Research Article

Feasibility and validity of the push-up test for synchronous and asynchronous strength tele-assessment in spinal cord injury individuals with paraplegia

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Objectives: This study aimed to determine whether the synchronous and asynchronous push-up tele-assessment in individuals with spinal cord injury (SCI) is feasible and valid and to identify the relationship between the participants' self-reported asynchronous strength tele-assessment and asynchronous push-up tele-assessment.
Study design: Cross-sectional study
Methods: Thirty-three men and women with SCI were included in this study. The participants were assessed using the one-maximum repetition test (1RM), the maximum repetitions with 60% of 1RM (MRT) of the bench press exercise, and synchronous and asynchronous push-up tele-assessment. The videos and the total repetitions performed were recorded. The primary outcomes were 1RM, MRT, synchronous push-up tele-assessment and asynchronous volume loads, and the participants' self-reported asynchronous strength tele-assessment volume load.
Results: The synchronous push-up tele-assessment and asynchronous volume loads presented significant correlations with 1RM (0.73 and 0.45, $p < 0.001$, respectively) and MRT volume loads (0.87 and 0.66, $p < 0.001$, respectively). The asynchronous push-up tele-assessment presented significant correlations with the synchronous version (intraclass correlation coefficient, ICC = 0.86; 95% CI: 0.72–0.93, $p < 0.001$) and participants' self-reported asynchronous strength tele-assessment volume loads (ICC = 0.88; 95% CI: 0.75–0.94, $p < 0.001$). The difference between the synchronous push-up tele-assessment and asynchronous volume load means was 254.9 kg, and the interval around the differences was 1856.1 kg. The difference between asynchronous push-up tele-assessment and participants' self-reported asynchronous strength tele-assessment means was −239.4 kg, and the interval around these was 1884.1 kg.
Conclusion: The synchronous push-up tele-assessment is a feasible and valid way to assess the maximum resistance strength of individuals with SCI. Although the asynchronous push-up tele-assessment demonstrated excellent and significant correlations with the synchronous push-up tele-assessment and participants' self-reported asynchronous strength tele-assessment, the test repetitions and the volume loads were underestimated by 15.5% (synchronous push-up tele-assessment vs. asynchronous) and overestimated by 17.3% (asynchronous push-up tele-assessment vs. participants' self-reported asynchronous strength tele-assessment), and the effect sizes ranged from 0.19–0.38. The authors suggest emphasizing the criteria of repetition validity to reduce test error.

Keywords: Exercise, Physical education and training, Muscle strength, Pandemics, Spinal cord injuries, Task performance and analysis

Introduction

Different methods to assess muscle strength in individuals with SCI have emerged, contributing to adequate guidance on physical activity during an in-person

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rehabilitation program and after discharge (e.g. bench press exercise[1,2] and isokinetic dynamometry).[3,4] However, given the social isolation imposed by world governments due to the coronavirus disease 2019 (COVID-19) pandemic,[5,6] many individuals worldwide have been deprived of access to health-related interventions, monitoring, or assessment.[6,7] This access restriction also occurs in rural areas[8] or individuals with transportation barriers.[9] Thus, alternative strength tele-assessments for individuals with SCI that overcome the limitations of distance are needed.

Tele-assessment is defined as a technique that enables professionals to collect data regarding patient progress remotely[10] and can be grouped into two categories: 1) synchronous: characterized by a real-time approach, in which the service takes place simultaneously between the individual and the professional by video conference, audio, or text-based conversations; and 2) asynchronous: an alternative to traditional synchronous technologies, allowing communication without the need for real-time interaction (e.g. e-mail and other messaging systems).[11,12] To the best of our knowledge, there is one strength tele-assessment for individuals with SCI to assess lower limb strength,[13] using a customized device with a force sensor to measure strength with a computer for data acquisition in real-time (synchronous tele-assessment). However, the need for specific customized devices is an important limitation to a wide application in the SCI population. Moreover, although this tele-assessment enables lower limb muscle strength assessment, individuals who present only upper limb muscle strength are excluded. Upper limb strength is a predictor of functional independence and wheelchair ability and should be included in assessments of the SCI population.[2,4,14] Therefore, it is crucial to investigate a low-cost alternative for upper limb strength tele-assessment in SCI.

In this context, the push-up test may be a useful strength test for tele-assessment.[15–17] The push-up test is simple and practical because it does not require any attachments or implements, is easy to perform, and is not time-demanding.[17] Only one study using the push-up test in individuals with physical disabilities (para badminton amputee athletes) was found in the literature;[18] however, the authors did not describe the efficacy or clinimetric analysis of the push-up test. Therefore, using the push-up test for synchronous and asynchronous strength tele-assessment in rehabilitation medicine is one possibility for measuring performance changes in the new telerehabilitation and sports contexts. In addition, to provide fast data collection and increase the number of assessed participants independent of the setting,[19] self-reported tele-assessment may enhance the applicability of the synchronous and asynchronous push-up tele-assessments. To the best of our knowledge, only one study has developed a self-assessment technique to evaluate shoulder external-rotation and internal-rotation isometric strength in young healthy adults without pathological conditions.[20] However, this study did not use the self-reported assessment remotely and the participants did not present injuries.

Thus, the present study aimed to: (1) to determine whether the push-up test for synchronous and asynchronous strength tele-assessment in individuals with SCI is feasible and valid; and (2) to identify the relationship between the participants' self-reported asynchronous push-up tele-assessment results and those of the evaluator. The initial hypotheses were: (1) the synchronous and asynchronous push-up tele-assessments are feasible and valid strength tests; and (2) the participants' self-reported asynchronous strength tele-assessment will present a significant and positive correlation with the asynchronous push-up tele-assessment.

Methods

Participants

Thirty-three men and women with SCI were recruited from the rehabilitation program of a Network Centre of Rehabilitation Hospitals. Data were collected from October 2020 to December 2020. The study was approved by the institutional Ethics Committee (protocol n. 4.388.892) and all participants provided written informed consent.

Inclusion criteria were: 1) diagnosed with traumatic SCI paraplegia defined as impairment or loss of motor and/or sensory function in the thoracic, lumbar or sacral (but not cervical) segments of the spinal cord;[21] 2) at least 6 months since the injury; 3) complete motor lesion (ASIA Impairment Scale A or B) (21); and 4) participants with internet access with sufficient capacity for video calling. Participants were excluded if they had a history of metabolic disorders, or cardiovascular, cardiac or orthopedic surgery that would hamper performance in functional tests or adequate exercise technique.

Procedures

On day one, in the rehabilitation hospital, the participants were advised of the procedures, received instructions, and underwent a clinical assessment (body mass and height). On the same day, the one maximum repetition test (1RM) and resistance strength test (MRT) on the bench press exercise were conducted. After a

48- to 72-hour interval, the push-up test was performed synchronously using video calling and guided by the evaluators (the synchronous push-up tele-assessment) at the participant's home. After another 48- to 72-hour interval, the participants performed the push-up test at home and sent the test video to the evaluators (the asynchronous push-up tele-assessment) as well as the self-reported total of executed repetitions (Figure 1). Before each maximum test attempt, the participants reported their recovery using the perceived recovery status scale,[22] and performed the test only if the score was above or equal to 5 (adequate recovery). The time of day was not standardized within participants for all exercise tests.

Bench press: one-repetition maximum test (1RM)

The 1RM of the bench press exercise was used to assess maximum strength. This exercise is considered the best-isolated assessment to predict total dynamic strength,[23] upper limb strength,[24] and loads for tests and exercises.[24]

The participants' legs were extended on the bench and, if necessary, stabilized at the hips and legs with straps. Each repetition had four phases: (1) extended elbows and hands holding the bar; (2) elbow flexion and horizontal shoulder extension (eccentric phase of approximately 2 s); (3) light touch of the barbell at the mesosternal point; and (4) elbow extension and horizontal shoulder flexion (concentric phase). For the first repetition, the barbell was placed in the participant's hands. Grip width was measured prior to this, with elbows at 90 degrees and arms parallel to the ground. The mesosternal point was marked before execution, and no physical support was allowed in valid repetitions.

Before the 1RM test, participants performed a warm-up of 5–10 repetitions, with 50% of the perceived maximum load. After 1 min of rest, 3–5 repetitions were performed, with 70% of the perceived maximum load.[1,23,25–27] The perceived maximum load was estimated based on researcher and participant perceptions. After the warm-up, the participant rested for 2 min, the load was increased, and the exercise was performed. After a 5-minute interval, the participant performed the first attempt. If the participant was successful, 1–10 kg was added for the next attempt until the participant could not lift the barbell. The total weight lifted successfully was recorded as the 1RM. The maximum number of attempts during the same session was five.[1,25–27] The weight lifted in the 1RM was considered as the absolute load.

Bench press: maximum resistance strength test (MRT)

The maximum resistance strength test on the bench press was performed with 60% of the maximum load obtained in the 1RM test.[28] A 10-minute interval was allowed after

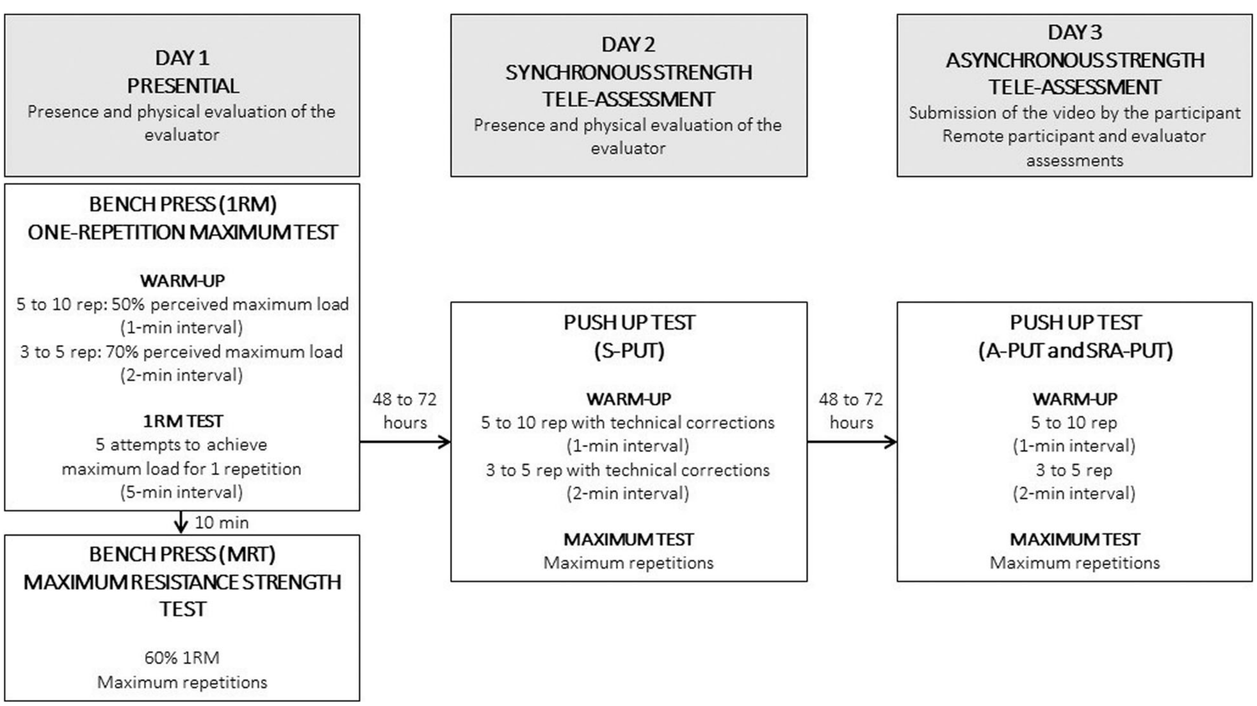

Figure 1 Protocol for bench press (1RM and maximum resistance strength test) and push-ups (asynchronous and synchronous strength tele-assessment).

the 1RM test to avoid muscle fatigue, and then the participant performed the maximum number of consecutive repetitions without rest. The performance criteria were the same as adopted in the 1RM test.

Push-up test

The push-up test was performed in the prone position, with hands separated by a distance equivalent to shoulder width, a straight back, and the head in a neutral position.[28] The participant's modified position consisted of legs together, supported on the mat during the test execution, and ankles in plantar flexion. The participant was required to lower their body until their chest touched the mat and then raise their body until elbow extension. The maximum number of repetitions performed consecutively without rest was counted by the evaluator. A valid repetition was considered when the chest touched the floor (mat) and the elbows extended entirely (Figure 2).

Before the synchronous push-up tele-assessment, the evaluator by WhatsApp (WhatsApp, California, USA) video call oriented the participant at home about safety such as putting a mat on the floor to avoid hurting the skin (e.g. rug), and assistance during the transfer from the floor to the wheelchair at the end of the test to avoid injury. The synchronous push-up tele-assessment was performed before the asynchronous push-up tele-assessment so that the evaluator could verify the participant's movement biomechanics, whether the execution was correct. During the asynchronous push-up tele-assessment (at home), the participant filmed the test and self-reported the test repetition number. The video was sent by WhatsApp (WhatsApp, California, USA) to two independent evaluators for assessment and if the difference in their evaluations was greater than 5%, a third evaluator examined the data. The total number of repetitions reported by the participants was compared to the correct repetition number registered by the evaluators.

The push-up test was not performed in the presence of the evaluator and participant to avoid the learning effect and increase the external validity of the test application for the first remote application.

Outcomes

After each test, the total volume-load was calculated by multiplying the number of repetitions completed by the external load used (kg). For 1RM and MRT, the external loads were the participant's total load lifted during the tests. For the push-up test, the external load was considered to be 67.8% of the body mass (head, arms and trunk), since the participant's pivot point was the hips.[29] The primary outcomes were 1RM, MRT, synchronous push-up tele-assessment and asynchronous volume loads, and participants' self-reported asynchronous strength tele-assessment volume load.

Statistical analysis

A sample size of 33 individuals was calculated considering an *a priori* correlation with a two-tailed distribution, a moderate effect size (f = 0.45), α = 5%, and a power of 80% (1-β).[30,31] The Kolmogorov–Smirnov test was used to assess the data normality assumptions. Descriptive data are presented as mean and standard deviation or median and interquartile range (25th and

Figure 2 The positioning of subject in push-up test.

75th percentiles) for the outcomes defined as parametric or nonparametric, respectively.

The Pearson correlation was used to correlate 1RM and MRT volume loads with the synchronous push-up tele-assessment and asynchronous volume loads. The intraclass correlation coefficient (ICC) was also used to correlate: (1) the synchronous push-up tele-assessment volume load with the asynchronous push-up tele-assessment volume load; and (2) the asynchronous push-up tele-assessment volume load with participants' self-reported asynchronous strength tele-assessment volume load. The Pearson correlation and ICC were classified based on the Cicchetti standards: below 0.40 – the level of clinical significance is poor; 0.40–0.59 – fair; 0.60–0.74 – good; and 0.75–1.00 – excellent.[32] Confidence intervals of 95% (95% CI) were used between comparisons.

Student's T-test and the Bland–Altman plot were used to compare: (1) synchronous push-up tele-assessment volume load mean and asynchronous push-up tele-assessment volume load mean; and (2) asynchronous push-up tele-assessment volume load mean and participants' self-reported asynchronous strength tele-assessment volume load mean. Cohen's *d* effect size (ES) was calculated and classified in the following manner: trivial (*d* lower than 0.10); small (*d* 0.10–0.29); moderate (*d* 0.30–0.49); large (*d* 0.50–0.69); very large (*d* 0.70–0.89); and perfect (*d* 0.90 or greater).[33]

The IBM SPSS Statistics package (version 22.0; SPSS Inc, Armonk, NY, USA) and G*Power Statistical Power Analyses software (version 3.1.9.2; Universität Kiel, Germany) were used. The threshold of statistical significance was set at 5% ($P \leq 0.05$; two-tailed).

Results

There were no dropouts from this study. A total of 33 individuals with SCI (eight women and 25 men) were recruited, with a mean age (standard deviation) of 39.5 ± 9.8 years. All participants were mixed-race (pardo). The complete demographic and clinical data of the participants are presented in Table 1.

Feasibility of push-up tele-assessment

All participants performed synchronous and asynchronous push-up tele-assessment. There were no falls but all participants needed assistance for transfer from the wheelchair to the floor and to back to the wheelchair. All participants needed assistance to perform the test and, simultaneously, to make the video call (synchronous push-up tele-assessment) and to record the video (asynchronous push-up tele-assessment).

Table 1 Participants' demographic data. All variables were presented as mean (standard deviation). Time since injury was presented as median (25th and 75th percentiles). Etiology was expressed in absolute values (frequency).

n	33
Relation women:men	8:25
Injury level	
T1.	1 (3.0%)
T2	1 (3.0%)
T3	3 (9.1%)
T4	3 (9.1%)
T5	7 (21.2%)
T6	4 (12.1%)
T7	1 (3.0%)
T8	2 (6.1%)
T9	2 (6.1%)
T10	2 (6.1%)
T11	3 (9.1%)
T12	3 (9.1%)
L1	1 (3.0%)
Age (years)	39.5 (±9.8)
Time since injury (months)	67.4 (22.0 - 179.2)
Age at injury (years)	30.5 (±10.3)
Body mass (kg)	73.1 (±17.4)
Height (cm)	170.1 (±8.8)
BMI (kg/m^2)	25.1 (±5.0)
1RM (kg)	72.5 (±31.1)
1RM/Body mass	0.98 (±0.32)
MRT (reps)	19.3 (±3.8)
Etiology (n)	
Auto accident	11 (33.3%)
Diving	1 (3.0%)
Falls	4 (12.1%)
Gunshot wound	13 (39.4%)
Hit by a falling object	1 (3.0%)
Motorcycle accident	3 (9.1%)

1RM: one maximum repetition test; BMI: body mass index; MRT: maximum resistance strength test.

Synchronous and asynchronous push-up tele-assessment validity

The synchronous push-up tele-assessment volume load presented significant correlations with 1RM (classified as good) and MRT (classified as excellent) volume loads (r = 0.73, 95% CI: 0.56–0.87, $P < 0.001$ and r = 0.87, 95% CI: 0.76–0.93, $P < 0.001$, respectively). The asynchronous push-up tele-assessment volume load demonstrated significant correlations with 1RM (classified as fair) and MRT (classified as good) volume loads (r = 0.45, 95% CI: 0.15–0.71, $P < 0.008$, and r = 0.66, 95% CI: 0.47–0.81, $P < 0.001$, respectively).

The synchronous push-up tele-assessment presented significantly higher total repetitions and volume load compared to the asynchronous push-up tele-assessment (Δ% = 15.8; ES = 0.21, small, 95% CI: −0.04–0.94, $P < 0.001$ and Δ% = 15.5; ES = 0.38, moderate, 95% CI: 0.11–0.86; $P < 0.001$, respectively) (Table 2). The asynchronous push-up tele-assessment volume load

Table 2 Pearson correlation between one maximum repetition test (1RM) and maximum resistance strength bench press test (MRT) volume loads with the S-PUT (synchronous push-up tele-assessment) and A-PUT (asynchronous push-up tele-assessment) volume loads. The confidence interval was set at 95% (95%CI).

	1RM	MRT
S-PUT	0.73* (0.56–0.87)	0.87* (0.76–0.93)
A-PUT	0.45* (0.15–0.71)	0.66* (0.47–0.81)

*$p \leq 0.05$.

presented a significant correlation with the synchronous push-up tele-assessment volume load (ICC = 0.86; 95% CI: 0.72–0.93) (Table 3). The Bland–Altman analysis showed a difference between synchronous push-up tele-assessment volume load and asynchronous push-up tele-assessment volume load of 254.9 kg, and the interval around the differences (±1.96 times S.D.) was 1856.1 kg. Two points were outside these limits (Table 3, Figure 3).

Comparison between synchronous push-up tele-assessment and participants' self-reported asynchronous strength tele-assessment

The asynchronous push-up tele-assessment showed significantly lower total repetitions and volume load compared to participants' self-reported asynchronous strength tele-assessment (Δ% = −16.7%; ES = 0.19, small, 95% CI: 0.09–0.88, $P < 0.001$, and Δ% = −17.3%; ES = 0.34, moderate, 95% CI: 0.15–0.82; $P < 0.001$, respectively) (Table 2). The asynchronous push-up tele-assessment volume load presented a significant correlation with participants' self-reported asynchronous strength tele-assessment volume load (ICC = 0.88; 95% CI: 0.75–0.94) (Table 4). Using the Bland–Altman method, the difference between the asynchronous push-up tele-assessment and participants' self-reported asynchronous strength tele-assessment means was −239.4 kg and the interval around these differences (±1.96 times S.D.) was 1884.1 kg. Two points were outside these limits (Table 3, Figure 4).

Discussion

The main aim of this study was to determine whether the synchronous and asynchronous push-up test for individuals with SCI is feasible and valid. The synchronous push-up tele-assessment demonstrated good and excellent correlations with the strength test volume loads (1RM and MRT, respectively), indicating that this strength tele-assessment is an alternative for measuring performance changes in the new tele-rehabilitation approach, for sports or fitness. The asynchronous push-up tele-assessment presented significant correlations with 1RM, MRT and the synchronous push-up tele-assessment volume loads; however, the asynchronous push-up tele-assessment underestimated test results by 5.3 repetitions (15.8%). Therefore, the asynchronous push-up tele-assessment is a valid option for strength tele-assessment, but coaches and health professionals must consider the measurement error when adopting the current test protocol. Regarding the second aim of the study, participants' self-reported asynchronous strength tele-assessment demonstrated an excellent correlation with asynchronous push-up tele-assessment volume load, but overestimated by 4.7 repetitions (16.7%). The authors suggest further studies to acquire more precise data on the self-report strength tele-assessment.

These findings on the strength tele-assessment in individuals with SCI can be useful, as the vulnerabilities of people with disabilities to a lack of care have recently been highlighted. In times of crisis, for example, during the COVID-19 pandemic, or situations where distance and transportation prevent in-person assessment there is a possibility that people with SCI may have care denied when lawmakers and healthcare systems determine who will receive the limited services available.[34] In this context, the synchronous push-up tele-assessment validity in individuals with SCI is an alternative tool to enhance continuous assessments in this population. In reviewing the recent literature, we found only one study that presented strength teleassessment of individuals with SCI, but it did not assess upper limb strength and demanded specific customized

Table 3 Comparison of repetitions and volume load between S-PUT (synchronous push-up tele-assessment) with A-PUT (asynchronous push-up tele-assessment) and A-Tele with SRA-PUT (participants' self-reported push-up repetitions). The comparisons are exhibited in percentual mean difference (Δ%), effect size, and confidence interval (95%CI).

	S-PUT	A-PUT	SRA-PUT	Δ% (Effect size; 95%CI)	
				S-PUT vs. A-PUT	A-PUT vs. SRA-PUT
Repetitions	33.5 (±11.3)*	28.2 (±12.3)	32.9 (±11.6)*	15.8% (0.21; −0.04–0.94)	−16.7% (0.19; 0.09–0.88)
Volume Load (kg)	1639.9 (±628.7)*	1385.0 (±716.0)	1624.3 (±703.1)*	15.5% (0.38; 0.11–0.86)	−17.3% (0.34; 0.15–0.82)

*significant difference compared with A-PUT ($p \leq 0.05$).

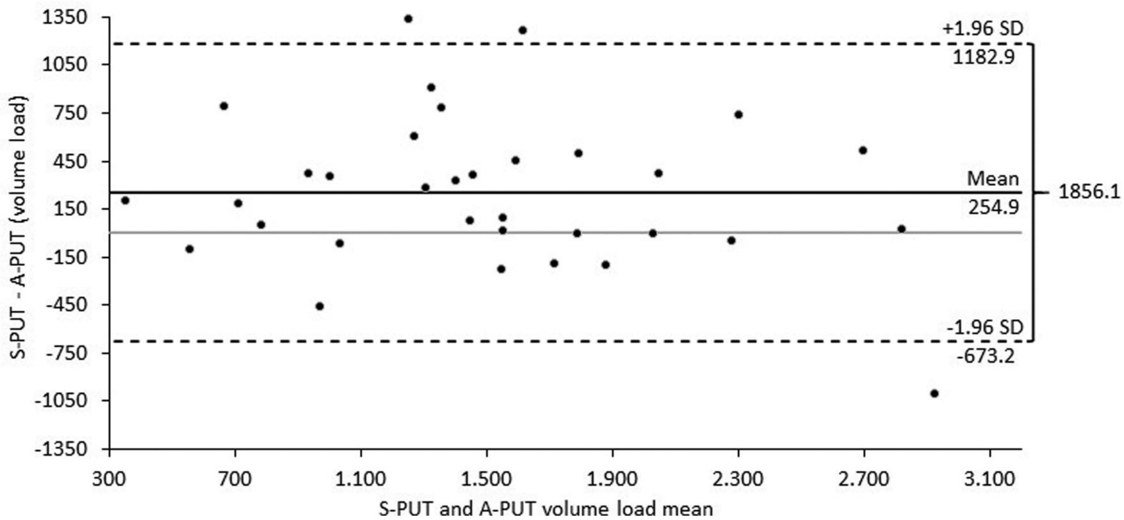

Figure 3 Bland-Altman method comparing the synchronous and asynchronous push-up tele-assessments. The confidence interval was set at 95% (95% CI). ±1.96 s.d.: range of the interval around the differences.

devices.[13] The present results offer an innovative strategy to improve patient management and healthcare in this population. The assessment of muscle strength in individuals with SCI has emerged to contribute to in-person rehabilitation programs, with significant relationships with functional scales and wheelchair skill abilities.[1–3] In the context of sport, the synchronous push-up tele-assessment is useful for coaches or telecoaches to assess athletes when they are not in the same training location, as well as for widespread strength monitoring during the periodization phases or after specific interventions.

Asynchronous communication presents several advantages: providing opportunities for exercise data to be saved after internet disconnection and resumed once the connection is restored and reducing the cost for the participant and time required by the telecoach.[35] The present study demonstrated that the asynchronous push-up tele-assessment showed significant correlations with 1RM, MRT, and synchronous push-up tele-assessment, but presented 15.8% fewer repetitions (5.3) than synchronous push-up tele-assessment. This result minimizes a possible learning effect since the second test (asynchronous push-up tele-assessment) presented lower repetitions compared to the first (synchronous push-up tele-assessment). The reason for the underestimation of the results was the number of invalid repetitions during the asynchronous push-up tele-assessment. Although the valid push-up test criteria were explained during the synchronous test, participants counted all repetitions even when the chest did not touch the floor, or the elbows did not extend entirely. Therefore, the authors suggest emphasizing the repetition validity criteria in order to reduce asynchronous push-up tele-assessment error. The only study that used strength tele-assessment for individuals with SCI performed the data acquisition synchronously,[13] with no existing studies using asynchronous strength tele-assessment, to the best of our knowledge. Asynchronous communication improves community sustainability,[35] and the asynchronous push-up tele-assessment could potentially reduce the participant cost (patient or athlete) and time required for the tele-assessment. In addition, with asynchronous assessments, the professional can evaluate more participants in less time. It is important to note that the synchronous test was performed previously to the asynchronous to ensure that all care was taken to prevent any harm to the participants in the present study. However, no injury was reported and the authors consider that the asynchronous test might be performed solely and, using these findings, the professional is able to choose

Table 4 Bland and Altman method and intraclass correlation coefficient (ICC) comparing the S-PUT (synchronous push-up tele-assessment) with the A-PUT (asynchronous push-up tele-assessment) volume loads and A-PUT with SRA-PUT (participants' self-reported push-up repetitions) volume loads. The confidence interval was set at 95% (95%CI).

	MD	Δ	ICC	95%CI
S-PUT vs. A-PUT volume loads (kg)	254.9	1856.1	0.86	0.72–0.93
A-PUT vs. SRA-PUT volume loads (kg)	−239.4	1844.1	0.88	0.75–0.94

*$p \leq 0.05$.
MD: mean difference (volume load); Δ: range of the interval around the differences (± 1.96 s.d).

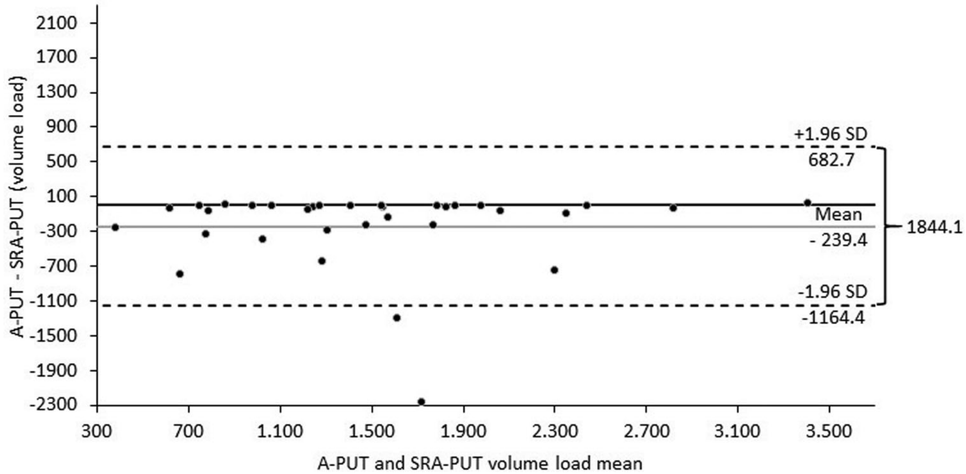

Figure 4 Bland-Altman method comparing the synchronous push-up tele-assessment and participants' self-reported asynchronous strength tele-assessment. The confidence interval was set at 95% (95% CI). ±1.96 s.d.: range of the interval around the differences.

better between the strength assessment tool considering its limitations and benefits. However, it is important to consider that the participants must be instructed regarding assistance for safety transfer from the wheelchair to the floor and to return to the wheelchair before using the asynchronous test.

Another alternative adopted for strength tele-assessment was the self-reported push-up test. The participants' self-reported asynchronous strength tele-assessment presented a significant correlation with the asynchronous push-up tele-assessment volume load, showing an overestimation of 16.7% of the total repetitions (4.7). The same explanation for the lower repetition results of the asynchronous push-up tele-assessment can be used to explain participants' overestimation of total repetitions in the self-reported asynchronous strength tele-assessment. The participants registered all repetitions even when they were not valid, and the result was compared to the correct asynchronous push-up tele-assessment as assessed by the two evaluators. The authors reinforce the necessity to better explain the validity criteria of the push-up test in order to perform the asynchronous push-up tele-assessment and participants' self-reported asynchronous strength tele-assessment with reduced measurement error. To the best of our knowledge, only one study developed a self-assessment technique for the isometric strength evaluation of shoulder external rotation and internal rotation,[20] demonstrating that the self-assessment of the studied isometric strength movements was valid. The current study found that, although the participants' self-reported asynchronous strength tele-assessment presents limitations (overestimated result), adjusting the test explanations may lead to a useful strength tele-assessment in the context of overcoming distance and time limitations.

Another finding refers to the significant correlations between the results of the synchronous push-up tele-assessment and the bench press in two different protocols: 1RM and MRT. To date, no studies have evaluated the push-up test and correlated the results with those of the bench press in individuals with SCI. Prior studies investigated the relationship between the push-up test and bench press in able-bodied individuals.[36–39] Invergo *et al.*[37] and Mayhew *et al.*[38] found that the number of push-ups completed in 60 s could not predict the 1RM bench press load. However, other studies found that the push-up test was able to predict the 1RM bench press load based on the mean power measured by a force plate[36] and on the load-velocity relationship measured by a linear encoder.[39] The present study demonstrated significant correlations without using a force plate or linear encoder. The push-up test without using a force plate or linear encoder has potential benefits for large-scale administration. One of the possible explanations for the excellent correlation compared to other studies is the protocol used in the push-up test. The present study adopted the maximum number of repetitions until fatigue, while other studies (unable to predict the 1RM bench press load) used a 60-second period for the test.[37,38] The authors suggest further studies that compare different methods of evaluating the push-up test to investigate this hypothesis.

Study limitations

The level of physical activity was not controlled, but the participants engaged in a spinal cord rehabilitation program in person. The participants included women and men, and the sex-based strength differences were not controlled. Women have 50–60% lower upper body strength, shorter stature, arm length, and reduced body mass in the upper body compared to men.[40] Another study limitation was the heterogeneity in SCI injury level. The present study recruited individuals with traumatic SCI with paraplegia and complete motor lesion (ASIA Impairment Scale A or B), but there may have been differences between those with high and low paraplegia.[41] For example, high and low paraplegia differ in several aspects, such as normalized strength by body mass,[42] peak torque,[42,43] and power.[43] Further studies including only women and other SCI injury levels might provide new insights about the push-up test in individuals with SCI. At last, the frequency and the type of the push-up test errors during the self-reported asynchronous tests were not registered. These procedures would allow the comparison between evaluators (inter-assessment agreement) and a better explanation to perform participants' self-reported asynchronous strength tele-assessment.

Conclusion

The present study demonstrated that synchronous push-up tele-assessment is a feasible and valid strength tele-assessment to assess strength in individuals with SCI and presented significant correlations with maximum strength and maximum resistance strength. The push-up test for asynchronous strength tele-assessment underestimated total repetitions by 15.8%, and the participants' self-reported asynchronous strength tele-assessment overestimated by 16.7%. Although the asynchronous strength tests (asynchronous push-up tele-assessment and participants' self-reported asynchronous strength tele-assessment) showed an excellent and significant correlation, the authors suggest emphasizing the criteria of repetition validity to reduce test error. The results suggest that the push-up test for strength tele-assessment may be valuable as a screening tool in telerehabilitation and strength training of athletes, assisting in the evaluation, prescription of training in individuals with SCI, and monitoring an individual's progress towards achieving their strength goals.

Abbreviations

1RM: one-maximum repetition test; MRT: maximum repetitions with 60% of 1RM

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Contributors None.

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