Chapter 5

Changes in speed of information processing in the brain following tendon repair

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Abstract

The objective of this study was to measure the ‘preparation time’, that is the speed of information processing in the brain, and discuss the relevance of this parameter in the restoration of hand function following flexor tendon repair. The preparation time of 48 healthy adult participants was measured twice at a 6 week interval and compared with that of 12 patients after flexor tendon repair. There was no difference between the left and right hands of the healthy participants. The correlation between repeated measurements was high, although healthy participants performed 2.6% faster 6 weeks after the first measurement. After 6 weeks of immobilization, patients showed a significant deterioration in respect of the speed of information processing by the brain on both the injured and uninjured sides compared with healthy participants, who had improved between the first and the second measurements. The results indicate that a period of lack of normal use of the hand leads to a change in cerebral control of hand movements.
Introduction

Flexor tendon injury is one of the most common hand injuries. Treatment is focused on rapid recovery of hand function. Although there is ongoing discussion about the specific methods of tendon repair and rehabilitation, surgical repair of the injured tendon followed by several weeks of dynamic splinting is the most common treatment procedure\(^1\). In order to assess hand function after flexor tendon surgery, several hand assessment tools have been developed, such as questionnaires, range of motion and other functional tests\(^3\)\(^-\)\(^9\). In general, hand function assessment is focused on scores that reflect the adequacy of the involved effector organ. These assessment procedures have been termed ‘result oriented’, since they focus on the results of a specific performance measure such as time to completion of a task compared with a norm score. Although result oriented assessment is of clear value, it also has an important shortcoming in that, by focusing solely on the visible end-result, or the performance of a test, little is learned about the central (motor) control processes that led to that result.

‘Preparation time’ is defined as the speed of information processing in the brain and is a sensitive measure of an important aspect of central control\(^10\)\(^-\)\(^12\).

The purpose of the present study was to measure preparation time after flexor tendon injury and to consider this measurement as a reflection of the (central) recovery process that takes place following surgical tendon repair.

Participants and methods

Forty-eight healthy, volunteer participants were recruited into this study from personnel in the plastic surgery department. Among them were nurses, secretaries, medical students, cleaning personnel and medical staff. Pathology of the upper extremity and neurological disorders were exclusion criteria. Nine participants could not be re-tested within a reasonable time due to part-time jobs and holidays; they were precluded from the analysis.

Twelve patients with isolated zone II flexor tendon injuries with a mean age of 36 (range 18 - 65) years who had been referred to our clinic for primary tendon repair and were suitable for our standard after-care protocol (see below) were also included in the study. Fractures, nerve damage, neurological disorders, pre-existent pathology of the upper extremity and postoperative tendon adhesions were exclusion criteria. The local medical ethics committee approved the study and all participants gave their written informed consent. Table 5.1 shows the demographic and clinical characteristics of the healthy participants and the patients with flexor tendon lesions. The type of anaesthesia used was recorded (general or regional anaesthesia).
Table 5.1 Demographic and clinical characteristics of healthy participants and patients

<table>
<thead>
<tr>
<th></th>
<th>Healthy Participants</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>39</td>
<td>12</td>
</tr>
<tr>
<td>Mean (range) age (years)</td>
<td>34.1 (20.1-60.1)</td>
<td>35.5 (18.4-56.9)</td>
</tr>
<tr>
<td>Gender (% females)</td>
<td>64</td>
<td>17</td>
</tr>
<tr>
<td>Hand dominance (% right hand)</td>
<td>85</td>
<td>92</td>
</tr>
<tr>
<td>Typing diploma (% with diploma)</td>
<td>62</td>
<td>n/a</td>
</tr>
<tr>
<td>Side of injury (% dominant)</td>
<td>n/a</td>
<td>75</td>
</tr>
</tbody>
</table>

n / a = not applicable

Post-operative mobilization protocol

Our standard after-care protocol consists of 6 weeks of dynamic splinting with a modified Kleinert controlled mobilization splint\textsuperscript{15}. Four weeks after surgery the use of the splint is reduced and place-hold exercises are performed for another 2 weeks.

Preparation time measurements

Preparation time (the speed of information processing in the brain) measurements took place in a quiet environment with the participant sitting at a table. The distance between the eyes and the monitor was approximately 80 cm. The test was explained to each participant and it was stressed that they react as quickly as possible. One exercise trial was performed before the actual measurements were made.

A 4-choice preparation time procedure was used. An abstract representation of two real-sized hands was projected on a standard 17-inch cathode ray tube monitor. Each finger corresponded to a key on a standard qwerty-keyboard: the characters (A), (S), (D) and (F) for the left hand and (J), (K), (L) and (;) for the right hand. The thumbs were excluded. The participants had their fingers resting on the keys. The test started with a fingernail on the projected hand lighting up (Fig 5.1, see Appendix). As soon as the fingernail was lighted, the participant had to press as quickly as possible on the corresponding key on the keyboard. The time between lighting up and pressing the key was recorded as the preparation time in milliseconds. Immediately after the correct key was pressed, the lighting up of the fingernail turned off and randomly a new nail lit up. The series was continued until each finger of the measured hand was tested 10 times. From
all preparation times of the index, middle, ring and little fingers of one hand (40 in total) an average preparation time for each hand was calculated.

Both hands of the healthy participants were measured twice within a time interval of 6 weeks. The hands of the patients were also measured twice. However, only the uninjured hand was measured before surgery. Six weeks later, after splint removal, both hands were measured. The fact that the uninjured hand could be used as an indicator for the injured hand before surgery is justified by a study by Peters and Ivanoff, showing there is no significant difference in preparation time between the left and the right hand in normal participants for this simple task. This study also proves that this is the case.

Clinical assessment of patients
Six weeks postoperatively patients were examined for adhesions and asked about their subjective feelings of hand function.

Statistical analyses
In healthy participants, preparation times were analysed by using a General Linear Model. The side (dominant or non-dominant) and the day of measurement (first day vs. 6 weeks later) were entered as within-subject factors in an ANOVA of repeated measures. Table 5.2 shows the average scores. Gender, age and possession of a typing diploma were entered as covariates. Test-retest reliability was assessed by calculating Pearson’s correlation coefficients. Sensitivity of the test was evaluated by comparing the actual measurements of healthy participants with those of the patients by using a Mann-Whitney test. To compensate for effects caused by group differences, we not only compared the preparation times but we also compared improvement percentages with respect to the first measurement.

| Table 5.2 Mean preparation times in healthy participants |
|--------------------------------|------------------|
|                                   | Day 1       | Six Weeks Later |
|                                   | msec (SD)   | msec (SD)       |
| Dominant hand                     | 537 (95)    | 526 (102)       |
| Non-dominant hand                 | 553 (89)    | 527 (81)        |
| Both hands                        | 545 (92)    | 527 (91)        |

msec = milliseconds
Results

Healthy Participants

Analysis of the data of healthy participants revealed that gender or possession of a typing diploma did not influence finger flexion preparation times ($F(1,35) = 2.7, p = 0.109$, respectively $F(1,35) = 0.036, p = 0.850$). Higher age, however, resulted in a significantly longer preparation time ($F(1,35) = 9.6, p = 0.004$), but the correlation between age and preparation time was rather low (Pearson’s correlation coefficient $= 0.122, p = 0.027$).

A pair-wise comparison of the within-subjects factors showed no significant difference between the preparation times of the dominant and non-dominant hands in healthy participants (Table 5.3). Correlation between both hands was high (Pearson’s correlation coefficient $= 0.905, p < 0.001$). No significant differences were observed between the preparation times of the dominant and non-dominant hands in healthy subjects. Therefore, these measurements were pooled and the scores of the uninjured hands in patients on the first day were considered as good approximations of the scores of the injured hand (which, of course, could not be measured at that time). This made it possible to estimate the improvement rate of the injured hand.

The correlation between the measurements on the first day and 6 weeks later was significant ($p < 0.001, r = 0.788$). It could be shown that, 6 weeks after the initial measurement, healthy participants experienced significant improvement from the first measurement. Compared with the first measurement, healthy participants were, on average, 2.6% faster (95% CI: 0.7 to 5.2%) 6 weeks later.

<table>
<thead>
<tr>
<th>Table 5.3</th>
<th>p-values and 95% confidence intervals of pairwise comparisons of within-subject factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Significance (p-value)*</td>
</tr>
<tr>
<td>Side</td>
<td>0.438</td>
</tr>
<tr>
<td>Day of measurement (Day 1 versus 6 weeks later)</td>
<td>0.019</td>
</tr>
</tbody>
</table>

The high p-value for ‘Side’ means that the results of the dominant and non-dominant hand are not significantly different. The low p-value for ‘Day of measurement’ means that participants significantly improved 6 weeks after the first measurement.

msec = milliseconds

*Adjustment for multiple comparisons: Bonferroni

Comparison of healthy participants and patients

Table 5.4 displays average preparation times of both healthy participants and patients. During the first measurement, patients and healthy participants showed no difference in preparation
times (U = 363.5, p = 0.145). However, the results during the second measurement, 6 weeks later, show interesting differences (Fig 5.2). Although none of the patients appeared to have tendon adhesions or joint stiffness after splint removal, they reported a feeling of clumsiness when asked about their movement capacities. Patients who had worn a splint for 6 weeks showed significantly longer preparation times with the recovered hand than healthy participants (U = 193, p = 0.001).

### Table 5.4 Average preparation times on day 1 and day 2 for healthy participants and patients

<table>
<thead>
<tr>
<th></th>
<th>Preparation Time</th>
<th>Preparation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
<td>6 weeks later</td>
</tr>
<tr>
<td>Healthy participants</td>
<td>545 (92)</td>
<td>527 (91)</td>
</tr>
<tr>
<td>Patients uninjured side</td>
<td>587 (82)</td>
<td>633 (139)</td>
</tr>
<tr>
<td>Patients injured side</td>
<td>587 (82) *</td>
<td>676 (47)</td>
</tr>
</tbody>
</table>

msec = milliseconds

* = estimation, based on uninjured side

**Figure 5.2** Error bars of preparation times 6 weeks after the initial measurement day in milliseconds with 95% confidential intervals. The left bar represents healthy participants, the middle bar represents the injured side of patients and the right bar represents the uninjured side of patients.
This finding was confirmed when we look at the individual changes between the two measurements of healthy participants and patients. Healthy participants improved significantly more than patients ($U = 247$, $p = 0.006$). Six weeks later healthy participants performed on average 2.6% faster, while patients performed 14.1% slower with their formerly injured side (Fig 5.3). Interestingly, the uninjured side also deteriorated, although less than the injured side. Six weeks after the initial measurement patients performed 7.9% slower with their uninjured hand, which is significantly different from the performance of healthy participants ($U = 306.0$, $p = 0.035$).

The type of anaesthesia used did not influence the improvement on preparation time in patients ($U = 17$, $p = 0.937$).

![Figure 5.3 Error bars of improvement rates on response times between the first measurement and six weeks later in percentage with 95% confidential intervals. The left bar represents healthy participants, the middle bar represents the injured side of patients and the right bar represents the uninjured side of patients.](image)

**Discussion**

A ‘normal reaction time procedure’, is one in which a participant is instructed to react as fast as possible after a stimulus, such as a button lighting up, appears. The response may be, for example, to push a button as fast as possible. In simple reaction time procedures there is only one type of stimulus and one desired response. In ‘choice reaction time procedures’, there are
several stimuli presented and each stimulus requires a particular response. The time that elapses between the appearance of a stimulus and the actual start of the movement reflects the time that is required to prepare the movement\textsuperscript{10,15}. These findings may be relevant for rehabilitation research, since it has been shown that preparation time is shorter for well learned skilful movements, compared with novel and/or complex movements. In other words, the response-programming time for a well known movement is shorter than for a novel movement\textsuperscript{11}.

In an earlier Positron Emission Tomography study we showed that a 6-week period of relative immobilization (dynamic splint therapy) after surgical tendon repair led to cortical reorganization\textsuperscript{16}. The Positron Emission Tomography data indicated that after the splint period, brain areas relevant for the automatic, or skilful, control of finger movements, namely the corpus striatum, showed significantly less activity. This was reflected behaviourally in a (temporary) lack of skilfulness. If a relationship exists between preparation time and the level of skilfulness, it becomes interesting to study whether after 6 weeks of splinting, the preparation time of patients recovering from tendon repair would be longer than the preparation time of healthy controls. When the preparation time is, indeed, increased this may be seen as a behavioural reflection of the central reorganization mentioned above.

The aim of this study was to find out whether a 6-week period of relative hand immobilization would lead to significant changes in the preparation time, that is the speed of information processing in the brain, of finger flexion movements. The study showed that, after the splinting period (lack of normal use of the hand) the preparation time in the patients was significantly increased while the healthy control group showed a decrease in preparation time.

How can we explain this result? There is ample evidence that a period of distorted afferent (peripheral) information leads to a reorganization of central control processes\textsuperscript{17-19}. This was also shown in our Positron Emission Tomography study\textsuperscript{16}. Skilful control of movement depends on the permanent availability of response-produced sensory information. In the patient group, the quality of this information has been compromised by a period of relatively little information. The patients’ uninjured hands showed an increase in preparation time after 6 weeks, just like their injured hands. This suggests that the findings for the injured hands are not simply the result of the mechanical effects of the surgery (i.e. adhesion and/or pain) or rehabilitation, which were applied to that hand. Although the activities of both hands are influenced by the fact that the patients are not performing normal activities and work during the splinting period, one might think that the uninjured hand will perform better because it will have to take over some tasks of the injured hand. We think the deterioration of the uninjured hand can be better explained by the fact that motor control at the highest level is to a large extent muscle or effector independent.
This means that the cerebral representation of an action is independent of the specific muscle activation pattern\textsuperscript{20-22}. Famous and classic examples of this effector independency of control can be found in Merton (1972) and Raibert (1977)\textsuperscript{23,24}. They compared handwriting produced by the left and right hands, feet, mouth and shoulder movements and found striking similarities in the shape of the letters produced by one subject.

Even though this is an intriguing and important result, some caution is necessary. Firstly, because of the injury, we were not able to measure the injured hand in the first measurement session. Although no differences in preparation time in healthy participants were found between the left and right hand for the employed task, so that a comparison between hands seemed to be justified, it can still be argued that our evidence for a preparation time increase is an indirect one. Secondly, an increase in preparation time may also be caused by general anaesthesia. Although there is some debate whether or not modern general anaesthesia affects cognitive functions, some studies report a preparation time increase after general anaesthesia\textsuperscript{25}. However, since no significant difference in preparation time was shown between the patients who underwent the tendon repair under general anaesthesia and those who received regional anaesthesia, we think the preparation time increase could not be attributed to the effects of anaesthesia. The same is true for gender. Although the male/female ratios of the healthy participants and patients did not match, it is unlikely that a gender difference would cause the difference in preparation time since we did not find any influence of gender on preparation time in healthy participants. The difference between healthy participants and patients persisted when we looked at improvement percentages.

The results of this study indicate that a period of relative immobilization after surgical tendon injury and repair leads to a change in the control of the involved movements. It was shown previously that immobilization after tendon repair results in structural cerebral reorganization using Positron Emission Tomography\textsuperscript{16}. The results of the present study using a simple behavioural measurement (movement preparation time) point in the same direction. In this present paper we argue that the preparation time, that is the speed of information processing in the brain, is a variable that could be relevant to rehabilitation of flexor tendon injuries. Although it may not be likely that preparation time could be used as a practical test to assess hand function, it is important to consider the central nervous system component in the development of new treatment protocols for flexor tendon injuries and other peripheral lesions that are followed by a period of lack of normal use of the hand.
Acknowledgements

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References


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