm movements during training (6,7), and virtual reality, which has been shown to be beneficial when combined with conventional interventions for restoring motor function in the upper extremities after stroke(8).

A meta- analysis of studies about the use of Wii gaming technology combined with conventional rehabilitation interventions, showed that this combination could also be potentially useful in restoring upper arm functionality after stroke (9). Furthermore, repetitive task practice, constraint–induced or modified, constraint-induced movement therapy, among other interventions, can improve motor function in the upper extremities after stroke (10). The use of goal direction and individualized tasks that promote frequent repetition of task related or task – specific movement, is characteristic of these interventions (10).

The post hospital rehabilitation programs are focused on maintaining the achieved rehabilitation results from the hospital. To ensure the quality of the rehabilitation, the testing and overall evaluation of patient progress takes place on an ongoing basis by a therapist, which uses appropriate and validated tests for the purpose (11).

The testing of progress is a challenge because the patient is completely reliant on therapist assistance to perform the test. A possible solution might be, to replace the manual therapist assisted hand function test, with an automated hand function test system. Such a solution could prove to be motivating for patients, who would no longer be reliant on a therapist and instead could perform the test independently at home (13, 14).

An automated solution would however have to test the effectiveness of the hand function training program equally well, or so close to the testing done manually by a therapist, that no significant difference could be detected, in order to be an acceptable solution.

A recent study of remotely monitored post stroke home training concluded, that home based training of hand and arm with the physical support from a dynamic orthosis, was a feasible tool to enable self-administered practice at home. Upper extremity function and quality of life improved after training but dexterity did not (15). Such an approach to training after stroke is a step towards training without depending on therapist availability and if the homebased training were coupled with an automated test, that could be taken independently, yet another step towards independent post stroke in-home training could be made.

There are several available hand function tests that measures the level of motor control of the hands and these are usually crafted to match a set of common daily activities (ADL), to ensure proper transfer value. Movements like lifting a spoon with beans and dropping them into an empty cup for example, can easily be transferred to that of eating soup with a spoon, which is also an appropriate goal for the patient, who wants to attain a higher level of control over his/ her own eating situation (12).

Choice of hand test

Studies of systematic reviews of the most relevant, commonly used and validated hand function tests for stroke victims were performed. Seven hand function tests were chosen for further research, Box and Block Test (BBT)(16,17); Action Research Arm Test (ARAT)(18,19,20);Fugl-Meyer(FMA)(20,21)

Stroke Rehabilitation Assessment of movement Measure (STREAM)(22,23,24,25),Nine Hole Test (NHPT)(26,27) Wolf Motor Function Test(WMFT)(28,29,30) and the Jebsen Taylor Hand Function Test (JTHFT) (31,32,33,34). These tests were analyzed with regards to the following criteria: the test had to be able to test upper body function, shoulder arm synergies, wrist extension and circumduction, hand flexion and extension, hand grasp and hand coordination and speed. The test had to fit a wide age range and the time required to perform the test, had to be less than 30 – 60 minutes. The test had to be able to be used by people with acquired brain injury or stroke. The list of criteria's also included documented tests of validity, reliability, interrater reliability, test re-test reliability, responsiveness and the test had to be compatible with the kinect technology, used for automating the test.

The JTHFT was found to meet all criteria, set up for the test. JTHFT was the only test that was easily compatible with the Microsoft kinect technology used in this study, since the JTHFT test takes place at a table and movements in this test can be recorded by a Microsoft Kinect camera.

For the trial in this study a modified version of the JTHFT (MJT) that includes three of the seven subtests (subtest 2, 4 and 5) from the full JTHFT was chosen (35). The MJT is tested positive for validity, reliability, test re-test reliability and responsiveness, and includes testing of the wrist flexibility, extension and circumduction, hand flexion and extension, hand grasp, hand coordination and speed. The time it takes to complete each subtest indicates patient progress and the test is widely used for stroke patients aged 6 - 65 years old and takes approximately 15 to 30 minutes to administer (35).The aim of this study was therefore to validate an automated version of the MJT, by comparing it to the standard therapist administered MJT .

Methods

Subjects

Eleven healthy subjects, 4 women and 7 men aged 20-30 years old participated in the study. Signed consent was obtained from all participants and the Declaration of Helsinki was respected. The study was approved by the local ethical committee (N-20130053). Inclusion criteria's were: age range between 18--80 years. Exclusion criteria's: Pregnancy, addictions or previous behavior defined as addiction of hash, opioids or other narcotics .Cognitive and language disorders making it impossible to understand the purpose of the study, thus unable to implement the trial. Severe generalized weakness, including severe heart and lung disease and other conditions including significant disease of the motoric system which could affect the project participation.

Procedures

All subtests took place in a well-lighted room. The participants were seated on a chair of approximately 18 inch (45.7 cm) of height, at a desk of 30 inch (76.2 cm) of height. A Microsoft kinect camera was placed above the table at a height of approximately 47.25 inch (120 cm). All activities on the table in the test area (Fig.1) were recorded during each subtest.

(Fig. 1) Room for the trial with the activity table with the wooden board and the Microsoft kinect camera set up.

Each subtest was administered in the precisely same manner to each subject. Subjects were asked to keep the hand not used, off the table and on their lap, while performing the standardized tests (33). The results were captured manually with a digital clock, and simultaneously with a Microsoft Kinect camera. The automatically generated outcomes were extracted from the data recorded with the Microsoft Kinect camera (34). The results of the manual measurements were recorded and stored for later analysis.

Hand tests

Subtest 2. (Card turning)

Five 3 by 5 inch (5 x 12.7 cm) white cards made of cardboard with a green spot in the center, for easy recognition for the camera, were placed with the green spot upwards. Each card was placed in a horizontal row, 2 inches apart and vertically oriented 5 inch from the front edge of the table that the participant was sitting at.

The subject was instructed to turn the cards over, as fast as possible and not to care about the accuracy of the placement of the cards after turning. The manual measurement of time started from

the word “go” and finished, when the last card had been turned over, and was positioned flat on the table. The recording of the test area started, when the therapist asked the kinect camera assistant if he was ready and he had nodded his head. The automated measurement of time started, when the test started and ended when the last card had been turned over and was positioned flat on the table. The automated time on the extraction of information from the pictures, from the kinect recordings were done the same way for each subtest, as described in (36).The card turning was done with the non-dominating hand (NDH) first and repeated with the dominating hand (DH) last.

Subtest 4. (Simulated feeding)
Five kidney beans approximately 5/8 inch each in length were placed on a wooden board.
The wooden board measured 41.5 inches long (11.4 cm)11-1/4 inches (29.8 cm) wide and 0.75 inch thick (1.8 cm). The front edge was 0.75 inch thick, (1.8 cm) and marked at 4 inch (10.2 cm) intervals, for easy reference when placing objects.

A center piece of plywood, 20 inches (50.8 cm) long, 2 inches (5.1 cm) high and 0.5 inch (1.3 cm) thick was glued to the board 4.5/8 inches (11.6 cm) from the right end and 6 inches (15.2 cm) from the front of the board. The front of the center upright on the wooden board was marked at 2 inch (5.1 cm) intervals beginning 1 inch (2.5 cm) from each end for convenience when placing objects. The board was placed 5 inches (12.7 cm) in front of the edge of the desk.

The beans were oriented to the left of the center of the table, parallel to one another and touching the upright piece of wood at the center of the wooden board, 2 inches (5.1 cm) apart from one another. An empty metal can 3.2 inch (8.2 cm) diameter by 5.6 inch (14.1 cm) height was placed centrally, in front of the board and the participant.

The participant was provided with a teaspoon and was instructed to take the tea spoon and pick up the beans, one after another and put them into the empty metal can. The manual measurement of time started from the word “go” and finished when the last bean had touched the bottom of the metal can. The recording of the test area started, when the therapist asked the kinect camera assistant if he was ready, and he had nodded his head. The automated measurement of time started when the test started and ended when the last bean had touched the bottom of the metal can. The simulated feeding was done with the NDH hand first and repeated with the DH last.

Subtest 5. (Checkers)
Four standard sized 1.75 inches (3.2 cm) in diameter red wooden checkers were placed on the table, touching a wooden board, like the one described in subtest 4. The checkers were placed in front of the participants, 5 inches (2 cm) from the front edge of the desk and oriented, next to each other touching each other.

The participants were instructed to use one hand to stack the checkers one on top of another, on to the wooden board in front of them, as fast as they could, and that they could take the checker of their own choice first. They were also instructed that it did not matter, if the stack was not completely in place as long as the checkers stayed balanced in the stack.

The manual measurement of time started from the word “go” and finished, when the last checker was in place and the stack was stable. The recording of the test area started, when the therapist asked the kinect camera assistant if he was ready, and he had nodded his head. The automated measurement of time started when the test started and ended, when the last checker was in place and the stack was stable. The checkers test was done with the (NDH) first and repeated with the (DH) last.

Statistical analysis

The duration of the time in seconds, which it took for the 11 participants, to perform the subtests of the MJT was recorded automatically and manually. The two measuring methods were compared by analyzing data with excel software from Microsoft Windows 10, using the method described by Bland Altman (37). The mean differences between the two methods and the 95 % limits of agreement with the mean difference were calculated. The 95 % limits of agreement included 95 % of the differences between the two methods. Data from this study are presented for visualization as the difference of the measurements, (automated measurement minus the manual measurement), versus the mean of the measurements in Bland Altman plots. Descriptive data are presented as ±mean ±standard deviation.

Results

Subtest 2 (Turning cards)
The measurements in subtest 2 (fig.1) showed no indication of any overall systematic discrepancies between the manual assessments and the automatic assessments, since the mean difference between the methods was -0.02±0.29 sec. for the DH and -0.11±0.22 sec. for the NDH. There were

some differences between the two measurement methods, but they were not larger than 0.43 sec. for the NDH and 0.57sec.for the DH (fig 1).

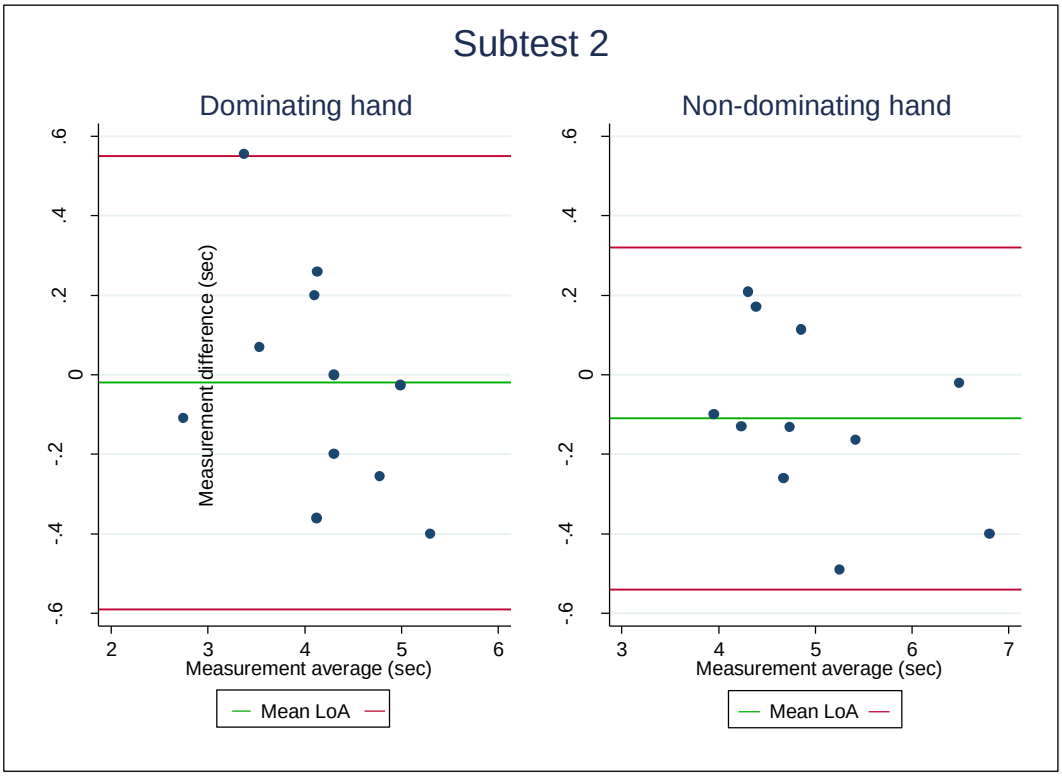

Fig.1. Bland -Altman plots for MJT subtest 2 (turning cards) for two methods of observing time. The Y- axis shows the difference between measurements performed by the two methods (in seconds) and the X- axis shows the average measurement time, for the two measurement methods (in seconds). The two red lines show the limits of agreement (LoA), i.e. - were 95% of the data lies, and the green line shows the mean of the differences between the two methods. The plots shows the result of the collected data, from 11 subjects who performed subtest 2, (turning cards) with their DH (Upper plot) and their NDH (Lower plot).

Subtest 4 (Simulated eating)

For the measurements in subtest 4 (fig.2) there was an indication of a systematic difference, between the two measurement methods, since the mean difference between the methods was -0.32±0.30 sec. for the DH and -0.55±0.55 for the NDH. Only data from 10 measurements were useable in subtest 4 for the NDH. There were some differences between the two measurement methods, but none greater than -1.08 sec. for the NDH and -0.59sec.for the DH (fig 2).

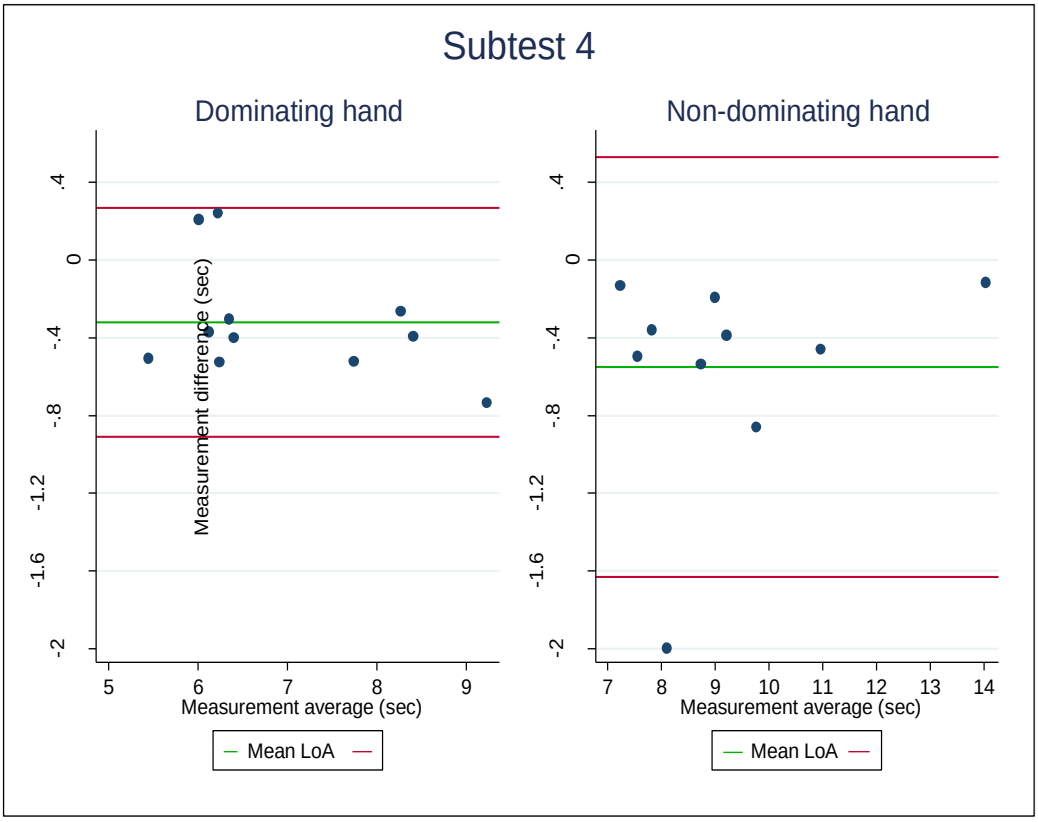

Fig.2.Bland -Altman plots for MJT subtest 4 (simulated eating) for two methods of observing time. The Y- axis shows the difference between measurements performed by the two methods (in seconds) and the X- axis shows the average measurement time for the two measurement methods (in seconds). The two red lines show the limits of agreement (LoA), i.e. - were 95% of the data lies, and the green line shows the mean of the differences between the two methods. The plots shows the result of the collected data from 11 subjects who performed subtest 2, (turning cards) with their DH (Upper plot) and their NDH (Lower plot).

Subtest 5 (stacking checkers)

For the measurements in subtest 5 (fig.3) there is an indication of systematic difference between the two measurements methods, since the difference between the methods is 0.57±0.26 sec. for the DH and 0.46±0.37 (green line) for the NDH. (fig.3.). There is some variation between the two measurement methods, but none greater than 0.7 sec for the NDH and 0.51 seconds for the DH (fig.3.).

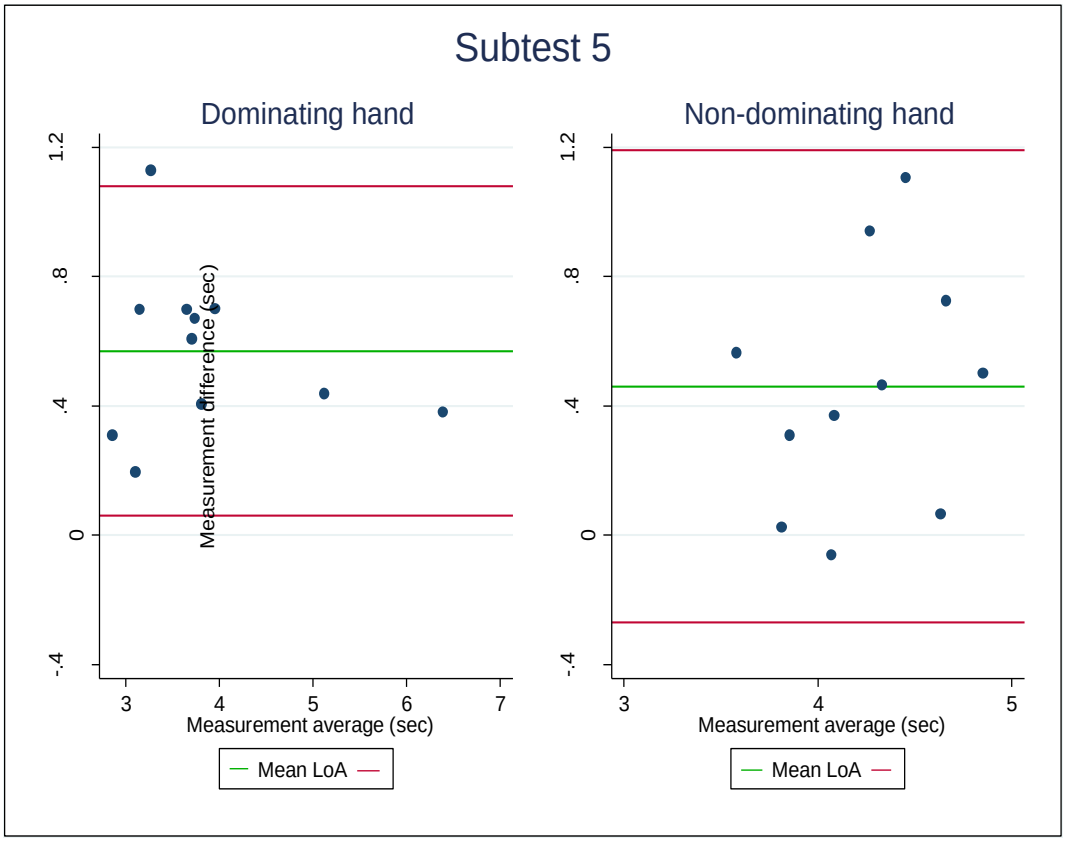

Fig 3. Bland Altman plots for MJT subtest 5 (stacking checkers) for two methods of observing time. The Y- axis shows the difference between measurements performed by the two methods (in seconds) and the X- axis shows the average measurement time for the two measurement methods (in seconds). The two red lines show the limits of agreement (LoA), i.e. - were 95% of the data lies, and the green line shows the mean of the differences between the two methods. The plots shows the result of the collected data from 11 subjects who performed subtest 2, (turning cards) with their DH (Upper plot) and their NDH (Lower plot).

Discussion

Results

Subtest 2

The results of the subtest 2 (turning cards) for the DH in this study, did not appear to have any detectable pattern in the observations, which indicates that there was no association between the average time spent on the task and the magnitude of measurement difference. For the non-dominating hand in subtest 2, the difference in measurement methods were smaller in general, as the interval given by the limits of agreement was narrower. The average duration of the task was prolonged by approximately one second, compared to the DH. This is in agreement with previous findings that show that performing task with the NDH takes longer, than when done with the DH (38).The time difference

for subtest 2, was not larger than 0.43 sec. for the NDH and 0.57sec.for the DH (fig.1), which means that the measuring of the duration of the card turning test with one method or the other, will yield at a time difference smaller than 1 second. This put in perspective of the average time it takes to perform the task (0.50 sec.) could be considered as an acceptable error.

Subtest 4 (Simulated feeding)

For subtest 4 (fig. 2) there was an indication of a systematic difference between the two measurement methods, as all but two assessments had a shorter duration, when using the kinect method compared to the automated method. The difference between the two measurements might have been caused by the fact that the manual measurement of this test stopped, when the sound of the last bean hit the bottom of the metal can. The metal can was positioned, so the therapist could not see when the bean landed in the bottom of metal can, so the therapist relied on the sound, from the bean hitting bottom. Sound travels slower than light (39)and since the Kinect camera relied on visual output from the bean hitting the bottom of the metal can, as the Kinect camera was positioned above the table, it might have seemed as if, the bean touched the bottom of the metal can earlier, than when the sound of the bean was heard by the therapist, thus causing a discrepancy between the measurements methods in terms of seconds.

One subject accidently put a bean into the metal can, with his NDH hand instead of with the spoon, causing the measurement to become invalid and only 10 plots could be formed in subtest 4 for the NDH, as a re- take was not made.

There were some differences between the two measurement methods, but none greater than -1.08 sec. for the NDH and -0.59 sec. for the DH (fig 2), which means that the measuring of the duration of the simulated feeding with one method or the other, will yield at a time difference no greater than 1.1 second. This put in perspective of the average time it takes to perform the task (1.0 sec.) could be considered as an acceptable error.

As a consequence of the outlier in subtest 4 for the NDH, the average difference for the non-dominating hand was well below 0 and the limits of agreement were wider apart, than results for the DH. Although it appears that the observations were biased downwards, with regard to the measurement difference, there was no sign of association between the measurement difference and the measurement average. For the ND hand in subtest 4, the average duration for completion of the

task was as expected, as the DH is used more often than the NDH, thus performs movements faster than a hand used less often as found in a study, that found differences in ability between NDH and DH regarding dexterity and grip strength (38).

Subtest 5 (Stacking checkers)

For subtest 5 (fig. 3) there was a clear indication of systematic difference between the two measurement methods, as all but one assessment, had a longer duration, when using the kinect method compared to the manual method. The difference between the two measurements might have been caused by the fact that the manual measurement of this test stopped, when the pile of checkers was in place which was easily observed by the therapist, who was positioned next to the subject thus could observe when the subject let go of the pile of checkers. The Kinect camera on the other hand was placed above the test area and when the subject held all of the checkers in the hand and was about to let go of the pile, the back of the hand holding the checkers, overshadowed them and it made it more difficult for the kinect camera to detect, when checkers were let go of. Furthermore the subject did not move their hand away from the table immediately after placing the checkers, because they had to hold on to the pile for a few seconds after landing the pile on the wooden board to ensure that they did not fall. This might have been the cause of the discrepancies between the measurements methods in terms of seconds, thus causing the differences between the methods to be larger than they could have been, had the Kinect camera been placed on the side, next to the subject for instance.

There is some variation between the two measurement methods, but none greater than 0.7 sec. for the NDH and 0.51 sec. for the DH (fig.3), which means that the measuring of the duration of the simulated feeding with one method or the other will yield, at a time difference no larger than a 0.51 sec. This put in perspective of the average time it takes to perform the task (0.60 sec.) could be considered as an acceptable error.

Methodological issues

The manual scoring is somewhat subjective, as the measurements relied on the speed, reaction time with which the person recording started and ended the measurement. This issue could to some degree have been prevented had a re -scoring of each test been done. This could help the therapist to practice and an average of the results of a second testing, could have been calculated and used for as data for a later statistical analysis. The use of re-scoring was found to be a relevant solution, in the

scoring of subjective tests, in a study that concluded that scoring of subjective tests, remains problematic why centralized re-scoring is recommended (40).

A concern during the trial was un-expected situations, like verbal orders, that were not correctly spoken and that had to be repeated, or when a subject did not quite understand, what was said and consequently started the test before the signal to start, had been given, or when the next subject knocked on the door and interrupted the test. In these cases the test was started over.

Use of test

Understanding the importance of and extent of manual performance asymmetry, is important when diagnosing and treating hand injuries or impairments of the hand funktion. This was found in a study were right handed subjects showed dominant hand superiority in manual dexterity and grip strength, while left handed subjects showed no such differences (38).This study did take note of which hand was the dominant hand in each subject, but the information was only used to determine, which hand the subject had to start the test with. The hand domination was not correlated for possible differences in dexterity and grip strength in the DH and the NDH in the statistical analysis, as this would have no influence of on the results of the measurements between the methods. A correlation for the NDH and the DH would however, have provided data showing the difference in movements of the two different hands. This kind of information would not be very useful to the subjects in this study, as everyone in the group had normal hand function and was not in the process of testing the progress in a hand rehabilitation program. A correlation might prove to be useful for hemiplegic patients however, as it could serve as a possible baseline measure (40).

Use of test for evaluation at home

This study established the validity of the automated handtest, by comparing a new way of testing with a “gold standard” (41). It was possible to automatize the MJT test on a kinect system and to extract measurements of time from the video images. These measurements showed some discrepancies with the measures obtained with the manual methods, but none larger than 1 second.

Further studies, including clinical trials following the same protocol as used in this study, are needed to asses if the automated validated test of this study, is suitable for stroke patients, thus exploring the possibility, that this automated hand test, could be used for hand testing by stroke patients at home, without the need for therapist assistance.

Conclusion

This study managed to show that the automated MJT works, and that it was possible to retrieve useful measurements and pictures from the Kinect Camera. Some differences were found between the two measuring methods and the automated measurement in subtest 4,that showed shorter times than the manual measurement, while the opposite was found in the measurement for subtest 5.

All time differences between the methods were within 1.1 sec. and if put in perspective of the average time it took to perform each of the three subtests subtest 2 (0.50 sec), subtest 4(1.0 sec.) and subtest 5 (0.60 sec.) it is considered an acceptable error. Therefore this study concludes that the automated test is as useful, as the manual test, and that the automated MJT test, can measure time just as well as the manual MJT.

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