*Original Research Article*

CLINICAL REHABILITATION

Clinical Rehabilitation
1–11

DOI: 10.1177/02692155241295979
journals.sagepub.com/home/cre

Sage

# Reliability, validity and usability of the K-force® grip dynamometer to evaluate handgrip-strength in patients with intensive care unit-acquired weakness

**Ingrid D van Iperen[1,2], Daphne Stegink[3], Barbara L Tempert- de Haan[4], Marleen Flim[1,2], Robert van der Stoep[5] and Peter E Spronk[1,2]**

## Abstract

**Objective:** Handgrip dynamometry is recognised as a method for evaluating volitional muscle strength in the intensive care, but conventional handgrip dynamometers cannot accurately measure grip strength in very weak patients. The aim of this study was to determine the reliability, validity and usability of the K-force® grip in patients with intensive care unit-acquired weakness.

**Design:** Evaluation of measurement properties of the K-force® grip.

**Setting:** Two Intensive Care Units in The Netherlands.

**Participants:** Patients diagnosed with intensive care unit-acquired weakness according to a Medical Research Council sum score <48.

**Intervention & Main measures:** Intra- and inter-rater reliability of the K-force® grip were assessed using the intraclass correlation coefficient. Concurrent validity was examined using calibration weights. The usability was evaluated with the System Usability Scale.

**Results:** Intra-rater reliability showed an intraclass correlation coefficient of 0.987 for the dominant hand and 0.972 for the non-dominant hand. Inter-rater reliability showed coefficients of 0.944 for the dominant hand and 0.942 for the non-dominant hand. There was a perfect correlation ($r = 1$) between the K-force® grip and the calibration weights. The usability of the K-force® grip was rated excellent by 11 healthcare professionals with a System Usability Scale score of 86.

**Conclusions:** The K-force® grip is a promising new tool for the evaluation of muscle strength in intensive care unit-acquired weakness patients who are too weak to use conventional hand dynamometers.

[1]Department of Intensive Care Medicine, Gelre Hospitals, Apeldoorn, The Netherlands
[2]Expertise Center for Intensive Care Rehabilitation – ExpIRA, Apeldoorn, The Netherlands
[3]Twente University, Enschede, The Netherlands
[4]Department of Intensive Care Medicine, Medisch Spectrum Twente, Enschede, The Netherlands
[5]Department of Orthopaedics, Physiotherapy Unit, Erasmus MC University Medical Center, Rotterdam, The Netherlands

**Corresponding author:**
Ingrid D van Iperen, Department of ICU, Gelre Hospitals, Albert Schweitzerlaan 31, 7334DZ. Apeldoorn, The Netherlands.
Email: i.van.iperen@gelre.nl

**Keywords**
Intensive care units, muscle weakness, hand strength, dynamometry, validity

Received June 21, 2024; accepted October 11, 2024

## Introduction

Severely ill patients admitted to the Intensive Care Unit are prone to the development of intensive care unit-acquired weakness.[1] There is a widespread consensus that mobilisation should be initiated early, as muscle weakness is associated with an increased duration of hospitalisation, duration of mechanical ventilation, mortality and a decreased functional capacity.[2–4] Handgrip dynamometry is recognised as a method for evaluating volitional muscle strength in the intensive care unit.[5,6] Despite the widespread use of handgrip dynamometry, conventional handgrip dynamometers often face limitations in accurately measuring grip strength in very weak patients.[5,7,8]

The most widely used dynamometer for measuring handgrip strength in clinical settings is the Jamar®, which is considered the gold standard.[9,10] However, emerging evidence suggests limitations in its applicability, particularly among weak patients who may lack the requisite grip strength.[11–14] This holds significant implications as individuals diagnosed with severe intensive care unit-acquired weakness often exhibit insufficient muscle force to engage the Jamar® dynamometer effectively.[11] Additionally, the Jamar® may not be sensitive enough to detect small changes in handgrip strength.[15] The reading error is also reported to be more pronounced at lower loadings.[14] Furthermore, the Jamar's® larger dimensions and weight pose practical challenges.[16] In response to these limitations, the K-force® grip dynamometer emerges as a potential favourable alternative.

However, despite evidence demonstrating the reliability and validity of the K-force® grip dynamometer in healthy individuals[17–19] and patients with shoulder impingement syndrome,[18] its applicability and usability in patients with intensive care unit-acquired weakness remains unexplored. This study aims to investigate the reliability of the K-force® grip in patients with intensive care unit-acquired weakness as its primary objective. The secondary objectives are to evaluate the validity and usability of the device.

## Material and methods

### Patients

The study was conducted among patients admitted to a mixed medical and surgical intensive care unit and a medical, surgical and trauma intensive care unit, both situated in the Netherlands. Inclusion criteria comprised patients aged 18 years or older, with an intensive care unit stay exceeding 48 h, a Medical Research Council sum score of less than 48, a Richmond Agitation Sedation Scale score between −1 and +1, and a negative score on the Confusion Assessment Method for the intensive care unit. Patients with neurological disorders affecting hand function were excluded from the study.

## K-force® grip dynamometer

The K-force® grip (K-invent, Montpellier, France) is used to evaluate and rehabilitate hand grip muscle strength. Additionally, the device features interactive games. The K-force® Grip V2 devices were customised by adjusting the amplifier gain of the electronics to a max of ×1000 thus focusing the input to the lower end scale of forces. Additionally, special Teflon low friction coating was added at the load cell mounting to reduce hysteresis and zero balance offsets and the sensor pair was selected to have the same mV/V gain. Finally, the firmware was customised to increase the oversampling and reduce peak-to-peak noise. The device was calibrated by the manufacturer using

dead weights of 100, 500, 1000, 2000 and 4000 g and combinations of those to fine tune a 7-point linear correction equation. The weights were placed on the device in a special 2-jaw holding jig that has very low friction so that there is minimal tare drift. The calibration was tested and readjusted twice and validated three times. The default threshold of 600 g was removed before data collection to measure grip in even lower force ranges. The device is connected to a tablet through a Bluetooth connection to enable real-time biofeedback of data generated by the patient. The data are shown in a corresponding application using different graphs to give a clear overview of the progress, both for health professionals and for the patients themselves. The dimensions of the K-force® grip are 40×45×120 mm with a weight of 150 g. The device is CE certified (Europe), and FDA registered (USA). The software (version 1.3.2) was operated on an Apple iPad. Output was given in kilograms and converted to grams.

## Measurements

Reliability was evaluated in terms of both intra- and inter-rater reliability, with adherence to a standardised protocol throughout the study (Supplemental File 1). Considering that the original measurement standards of the American Society of Hand Therapists were established for healthy individuals in a seated position, we used a modified testing position for intensive care unit patients.[11] Consequently, assessment took place with patients lying in their beds in a semi upright position (the upper body raised in an angle between 30° and 45°). The forearm and the base of the device were resting on the bed with zero degree of shoulder adduction and a neutral wrist position (Figure 1).[9,11,20] Each participant underwent three consecutive measurements, with a 1-min interval between each trial, conducted on both hands, which was repeated by the same assessor and by another team-member to evaluate reliability. All measurements were conducted on the same day whenever possible to minimise variability due to changes in health status and other influencing factors. Raters were independent, with only one rater present during each measurement session. However, raters were not blinded to the data collection process. The mean grip strength per hand was calculated by averaging the results of the three trials for each subject. In addition, the difference between the three trials was assessed. The Jamar® handheld dynamometer recognised as the gold standard for measuring hand grip strength,

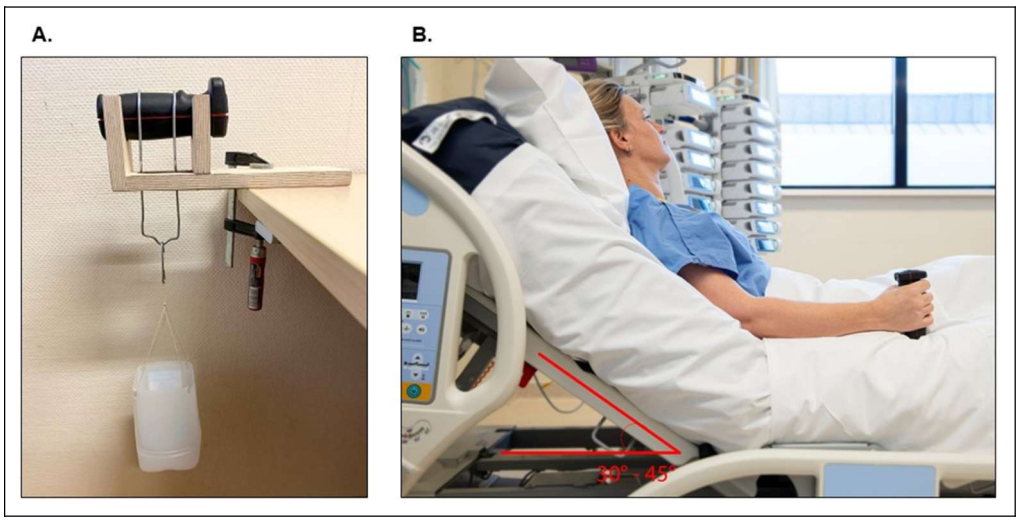


**Figure 1.** Standardised testing positions for (A) concurrent validity measurements and (B) reliability measurements.

presents limitations in capturing lower ranges of muscle force. Consequently, the concurrent validity was assessed using calibration weights that varied from 100 to 10,000 g.[21] The accuracy of the calibration weights was confirmed by the department of medical technology. These weights were suspended from the centre of the K-force® grip, securely positioned in a holder (Figure 1).[22] This process was repeated three times and the mean was used for further analyses.

The System Usability Scale was used to evaluate the usability of the K-force® grip in intensive care unit patients.[23] Healthcare professionals were invited to complete the System Usability Scale questionnaire, providing insights into their experiences with the K-force® grip. The scoring methodology of J. Brooke was used to create a System Usability Scale score out of 100.[24] The System Usability Scale scores can be associated with a seven-point adjective scale containing adjectives including 'worst imaginable', 'awful', 'poor', 'okay', 'good', 'excellent', 'best imaginable'.[25]

### Statistical analysis

The normality of the data distribution was assessed using the Shapiro–Wilk test. Accordingly, continuous variables were described as mean and standard deviation or as median and interquartile range. Categorical variables were summarised using frequencies and percentages. For non-normally distributed data, a log10 transformation was applied before conducting statistical analyses to meet the assumptions of the statistical test. Sample-size calculations were based on the intraclass correlation coefficient measurement, assuming a minimum acceptable reliability intraclass correlation coefficient of 0.6, a two-tailed significance level of 0.05, a power of 80%, two assessors per subject and a drop-out rate of 10%, resulting in the required sample size of 20 patients.[26,27] Intra-rater reliability and inter-rater reliability were assessed using the intraclass correlation coefficient,[28,29] employing a Two-Way Mixed-Effect model for intra-rater reliability and a One-Way Random-Effect model for inter-rater reliability. For the intra-rater reliability, the mean between the consecutive measurements and absolute agreements were used.[29] The difference between the three trials was assessed using a repeated measures ANOVA for the first round of measurements. If no significant difference is present between the trials, the intra-class correlations per trial are shown. Measurement error was assessed using the standard error of the measurement ($SEM = (SD\sqrt{(1-ICC)})$ and sensitivity to change was calculated using the minimal detectable change (MDC = standard error of measurement X 1.96 X $\sqrt{2}$).[30,31] The linear association between the calibration weights and the k-force® grip output was evaluated using Pearson's correlation coefficient and visually inspected via a scatter plot. Since the Bland Altman plot has the ability to over-diagnose the existence of fixed bias, Ludbrook (1997) suggests that the ordinary least squares regression is the best method to determine whether fixed- and proportional biases exist when the X-values are fixed in advance.[32] Fixed bias indicates that one method yields values that differ from the other method by a fixed amount, whereas proportional bias denotes that one method produces values that differ from the other method by an amount proportional to the level of the measured value. To determine if proportional bias in the ordinary least squares regression exists, the 95% confidence interval for the slope should not include 1, whereas fixed bias could be detected if the 95% confidence interval for the intercept should not include 0.[33] Data were analysed with SPSS (version 28) and RStudio (version 2023.06.0).

## Results

### Patients

A total of 30 patients were included in the intensive care units of the hospitals. Baseline characteristics are summarised in Table 1. Seventeen of the patients (56.7%) were male. Median age was 69.5 years (interquartile range 66.0–74.8). Of the patients, 20(66.7%) were admitted for medical reasons, 4(13.3%) for emergency surgery and 6(20.0%) for elective surgery. Median intensive

**Table 1.** Baseline characteristics.

| Characteristic | N = 30 |
|---|---|
| Gender (%) | |
| Male | 17(56.7%) |
| Female | 13(43.3%) |
| Age | 69.5 [66.0, 74.8] |
| Total days of mechanical ventilation | 29.6 ± 17.8 |
| Medical Research Council sum score | 22.7 ± 12.6 |
| Diagnosis at time of admission (%) | |
| Medical | 20(66.7%) |
| Emergency surgery | 4(13.3%) |
| Planned surgery | 6(20.0%) |
| Length of intensive care unit stay (days) | 35.5 [20.5, 52.2] |
| Mortality during intensive care unit stay (%) | 22(73.3%) |
| No | 8(26.7%) |
| Yes | |
| APACHE II | 19.8 ± 7.7 |

Continuous variables are presented as either mean ± standard deviation or median [interquartile range] based on distribution.
Categorical variables are presented as *n* (%).
N: number of patients; APACHE II: Acute Physiology and Chronic Health Evaluation II.

care unit length of stay was 35.5 days (interquartile range 20.5–52.2) and the mean Medical Research Council score was 22.7 ± 12.6.

## *Reliability of the K-force® grip*

All patients were able to generate output on the K-force grip®. The median hand grip strength for both the dominant and non-dominant hands were 2017 g (interquartile range: 735–4517) and 1820 g (interquartile range: 885–5722), respectively. The intraclass correlation coefficients indicate excellent reliability. To simplify the interpretation of the standard error of the measurement and minimal detectable change, the standard deviation from the non-transformed data was used. The detailed results are shown in Table 2. Regarding intra-rater reliability, 20 (66.7%) measurements took place on the same day, with a total median days difference of 0 (interquartile range: 0–1). For inter-rater reliability measurements, 26 (86.7%) were conducted on the same day, with a total median days difference of 0 (interquartile range: 0–0).

During the first round of measurements, the mean handgrip strength did not significantly differ across the three trials for the dominant hand $F(1.2, 30) = 0.81$, $p = 0.39$. There was also no difference across the three trials for the non-dominant hand $F(2, 54) = 0.74$, $p = 0.48$. Table 3 shows the results of the intraclass correlation coefficients per trial.

## *Validity of the K-force® grip*

There was a perfect correlation between the results measured with the K-force® grip and the calibration weights with a Pearson's Correlation Coefficient of $r = 1$. This indicates that the readings generated by the K-force® grip ($y$) was a perfect reflection of the calibration weights ($x$), hence $y = x$. Data dispersion is shown in a scatterplot in Figure 2. The intercept of the Ordinary Least Squares regression test was −1.465 (95% confidence interval: −13.875; 10.945), the slope of the ordinary least squares regression test was 0.997 (95% confidence interval: 0.994; 1.000). The ordinary least squares regression showed that there was no fixed or proportional bias, since the 95% confidence interval of the intercept contained 0 and the 95% confidence interval of the slope contained 1.[33]

## *Usability of the K-force® grip*

Eleven Healthcare professionals completed the System Usability Scale. The mean total System

**Table 2.** Intra-class correlation coefficients with the 95% confidence interval, the standard error of the measurement and the minimal detectable change.

| | | ICC (95% confidence interval) | SEM (g) | MDC (g) |
|---|---|---|---|---|
| Intra-rater reliability | Dominant hand | 0.987(0.972–0.994) | 414 | 1147 |
| | Non-dominant hand | 0.972(0.939–0.987) | 669 | 1854 |
| Inter-rater reliability | Dominant hand | 0.944(0.878–0.974) | 912 | 2528 |
| | Non-dominant hand | 0.942(0.877–0.972) | 887 | 2459 |

ICC: intra-class correlation coefficient; SEM: standard error of the measurement; MDC: minimal detectable change.

**Table 3.** Intra-class correlation coefficient with the 95% confidence intervals per trial.

| ICC (95% confidence interval) | | | | |
|---|---|---|---|---|
| | | Trial 1 | Trial 2 | Trial 3 |
| Intra-rater reliability | Dominant hand | 0.983 (0.964–0.992) | 0.946(0.882–0.975) | 0.988(0.973–0.995) |
| | Non-dominant hand | 0.976(0.949–0.989) | 0.972(0.937–0.987) | 0.865(0.699–0.939) |
| Inter-rater reliability | Dominant hand | 0.992 (0.982–0.996) | 0.991(0.980–0.996) | 0.910(0.786–0.962) |
| | Non-dominant hand | 0.941(0.875–0.972) | 0.812(0.602–0.911) | 0.723(0.388–0.875) |

ICC: intra-class correlation coefficient.

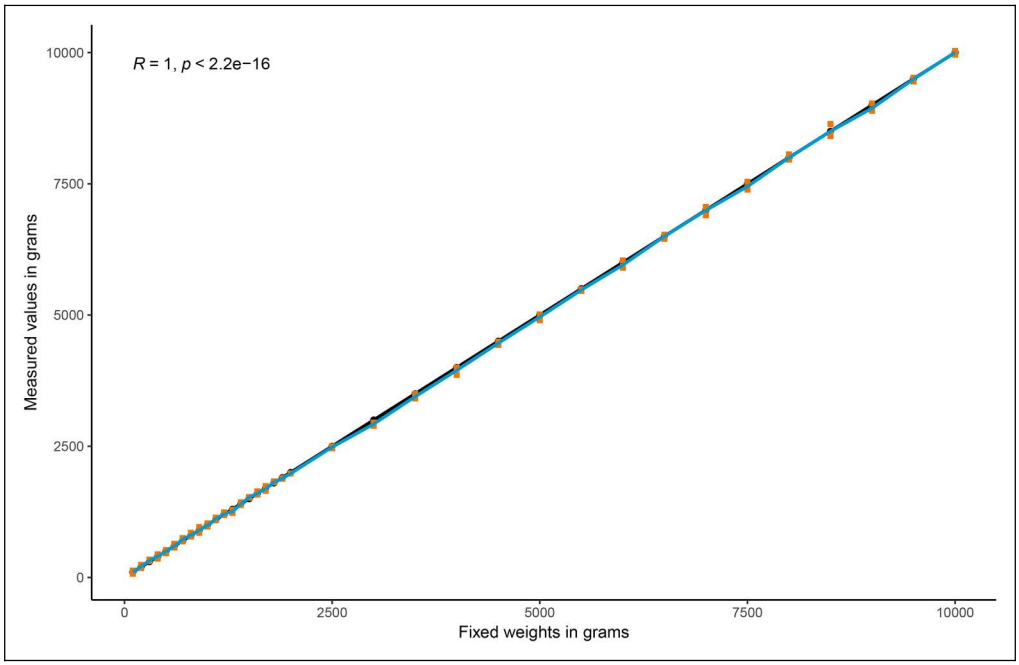


**Figure 2.** Scatterplot of the linear association between the calibration weights and the mean readings of the K-force® grip (blue line). The black line represents the ideal situation of all readings being equal to the calibration weights, where the orange dots represent the readings of the different measurement sessions.

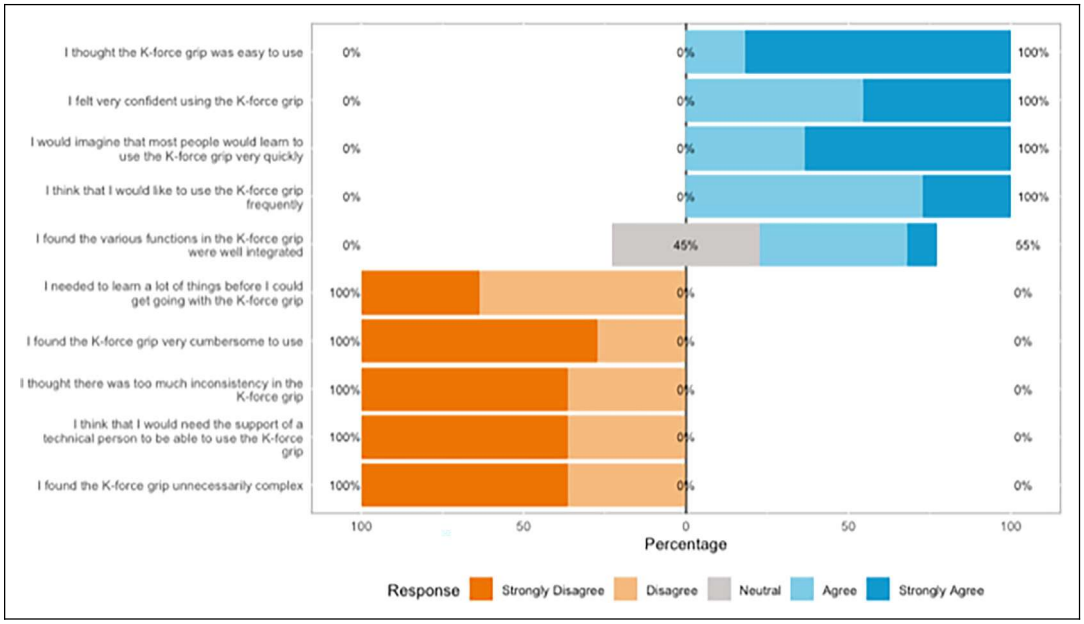


**Figure 3.** Likert plot of the results of the System Usability Scale.

Usability Scale score was 86 ± 8.3 varying on an individual level between 73 and 100. The participants (72.7% were female) had a mean age of 41.5 ± 21.1 with a median of 4 [2.0, 10.5] years of intensive care unit experience. The majority of the participants were physiotherapists (45.5%) who had prior experience measuring hand grip strength with other devices, while the other professions had no prior experience measuring hand grip strength (54.5%).

Figure 3 shows the result of the System Usability Scale in a Likert bar plot. It demonstrates that nearly all statements received scores in or around the desirable range, with the statement '*I believed the K-force® grip was easy to use*' receiving the highest score of '*strongly agree*'. This was reflected in the high mean total System Usability Scale score. Only the statement '*I found that the various functions in the K-force® grip were well integrated*', received a 45% neutral rating. According to the adjective rating scales corresponding with the total mean System Usability Scale score of 86, the K-force® grip and the corresponding application as a system are perceived as having excellent usability.

## Discussion

Our study demonstrates that the K-force® grip system is a reliable, valid and usable tool for assessing grip strength in very weak intensive care unit patients.

Intra-rater reliability for both dominant and non-dominant hands were excellent, confirming previous research in other patient populations. Previous research has demonstrated excellent intra- and inter-instrument reliability for the K-force® grip in healthy individuals and patients with shoulder impingement syndrome.[18] Moreover, the K-force® grip had a high test-retest reliability in a sitting and standing position,[17] as well as excellent intra-rater reliability in healthy subjects.[19] Reliability measurements were conducted by researchers with backgrounds in healthcare or healthcare professionals, reflecting the characteristics of the users who will eventually

employ the device in clinical settings. Our study involving patients with intensive care-acquired weakness revealed no variation in handgrip strength throughout the three trials during the initial round of measurements. This finding is consistent with a previous study that demonstrated no significant difference in handgrip strength across three trials in healthy subjects.[19] These results suggest that a single trial may suffice to obtain a reliable measurement, potentially enhancing patient comfort and reducing fatigue. Such an approach could be particularly beneficial in the intensive care setting, where minimising the physical strain of repeated assessments is important. The intra-class correlation coefficients indicate excellent intra-rater reliability for handgrip strength measurements in the dominant hand, suggesting consistent results across trials. However, the non-dominant hand displays some variability, particularly in the third trial, indicating potential inconsistencies in measurements. Future research may explore the feasibility of implementing a single-trial protocol further, particularly in a more diverse patient population.

The standard error of measurement ranged between 414 and 912 g and the minimal detectable change ranged between 1147 and 2528. Comparing the findings to existing literature is challenging because, to our knowledge, no previous studies have calculated the standard error of measurement and minimal detectable change in patients with such severe intensive care unit-acquired weakness. In this population, even small changes in muscle strength can be clinically significant. However, the standard error of measurement and minimal detectable change values in this study are relatively large compared to the patients' capabilities. This disparity suggests that the K-force dynamometer may lack the sensitivity needed to detect meaningful changes in grip strength within this severely weakened cohort.

Our study showed that the K-force® grip is considered valid in the lower ranges of the muscle force in a test-setting, which is essential in patients with intensive care unit-acquired weakness and severely impaired handgrip strength. In a prior study involving patients on mechanical ventilation, six patients were unable to generate any grip strength on the Jamar.[11] In another study 18 patients with low grip strength could not produce any grip strength readings using the Jamar®, whereas an alternative electronic handheld dynamometer (Grippit) successfully recorded measurements.[13] However, in our study, all patients were able to generate output on the K-force grip®.

Furthermore, our study compared the K-force® grip with calibrated weights resulting in a correlation coefficient of $r = 1$. Two other studies compared the Jamar® with the K-force® grip to assess the validity in healthy subjects[17] and patients with shoulder impingement.[18] Both measures correlated well, although the K-force underestimated the grip strength compared to the Jamar in the higher ranges of grip strength.[17–19] Neither of the beforementioned studies reported the performance of both devices in the lower range of strength, as we encountered in our study where average grip strength was around only 2 kg. The customised k-force grip devices were calibrated specifically for lower force ranges, tested and readjusted twice and validated three times. This likely contributed to the perfect correlation observed in our study. A strength of the current study is that our selection of calibration weights up to 10 kg was carefully tailored to match the low muscle force typically observed in patients diagnosed with intensive care unit-acquired weakness.[34]

It is surprising that despite the evaluation of the validity of using the K-force grip, no usability evaluations in the intensive care unit have been described thus far to our knowledge.

Our study has several limitations. First, even though the achieved sample size exceeded the calculated sample size in specific patient population with established intensive care unit-acquired weakness, the study was done in two intensive care units in The Netherlands. Therefore, these findings might not be generalisable to broader populations or settings. The results should be corroborated in other settings and case-mixes before definite conclusions may be drawn.

Second, while the measurements were recorded objectively via the tablet, the raters were not blinded to the data collection process. This lack of blinding may have influenced factors such as

the level of encouragement or instructions provided to patients, potentially affecting their performance.

In conclusion, our study demonstrates that the K-force® grip system exhibits excellent reliability, validity and usability in measuring grip strength among intensive care unit patients with severe muscle weakness. Furthermore, by evaluating its performance we have established the K-force® grip system as a reliable tool for clinical assessment in this specific patient population. This research can benefit patients by utilising the K-force® grip dynamometer to accurately measure handgrip strength in patients with severe intensive care unit-acquired weakness. The device also features interactive games to support handgrip strength training during rehabilitation, providing an engaging experience for patients and potentially enhancing their participation.[35] Moving forward, further research is warranted to explore the broader clinical applications in more diverse settings and potential benefits of integrating the K-force® grip system into routine practice.

### Clinical messages

- The K-force® grip reliably measures grip strength in patients with severe intensive care unit-acquired weakness.
- The system's validity supports its use for clinical assessments in this patient population.
- The system demonstrates excellent usability.
- Integrated games can enhance patient engagement and participation in rehabilitation.

## Acknowledgements

We extend our sincere thanks to the Department of Medical Technology for their assistance in creating the test setting for the validity measurements and their confirmation of the calibration weights used in the study.

## Author contributions

IDVI: conceptualisation, methodology, data curation, formal analysis, investigation, writing—original draft preparation, writing—review & editing. DS: conceptualisation, methodology, writing—review & editing. BTDH: data curation, investigation, writing—review & editing. MF: data curation, investigation, project administration, writing—review & editing. RVDS: conceptualisation, writing—review & editing. PES: conceptualisation, supervision, writing—original draft preparation, writing—review & editing.

## Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Gelre hospitals science fund, Apeldoorn. The study received support in the form of two customised K-force® grip devices, which were calibrated for the research.

## Ethical considerations

The study was approved by the Medical Research Ethics Committee Isala Zwolle and deemed exempt from the Medical Research Involving Human Subjects Act (221007).

## Informed consent

All participants gave written informed consent before data collection began.

## ORCID iD

Ingrid D van Iperen https://orcid.org/0009-0009-7564-6248

## Supplemental material

Supplemental material for this article is available online.

## References


1. Vanhorebeek I, Latronico N and Van den Berghe G. ICU-acquired weakness. *Intensive Care Med*; 46. Epub ahead of print 2020. DOI: 10.1007/s00134-020-05944-4.
2. Bragança RD, Ataíde TBLS, Mourão LMB, et al. Intensive care unit acquired weakness, handgrip strength, and mortality in critically ill patients. *J Crit Care*; 42. Epub ahead of print 2017. DOI: 10.1016/j.jcrc.2017.09.056.
3. Rousseau AF, Prescott HC, Brett SJ, et al. Long-term outcomes after critical illness: recent insights. *Crit Care*; 25. Epub ahead of print 2021. DOI: 10.1186/s13054-021-03535-3.
4. Hermans G and Van den Berghe G. Clinical review: Intensive care unit acquired weakness. *Crit Care*; 19. Epub ahead of print 2015. DOI: 10.1186/s13054-015-0993-7.
5. Ali NA, O'Brien JM, Hoffmann SP, et al. Acquired weakness, handgrip strength, and mortality in critically Ill patients. *Am J Respir Crit Care Med*; 178. Epub ahead of print 2008. DOI: 10.1164/rccm.200712-1829OC.
6. Chlan LL, Tracy MF, Guttormson J, et al. Peripheral muscle strength and correlates of muscle weakness in patients receiving mechanical ventilation. *Am J Crit Care* 2015; 24: e91–e98.
7. Bittner EA, Martyn JA, George E, et al. Measurement of muscle strength in the intensive care unit. In: *Crit Care Med*. 37(10), October 2009. DOI: 10.1097/CCM.0b013e3181b6f727
8. Parry SM, Berney S, Granger CL, et al. A new two-tier strength assessment approach to the diagnosis of weakness in intensive care: An observational study. *Crit Care*; 19. Epub ahead of print 2015. DOI: 10.1186/s13054-015-0780-5.
9. Fess EE. *Clinical assessment recommendations*. Chicago, IL: American Society of Hand Therapists, 1992.
10. Härkönen R, Harju R and Alaranta H. Accuracy of the Jamar Dynamometer. *J Hand Ther*; 6. Epub ahead of print 1993. DOI: 10.1016/S0894-1130(12)80326-7.
11. Chlan LL, Tracy MF, Guttormson J, et al. Description of peripheral muscle strength measurement and correlates of muscle weakness in patients receiving prolonged mechanical ventilatory support. *Am J Crit Care* 24.
12. Richards LG, Olson B and Palmiter-Thomas P. How forearm position affects grip strength. *Am J Occup Ther* 1996; 50: 133–138.
13. Massy-Westropp N, Rankin W, Ahern M, et al. Measuring grip strength in normal adults: Reference ranges and a comparison of electronic and hydraulic instruments. *J Hand Surg*; 29. Epub ahead of print 2004. DOI: 10.1016/j.jhsa.2004.01.012.
14. Roberts HC, Denison HJ, Martin HJ, et al. A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardised approach. *Age Ageing*; 40. Epub ahead of print 2011. DOI: 10.1093/ageing/afr051.
15. Richards L and Palmiter-Thomas P. Grip strength measurement: A critical review of tools, methods, and clinical utility. *Crit Rev Phys Rehabil Med*; 8. Epub ahead of print 1996. DOI: 10.1615/CritRevPhysRehabilMed.v8.i1-2.50.
16. Bragança RD, Ravetti CG, Barreto L, et al. Use of handgrip dynamometry for diagnosis and prognosis assessment of intensive care unit acquired weakness: a prospective study. *Heart Lung* 2019; 48: 532–537.
17. Cildan Uysal S, Tonak HA and Kitis A. Validity, reliability and test-retest study of Grip strength measurement in two positions with two dynamometers: Jamar® Plus and K-Force® Grip. *Hand Surg Rehabil*; 41. Epub ahead of print 2022. DOI: 10.1016/j.hansur.2022.02.007.
18. Nikodelis T, Savvoulidis S, Athanasakis P, et al. Comparative Study of Validity and Reliability of Two Handgrip Dynamometers: K-Force Grip and Jamar. *Biomechanics*; 1. Epub ahead of print 2021. DOI: 10.3390/biomechanics1010006.
19. Magni N, Olds M and McLaine S. Reliability and validity of the K-force grip dynamometer in healthy subjects: do we need to assess it three times? *Hand Ther*; 28. Epub ahead of print 2023. DOI: 10.1177/17589983231152958.
20. Mathiowetz V, Rennells C and Donahoe L. Effect of elbow position on grip and key pinch strength. *J Hand Surg Am* 1985; 10: 694–697.
21. West CP and Beckman TJ. Concurrent Validity. In: *The SAGE Encyclopedia of Educational Research, Measurement, and Evaluation*. 2455 Teller Road, Thousand Oaks, California 91320 : SAGE Publications, Inc., 2018. Epub ahead of print 2018. DOI: 10.4135/9781506326139.n135.
22. Fess EE. A method for checking Jamar dynamometer calibration. *J Hand Ther*; 1. Epub ahead of print 1987. DOI: 10.1016/S0894-1130(87)80009-1.
23. Bangor A, Kortum PT and Miller JT. An empirical evaluation of the system usability scale. *Int J Hum Comput Interact* 2008; 24: 574–594.
24. Brooke J. SUS -A quick and dirty usability scale Usability and context. *Usability Eval Ind* 189.
25. Bangor A, Kortum P and Miller J. Determining what individual SUS scores mean: Adding an adjective rating scale. *J Usability Stud* 2009; 4.
26. Giraudeau B and Mary JY. Planning a reproducibility study: how many subjects and how many replicates per subject for an expected width of the 95 per cent confidence interval of the intraclass correlation coefficient. *Stat Med* 2001; 20: 3205–3214.
27. Arifin WN. A web-based sample size calculator for reliability studies. *Educ Med J* 2018; 10: 67–76.
28. Rankin G and Stokes M. Reliability of assessment tools in rehabilitation: An illustration of appropriate statistical analyses. *Clin Rehabil*; 12. Epub ahead of print 1998. DOI: 10.1191/026921598672178340.
29. Koo TK and Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med* 2016; 15: 155–163.
30. Mokkink LB, Prinsen CA, Patrick D, et al. COSMIN Study Design checklist for Patient-reported outcome measurement instruments. *Department of Epidemiology and Biostatistics Amsterdam Public Health research institute Amsterdam University Medical Centers, location VUmc*.

31. Denegar CR and Ball DW. Assessing reliability and precision of measurement: an introduction to intraclass correlation and standard error of measurement. *J Sport Rehabil*; 2. Epub ahead of print 1993. DOI: 10.1123/jsr.2.1.35.
32. Ludbrook J. Special article comparing methods of measurement. *Clin Exp Pharmacol Physiol*; 24. Epub ahead of print 1997. DOI: 10.1111/j.1440-1681.1997.tb01807.x.
33. Ludbrook J. Statistical techniques for comparing measurers and methods of measurement: A critical review. *Clin Exp Pharmacol Physiol*; 29. Epub ahead of print 2002. DOI: 10.1046/j.1440-1681.2002.03686.x.
34. Piva S, Fagoni N and Latronico N. Intensive care unit–acquired weakness: unanswered questions and targets for future research: [Version 1; peer review: 3 approved]. *F1000Res*; 8. Epub ahead of print 2019. DOI: 10.12688/f1000research.17376.1.
35. Lohse K, Shirzad N, Verster A, et al. Video games and rehabilitation: Using design principles to enhance engagement in physical therapy. *J Neurol Phys Ther*; 37. Epub ahead of print 2013. DOI: 10.1097/NPT.0000000000000017.