Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Test - retest reliability of a static hand grip and pinch motor fatigability protocol in typically developing children

Liesbeth Marai
Marie Merckx

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen

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Boekweitstraat 52, 3660 Oudsbergen, Belgium, June 1, 2019 L.M.

Weyerstraat 15, 3750 Hoeselt, Belgium, June 1, 2019 M.M.

Research context

This master thesis is the second and final part of our master program in 'Rehabilitation Sciences and Physiotherapy' at the University of Hasselt and is situated in the domain of pediatric rehabilitation.

This master thesis can be situated in an ongoing research project "Muscle fatigability in upper limb strength tasks in children with cerebral palsy", which is the joint PhD project of L. Brauers between UHasselt (prof. dr. Klingels, prof. dr. Feys) and UMaastricht (prof. dr. R. Smeets and prof. dr. E. Rameckers).

Part 1 of this master thesis consisted of a literature study towards 'Assessment tools and protocols to evaluate upper limb static motor fatigability in patients with neurological disorders'. This literature study showed that a 30 second isometric continuous maximal motor fatigability protocol measured using hand grip dynamometers such as E-Link H500 hand-kit and JAMAR is considered as the most reliable motor fatigability protocol in a neurological population.

Test-retest reliability showed to be highly reliable in persons with MS [1]. However, to apply these protocols and assessment tools to examine motor fatigability in children with neurological disorders, such as CP, test-retest reliability should first be examined in typically developing children. Examining test-retest reliability of this 30 second static maximal motor fatigability protocol using an E-link hand grip dynamometer in a population of typically developing children was thus the main aim of this second part of our master thesis. This reliability study is intended to be the basis of further research of these assessment tools and protocols in a pediatric neurological population.

A central format was used to describe the context.

This master thesis was supervised by prof. dr. K. Klingels and dra. L. Brauers. Research design and methods were designed by prof. dr. K. Klingels and dra. L. Brauers within a current PhD project. Two master students (L.M. and M.M.) worked together in a duo-master thesis, with contribution from four other master students researching within the pediatric domain (P.H., J.V., D.B., L.S.) and dra. L. Brauers (PhD project). All six students contributed to both recruitment and testing of the typically developing children. Dra. L. Brauers contacted the parents of the children when interest was shown. Academic writing of the abstract, introduction, methods, results, discussion and conclusion together with data processing was performed by L.M. and M.M and reviewed by dra. L. Brauers en prof. dr. K. Klingels.

[1] Schwid, S.R., Thornton, C. A., Pandya, S., Manzur, K.L., Sanjak, M., Petrie, M. D., … Goodman, A. D. (1999) Quantitative assessment of motor fatigue and strength in MS. *Neurology, 53*(4), 743-750.

Test-retest reliability of a static hand grip and pinch motor fatigability protocol in typically developing children

Abstract

BACKGROUND: In upper limb, test-retest reliability of a static maximal isometric motor fatigability protocol of grip and pinch strength was considered as highly reliable in persons with Multiple Sclerosis, using the Static Fatigue Index 3. In a pediatric population, no research has been done regarding this protocol. As a base, test-retest reliability of this protocol should be investigated in typically developing children (TDC) before further investigation in children with CP.

OBJECTIVES: To investigate test-retest reliability of a static motor fatigability protocol of pinch and grip strength in TDC.

PARTICIPANTS: 40 TDC (13 boys, 27 girls; mean age 10y 4m (SD: 2y 6m) ranging from 6y 6m to 17y 11m) were included.

MEASUREMENTS: test-retest reliability was measured with an E-Link hand grip dynamometer and pinchmeter in a 30 seconds static maximal motor fatigability protocol. SFI3, mean force (Fmean) and slopes were calculated. Intraclass correlation coefficient (ICC), standard error of measurement (SEM) and minimal detectable change (MDC) (together with the calculation of the MDC as percentage of the mean of the original data) were calculated of all three outcome measures.

RESULTS: For the pinch and hand grip dynamometer of the dominant and non-dominant hand (DH; NDH), Fmean and SFI3 ICC data indicated a moderate to very high reliability. ICC values of the slopes were low or negative.

Using the pinchmeter, MDC data of the DH and NDH ranged from 0.71401 (31,33%) to 1.27675 (42,42%) for Fmean and from 0.00003 (0.01%) to 0.00029 (-29.44%) for slope. The MDC values of the SFI3 were 14.91686 (38,68%) and 19.25671 (45.39%) for the DH and NDH, respectively. Using the dynamometer, MDC data of the DH and NDH ranged from 5.00307 (60.98%) to 5.65770 (56.21%) for Fmean and from 0.02408 (-502.05%) to 0.04404 (14.65%) for slope. The

MDC values of the SFI3 were 24.88167 (52.66%) and 20.25400 (41.28%) for the DH and NDH, respectively.

CONCLUSION: ICC values of the SFI3 and Fmean were at least moderately high, except for the SFI3 of the pinch NDH (moderate), indicating a good reliability. Calculations of the slopes need to be elaborated or a reliable alternative must be found.

Introduction

Fatigue is a symptom commonly reported by populations with neurological disorders and is associated with decreased quality of life and disability (Amato et al., 2001; Gallagher, Lees, & Schrag, 2010; van de Port, Kwakkel, Schepers, Heinemans, & Lindeman, 2007). Despite this clear presence and impact of fatigue, there is still a lack of clarity in its terminology (Kluger, Krupp, & Enoka, 2013). In an effort to create clarity, Kluger et al. (2013) proposed a unified taxonomy in which performance fatigability is described as “the magnitude or rate of change in a performance criterion (thus **objective**) relative to a reference value over a given time of task performance or measure of mechanical output”. Perception of fatigue, on the other hand, is defined as “the **subjective** sensation of weariness, increasing sense of effort, or exhaustion” (Kluger et al., 2013).

Furthermore, performance fatigability can be subdivided in a motor and cognitive domain. In the motor domain, fatigability is usually quantified as the decline in peak force (torque) after performing an exercise intervention, but declines in power, speed or accuracy are also used. In the cognitive domain, fatigability is mostly measured as a decline in reaction time or accuracy over time on a continuous performance task, or a probe task given before and after a fatiguing cognitive task. In our study we will be focusing on the motor domain of fatigability, and will refer to this as motor fatigability (Kluger et al., 2013).

According to Kluger et al. (2013), two main origin factors can be attributed to motor fatigability, being peripheral and central factors. In healthy humans, peripheral factors include physiologic changes in the muscle, neuromuscular junction, and peripheral nerves (Kluger et al., 2013). In a pathological population, changes in the peripheral nervous system and muscle may also influence fatigability (Kluger et al., 2013). Central factors are related to deficits in central drive of the central neural system, which are responsible for a significant percentage of motor fatigability depending on the demands of the task (Kluger et al., 2013).

When measuring motor fatigability, it is important to acknowledge the task which causes the fatigability. Among others, it can be induced by tasks requiring continuous (i.e. sustained) contractions and is then called static motor fatigability. Static motor fatigability of the upper limb (UL) can for example be induced by performing a grip contraction with a hand grip dynamometer or pinchmeter over a prolonged period of time. Different ways to map static motor fatigability are available, of which most of them can be measured based on a force-time curve. Among others, a static fatigue index (SFI) can be used. An SFI is an index based on time and strength to effectively measure motor fatigability. Different types of SFI's exist, of which the third (SFI3) is the most commonly used because of its proven high reliability in People with Multiple Sclerosis (PwMS) (Schwid et al., 1999). The SFI3 is the ratio of the observed area under the force-time curve (AUC) of a sustained contraction over the hypothetical area under the curve (HAUC) (i.e. the curve if no motor fatigability would be present), starting at the time maximal force is reached. Schwid et al. (1999) calculates the SFI3 based on a 30s time unit (Schwid et al., 1999). Further explanation of the SFI3 and its application is provided in the method of this study.

Schwid et al. (1999) also describes a conventional model for motor fatigability analysis besides the SFI3, which is based on a ratio of the maximal force generated in the final five seconds to the initial five seconds of the 30 seconds sustained contraction (Schwid et al., 1999). Thus, this method is directly based on decrease in strength.

Thirdly, decline in slope can be used as a measure of the speed at which motor fatigability occurs. A steep fall in slope indicates a fast decrease in strength and thus a fast increase in motor fatigability. However, this method has not yet been used in earlier research.

Concerning grip strength motor fatigability in a neurological population, Schwid et al. (1999) and Severijns, Lamers, Kerkhofs and Feys (2015) showed a higher static hand grip motor fatigability in PwMS compared to healthy controls when measured with a 30 seconds static maximal protocol using the SFI3 (Schwid et al., 1999; Severijns, Lamers, Kerkhofs, & Feys, 2015). In children with Cerebral Palsy (CP), one study of van Meeteren et al. (2007) showed higher static hand grip motor fatigability measured with a 20 seconds static maximal protocol using the SFI3 in young adults with CP when compared to healthy subjects (van Meeteren, van Rijn, Selles, Roebroeck, & Stam, 2007).

The above mentioned author Schwid et al. (1999) also examined the test-retest reliability of this protocol in PwMS, and proved it to be highly reliable (Schwid et al., 1999). In the study of van Meeteren et al. (2007) test-retest reliability of his protocol was examined in the healthy control group with a mean age of 21.8 years, showing a moderate reliability.

To our knowledge, no other research has been done regarding test-retest reliability of an UL motor fatigability protocol in typically developing children (TDC) nor in children with CP. This indicates a need for research in this topic.

Thus, in order to gain insights in the extent of motor fatigability of the UL in children with CP, first, research should be done regarding the extent of it in TDC. In order to do so, a reliable measurement protocol on static motor fatigability will allow gaining insights in this phenomenon in children with neurological disorders, such as CP and how it impacts on activities of daily living and participation.
Therefore, the main aim of this study is to examine test-retest reliability of a 30 seconds static maximal motor fatigability protocol measured with a hand grip dynamometer and pinchmeter using the SFI3 in TDC.

Methods

Participants

Children were recruited from different pre-schools, high-schools, youth movements and friends and family in Belgium (region of Limburg) between December 2018 and March 2019. Children were included if they were aged between 6 and 18 years old, cognitively capable of understanding the instructions, Dutch speaking and sufficiently motivated to participate. Children were excluded if they suffered any type of UL motor disorder (neurological and/or orthopedic). The children were asked not to participate in intensive fatigable exercises of the UL the day before and the day of testing.

Children and parents received an information letter and signed a written informed consent prior to the measurements. The research proposal was approved by the Ethical Committee of Hasselt University (CME2018/069).

Materials

Descriptive characteristics such as age, gender and dominant hand were obtained from the included children.

To evaluate maximal strength and static motor fatigability of hand and pinch grip, the pinchmeter and hand grip dynamometer of the E-Link H500 hand-kit (Biometrics; UK) were used. For the dynamometer, the width of the hand grip was adapted to the size of the child's hand. In general, the second position of this digital device was used, except if this position did not fit with the size of the child's hand.

Measurements

Four raters were trained prior to the measurements by a professional (fifth rater) to standardize the measurements and instructions. Encouragement to the subjects was given as much as needed but in a standardized manner during the measurements. Also, sitting position of the children was standardized: feet flat, 90-degree hip and knee flexion, straight back and elbows on the armrests in 90-degree flexion.

Two examinations, with a duration of 20–30 minutes each, were performed by each child with at least 48 hours, but maximum seven days, in between.
First a maximal peak measurement of hand grip and pinch strength was performed, followed by the static motor fatigability measurements.

Peak measurement

To measure peak grip and pinch strength, three maximal voluntary contractions were performed. Within these peak measurements, the highest measurement of three was defined as the peak value. If the variability between these three peak contractions exceeded the range of 10%, another maximal measurement was performed until a variability of less than 10% was obtained. Children were instructed to squeeze the dynamometer or push the pinchmeter as hard as possible for 3-4 seconds and let go. Instructions were given prior to the test and children were encouraged during the peak measurement to achieve the highest strength.

Static motor fatigability protocol

To measure static motor fatigability in hand grip and pinch strength, children were instructed to squeeze the dynamometer or push the pinchmeter as hard as possible after a start signal given by the therapist. This static motor fatigability measurement was sustained for 30 seconds. A successful measurement was achieved if the peak force was reached within the first 10 seconds of the measurement. In case of an unsuccessful measurement, another trial was executed. During the performance of the static measurements, children received visual feedback about the remaining time.

Outcome measures

The primary outcome variables were static motor fatigability measured with the SFI3, mean strength (Fmean) and slopes. The applied force of grip and pinch strength was shown as 0.01 kg. Related to this, maximal strength (Fmax), measured with maximal voluntary contractions (MVC's), can be considered as an outcome measure to check the quality of the primary outcomes. Fatigability measurements cannot be seen as a maximal if children squeezed less than 60% of their Fmax in the actual fatigability protocols. This limit was set arbitrarily.

Calculations

First, we calculated the magnitude and the moment of achievement (in seconds) of the Fmax within the first 10 seconds. The remaining time period was divided into three equal parts. Fmeans and slopes were calculated of these three intervals.

Fmean

Fmean data were divided into three equal groups, being Fmean1, Fmean2 and Fmean3. Data of the force-time curve was acquired at a frequency of 20 Hertz. We eventually obtained 599 datapoints. Per interval, Fmean was calculated by taking the mean of all datapoints within that interval.

Slope

Slope data were divided into three equal groups, respectively slope1, slope2 and slope3. Per interval, slope data were calculated by taking a first degree equation of all datapoints within that interval.

SFI3

To calculate the SFI3, four steps were taken:

1. The magnitude and the moment of achievement (in seconds) of the peak hand grip or pinch strength was determined (Tmax).
2. The HAUC was calculated which is a representation of the force-time curve if no motor fatigability is present. To calculate this HAUC, the time between Tmax and end of the contraction was used and a rectangle was drawn between remaining second and the Fmax (HAUC, area 1 + 2 in figure 1).
3. The AUC (area 2 in figure 1) was calculated, starting from Tmax until the end of the sustained contraction.
4. Static motor fatigability was calculated as a ratio between the observed AUC and the HAUC, using the SFI3 with the following equation (Schwid et al., 1999; Severijns et al., 2015; Severijns, Van Geel, & Feys, 2018):

$$SFI3 = 100\% \times \{1 - (\text{area } 1/ (\text{area } 1 + \text{area } 2))\}$$

Figure 1 demonstrates a schematic overview of the calculation of the SFI3 in a 30 seconds force-time curve using a static maximal contraction. On the horizontal axis, time of the static contraction is shown in seconds. On the vertical axis, hand grip strength is represented in kilograms.

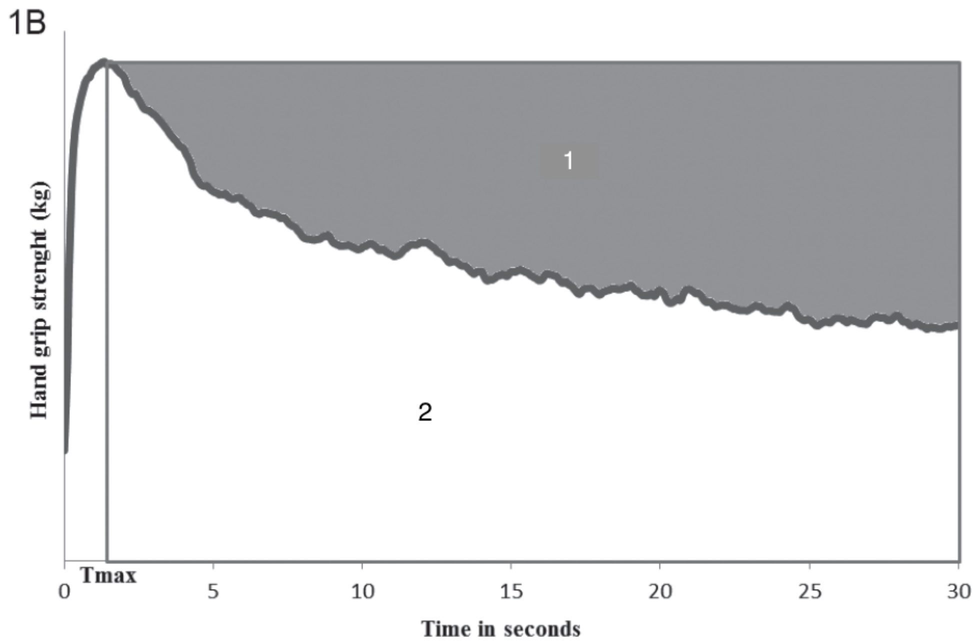

Figure 1. Schematic overview of the force-time curve of a 30s sustained maximal contraction, 1 + 2 = hypothetical area under the curve (HAUC), 2 = actual area under the curve (AUC)

Statistical analysis

Data from the dynamometer for the dominant hand (grip DH), dynamometer for the non-dominant hand (grip NDH), pinchmeter for the dominant hand (pinch DH) and pinchmeter for the non-dominant hand (pinch NDH) were analyzed. The normality of data was checked using a Shapiro-Wilk test for each component (Fmean1, Fmean2, Fmean3, slope1, slope2, slope3 and SFI3) with significance level set at $p<0.05$. If data were not normally distributed, log transformations were executed.

Test-retest reliability was calculated using multiple parameters:

1. ICC: with the use of Intra-Class Correlation Coefficients (ICC's, model 2.1) (Katz, Larson, Phillips, Fossel, & Liang, 1992). A confidence interval of 95% was set up with an alpha-value of $p<0.05$. In SPSS, a two-way random model, type absolute agreement was used to calculate the ICC's. ICC's could be interpreted as follows: ICC > 0,80 (very high); ICC 0.60 – 0.79 (moderately high); ICC 0.40 – 0.59 (moderate); ICC < 0.40 (low) (Katz et al., 1992).
2. Bland-Altman: Bland-Altman plots were used to determine the agreement or precision between the two examinations and to give information regarding the magnitude of the measurement error (Savva, Mougiaris, Xadjimichael, Karagiannis, & Efstathiou, 2018).
3. The standard error of measurement (SEM) represents the variability of the measurement errors between measurements obtained from the two examinations. The SEM gives an idea of the measurement precision. Following formule was used to calculate the SEM: StandarddeviationT1+T2 * (SQUARE (1-ICC)) (Savva et al., 2018).

SEM-scores can be used to calculate the minimal detectable change (MDC), which is defined as the smallest amount of change in score which is not due to measurement errors. The formule to calculate the MDC is as follows: SEM*1.96*SQUARE (2)

MDC values were calculated as percentage of mean values (mean of T1 and T2) to give a general representation that can be used in clinical practice by the following formule:
MDC/meanT1T2 (%) = (MDC/mean scores of test and retest) *100

Statistical analysis was performed using SPSS (IBM SPSS Statistics 20, ©IBM, Armonk, NY, US).

Results

Participants

40 TDC were included of which 13 boys and 27 girls (8 left-handed, 32 right-handed). The mean age was 10 years 4 months (SD 2 years 6 months) ranging from 6 years 6 months to 17 years 11 months. Appendix 1 shows the characteristics of all included children.

Fmean

Table 1 shows the test retest reliability of static motor fatigability measurements of hand grip and pinch strength in TDC.

For the pinch DH, the coefficient for the test-retest reliability was moderately high (ICC = 0.78) for Fmean1. For the mean strength in both the intervals Fmean2 and Fmean3, ICC values could be interpreted as very high (ICC = 0.84-0.90). SEM ranged between 0.26 and 0.46 and MDC was situated between 0.71 and 1.27 (26.33% - 42.42%).

In the pinch NDH, all test-retest correlations were moderately high within a range of 0.68-0.79. SEM values ranged from 0.37 to 0.46 and MDC values ranged from 1.02 to 1.28 (40.81% - 63.22%).

When determining ICC's of the grip DH, ICC's were very high ranging from 0.81-0.83. Values of the SEM were between 1.81 and 2.01 and those of the MDC ranged from 5.00 until 5.58 (49.06% - 60.98%).

ICC values were moderately high with a range of 0.72-0.80 when testing the non-dominant hand with a dynamometer. SEM values varied between 1.90 and 2.04. MDC values varied between 5.26 and 5.66 (56.21% - 76.94%).

Slope

In case of testing pinch DH, the ICC's ranged between 0.05 and 0.19 and were thus considered low. SEM's were ranged between 0.00002 and 0.00011, and MDC values ranged from 0.00003 to 0.0003 (-29.44% - 0.002%).

Pinch ICC values of the NDH of the first interval gave moderate reliable ICC values (ICC = 0.43). For the second and third interval the ICC's were low, being 0.30 and 0.14 respectively. The SEM values ranged between 0.00002 and 0.00009 and the MDC values between 0.003 and 0.004 (-25.96% - 0.02%).

The ICC of the third interval was moderate (ICC = 0.42) when testing the grip DH. The ICC's for both the first and the second interval were low, being -0.47 and 0.23 respectively. The SEM ranged from 0.009 to 0.016, and the MDC ranged from 0.02 to 0.04 (-502.05% - 9.31%). When testing slopes of the grip NDH, ICC's all had a negative value ranging from -0.29 to -0.20. SEM values ranged from 0.03 to 0.04 and MDC values ranged from 0.010 to 0.014 (-157.90% - 14.56%).

SFI3

Measuring the pinch DH, the ICC value of the SFI3 was moderately high (ICC = 0.61). The values of the SEM and MDC were respectively 5.38 and 14.92 (with the %meanT1T2 = 38.68%). In case of testing the pinch NDH, ICC's were moderate (ICC = 0.58). The values of the SEM and MDC were respectively 6.95 and 19.26 (45.39%). The ICC value of the grip DH was moderately high (ICC = 0.73). The SEM and MDC were respectively 8.98 and 24.88 (52.66%). The ICC value of the grip NDH, was also moderately high (ICC = 0.69). Values of the SEM and MDC were respectively 7.31 and 20.25 (41.28%).

Table 1

Test retest reliability of static motor fatigability measurements of hand grip and pinch strength in TDC

Calculations	N	ICC	95% ICC	SEM	MDC	STDT1+T2	MDC/MeanT1T2 (%)
Pinchmeter DH							
Fmean 0-10	29	0.78	0.55-0.90	0.45772	1.27000	0.985	42.42
Fmean 10-20	29	0.84	0.66-0.93	0.34616	0.95951	0.868	26.33
Fmean 20-30	29	0.90	0.79-0.95	0.25759	0.71401	0.815	31.33
Slope 0-10	29	0.19	-0.76-0.62	0.00002	0.00005	0.004	0.02
Slope 10-20	29	0.12	-0.94-0.59	0.00001	0.00003	0.003	0.01
Slope 20-30	29	0.05	-1.04-0.56	0.00011	0.00029	0.003	-29.44
SFI3	29	0.61	0.19-0.81	5.38154	14.91686	8.584	38.68
Pinchmeter NDH							
Fmean 0-10	31	0.79	0.56-0.90	0.39774	1.10249	0.868	40.81
Fmean 10-20	31	0.78	0.55-0.89	0.36902	1.02287	0.783	46.28
Fmean 20-30	31	0.68	0.35-0.85	0.46061	1.27675	0.818	63.22

Slope 0-10	31	0.43	-0.17-0.73	0.00009	0.00026	0.003	-4.52
Slope 10-20	31	0.30	-0.46-0.66	0.00009	0.00026	0.004	-25.69
Slope 20-30	31	0.14	-0.83-0.59	0.00002	0.00005	0.004	0.02
SFI3	31	0.58	0.15-0.79	6.94722	19.25671	10.657	45.39
Dynamometer DH							
Fmean 0-10	29	0.83	0.65-0.92	2.01257	5.57856	4.940	49.06
Fmean 10-20	29	0.83	0.64-0.92	1.8601	5.15595	4.538	57.46
Fmean 20-30	29	0.81	0.59-0.91	1.80495	5.00307	4.109	60.98
Slope 0-10	29	-0.47	-2.33-0.33	0.01518	0.04208	0.013	-170,59
Slope 10-20	29	0.23	-0.70-0.64	0.01007	0.02709	0.011	9.31
Slope 20-30	29	0.42	-0.25-0.73	0.00869	0.02408	0.011	-502.05
SFI3	29	0.73	0.41-0.88	8.97653	24.88167	17.372	52.66
Dynamometer NDH							
Fmean 0-10	30	0.80	0.58-0.90	2.04112	5.65770	4.519	56.21
Fmean 10-20	30	0.78	0.55-0.90	1.89608	5.25566	4.061	68.11
Fmean 20-30	30	0.72	0.41-0.86	2.02022	5.59976	3.791	76.94
Slope 0-10	30	-0.29	-1.84-0.40	0.01403	0.03890	0.012	-157.90
Slope 10-20	30	-0.20	-1.27-0.40	0.0114	0.03159	0.010	-723.14
Slope 20-30	30	-0.29	-1.82-0.40	0.01589	0.04404	0.014	14.65
SFI3	30	0.69	0.33-0.86	7.30700	20.25400	13.082	41.28

ICC, Intraclass Correlation Coefficient; CI, Confidence Interval; SEM, Standard Error of Measurements; MDC, Minimal Detectable Change; STDT1+T2, Standard Deviation of test and retest; MDC/meanT1T2 (%), percentage of the MDC/(meanT1 + mean T2); Fmean, Mean Strength; SFI3, Static Fatigue Index 3; DH, Dominant Hand; NDH, Non-Dominant Hand

Bland-Altman plots

Bland-Altman plots were set up for Fmean, slope and SFI3 for the grip DH, grip NDH, pinch DH and pinch NDH with SPSS to determine the precision or agreement between test and retest fatigability measurements and to give information about the magnitude of measurement errors. Appendix 2 gives an overview of all Bland-Altman plots. These represent the 95% confidence interval indicated with the two green lines, being the lower and upper limit of agreement (LOA). It is recommended that 95% data points lie within the LOA as this would indicate a normal distribution of the differences. Figure 2 represents the Bland-Altman plot of the SFI3 using the pinchmeter with the NDH as an example. In this example, one outlier in data points can be seen, indicating a bigger difference in test results between examination one and two for this data point. 96.7% of all data points are situated between the LOA, thus indicating a normal distribution. LOA were respectively -0.18 and 0.28 for the lower and upper LOA.

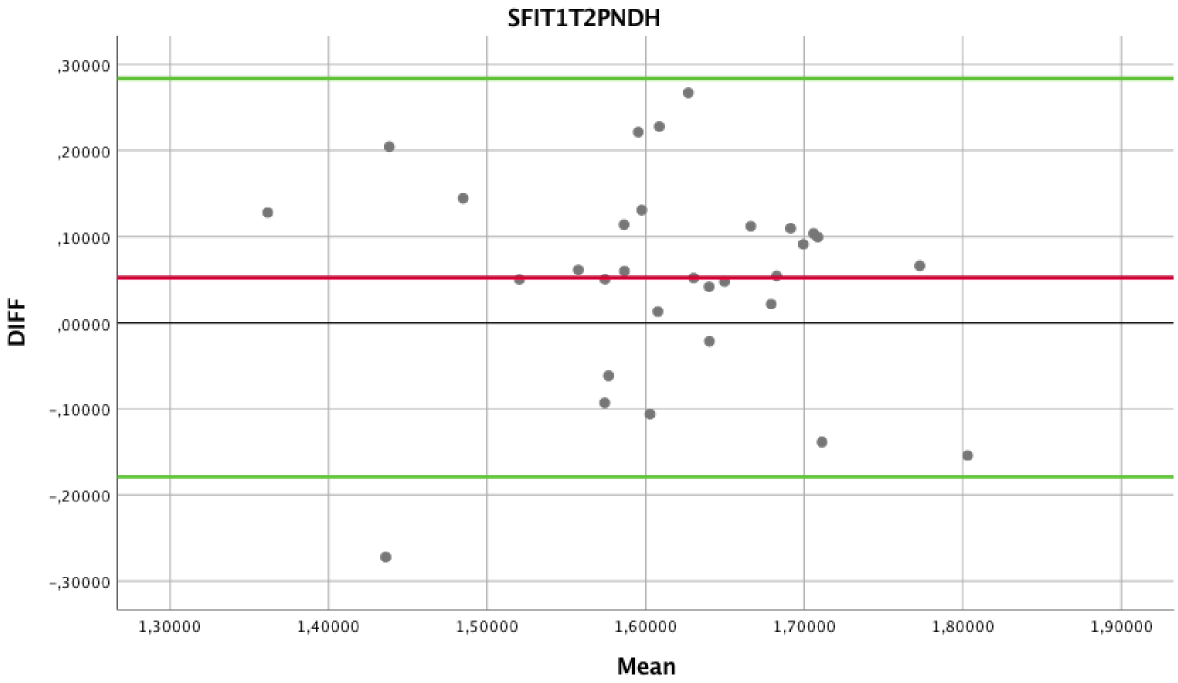

Figure 2. Bland-Altman plot of the SFI3 in the non-dominant hand, measured with the pinchmeter. The Y-axis represents the differences between SFI3 scores of different children. The X-axis represents the mean of the two fatigability measurements. The red line characterizes the mean difference between test and retest measurements. The green lines characterize the upper and lower limits of agreement.

Discussion

The purpose of this study was to examine test-retest reliability of a 30 seconds static maximal motor fatigability protocol measured with a hand grip dynamometer and pinchmeter using the SFI3 in TDC.

Regarding the ICC's for the Fmean measured with the pinchmeter, all values were either moderately high or very high. Since no comparable studies could be found which used these outcome measure in combination with a pinchmeter, no reference data were available. Looking at our results which showed good reliability, measures of Fmean can be used to calculate the ratio between the last and the first interval as measure of static motor fatigability in TDC. However, to use this ratio in other pediatric populations, such as children with CP, test-retest reliability of these Fmean outcome measures should first be investigated.

The ICC's measured with the dynamometer were also moderately high or very high regarding the Fmean data. Test–retest reliability of a static motor fatigability protocol was already examined by Schwid et al. (1999) using a ratio of the maximal strength generated during the final five seconds to the initial five seconds of the sustained contraction (Schwid et al., 1999). This study concluded that test-retest reliability of this ratio was moderate to moderately high. Our results of Fmean data show that this outcome measure can be measured reliably for both the pinch and hand grip dynamometer. This indicates that a ratio of Fmean3 over Fmean1 can possibly be used as an alternative or substitutive measurement method, besides the ratio used by Schwid et al. (1999), to map static motor fatigability (Schwid et al., 1999).

Slopes were used as a new and additional measurement method to measure the speed at which motor fatigability occurs. No previous research regarding this outcome measure is available. All ICC's of the slopes measured with the pinchmeter had low values. This indicates that the calculation of slopes is not a reliable measurement method.

Our results show that all ICC's of the slopes, measured with the dynamometer, were low or negative. As mentioned above, these low or negative values indicate that slopes are not a reliable measurement method. SPSS only gives negative ICC's when calculations are not optimal. These bad calculations may be due to the used method to calculate test-retest reliability. Another method (with more intervals) could probably be more optimal to map static motor fatigability. Further elaboration of these slopes regarding future research is provided in the paragraph ‘Further research’.

Previous research has already shown a high test–retest reliability of the SFI3 in UL to measure static motor fatigability when using a hand grip dynamometer (Schwid et al., 1999). However, test-reliability of the SFI3 using a pinchmeter has not yet been examined. Our results show that ICC values of the SFI3 were moderate or moderately high. When aiming at using the SFI3 as a static motor fatigability outcome measure for pinch grip in other pediatric populations such as children with CP, test-retest reliability of this outcome measure should first be examined in that particular population.

Our results show SFI3 data to be moderately high reliable when using a hand grip dynamometer. These results of the SFI3 were in line with previous findings in other studies. In terms of agreement of the ICC values of the SFI3, most agreement is found between our results and the results of Van Meeteren et al. (2007). This study concluded that the ICC’s for a 20 seconds static maximal hand grip motor fatigability protocol were moderate (ICC = 0.59) for both DH and NDH and comparable both in young adults with CP (mean age 20.6; SD 1.2) and healthy controls (mean age 21.8; SD 4.2) (van Meeteren et al., 2007). One should notice that both our study and the study of Van Meeteren et al. (2007) included TDC, which could explain the matching ICC values (van Meeteren et al., 2007).

Based on these results, we can conclude the use of the SFI3 to be reliable when measuring static motor fatigability with a pinchmeter and a hand grip dynamometer.

Also, it should be noted that children with CP might have more difficulty with pushing a pinchmeter than TDC. This is because of a higher demand of precision when executing a pinch grip compared to a power grip when using a hand grip dynamometer. This could possibly influence test-retest outcome measures in this population (Brauers et al., 2017).

Besides ICC’s, the SEM and MDC-values are important components of reliability measurements. In our study, relatively low values of SEM in comparison with their absolute values per outcome measure indicate a good measurement precision (Dekkers et al., 2019; Geijen et al., 2018; Savva et al., 2018). MDC-values can be used when testing an individual in clinical practice. In a clinical situation, one needs to know how much improvement is necessary to be sure that the improvement is not due to measurement error in order to correctly interpret the changes in motor fatigability. Thus, in order to know for sure the amount of change is real change, the change needs to be at least larger than the MDC. Furthermore, the MDC's should not be too large relative to the subject's real measurement, since otherwise the subject should improve a lot during the intervention in order to let the change be a real change.

For the pinchmeter, MDC percentages of the Fmean data for both the DH and NDH ranged between 26.33% and 63.22%. MDC percentages of Fmean data measured with the hand grip dynamometer for both the DH and NDH ranged between 49.06% and 76.94%. The high values of percentages within this range demonstrate that a child with low initial Fmean values should improve at least more than half of its initial value, which is difficult to overcome, to demonstrate a clinically relevant difference.

Since ICC values are seen as not reliable, and the MDC is based on the SEM (which is based on the ICC values), MDC percentages of the slope values are thus not reliable and difficult to interpret given the divergent percentages (negative or very high) for both the pinch and hand grip dynamometer.

MDC percentages of the SFI3 measured with the pinchmeter for the DH and NDH were moderately low. Children needed to improve their initial values with respectively 38.68% and 45.39%, which should be achievable if the initial value of the child is not too low.
Regarding SFI3 data of the dynamometer for both DH an NDH, MDC percentages were respectively 52.66% and 41.28%. These percentages are possible to overcome given that the child improves at least more than 41.28% of its initial value.

One should be cautious when children with very low initial measurements are tested, since these children might not improve enough to rise above the MDC-value. When testing a child in a clinical setting, one should take into account the age and the initial value of the child to interpret MDC values, and to determine the boundary for clinical relevance.

Bland-Altman plots can be used to indicate the degree of agreement between test and retest. Small distance between the lower and upper LOA reflect a narrow variation of the differences between test and retest measurements. The narrower the variation of the differences, the more reliable the measurements. Looking at the example given in our method section (SFI3 of the pinch NDH), the small distance between the LOA indicates a small variation of the differences. However, LOA of some Bland-Altman plots were quite far apart, indicating a wide variation of the differences (Geijen et al., 2018; Savva et al., 2018).
Thereby, it is recommended that 95% data points lie within the LOA as this would indicate a normal distribution of the differences. In our example, only one outlier is present of all 31 data points. Thus, 96.77% of all data points lie between the LOA, indicating a normal distribution.
However, it should be noted that some of our Bland-Altman plots have more outliers, but never more than 3. Outliers are extreme values that deviate from other values in the dataset. The bigger number of outliers in some Bland-Altman plots can be explained by a large difference between test and retest measurements for some children. These differences could be due to within-subject variations (such as concentration level, environmental influence or such) (Geijen et al., 2018; Savva et al., 2018).

Since all subjects were TDC, we expected the variance in fluctuation of the reliability measurement per child to be low, therefore, the sample size did not need to be very large. This is in contrast with neurological disorders such as PwMS or CP, in which differences in disease progression exist which should be taken into account when determining sample size (sample size should be larger in these populations).

At last, our experience shows that instructions given and concentration of the child is age dependent. Children of younger age categories sometimes needed a repetition of the instructions to understand what was expected of them.

Limitations

Some limitations in our study need to be cited. A first limitation is the high number of raters. On one hand, this encourages high measurement errors but on the other hand, a high number of raters is also a good representation of clinical practice. A second limitation of our study is the unequal distribution of gender (13 boys; 27 girls) and age (78 - 215 months). Therefore, one must pay attention when generalizing these data to the older age categories (14y 1m - 17y 11m) because only two children participated in this age category. Due to this, test-retest reliability outcome measures could be lower in our study when compared to studies with a more selected age category due to the changing of strength and associated fatigability in different age categories. A third limitation is the presence of a carry-over effect between examination one and two. This should be taken into account when testing test-retest reliability. A carry-over effect is an effect that “carries over” from examination one to examination two. Children knew what to expect on examination two and thus could perform the motor fatigability measurements more accurately. Normally, a familiarization period of the static motor fatigability protocol (both grip and pinch) should be given to minimize this effect, but since this could already provoke motor fatigability, we decided not to. Therefore, we expect the carry-over effect to be larger in our study. A fourth limitation of our study is the lack of a measurement method of perceived fatigue, such as questionnaires. At last, it should be noted that static motor fatigability is a complex phenomenon that may not be optimally evaluated by a simple grip or pinch task (van Meeteren et al., 2007).

Further research

First, the existing measurement methods used in this study should be developed further, in particular the calculations of the slopes. Possibly, smaller intervals (for example per 3 or 5 seconds) are more likely to give better test-retest results. This way, the speed of static motor fatigability could possibly be mapped more accurately. If further research succeeds in developing reliable calculations of slopes in different populations, differences in shape of the curves can be compared between persons with neurological diseases and healthy controls. Second, when recruiting children, one should pay attention to the equalization of the number of children per age category and include a limited number of raters to guarantee a good reliability. A presupposed number of ideally 10 children, of which five boys and five girls, per age category should be set a priori to make generalization possible. Third, research should include other psychometric methods for perceived fatigue to gain more insight in validity and should provide a familiarization period. Also, less raters should be included to decrease inter-rater variability and to obtain higher reliability values. Fourth, protocols and instructions given should be adjusted to the child's age. If multiple researchers confirm our results, reliability research can be extended to children with a motor disorder (such as CP or Duchenne).

Conclusion

Our study is the first to compare test-retest reliability of three measurements methods (Fmeans, slopes and SFI3's) for a 30 seconds static maximal motor fatigability protocol in TDC as a base to future research in this topic. Based on the ICC's, our study demonstrates that motor fatigability can be measured quite reliably using the Fmeans and SFI3's. In this study, slopes are considered as a not reliable measurement method to map static motor fatigability.

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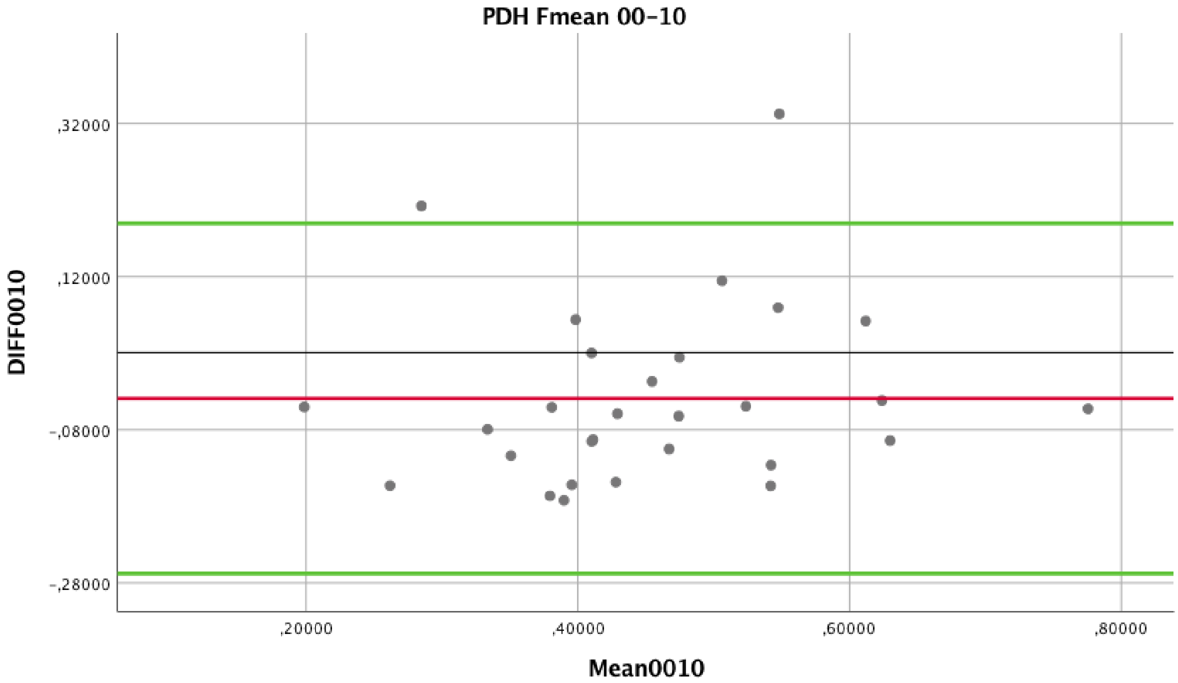
Appendix 1: descriptive data included children

Age (years)	Age (months)	Gender	Age in months	Dominant hand	# children
6	73-84				
		F	80	L	
		F	78	R	2
7	85-96				
		F	85	R	
		F	95	R	
		F	95	R	
		F	86	R	
		M	93	L	
		F	93	R	
		F	95	R	
		F	93	R	
		F	95	R	9
8	97-108				
		M	100	R	1
9	109-120				
		F	109	R	
		F	113	R	
		M	112	R	
		F	116	R	
		F	111	L	
		F	112	L	
		M	112	R	7
10	121-132				
		M	124	R	
		M	127	R	
		F	130	R	
		M	129	R	
		M	126	R	
		F	130	L	
		F	125	R	
		F	126	R	8
11	133-144				
		F	142	R	
		M	140	R	
		M	142	L	
		M	140	R	
		F	132	R	
		F	133	L	
		F	132	R	

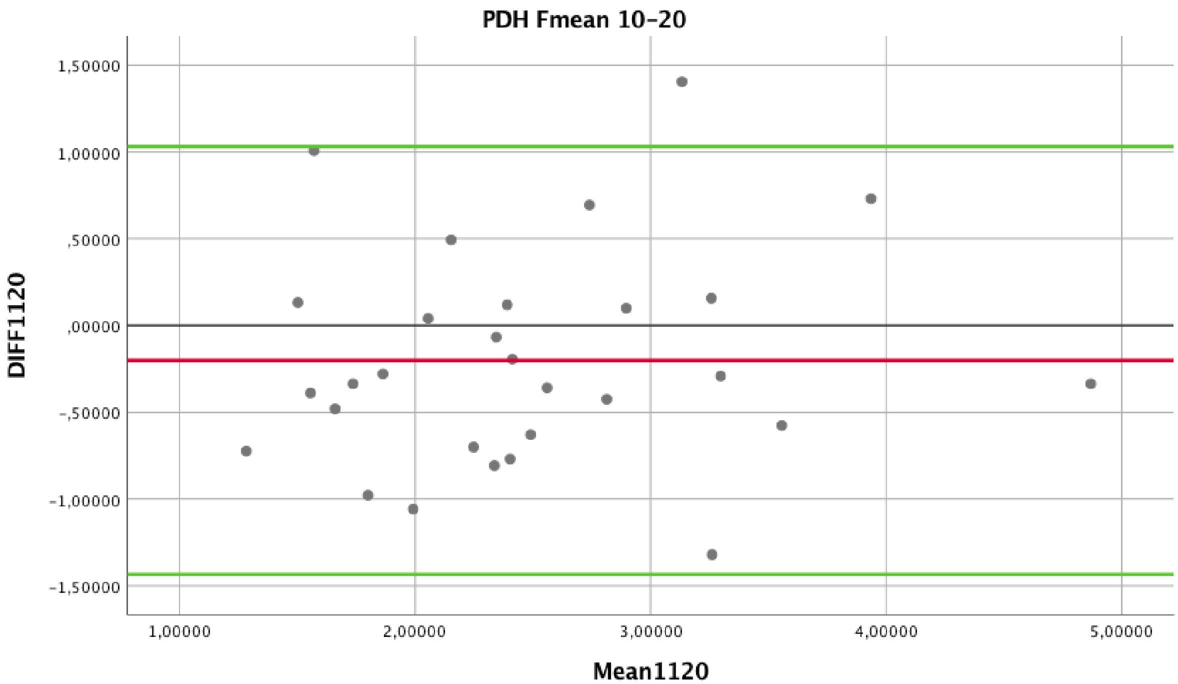
		M	140	R	8
12	145-156				
		M	149	R	
		M	145	R	
		F	154	R	3
13	157-168				
		F	167	L	
		F	164	R	
		M	157	R	
		M	167	R	4
14	169-180				
15	181-192				
		F	188	R	1
16	193-204				
17	205-216				
		F	215	R	1

Appendix 2: Bland-Altmann Plots

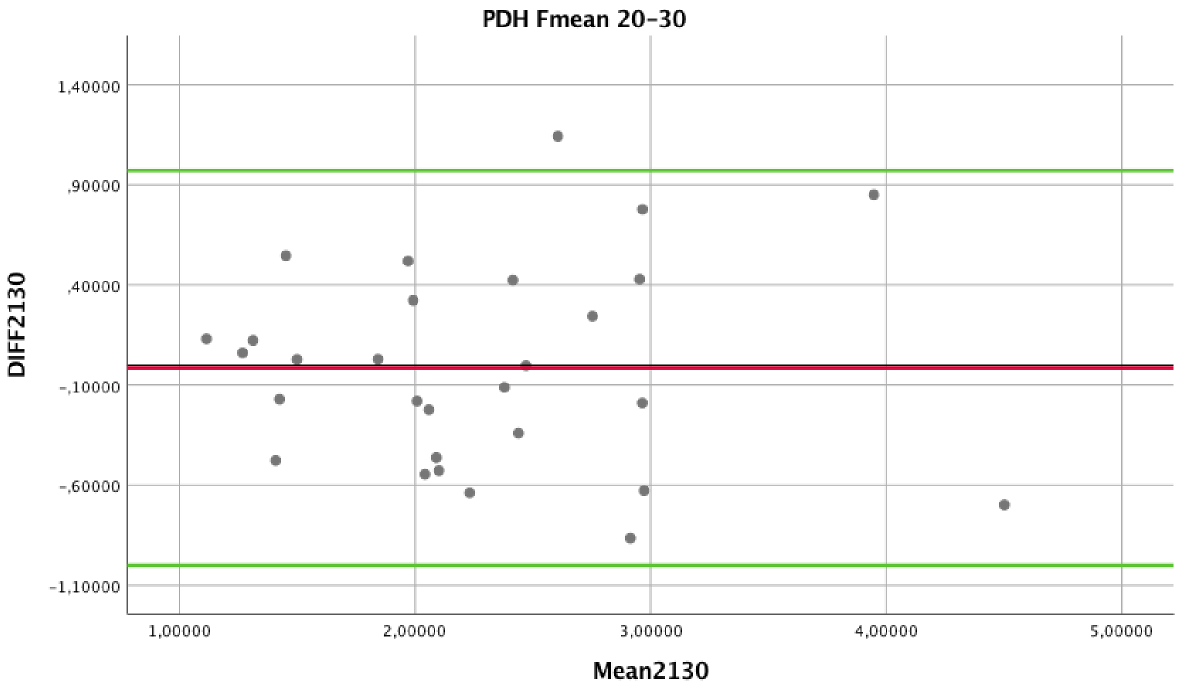
PDH, Fmean



Bland-Altman plots of the Fmean00-10, measured with the pinchmeter in the dominant hand

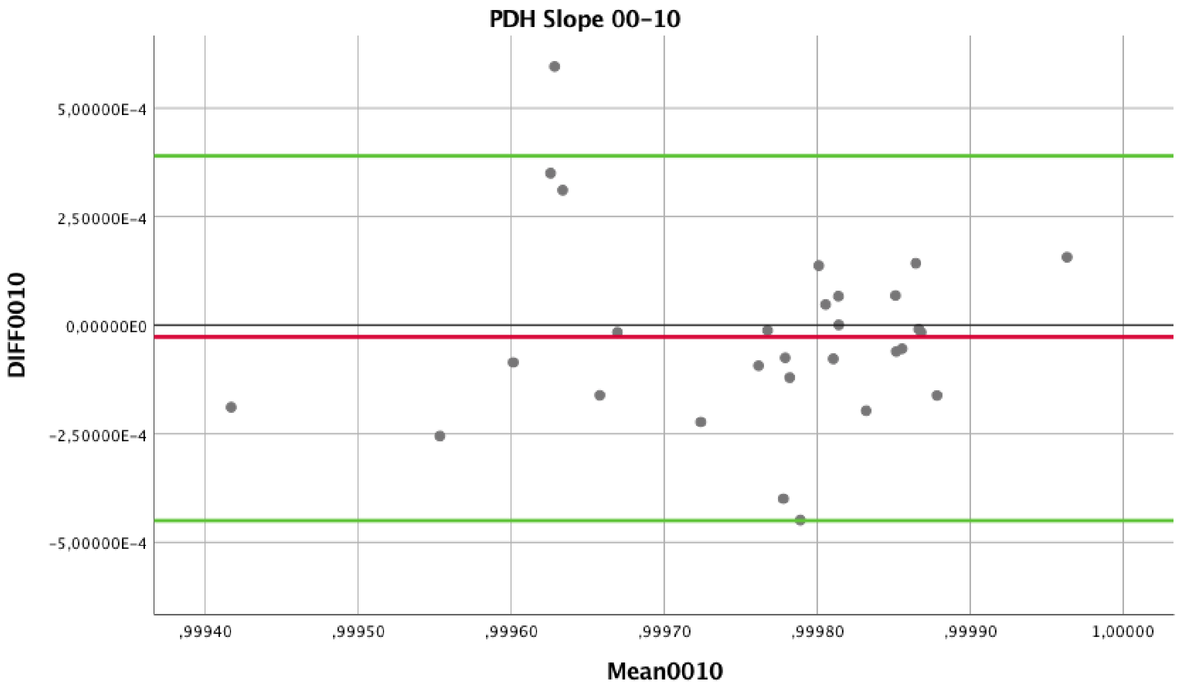


Bland-Altman plots of the Fmean10-20, measured with the pinchmeter in the dominant hand

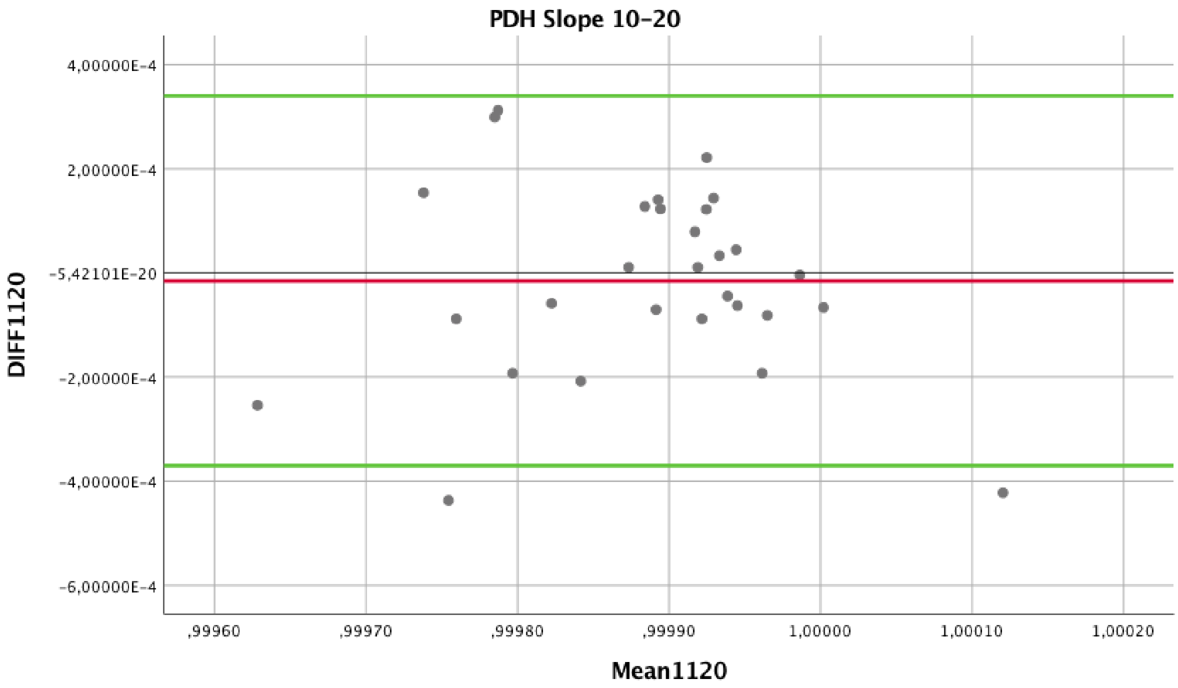


Bland-Altman plots of the Fmean20-30, measured with the pinchmeter in the dominant hand

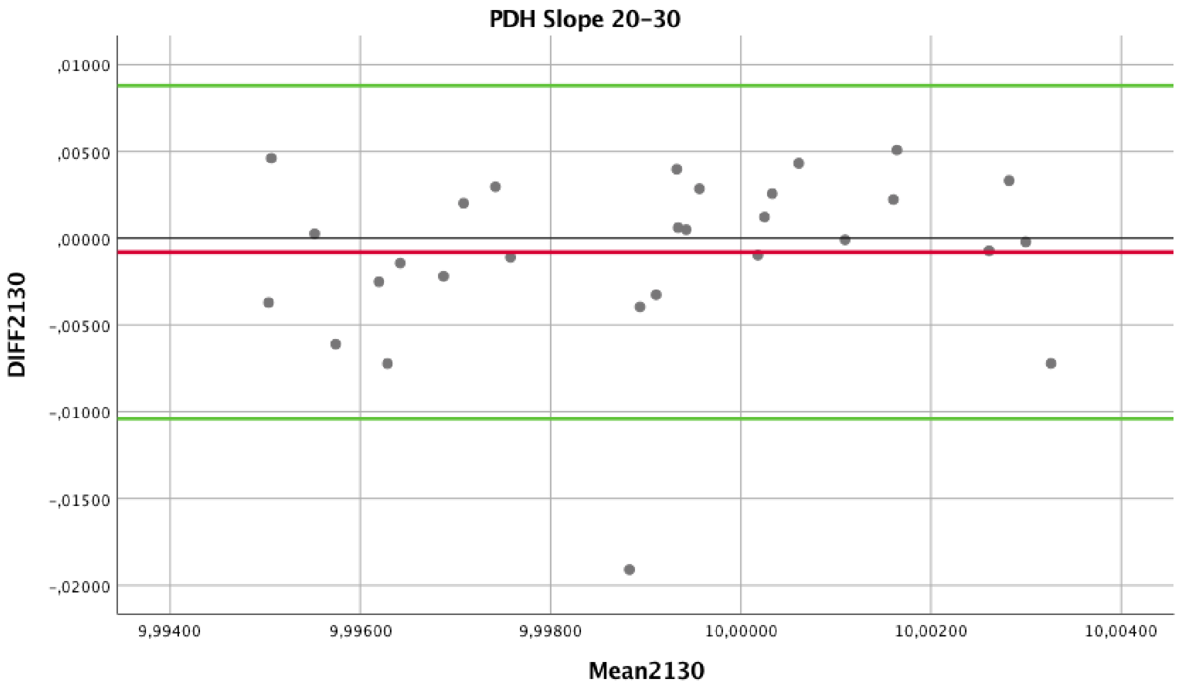
PDH, slopes



Bland-Altman plots of the Slope00-10, measured with the pinchmeter in the dominant hand

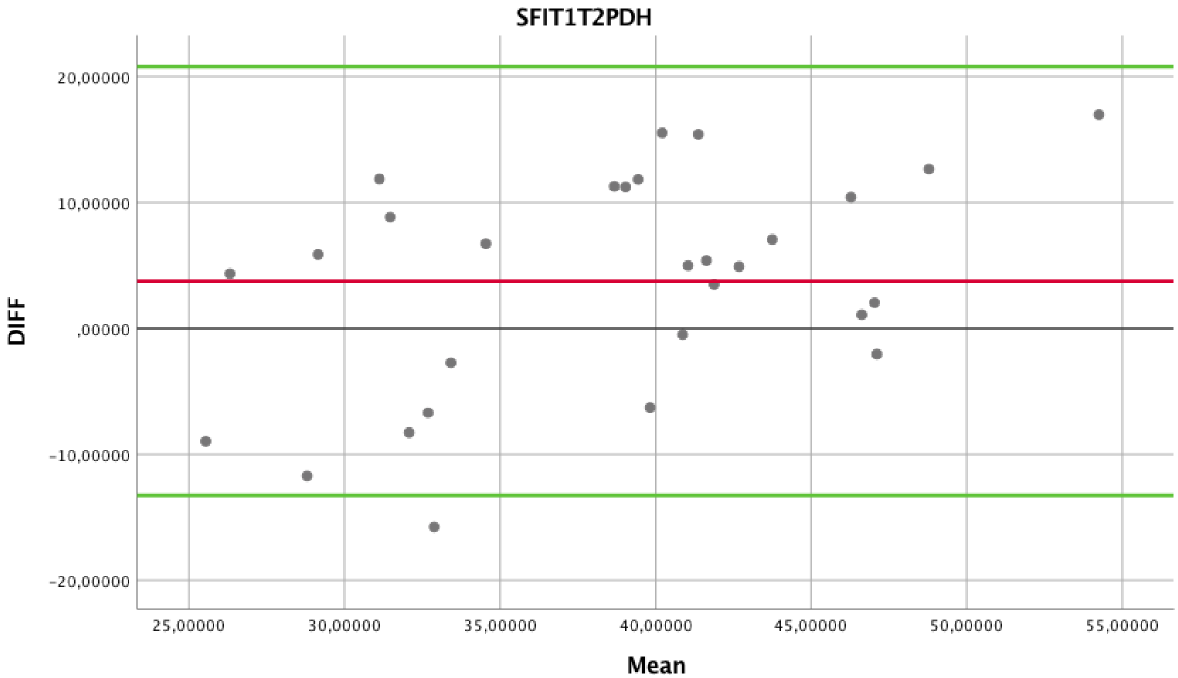


Bland-Altman plots of the Slope10-20, measured with the pinchmeter in the dominant hand



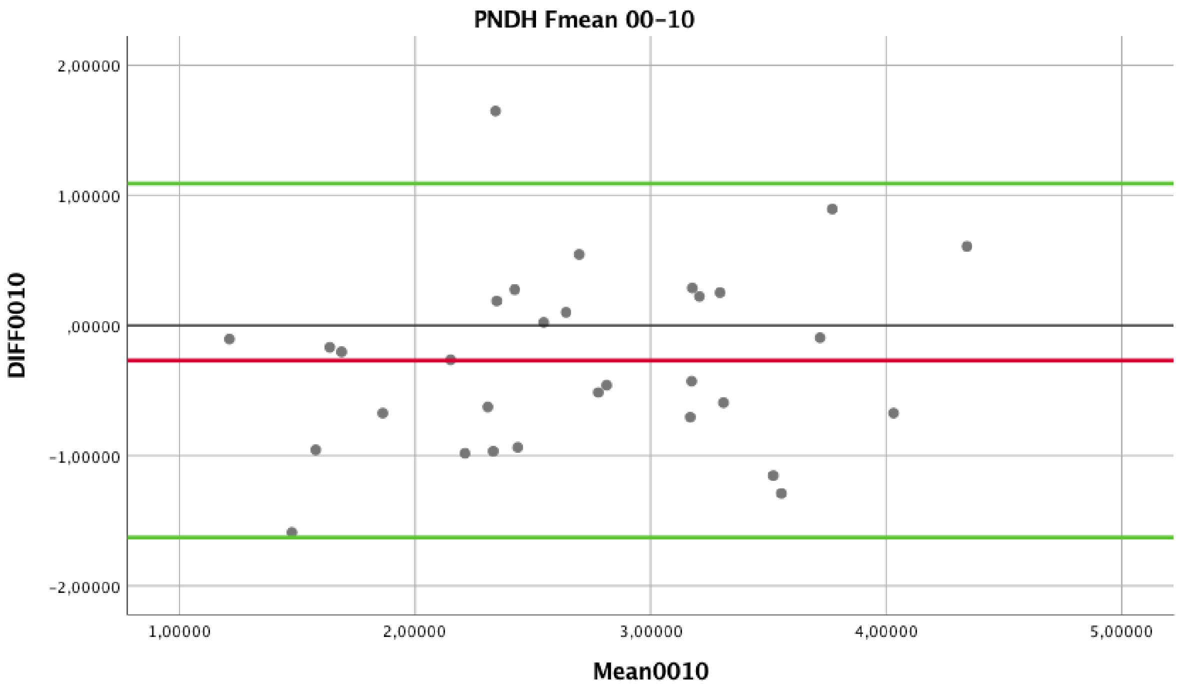
Bland-Altman plots of the Slope20-30, measured with the pinchmeter in the dominant hand

PDH, SFI3 T1-T2

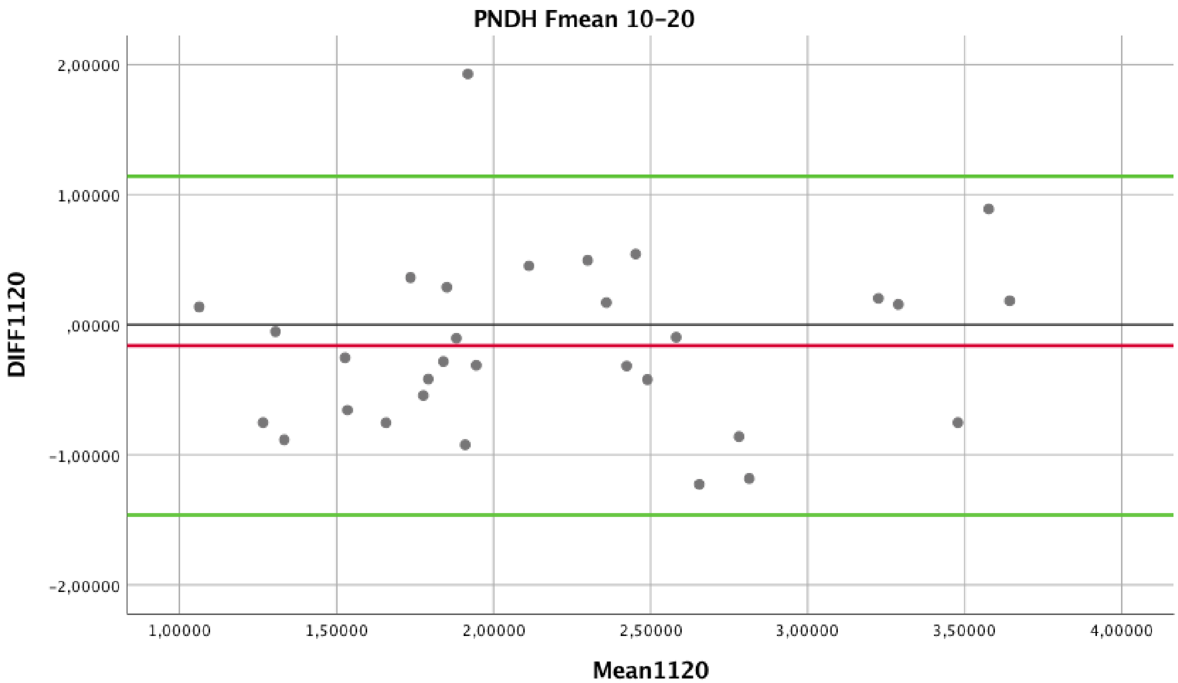


Bland-Altman plots of the SF1 T1-T2, measured with the pinchmeter in the dominant hand

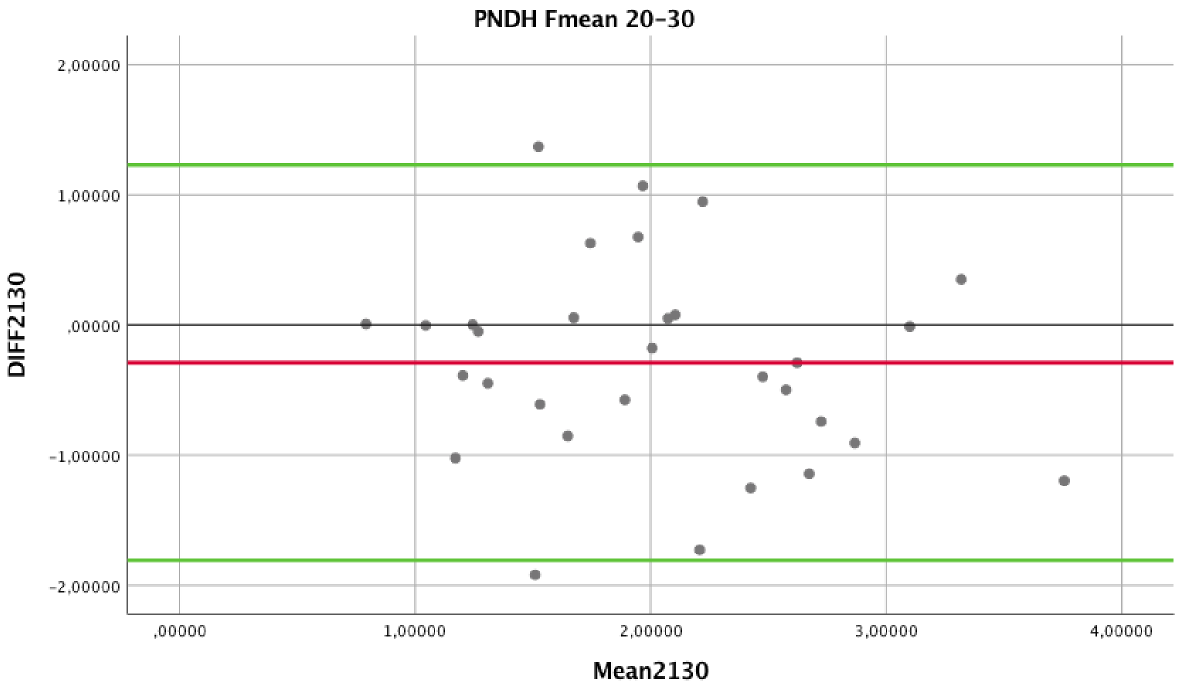
PNDH, Fmean



Bland-Altman plots of the Fmean00-10, measured with the pinchmeter in the non-dominant hand

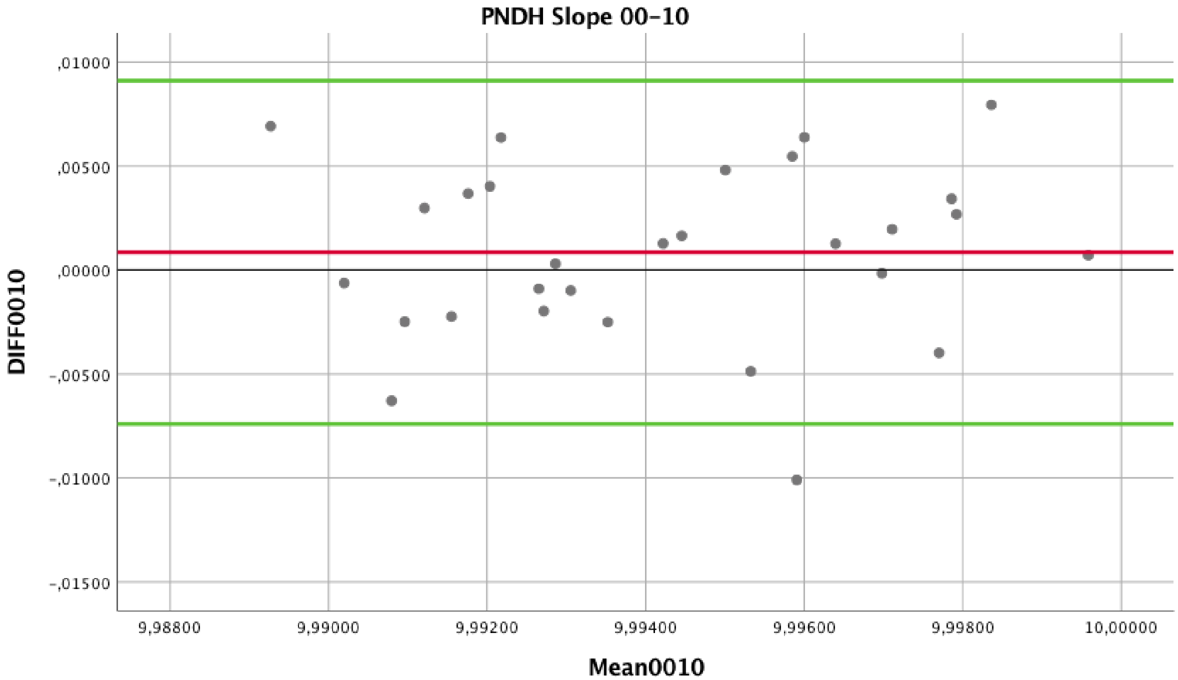


Bland-Altman plots of the Fmean10-20, measured with the pinchmeter in the non-dominant hand

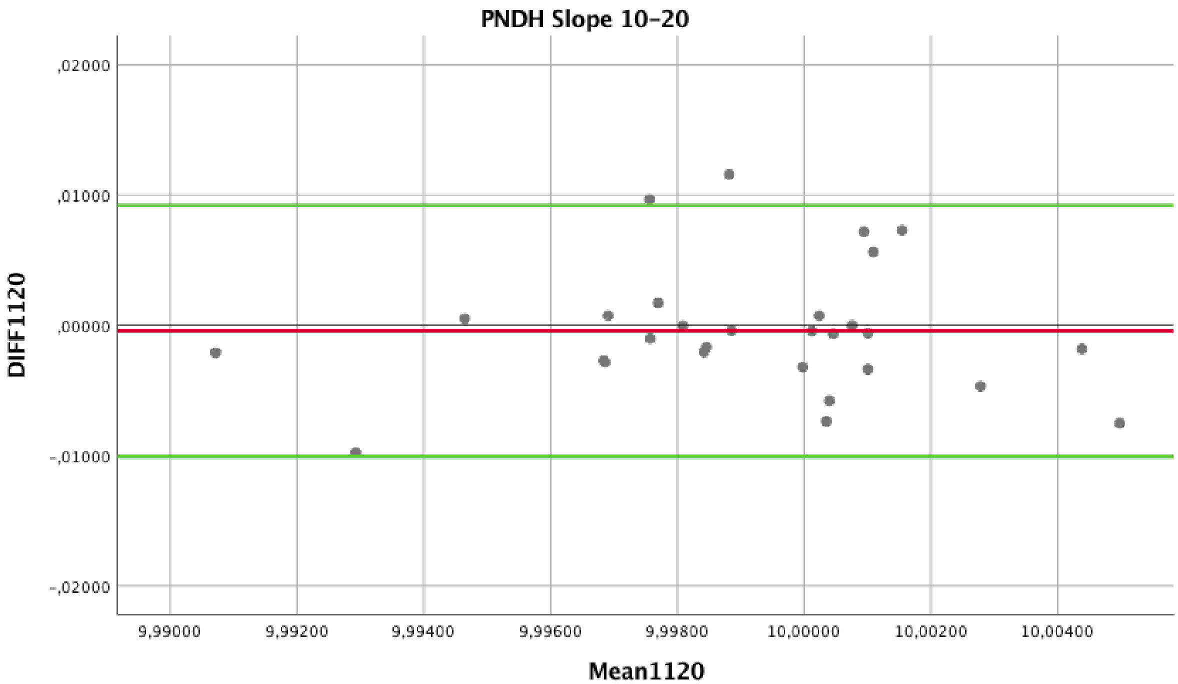


Bland-Altman plots of the Fmean20-30, measured with the pinchmeter in the non-dominant hand

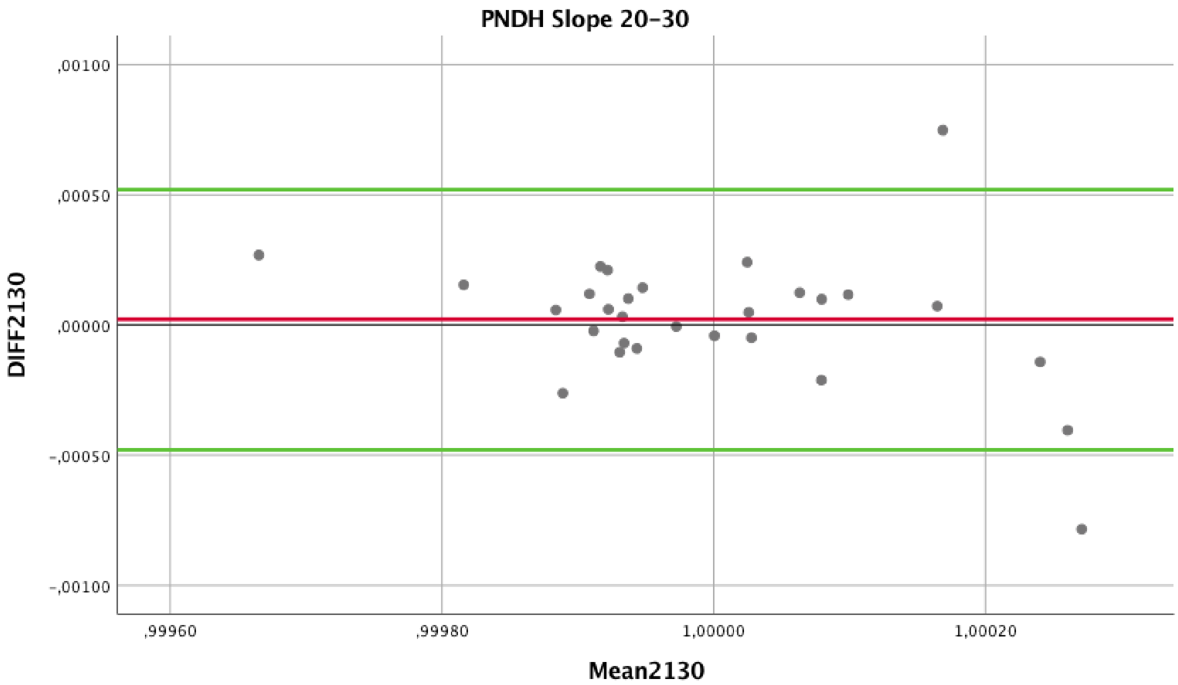
PNDH, slopes



Bland-Altman plots of the Slope00-10, measured with the pinchmeter in the non-dominant hand

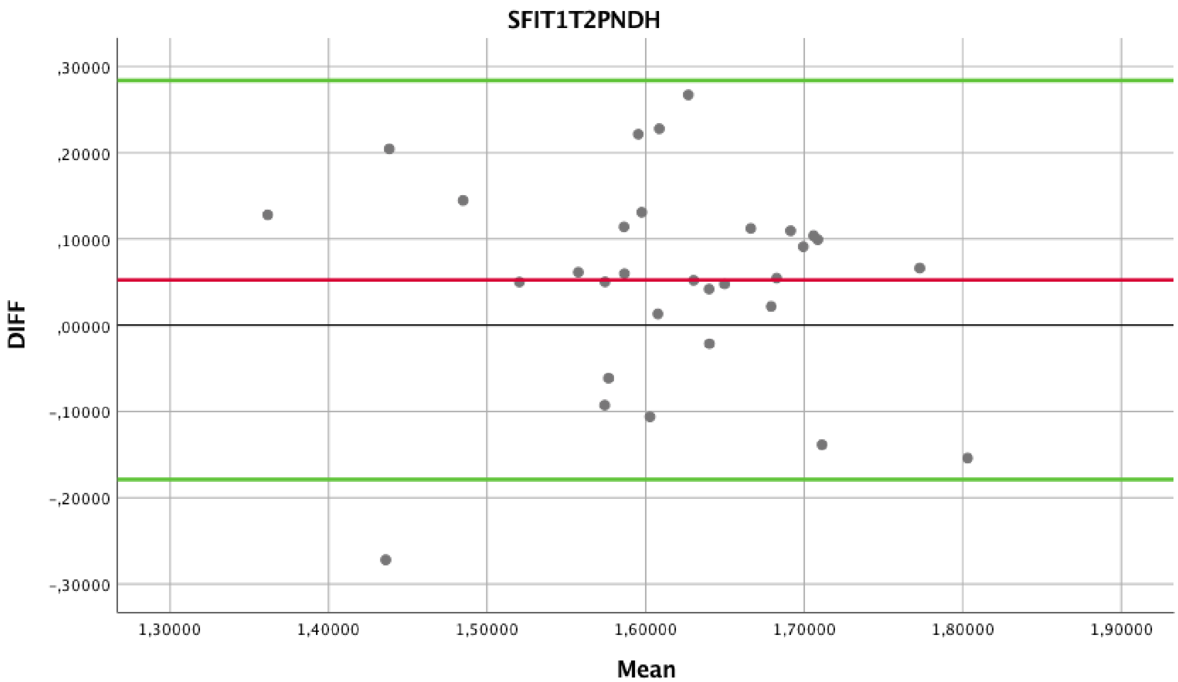


Bland-Altman plots of the Slope10-20, measured with the pinchmeter in the non-dominant hand



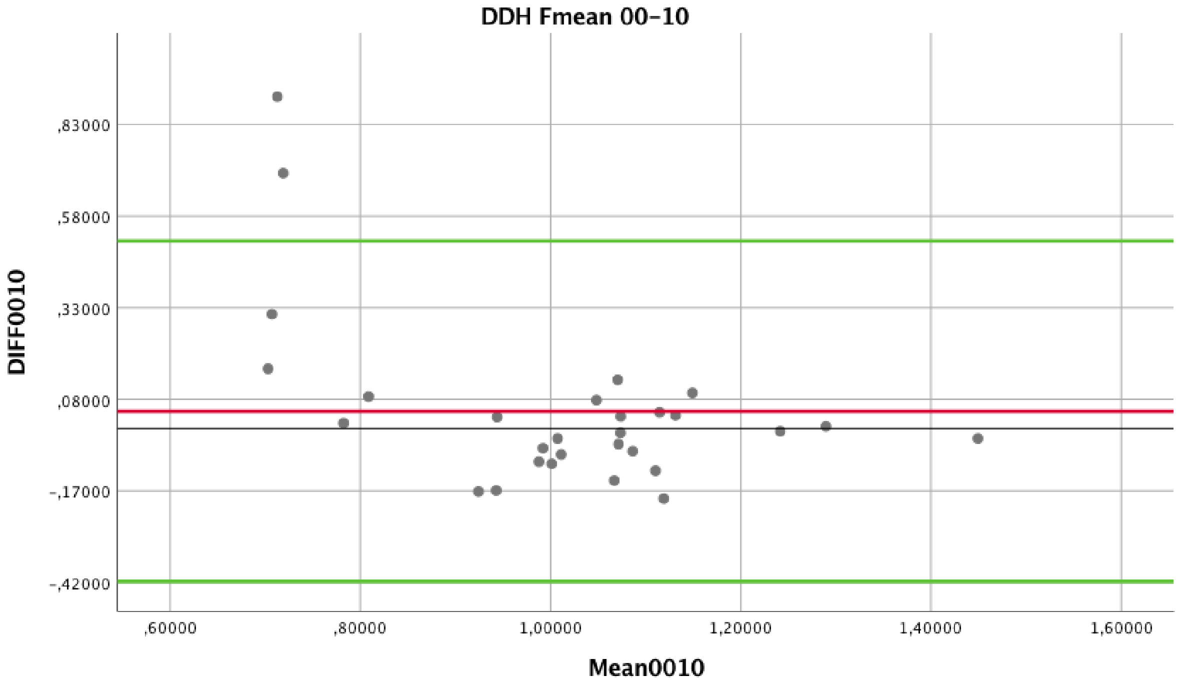
Bland-Altman plots of the Slope20-30, measured with the pinchmeter in the non-dominant hand

PNDH, SFI3 T1-T2

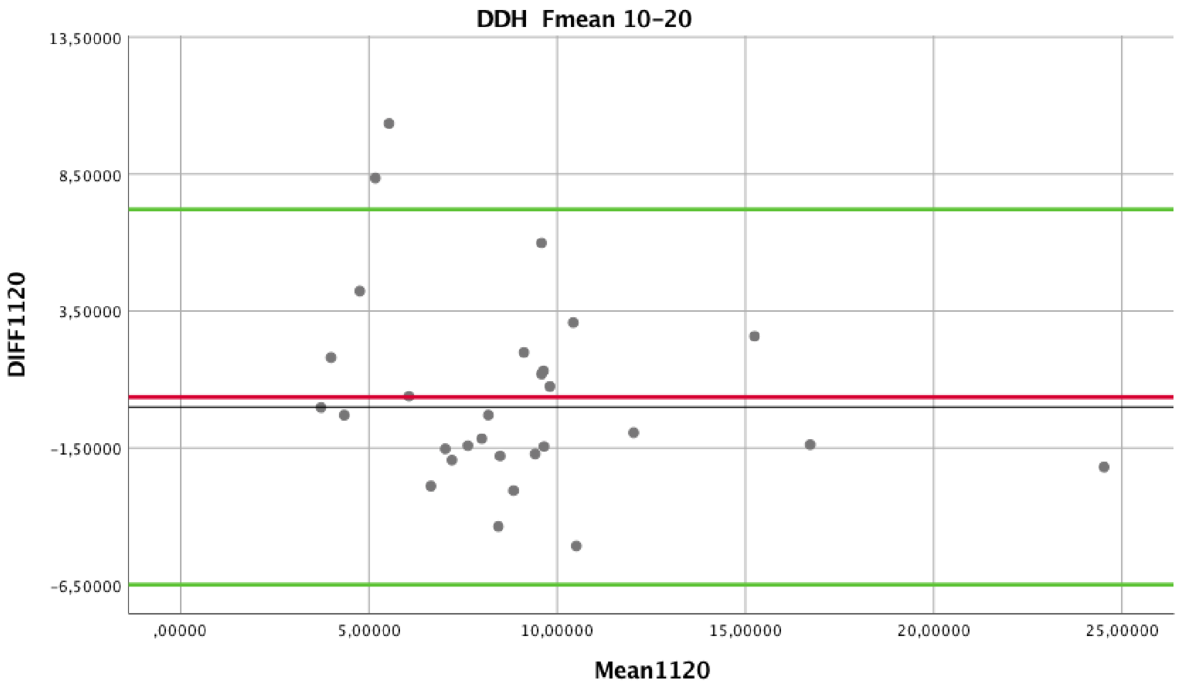


Bland-Altman plots of the SF1 T1-T2, measured with the pinchmeter in the non-dominant hand

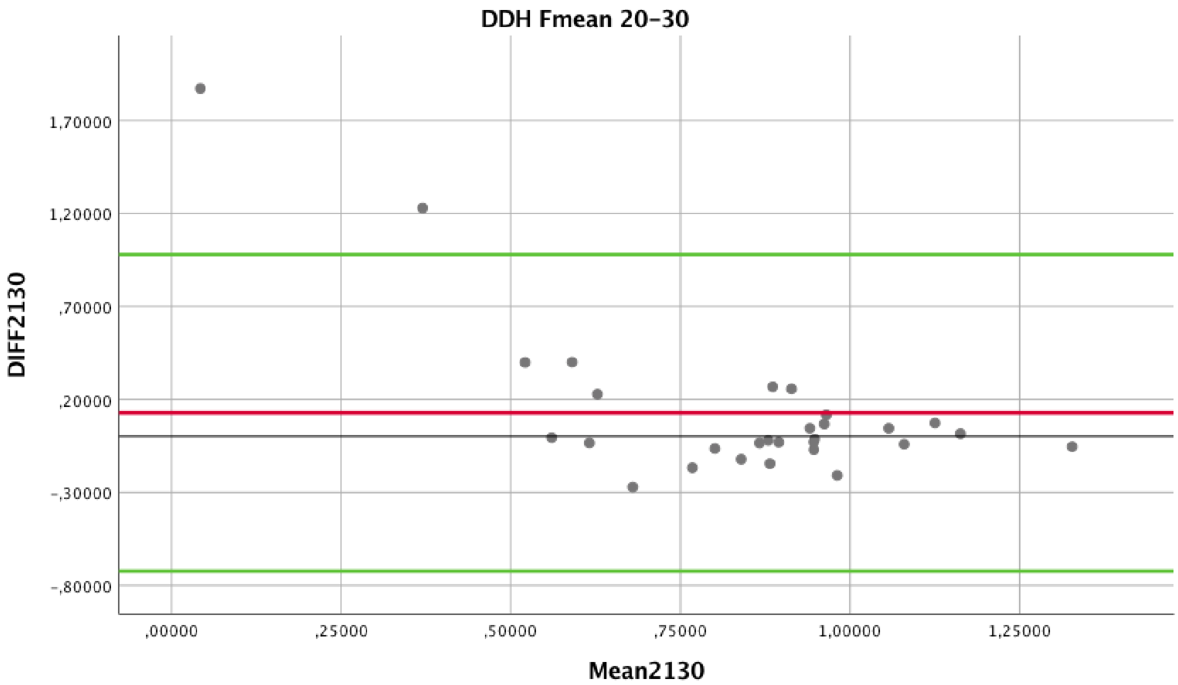
DDH, Fmean



Bland-Altman plots of the Fmean00-10, measured with the dynamometer in the dominant hand

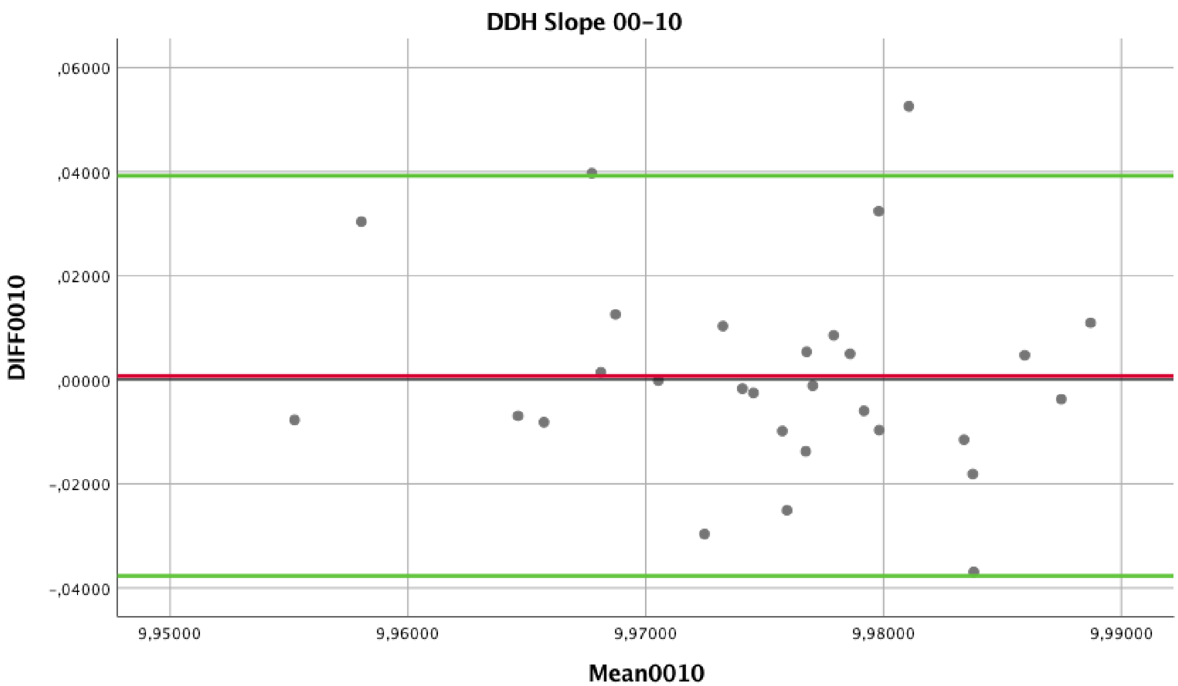


Bland-Altman plots of the Fmean10-20, measured with the dynamometer in the dominant hand

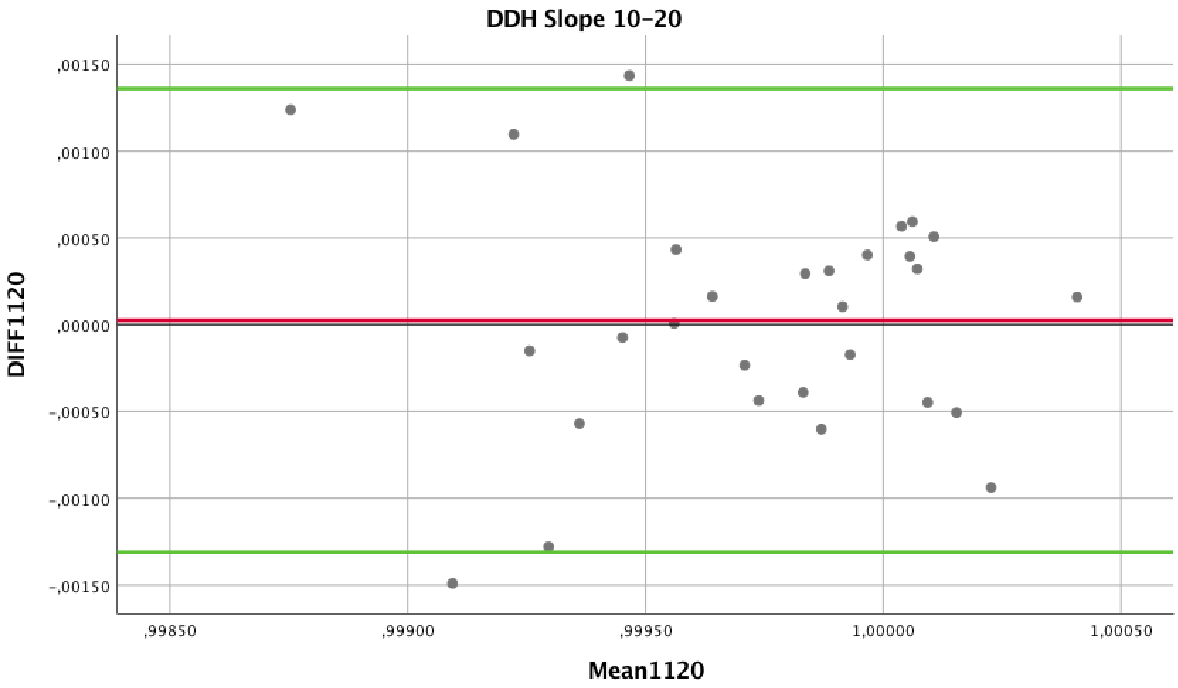


Bland-Altman plots of the Fmean20-30, measured with the dynamometer in the dominant hand

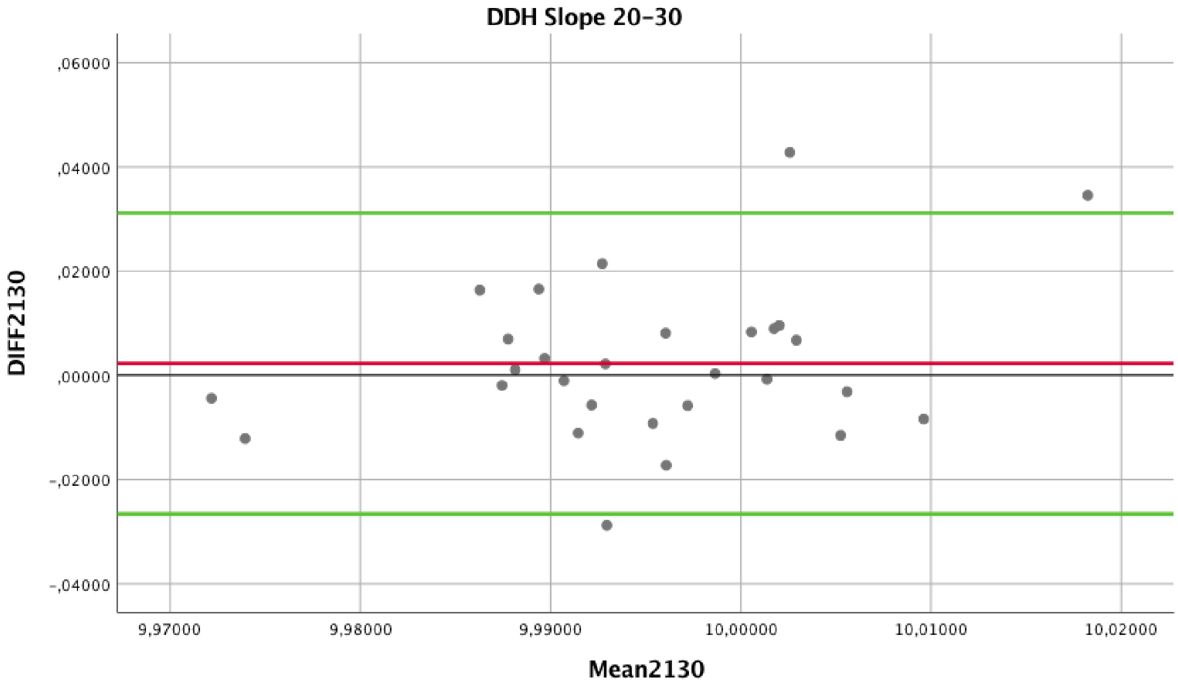
DDH, slopes



Bland-Altman plots of the Slope00-10, measured with the dynamometer in the dominant hand

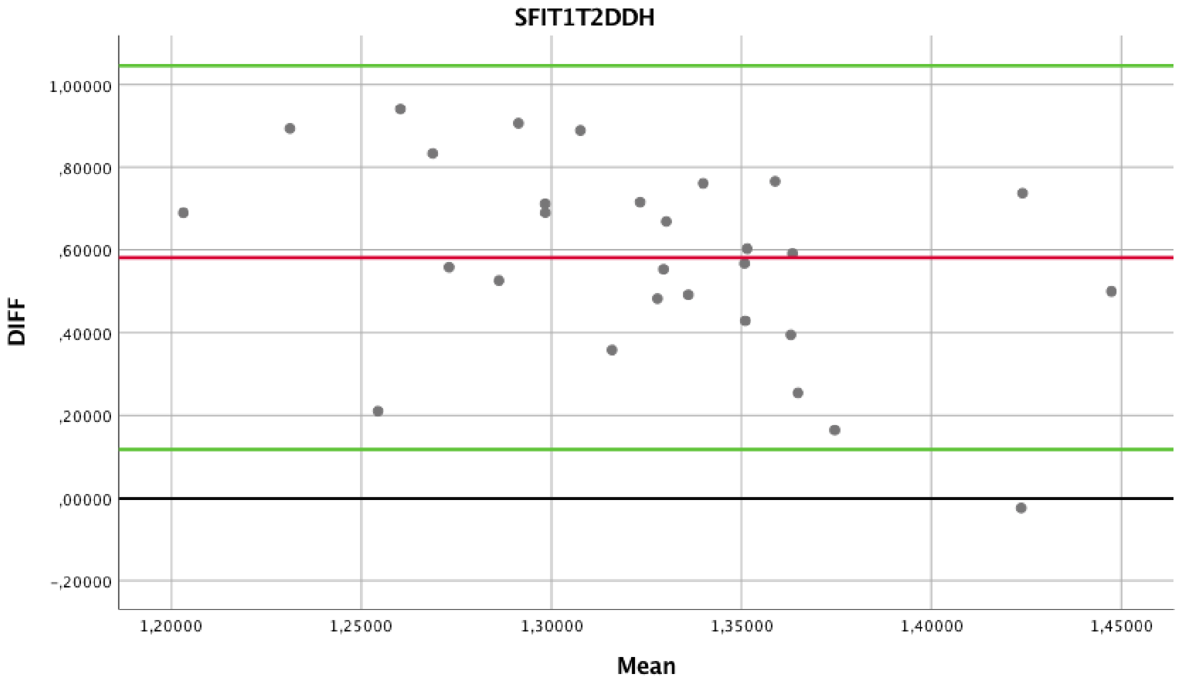


Bland-Altman plots of the Slope10-20, measured with the dynamometer in the dominant hand



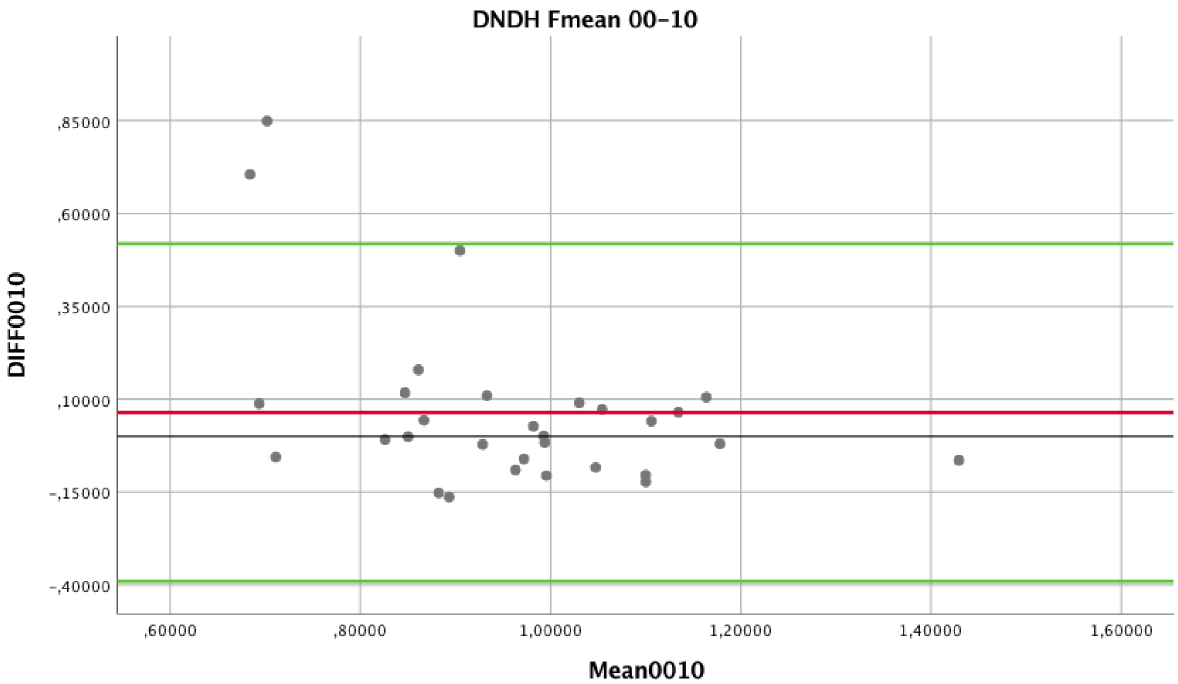
Bland-Altman plots of the Slope20-30, measured with the dynamometer in the dominant hand

DDH, SFI3 T1-T2

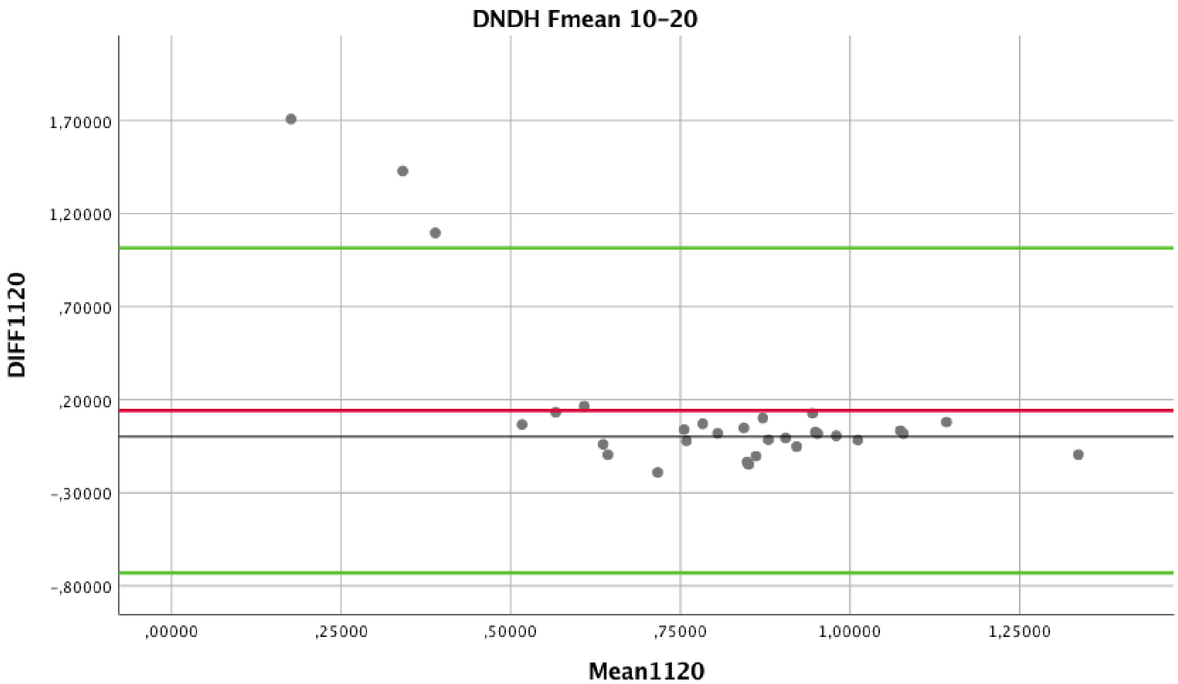


Bland-Altman plots of the SF1 T1-T2, measured with the dynamometer in the dominant hand

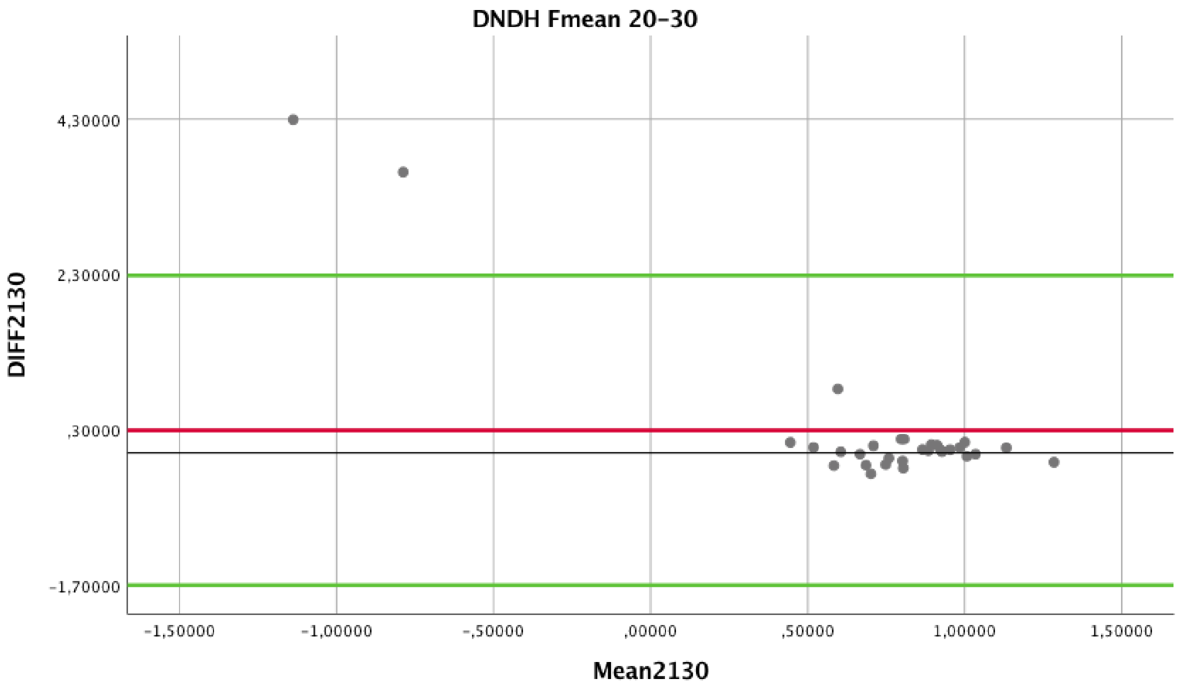
DNDH, Fmean



Bland-Altman plots of the Fmean00-10, measured with the dynamometer in the non-dominant hand

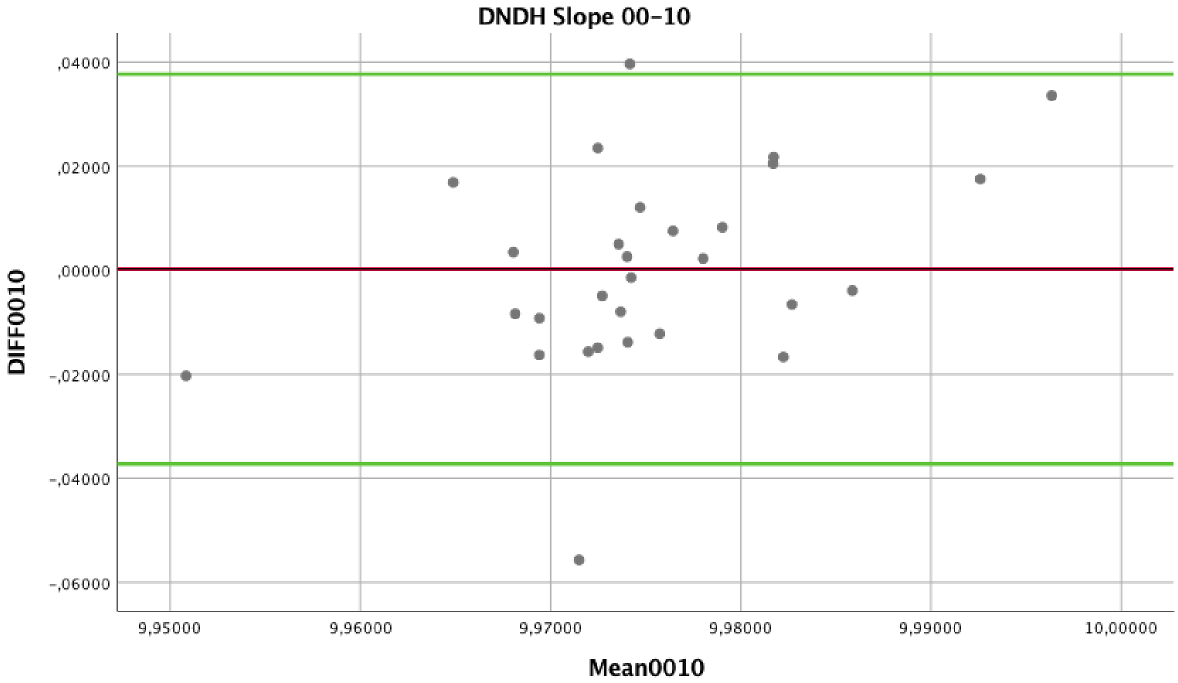


Bland-Altman plots of the Fmean10-20, measured with the dynamometer in the non-dominant hand

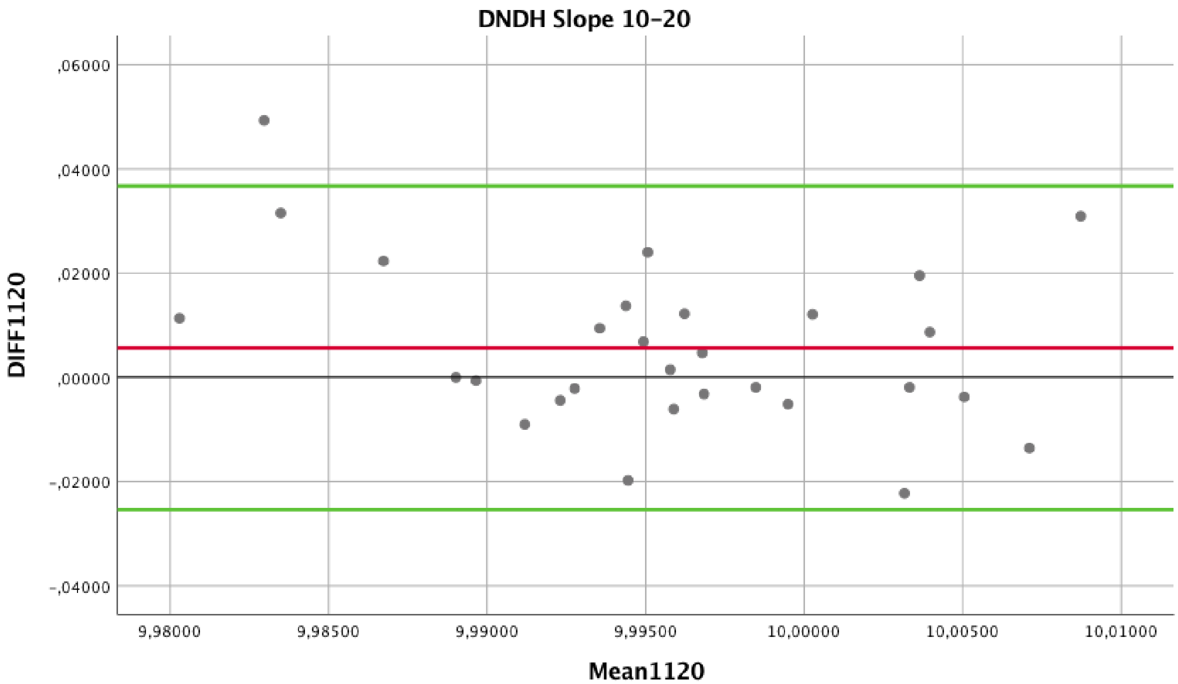


Bland-Altman plots of the Fmean20-30, measured with the dynamometer in the non-dominant hand

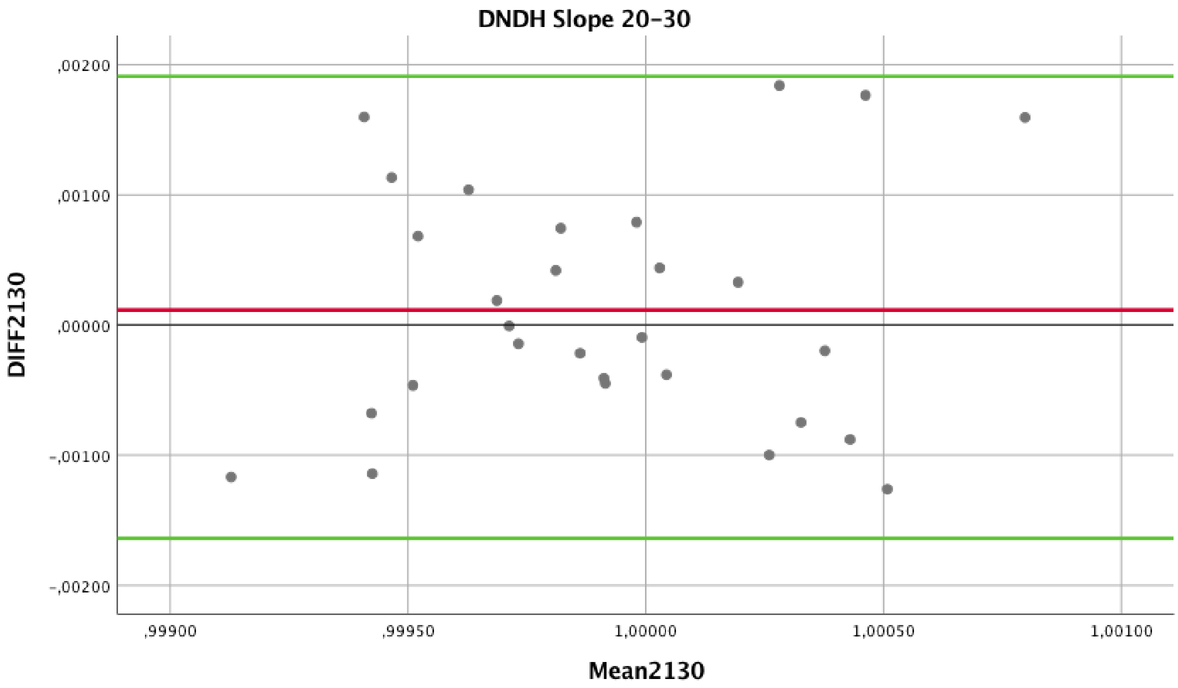
DNDH, slopes



Bland-Altman plots of the Slope00-10, measured with the dynamometer in the non-dominant hand

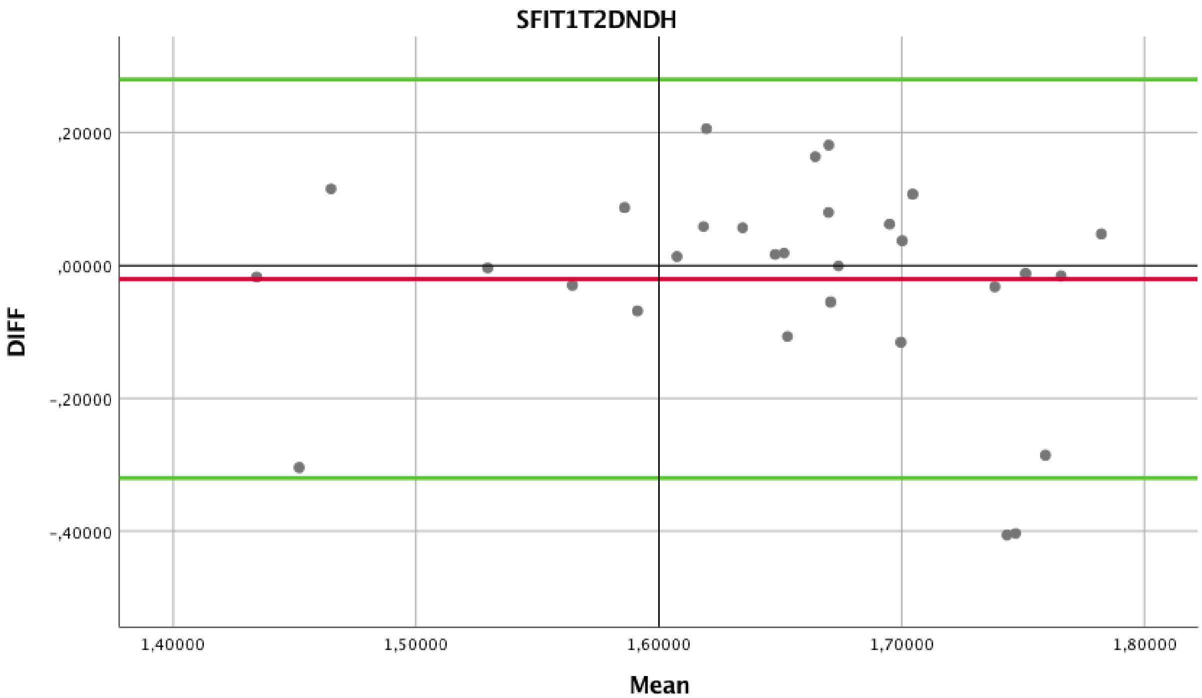


Bland-Altman plots of the Slope10-20, measured with the dynamometer in the non-dominant hand



Bland-Altman plots of the Slope20-30, measured with the dynamometer in the non-dominant hand

DNDH, SFI3 T1-T2



Bland-Altman plots of the SF1 T1-T2, measured with the dynamometer in the non-dominant hand

Appendix 3: inventarisation

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UHASSELT

INVENTARISATIEFORMULIER WETENSCHAPPELIJKE STAGE DEEL 2

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
24/10/18	Inoefenen protocol meting	Promotor: [signature] Copromotor/Begeleider: Student(e): [signature] Student(e): [signature]
28/10/18	Indeling inleiding (mail)	Promotor: [signature] Copromotor/Begeleider: Student(e): [signature] Student(e): [signature]
19/11/18	Verbetering methode (mail)	Promotor: [signature] Copromotor/Begeleider: Student(e): [signature] Student(e): [signature]
17/12/18	Bespreking documenten METC (mail)	Promotor: [signature] Copromotor/Begeleider: Student(e): [signature] Student(e): [signature]
10/04/19	Skype methode/resultaten	Promotor: [signature] Copromotor/Begeleider: Student(e): [signature] Student(e): [signature]
14/5/19	Overleg resultaten & discussie	Promotor: [signature] Copromotor/Begeleider: Student(e): [signature] Student(e): [signature]
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):