Journal Pre-proof

Intra-rater test-retest reliability of hip abduction, internal and external rotation strength measurements in a healthy cohort using a handheld dynamometer and a portable stabilisation device – A pilot study

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PII: S2590-1095(20)30015-X

DOI: https://doi.org/10.1016/j.arrct.2020.100050

Reference: ARRCT 100050

To appear in: *Archives of Rehabilitation Research and Clinical Translation*

Received Date: 8 November 2019

Revised Date: 3 February 2020

Accepted Date: 12 February 2020

Running Head:

Reliability of hip strength measurements via a stabilised handheld dynamometer

Title:

Intra-rater test-retest reliability of hip abduction, internal and external rotation strength measurements in a healthy cohort using a handheld dynamometer and a portable stabilisation device – A pilot study

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No conflicts of interest to declare

Non-funded research

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Title:

Intra-rater test-retest reliability of hip abduction, internal and external rotation strength measurements in a healthy cohort using a handheld dynamometer and a portable stabilisation device – A pilot study

Abstract:

Objective: To investigate the within-day and between-day test-retest reliability of hip abduction, internal rotation and external rotation strength measurements taken using a portable device externally stabilising a handheld dynamometer in healthy participants.

Design: Observational study.

Setting: Institute of Technology Carlow, Ireland - third level education institute.

Participants: *n* = 18 (11 males and 7 females) healthy participants, who participate in a field sport for more than two hours per week, recruited via convenience sampling.

Interventions: N/A

Main Outcome Measures: Hip abduction, internal rotation and external rotation peak force during a maximal voluntary isometric contraction (N). The three best values recorded for each movement, for each day were used to analyse within-day and between-day test-retest reliability. Intra-class correlation coefficients, coefficients of variance, standard error of measurement and minimal detectable change statistics were also calculated.

Results: External fixation of a handheld dynamometer produced excellent test-retest reliability for within-day (ICC's > 0.934) and between-day (ICC's > 0.802) contexts.

Conclusions: Clinical measurements of hip strength can be performed reliably, efficiently and cost effectively using the methods described. Furthermore, the use of external fixation eliminates the influence of tester strength on the HHD measurements.

Keywords:

Reliability, Handheld Dynamometry, Hip Strength, Gluteus Medius.

List of Abbreviations:

ERot: *External Rotation,*

IRot: *Internal Rotation*

HHD: *Handheld dynamometry*

PVC: *Polymerizing vinyl chloride*

CV: *Coefficient of variance*

ICC: *Intra-class correlation coefficient*

CI: *Confidence interval*

SEM: *Standard error of measurement*

MDC: *Minimal detectable change*

Introduction:

Hip strength is commonly measured in sports and musculoskeletal medicine as part of an objective assessment or as a marker for recovery. Hip strength has also been associated with injury incidence rates. Athletes who sustained a lower limb injury during a two-season period, reported significantly lower hip abduction strength (*p* = 0.02, 3 % body weight) and hip external rotation (ERot) strength (*p* = 0.001, 2.7 % body weight) when compared to their counterparts who did not sustain an injury[1]. Furthermore, when expressed as a percentage of body-weight, hip abduction and ERot strength of less than 35.4 % and 20.3 % respectively, classified an athlete as "high risk" for sustaining a non-contact anterior cruciate ligament injury[2]. Deficits in hip strength have also been associated with many other conditions such as ankle ligament sprains, patella-femoral pain syndrome, iliotibial band syndromes, groin strains, hip pain and low back pain, to name a few[3-9]. Furthermore, a recent consensus statement recommends future research to *"investigate, report and improve the measurement properties of tests of…muscle strength and functional performance"*[9].

Lateral hip musculature, namely gluteus medius is fundamental in hip abduction, while also contributing to hip ERot and internal rotation (IRot) in varying proportions depending on hip position[10, 11]. Glute medius' activity is notably high during single-leg tasks[12, 13], illustrating its important contribution to lumbo-pelvic hip or "core" stability which, along with hip strength, is a major target of many neuro-muscular training programmes used for injury prevention purposes[14-17]. Therefore, reliable clinical strength measurements for all movements to which gluteus medius can contribute to, are important for rehabilitation clinicians in assessment, tracking progress post-injury or in monitoring the effects of interventions carried out, such as neuro-muscular training programs..

The current and most common used strength measurement technique is manual muscle testing[18], which consists of a clinician's subjective rating of force along the Oxford Muscle Grading Scale, from zero to five; with zero being no palpable muscle contraction, and five being normal full muscle performance[19]. Although widespread in clinical practice over a large array of professions, its subjective nature and inability to be used to truly express small strength differences, are some of its limitations[20].

Previous research has led to the introduction and practice of handheld dynamometry (HHD) as an alternative to manual muscle testing, providing clinicians with an objective, numerical measurement of muscle generated force[18, 21]. HHD has also become more common in the scientific literature with normative HHD values have been reported for strength testing in the literature [21]. HHD has previously been shown to be valid and comparable to the gold standard in strength testing; isokinetic dynamometry, without sacrificing on ease of use, portability or cost[22, 23].

HHD is not without limitations, research dating back to 1991 highlights the importance of tester strength in the accuracy of HHD measurements, particularly upper-limb tester strength and its inverse relationship with strength values recorded by HHD[24]. These reliability discrepancies are most common in stronger movements of > 120N[25], as may be expected across lower limb movements or in highly trained individuals in particular[21, 26].

These findings have led to the development of externally stabilised dynamometers. Examples include, belt fixation to an adjacent wall[27] or fixation through the construction of cage-like structures around a treatment plinth[28]. Both the aforementioned studies resulted in satisfactory reliability for hip strength values (ICC = 0.76 - 0.95 and 0.73 - 0.89 respectively) but these procedures may not be as time-efficient as traditional handheld measurement methods.

A much simpler solution was recently proposed by using a polymerizing vinyl chloride (PVC) pipe-like structure which could be placed between the limb being tested and a wall[29]. One end was designed to accommodate the MicroFET2™ dynamometer and the other end, a flat plate, to aid in its stability against the wall. Using this method, excellent reliability was established with ICC's for hip abduction and external rotation (ERot) strength measurements (ICC = 0.96 and 0.98 respectively) across thirty limbs tested in *n* = fifteen participants however researchers omitted IRot measurement and did not investigate the between-day reliability of these methods.

The aim of this current study was to establish intra-tester reliability when measuring the strength of hip abduction, IRot and ERot, by the use of a simple pipe-like stabilisation device coupled with a MicroFET2™ dynamometer and additionally, to explore the between-day reliability of these strength values. This manuscript was formulated in accordance to the GRRAS guidelines – Reporting Guidelines for Reporting and Agreement Studies[30]

Methods

Participants

Convenience sampling was used to recruit *n* = 18 (11 males and 7 females) participants from the Institute of Technology Carlow. Sample size requirements for intra-class correlation coefficients were pre-determined with $R_0 = 0.0$, $R_1 = 0.7$ (as established during pilot testing) and statistical power = 0.9. *n* = 13 was the calculated sample size however to allow for potential dropouts, *n* = 18 was the target sample size.[31] Subjects were deemed eligible if they participated, for more than two hours per week, in a field sport. Subjects were excluded if, in the past 6 months, they had any incidence of injury to the lower back, hip, knee, ankle or foot of their self-selected preferred jumping leg (leg which they were most likely jump off)

Ethical Considerations

Ethical approval for the study was granted by the Ethics in Research committee of the Institute of Technology Carlow, Ireland. Following a description of the study, individuals were recruited for participation. Written informed consent and medical screening questionnaires were also collected prior to the initiation of testing procedures. There was no financial inducement offered to participants and no participants were in a dependent relationship to either the lead researcher or research supervisors at the time of testing. Participants were also free to withdraw from participation at any time. Personal information was protected in accordance to the IT Carlow Data Protection Policy and GDPR guidelines. This study was conducted as part of a PhD research programme, funded by the President's Fellowship Scheme at the Institute of Technology Carlow, Ireland.

Instrumentation

A MicroFET2™ dynamometer[1] (Hoggan Scientific LLC. UT, USA) was used to obtain all strength measurements. The stabilisation device was constructed using a PVC pipe, 11cm wide and adjoining duct pieces which were bonded together with adhesive so that one side contained a 100mm diameter circular opening which accommodated the shape of the HHD securely, and the opposing end consisted of a flat surface which would lay against the wall during testing procedures (See figure 1.).

[INSERT FIGURE 1 ABOUT HERE]

An adjustable treatment plinth (Plinth 2000)[2], which was sourced from a NHS approved supplier, was used for all participants.

Testing Procedures

All measurements were performed on the participants self-reported preferred jumping leg, by a single tester, a Certified Athletic Therapist. A pre-defined script was used to describe the tests so as not to bias efforts exerted by participants. Testing took place on two occasions, three days apart, in the Physiology Laboratory at Institute of Technology Carlow. Procedures as outlined hereafter, plinth height and position in proximity to the wall, apparatus used, rest periods, and time of day were replicated between both testing days. Participants were also urged to abstain from high intensity exercise for the 24 hours preceding both testing sessions.

Peak force in newtons (N) over a five second maximal voluntary isometric contraction was recorded for each movement. For each measurement, the pad of the HHD was positioned 5cm proximal to the malleoli[32] with the HHDstab perpendicular to the wall and supported by the tester[29]. All trials were separated by a thirty second rest period. Four trials were recorded for each movement with the best (highest) three scores tabulated for analysis[27, 32].

Hip Abduction Measure

Hip abduction strength was recorded with the participant lying supine on the treatment plinth, positioned parallel to the adjacent wall. A belt was secured around the participant and plinth, resting on both anterior superior iliac spines (ASIS's) to limit lateral pelvic motion during testing. The HHDstab was positioned perpendicular to wall and the target leg, contacting the leg 5cm proximal to the lateral malleolus (See figure 2). The participant was then instructed to *"cross your arms over your chest and push into the pad as hard as possible"* for five seconds.

Hip Internal Rotation Measure

Hip IRot strength was recorded with the participant seated on the end of the treatment plinth, thigh parallel to the adjacent wall and hip in neutral rotation. A belt was secured around participant and plinth, on the superior femur, with a standardised 11cm wide piece of PVC positioned between the knees to maintain knee position. The HHDstab was positioned between the wall and the target leg, contacting the leg 5cm proximal to the lateral malleolus (See figure 2). The participant was then asked to *"keep both hands on top of the pipe, squeeze both knees together and push into the pad as hard as possible"* for five seconds.

Hip External Rotation Measure

Hip ERot strength was recorded with the participant seated on the opposite end of the treatment plinth to the IRot measurement position, with thigh parallel to the adjacent wall and hip in neutral rotation. For ERot, the target leg was the leg furthest away from the wall and the longer length PVC device was utilised so that the plinth could remain in situ. A belt was secured around participant and plinth, on the superior femur, with a standardised 11cm wide length of PVC positioned between the knees to maintain knee position. The HHDstab was positioned between the wall and the target leg, contacting the leg 5cm proximal to the medial malleolus. The non-test leg was flexed so as to lie behind the HHDstab (See figure 2). The participant was then asked to *"keep both hands on top of the pipe, squeeze both knees together and push into the pad as hard as possible"* for five seconds.

[INSERT FIGURE 2 ABOUT HERE]

Statistical analysis:

All data was tabulated and analysed using IBM Statistical Package for the Social Sciences (SPSS) version 23 and Microsoft Excel 2013. Means, standard deviations (SD), coefficients of variance percentage (CV %), Intraclass correlation coefficients (ICC) along with the respective 95 % confidence intervals (CI) were calculated within SPSS with $\alpha = 0.05$ and $1 - \beta = 0.95$. ICC(3,1) was applied in within-day analyses, with ICC(3,k) applied in between-day analyses for intra-rater reliability [33-35]. ICC statistics were classified within the following ranges; poor (0 - 0.39), fair (0.4 - 0.59), good (0.6 - 0.74) or excellent (0.75 - 1)[33]. The standard error of measurement (SEM) and minimal detectable change (MDC□□) were calculated for both within-day and between-day reliability analyses using the following formulae[29, 33, 34]:

- SEM = SD × $\sqrt{1\text{-}r}$, (with "*r*" being the ICC value calculated prior)
- MDC□□ = 1.96 × $\sqrt{2}$ × SEM

Results

Participant gender, age, preferred jumping leg, and body mass is presented in table 1.

[INSERT TABLE 1 ABOUT HERE]

Within-day test-retest reliability statistics for strength measurements were highly reliable with all ICC values > 0.934, CV % < 6.2 % and the largest MDC□□ value was 5.09 N which was recorded in IRot strength.

Similar to within-day reliability, between-day reliability statistics for strength measurements were excellent, with all ICC values > 0.802, CV % < 14.7 % while the MDC□□ value was 13.41 N for ERot strength (table 2).

[INSERT TABLE 2 ABOUT HERE]

[INSERT FIGURE 3 ABOUT HERE]

Discussion

Findings from this current study suggest that external stabilisation of a hand-held dynamometer provided excellent reliability of measurements of hip Abduction, IRot and ERot strength in both within-day and between-day conditions. The methodologies conducted in this study took approximately 8 minutes to complete, including landmarking, positioning, 4 repetitions of each specific movement with a minimum of 30 seconds rest allotted between repetitions, demonstrating its time efficient nature, ideal for clinical settings.

Within-day reliability for Abduction and ERot strength was excellent[33] (ICC's = 0.947, 0.961 respectively) (figure 3). The abduction and ERot reliability observed in the current study was comparable to previous research using a similar stabilisation device (ICC = 0.96 and 0.98 respectively)[29]. In addition, IRot strength was measured with similarly excellent reliability (ICC = 0.934) as the aforementioned movements. MDC□□ values for within-day reliability were also low, the largest of which was in IRot at 5.09 N. Because any change in hip strength seen immediately, greater than 5.09 N, or 3.85 % of maximum muscle force, would suggest a change that cannot be attributed to measurement error alone[34]. The outlined procedures are therefore more sensitive to detect change than non-stabilised HHD measurements taken in comparable positions for abduction, ERot and IRot strength (MDC^{95} = 9.4, 12.4 and 26.6 N respectively) [32], even when those non-stabilised measurements were taken by an experienced tester.

Moreover from previous research which only examined within-day reliability for a similarly stabilised HHD[29], excellent between-day reliability was observed for Abduction, IRot and ERot strength (ICC = 0.953, 0.928 and 0.802 respectively) by comparing the averages of the three best scores recorded on each day. The largest MDC□□ value for between-day hip strength measurement was seen in ERot at 13.4 N, or 18.3 % of maximum muscle force, indicating that if upon measurement by a clinician, hip strength changed by greater than this MDC□□ value between days, one cannot attribute this change to measurement error alone[34].

Through the addition of IRot strength measurement, the protocol in this current study aims to build upon previous research conducted on abduction and ERot strength measurement, without sacrificing portability, cost or time. While the addition of a standard 11cm wide pipe section keeps femoral position consistent across all tests, unlike the non-uniform towel used previously[29]. The addition of IRot measurement to the already established abduction and ERot reliability, provides clinicians with an accessible method to measure hip abduction and rotational strength, which may be of particular importance to rehabilitation clinicians[9].

Study Limitations

The findings from the current study, although encouraging, should be considered with caution. The current procedures were only carried out on a healthy, physically active cohort. These same methodologies should be investigated in pathological populations prior to its adaptation to clinical practice.

Also unlike the previous studies which validated HHD measurements by comparing it's measurement to isokinetic dynamometry[22], this HHDstab method, to the author's knowledge, is yet to be validated nor has it been directly compared with measurements taken with hand-held dynamometry without external stabilisation.

Future Research

Future research should focus on directly comparing HHDstab to strength measurements taken with the HHD stabilised manually by the tester. Moreover, validating HHDstab by comparing it to isokinetic dynamometry, and assessing HHDstab reliability in pathological populations should be performed prior to its wide-scale adaptation to clinical practice.

Conclusions

The addition of external fixation to HHD addresses a previously documented limitation of handheld dynamometry. The removal of individual tester strength is possible and provides a high level of consistency in strength assessments about the hip. Hip Abduction, IRot and ERot strength can be reliably measured, with minimal additional time or financial costs to either clinicians or patients, allowing such objective markers to guide clinical decision making in rehabilitation settings.

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List of Suppliers:

[1] MicroFET2™ dynamometer
Sports Physio Supplies Ltd
Racecourse Road, Killinan
Thurles, Co. Tipperary, Ireland

[2] Plinth 2000 treatment plinth
Sports Physio Supplies Ltd
Racecourse Road, Killinan
Thurles, Co. Tipperary, Ireland

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Table 1. Participant Characteristics

Characteristic	Female (n = 7)	Male (n = 11)	Total (n = 19)
Age (years)	22.9 ± 2.7	21.4 ± 1.6	21.9 ± 2.2
Weight (kg)	73.2 ± 17.1	75.4 ± 12.2	74.6 ± 13.9
Preferred jumping leg	L = 4 R = 3	L = 8 R = 3	L = 12 R = 6

kg = Kilogram,
L = Left,
R = Right

Table 1. Within-day and Between-day Test-retest Reliability Statistics

Within-day Reliability (n=18)

Movement	**Trial 1 (N)**	**Trial 2 (N)**	**Trial 3 (N)**	**ICC (3,1) (95 % CI)**	**CV %**	**SEM**	**MDC□□**
Abduction	117.37 ± 43.78	115.90 ± 41.96	117.72 ± 41.74	0.947 (0.887 – 0.978)	6.2 %	1.75 N	4.85 N
Internal Rotation	132.24 ± 36.77	134.69 ± 37.01	129.50 ± 32.95	0.934 (0.863 – 0.973)	5.2 %	1.84 N	5.09 N
External Rotation	74.44 ± 24.96	76.36 ± 25.16	74.48 ± 26.07	0.961 (0.917 – 0.984)	6.1 %	0.85 N	2.36 N

Between-day Reliability (n=18)

Movement	**Day 1 (N)**	**Day 2 (N)**	**ICC (3,*k*) (95 % CI)**	**CV %**	**SEM**	**MDC□□**
Abduction	117.00 ± 41.74	121.57 ± 35.30	0.953 (0.875 – 0.982)	8.4 %	2.11 N	5.86 N
Internal Rotation	132.14 ± 34.84	133.06 ± 32.26	0.928 (0.806 – 0.973)	8.3 %	2.65 N	7.34 N
External Rotation	75.09 ± 25.07	70.64 ± 21.11	0.802 (0.470 – 0.926)	14.7 %	4.84 N	13.41 N

ICC (3,1) = Intra-class Correlation Coefficient - 2-way mixed-effects, single measures
ICC (3,*k*) = Intra-class Correlation Coefficient - 2-way mixed-effects, average measures
CI = Confidence Interval
CV = Coefficient of Variance expressed as a percentage
SEM = Standard Error of Measurement
MDC□□ = Minimal Detectable Change at 95% CI
N = Newtons

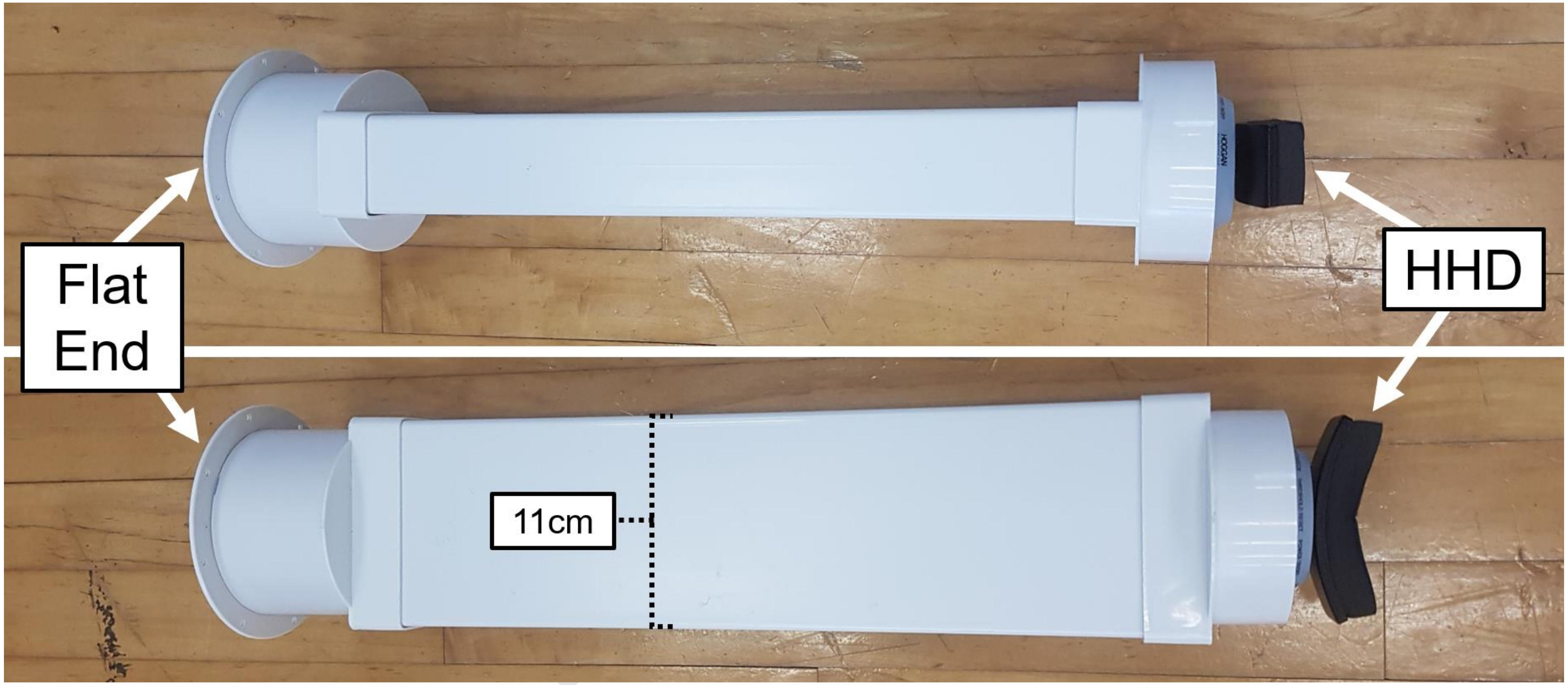

Figure 1. HHDstab Construction

Hip Abduction | Hip Internal Rotation | Hip External Rotation

Figure 2. Hip Abduction, Internal and External Rotation Strength Testing Positions

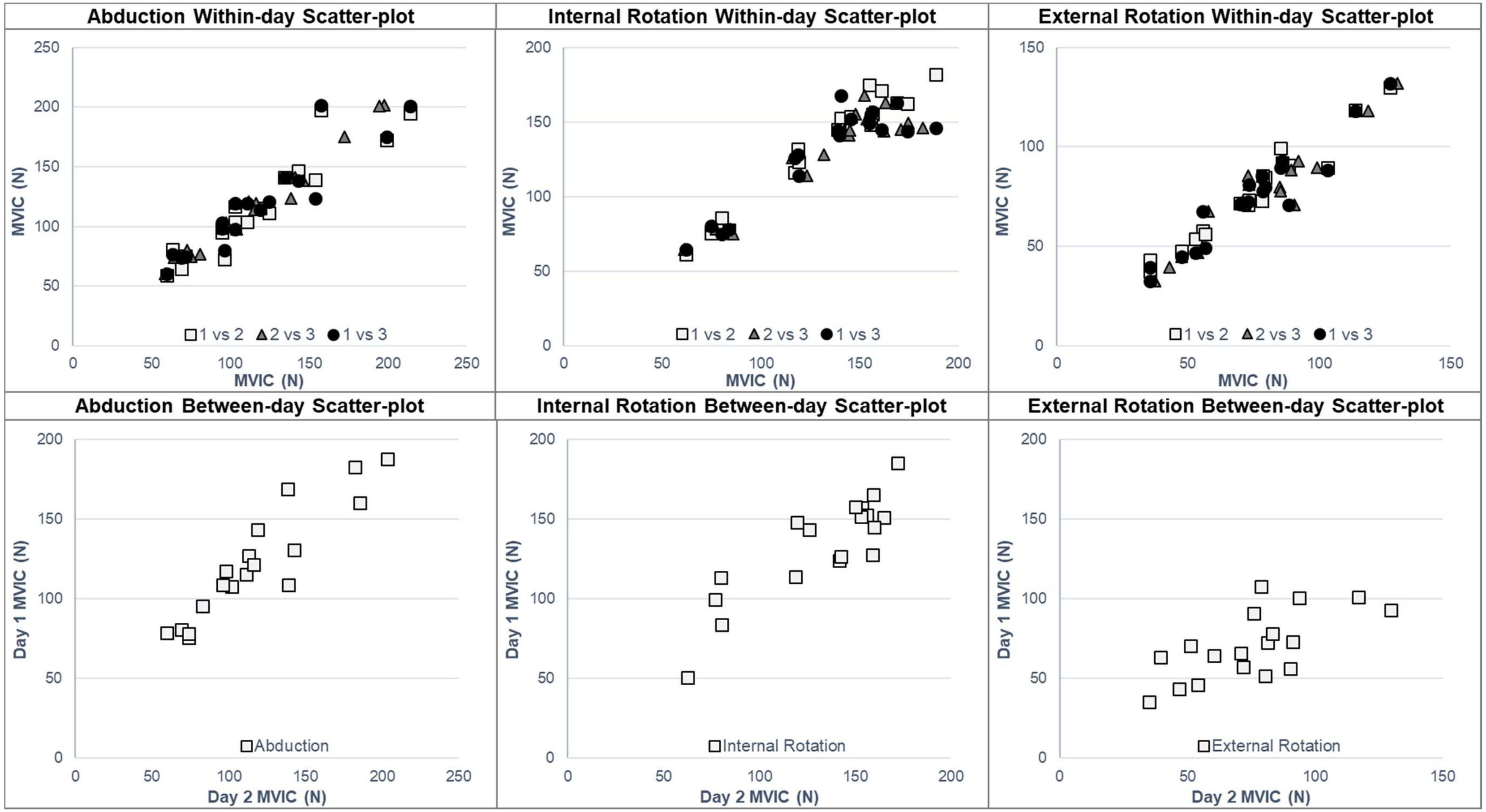

Figure 3. Within-day and Between-day Scatter-plots for Abduction, Internal and External Rotation