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RESEARCH ARTICLE

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Deficits in rate of force production during multifinger tasks are associated with cognitive status

Richard G. Carson[1,2] | Eimíle Holton[1]

[1]Trinity College Institute of Neuroscience and School of Psychology, Trinity College Dublin, Dublin 2, Ireland

[2]School of Psychology, Queen's University Belfast, Belfast, Northern Ireland, UK

Correspondence
Richard G. Carson, Trinity College Institute of Neuroscience and School of Psychology, Trinity College Dublin, Dublin 2, Ireland.
Email: richard.carson@tcd.ie

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Abstract

Objectives: The multifinger force deficit (MFFD) is the decline in force generated by an individual finger as the number of fingers contributing to the action is increased. It has been proposed that as a measure of neural sufficiency rather than muscle status, it provides a means of detecting individuals at risk of cognitive decline. Age-related deficits in central neural drive exert a disproportionate impact on the rate at which force can be generated. We examined whether a MFFD derived from the maximum rate at which force is generated, is more sensitive to individual differences in cognitive status, than one calculated using the maximum level of force.

Methods: Monotonic associations between each of two variants of the MFFD, and cognition (measured with the Montreal Cognitive Assessment), were estimated cross sectionally using generalized partial rank correlations, in which age, level of education and degree of handedness were included as covariates. The participants (n=26) were community dwelling adults aged 66-87.

Results: The MFFD derived using the maximum rate of force development was negatively associated with cognitive status. The association for the MFFD based on the maximum level of force, was not statistically reliable. The associations with cognitive status obtained for both variants of the MFFD were of greater magnitude than those reported previously for standard grip strength dynamometry.

Conclusion: The sensitivity with which the MFFD detects risk of cognitive decline may be enhanced by using the maximum rate of force developed by each finger, rather than the maximum force generated by each finger.

KEYWORDS
cognition, coordination, dexterity, grip strength, physical function

Key points

- The multifinger force deficit (MFFD) was not reliably associated with cognitive status, as determined by the Montreal Cognitive Assessment (MoCA)
- An estimate of the MFFD derived using the rate-of-force-development (rofMFFD) was negatively associated with cognitive status

- The magnitudes of the negative associations between the rofMFFD and the MFFD, with MoCA scores, were larger than those reported for standard grip strength dynamometry

1 | INTRODUCTION

Longitudinal studies indicate that in older adults, low grip strength is associated with subsequent manifestations of cognitive dysfunction, diagnoses of mild cognitive impairment (MCI), and the incidence of various types of dementia.[1–4] It is also apparent that rates of decline in grip strength and cognitive function are closely aligned.[5] Although grip strength is often treated as a proxy for "muscular fitness" (for example,[6]) there are no indications that cognitive and muscle function are linked.[7] Since the effective application of grip force demands sophisticated neural control, it has been argued that a decline in grip strength which emerges beyond middle age should instead be considered a marker of brain health.[8]

In view of its power to anticipate impairments that may only become evident several years later, there have been recommendation that measurements of grip strength be used to identify older adults at risk of neurological degeneration and cognitive decline (for example,.[9–11]) Morphometric factors, including height, body-mass, and hand size also contribute to individual differences in grip strength. They do so independently of variations in brain health that account for the associations between grip strength and cognition seen in large cohort studies. Differences in individual morphology therefore reduce the sensitivity with which a conventional measurement of grip strength can provide prognosis of cognitive function.

It has been proposed[12] that multifinger dynamometry[13] be used to overcome this limitation. The essential feature of this assessment is that the force production capacity of each finger (digits II to V) is registered in two contexts. In the first, force is applied by only one finger at a time (e.g., the index finger). In the second, force is applied by all four fingers simultaneously. The multifinger force deficit (MFFD) expresses the magnitude of the force that is applied by each finger when it is used in combination with the other fingers, *relative* to that generated when it is used in isolation. An individual for whom the sum of the forces generated by the four fingers in the multifinger condition is 40% of the sum of the forces produced by the fingers in their respective single-finger conditions, is deemed to have a greater MFFD than an individual for whom the corresponding figure is 60%. As the measure is relative, the absolute level of force that can be generated (by any finger) has no bearing on the magnitude of the deficit that is calculated. It is thus insensitive to the influence of morphometric factors that contribute to individual differences in conventional grip strength assessments. The MFFD is larger in older persons than in the young[14–16] and in those who have incurred brain damage following stroke.[17] Since it can be interpreted as a measure of neural sufficiency, it has been argued that the MFFD provides a candidate marker of incipient cognitive decline.[12]

During ageing, diffuse degenerative processes affecting muscles, motoneurons, and the CNS lead to a diminution of the force that can be generated during voluntary contractions. This is accompanied by an even faster decline in the facility to produce force rapidly.[18] Although attributable in part to a disproportionate atrophy of fast-twitch muscle fibres and reductions in the contractile velocity of single muscle fibres, deficiencies in central drive also play a determining role.[19] The rate at which force can be generated therefore provides a more sensitive measure of age-related changes in neural sufficiency than force magnitude.[20] Consistent with this supposition, age-dependent (60–81 vs. 21–37 years) differences in the maximum rate of force development (η^2 = 0.51) recorded in a grip task (engaging digits II to IV together) are markedly larger than differences in maximum level of force (η^2 = 0.09).[21] It is therefore hypothesised that a measure of the MFFD that is derived from the maximum rate at which force is generated will be more sensitive to individual differences in cognitive function, than a MFFD calculated from the maximum level of force.

The present report provides a test of this proposition, based on a convenience sample. The data were obtained in the context of a study that had a primary focus on adaptations to a resistance training program. Prior to the commencement of training, the participants were assessed using multifinger grip dynamometry. They also completed the Montreal Cognitive Assessment (MoCA).[22] The MoCA encompasses several cognitive domains, including short-term memory, visuospatial ability, executive functioning, attention, concentration and working memory, verbal fluency, orientation to time and place. It has good construct validity[23] and a sensitivity of 77-96% for mild cognitive impairment (MCI).[24] The internal consistency of the MoCA is reasonable, with a Cronbach alpha of 0.83 for the standardized items.[22]

2 | MATERIALS AND METHODS

2.1 | Participants

Recruitment was undertaken via advertisements in Parish newsletters and on noticeboards in Dublin City and County Dublin. Fifty-six respondents were first screened by telephone to assess eligibility. A medical history questionnaire was administered to establish whether there was evidence of: neurodegenerative disease, a history of previous neurological events (e.g., stroke), use of medications known to affect neural plasticity, difficulty using the hands or restricted movement of hands due to a diagnosed condition such as arthritis, or other age-related pathologies. The 26-point telephone version of the Mini Mental State Examination (MMSE) was used to identify and exclude individuals with discernible cognitive impairment. Volunteers

were required to be right-handed by self-declaration, and over 66 years of age. Twenty-seven took part in the study (10 females, 17 males). The median age was 71.5 years (range 66-87). All participants provided written informed consent to procedures approved by the Trinity College Dublin School of Psychology Research Ethics Committee (SPREC112018-06). The most recent iteration of the Declaration of Helsinki (2013) states, "Every clinical trial must be registered in a publicly accessible database before recruitment of the first subject". Excepting this requirement, all testing was conducted in accordance with the Declaration of Helsinki.

2.2 | Procedure

Height and weight were first recorded, followed by completion of the Edinburgh Handedness Inventory.[25] The MoCA was then administered. A standard assessment of grip strength (three attempts with each hand) was undertaken using a Jamar Plus Digital Hand Dynamometer. Participants then performed the Timed Up-and Go.[26] The 9 hole peg test[27] was carried out following.[28] The results of these additional assessments of motor function are not included in the present report.

2.3 | Multifinger dynamometry

Participants sat adjacent to a table, with their hand and forearm resting on a fabric covered board, palm facing down. The flexion angle of the elbow was approximately 90 degrees. (Figure 1). A piezoelectric sensor (Model FX190, compression load cell (Measurement Specialties Inc.) was placed under the finger pad of each digit (II to V), and affixed to the board using Velcro. The upper surface of each sensor was covered with sandpaper to increase contact friction. The positions of the sensors were adjusted to accommodate individual variations in hand and finger anatomy. A cloth covered Styrofoam hemi-sphere was placed under the palm to support the hand. The size of hemi-sphere that was most comfortable for each participant was established prior to testing.[14] The non-testing arm rested naturally on the opposite thigh. The sensor signals were amplified (BIOPAC, DA100C) and digitised at 200 Hz with 16-bit resolution (National Instrument, BNC-2090A). The control of data acquisition and cue presentation was implemented via custom MATLAB routines. The sensors were calibrated prior to testing using precision masses (1kg, 2kg, 3kg, 4kg, and 5kg).

The assessment protocol comprised instances in which a single finger applied force, and others in which all four fingers were to be used together to apply force. The participant was asked to exert as much pressure as possible on the sensor using the designated finger (s), without lifting the other fingers. The advice was that in single finger conditions, they were to ignore any pressure that they might be exerting with other fingers, and to focus on the application of force by the designated finger. At the start of each trial, an audio command (speech synthesised in an Irish female voice) indicated the finger or fingers to be used: “Index finger”, “Middle Finger”, “Ring Finger”, Little Finger”, or “All Fingers”. Thereafter a 500 Hz tone (1 s duration) signalled that the participant was to apply force. They were asked to continue generating force for 5 seconds. Once five seconds had elapsed, a positive feedback sound indicating the end of the trial was generated. Each of three assessment blocks consisted of 10 trials – two in each of the 5 different conditions. The order in which the conditions were presented within each block was randomised. A rest period of one-minute was provided between successive blocks. In order to familiarise the participants with the task, one block of ten practice trials was undertaken.[14] Both the left and right hand were assessed, in an order of testing that was counterbalanced across participants.

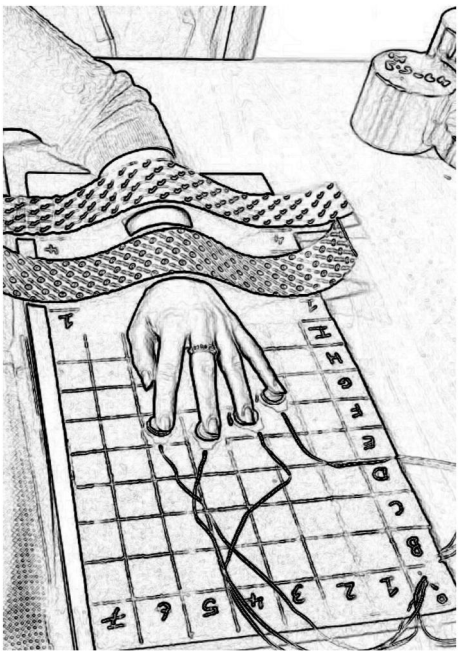

FIGURE 1 Multifinger dynamometry was implemented using four force transducers (each in the style of a “button”) placed on a flat surface. Downward pressure was applied upon each transducer by a single finger.

2.4 | Data processing

Level of education is one of the variables considered in the fully adjusted norms for the MoCA.[22] In the present study, this was scored in accordance with the Operational Manual Guidelines for classifying national education programmes and related qualifications[29] and with reference to the Irish National Framework of Qualifications (NFQ).[30]

Due to a technical malfunction that was undetected during the testing session, the data from one participant could not be used. The authors independently inspected visually all finger force recordings with the aim of identifying trials on which the finger(s) engaged by the participant were not in accordance with the instruction given. Any such trials (34 of 1248 trials) were excluded from analysis. Force

time series were low-pass filtered digitally at 6 Hz with a second-order, dual-pass Butterworth filter. Differentiation to obtain the rate of force application was by estimation of the slopes of five-point first order polynomials fitted to the force time series. For each trial, the maximum force applied by each finger (N), and the maximum rate of force (Ns^{-1}) was identified.

Following,[13] for each participant, the sum of the median (across trials) maximum force values recorded for the four individual digits in the multifinger condition, was expressed as a proportion of the sum of the (median) maximum force values recorded for each digit when it was used in isolation. The magnitude of the MFFD was obtained for each participant by subtracting this value from 1 (Figure 2). This formula cannot be extended logically to the rate-of-force MFFD. That is, by assigning as the numerator the sum of the maximum rates of force obtained for the four digits. The rate-of-force MFFD (rofMFFD) was therefore calculated by first expressing for each finger the (median) maximum rate of force generated in the multifinger condition, as a ratio of the the (median) maximum rate of force generated when that finger was used in isolation. The mean of the four ratios thus generated (i.e., one for each finger) was subtracted from 1 to obtain the rofMFFD for the participant (Figure 2). Although the formulae are related, it should be noted that for any given variable, the ratio of sums (used in this case for the MFFD) will not generally be equal to the average of ratios (used in this case for the rofMFFD) (for example,.[31]) They also have somewhat different statistical properties.[32]

2.5 | Statistical analysis

All analyses were implemented in R.[33] The MFFD and the rate-of-force MFFD were first computed separately for the left and right hands. For each variable, a robust inferential test of equivalence was conducted using the rtost function available via the "equivalence" package. Epsilon, which corresponds to the equivalence margin, defines the magnitude of difference below which the values for the left and right hands may be considered indistinguishable. Since there were no quantified predictions concerning the hand differences considered here, it was necessary to use a subjective justification of the smallest difference likely to be of interest. A value of 0.1 for epsilon appeared reasonable to the authors and was adopted in each case. Using this value, with respect to both the MFFD ($p = 0.003$) and the rate-of-force MFFD ($p = 0.009$), the left and right hand were deemed to be equivalent. Additional steps were taken to confirm that the subjective justification of epsilon produced equivalence test outcomes in accordance with other means of gauging the magnitude of the differences between the hands. Effect sizes for robust tests of difference (Yuen-Welch Test) were 0.12 for the MFFD and 0.01 for the rofMFFD. Both estimates were within the interval (0 – 0.15) that, for this test, defines a small effect size.[34] The mean of the values obtained for the left and right hand of each participant were therefore used in the subsequent analyses. The Laterality Quotient (LQ, derived from the

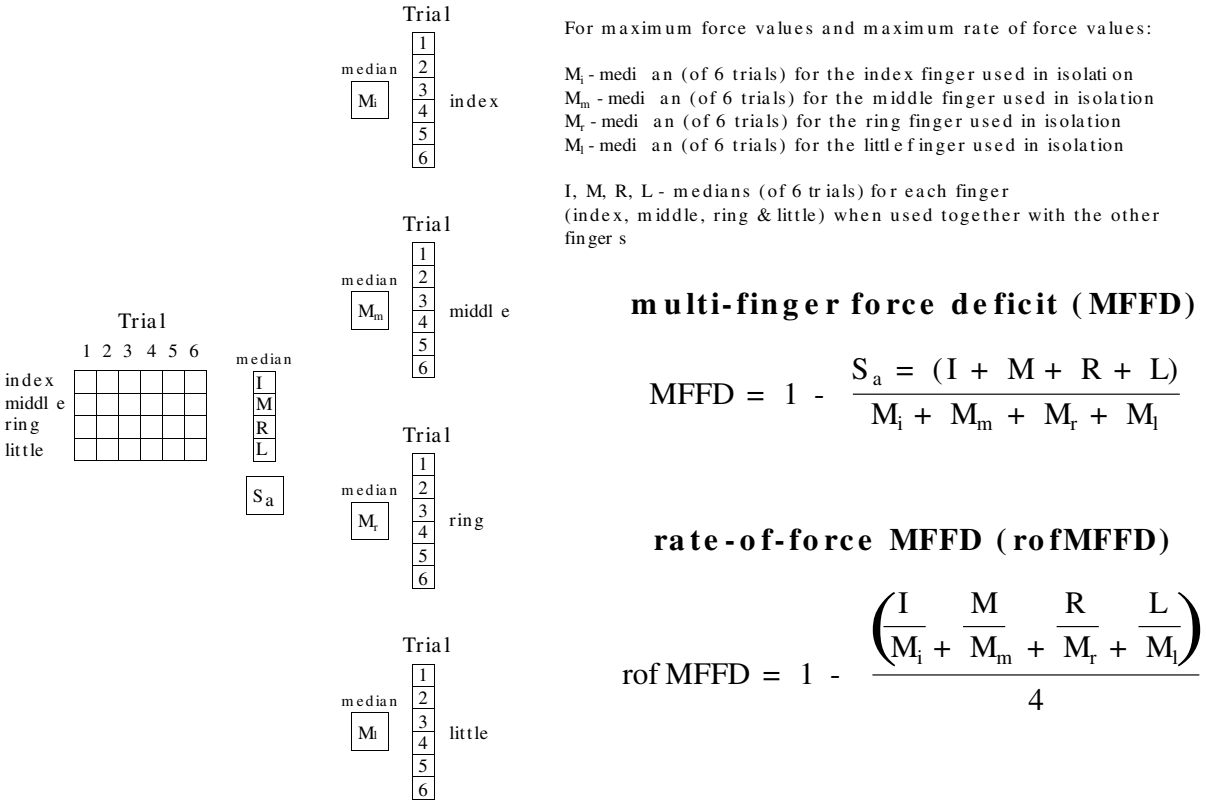

FIGURE 2 Schematic representation of the means by which the multi-finger force deficit (MFFD) and the rate-of-force MFFD (rofMFFD) were calculated.

Edinburgh Handedness Inventory) was available for inclusion as a covariate.

Both the MFFD and the rofMFFD are ratio measures. As these have disagreeable statistical properties (for example,[35]) robust statistical analysis methods were applied. A generalized partial rank correlation,[36] implemented via the taba package, was used to determine the degree of monotonic association between the MoCA and, respectively, the MFFD and the rofMFFD. With respect to the MoCA, age and ISCED classification were included as covariates. For the MFFD and rofMFFD, the covariates were age and LQ. As the motivating hypotheses specified negative relationships between the MoCA, and the MFFD and rofMFFD respectively, one-tailed tests were indicated.

Confidence intervals for the generalized partial correlation coefficients were calculated using a Fisher-Transformation. It has been demonstrated that for samples smaller than 30, this method compares favourably with bootstrapped confidence intervals.[37]

3 | RESULTS

The final sample consisted of 26 participants (Table 1). The range of MoCA scores was 21-29 (median = 26). The range of the MFFD was 0.12 to 0.66 (median = 0.43). The range of the rofMFFD was 0.11 to 0.59 (median = 0.44) (Figure 3). Notwithstanding the similarity in their ranges, the MFFD and rofMFFD differed in respect of covariate-adjusted association with the MoCA (Figure 4). The generalized partial rank correlation between the MFFD and the MoCA was -0.11 (p = 0.308 (one-tailed), -1 – 0.23 (95% c.i.)). That between the rofMFFD and the MoCA was -0.38 (p = 0.035 (one-tailed), -1 – -0.06 (95% c.i.)).

The formula used to calculate the rofMFFD (Figure 2) has been used in some cases to derive the MFFD (e.g.,.[15,16]) In recognition of the possibility that the means of calculation could have had a bearing on the magnitude of the association that was observed, we conducted an additional analysis, for which the MFFD was generated using the formula applied to the rofMFFD values (i.e., as per.[15,16]) The generalized partial rank correlation between this measure of the MFFD and the MoCA did not differ from zero (p = 0.50 (one-tailed), -1 – 0.33 (95% c.i.)).

TABLE 1 Summary of variables included in the analyses.

Participant	Age (years)	ISCED	LQ	MocA	MFFD	rofMFFD
100	66.3	3	100	25	0.66	0.59
101	73.5	1	90.9	25	0.44	0.39
102	69.7	2	50	23	0.44	0.47
103	68.2	5	81	28	0.2	0.11
104	72.2	4	81.8	27	0.49	0.39
105	76.4	2	100	27	0.47	0.44
106	67.3	6	100	22	0.38	0.42
107	74.5	2	81.8	26	0.47	0.5
108	67.2	4	75	26	0.54	0.49
109	67.3	3	91.7	25	0.5	0.43
112	80	3	91.7	24	0.39	0.44
113	85.4	6	16.7	27	0.56	0.54
115	87	4	66.7	21	0.32	0.33
116	71.4	3	100	26	0.18	0.33
117	79.2	5	91.7	24	0.56	0.56
118	78.9	6	91.7	29	0.48	0.42
119	67.6	4	91.7	26	0.12	0.11
120	67.1	6	100	29	0.42	0.41
121	68.4	4	58.3	28	0.43	0.47
122	82.2	1	96.2	25	0.47	0.5
123	69.7	4	100	25	0.4	0.47
124	82.4	5	44	29	0.39	0.38
125	72.1	4	100	27	0.35	0.47
126	69.3	5	96	23	0.46	0.53
127	69.5	5	41.7	28	0.41	0.22
128	74	5	96.7	26	0.3	0.28

ISCED: Level of education scored in accordance with the ISCED Operational Manual Guidelines for classifying national education programmes and related qualifications[29]; LQ: Laterality Quotient, calculated using the Edinburgh Handedness Inventory[25]; MocA: score on the Montreal Cognitive Assessment[22]; MFFD: multifinger force deficit; rofMFFD: rate-of-force MFFD.

4 | DISCUSSION

In relatively few instances (e.g.,[40,41]) have reliable associations between conventional measurements of grip strength and MoCA scores been obtained.[42] failed to do so when undertaking a pooled analysis of two studies comprising 152 participants (see also.[43–46]) Including data from 5980 adults enrolled in the Irish Longitudinal Study of Ageing (TILDA) (mean ± SD age of 62.29 ± 8.21 years), and a locally recruited sample of 250 adults (mean ± SD age of 73.12 ± 9.06 years),[47] reported a weak but statistically significant (i.e., p < 0.05) linear relationship between grip strength and MoCA, when age, sex and education were included as covariates. As standardized beta coefficients and partial correlations can be treated as being interchangeable with r, regardless of the number of covariates that have been included,[48] it is possible to compare the size of the effects obtained in the present study, with those generated by Hooyman and colleagues. The beta coefficients obtained for the TILDA sample (0.052, 0.037 – 0.061 (95% c.i.)), and for the locally recruited sample (0.03, 5.1e-5 – 0.071 (95% c.i.)), are considerably smaller (see also[41]) than the (absolute) magnitude (0.38) of the generalized correlation between the rofMFFD and the MoCA reported herein. Indeed, the (absolute) magnitude (0.11) of the generalized correlation between

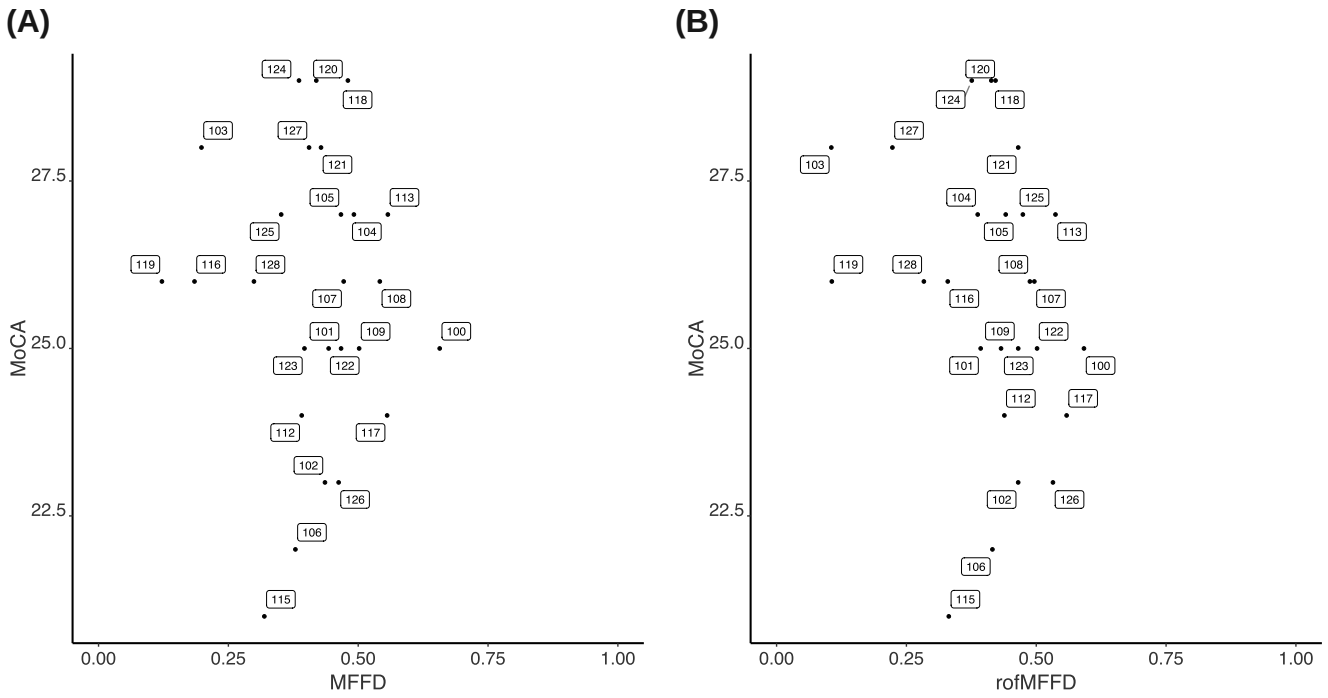

FIGURE 3 A. MoCA scores plotted with respect to the MFFD. The value of the correlation representing the degree of (robust) monotonic association between these variables, without the inclusion of covariates, was -0.09. B. MoCA scores plotted with respect to the rofMFFD. The value of the correlation representing the degree of (robust) monotonic association between these variables, without the inclusion of covariates, was -0.23. In both panels, the labels shown for individual datapoints correspond to the participant identifiers (IDs) given in Table 1.

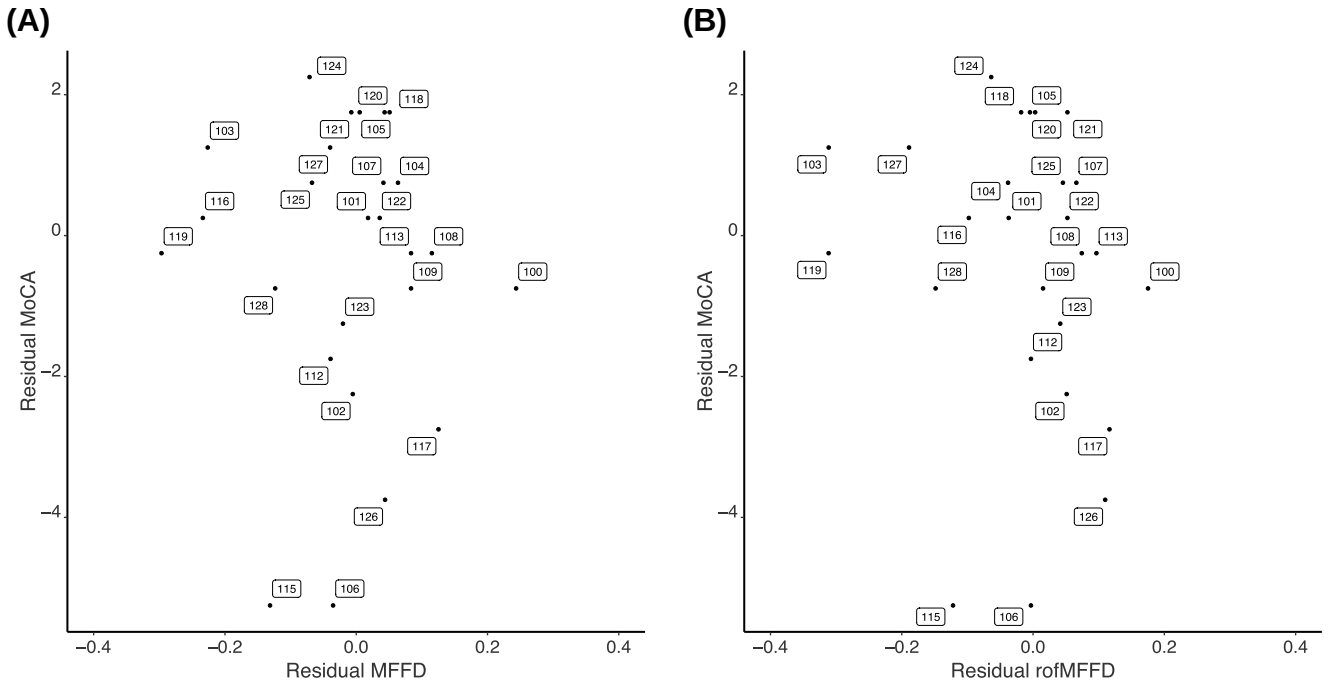

FIGURE 4 It is generally recommended that, in respect of the scatter of partial correlations, partial regression plots (residuals of Y on the corresponding covariates versus residuals of X on the corresponding covariates) be used.[38] For these illustrative purposes, a rank-based estimation model (implemented using the Rfit package in R[39] was used to generate the residuals. A. The residuals for the MoCA (i.e., which partial out the variation attributable to age and ISCED) plotted with respect to the residuals for the MFFD (i.e., which partial out the variation attributable to age and LQ). B. The residuals for the MoCA (i.e., which partial out the variation attributable to age and ISCED) plotted with respect to the residuals for the rofMFFD (i.e., which partial out the variation attributable to age and LQ). In both panels, the labels shown for individual datapoints correspond to the participant identifiers (IDs) given in Table 1.

the MFFD and the MoCA also exceeds the magnitude (and lies outside the confidence intervals) of the beta coefficients reported by.[47] It seems reasonable to conclude therefore, that the rofMFFD is more strongly associated with MoCA scores than conventional assessments of grip strength.

The MoCA was designed with a specific purpose in mind – to be deployed as a screening tool to detect individuals with MCI.[22] Used in this way, as tool with which to assess global cognition, it has stood the test of time.[49] Although its structure reflects an intent to sample from a broad range of cognitive domains, the sub-test scores do not associate strongly with those obtained using domain-specific test batteries.[50,51] It might therefore be argued that the content validity of the rofMFFD (or MFFD) as a marker of incipient cognitive decline should be established using test batteries that operationalise elements of cognition such as executive function, processing speed, attention, and memory.[12] In respect of the concurrent validity of the rofMFFD (or MFFD) however, the use of a measure of global cognition, such as the MoCA, appears valid. Indeed, since the rofMFFD may be best employed as part of a diagnostic algorithm (e.g.,[52]) to increase the efficiency with which a diagnosis of MCI can made (or excluded), it is appropriate to establish the magnitude of its association with an instrument, in this case the MoCA, which is used routinely for this purpose in clinical practice.

Coordinated muscle recruitment, upon which the effective application of force depends, is mediated by the coherent engagement of distributed brain networks. Accordingly, age-related decreases in the capacity to apply grip force are associated with a broad spectrum of markers that reflect waning brain health.[8] Areas of the brain and connecting white-matter tracts that regulate various facets of cognition and motor function overlap extensively.[53–55] Since they rely, at least in part, on common neural systems, the neurodegenerative processes that are a feature of ageing should have corresponding effects on cognitive function and the ability to recruit muscles precisely. It may therefore be instructive to examine the extent to which global cognition is related to measures of muscle coordination derived from tasks that share some of the demands imposed upon the CNS by multifinger dynamometry.

Using a pegboard test to assess manual dexterity in a cohort of 2,361 participants (mean age 74.5 years; 721 exhibiting MCI),[56] reported a correlation (r = 0.25, without the inclusion of covariates) with scores on the MMSE. Associations with the MMSE of similar magnitude (r = 0.267 for "placement"; r = 0.143 for "turning") were observed by Soysal Tomruk et al.[57] for 36 healthy individuals (mean age 60.8 years; MMSE 29.5 ± 1.19 SD) who performed two components of the Minnesota Manual Dexterity Test. In the only investigation of which we are aware that permits direct comparison with the results of the present study,[47] estimated a standardised beta coefficient of -0.06 (-0.1 – -0.03 (95% c.i.), n = 250) for the association between MoCA scores and performance on a functional reaching task, when age, sex, education, and grip strength were included as covariates. Based on the limited evidence that is available therefore, the magnitude of the association between the rofMFFD and global cognition, appears to be larger than that obtained for other tasks that require a high degree of muscle coordination.

The task employed in the present study differed from conventional grip dynamometry in the way in which the muscles that actuate the metacarpophalangeal joints and interphalangeal joints were engaged. Age-related differences in the magnitude of the MFFD have been obtained both using the task employed in the present study,[16] and when using one that (like conventional grip strength testing) involves flexion of the interphalangeal joints.[15] The specific demands imposed upon the CNS with respect to muscle recruitment, differ between the two tasks. It is possible therefore, that the degree of association between the rofMFFD (or MFFD) and measures of cognitive function will also vary accordingly.

4.1 | Limitations

This was a small-scale study based on an opportunistic sample. As the statistical power was therefore relatively low, it is possible that the size of the effect obtained is an inaccurate estimate of the magnitude of the true effect.[58] The present results do however suggest that additional investigations, conducted on a larger scale, are warranted. It should also be recognised that the MoCA is characterised by undesirable statistical properties arising from the truncated (maximum value of 30) range within which the scores lie. Although any impact of the distributional properties of the MoCA was obviated in the present study through robust statistical techniques (and all scores fell below the theoretical maximum of 30), it remains the case that most indices of global cognition (e.g., MMSE, the Addenbrooke's Cognitive Examination) exhibit ceiling effects, and may thus reduce the sensitivity with which associations with motor function may be detected.

All derivations of the MFFD reported thus far involve the calculation of ratios. The variant adopted herein, which corresponds to that employed by,[13] requires that one ratio be generated. Other variants (e.g.,[15,16]) have been obtained as an average of four ratios. The specific analytical problems arising from the use of ratios have been discussed widely. It has, for example, been noted that the use of ratios can alter the nature of correlations with other variables. Furthermore, the ratio of the means of the numerator and the denominator is not generally equal to the mean of the ratios.[35] Indeed, in the present study, the magnitude of the association with the MoCA depended on whether a single ratio of sums, or the mean of four ratios, was used to generate the MFFD. With respect to the rofMFFD, this measure was generated as the average of four ratios (one for each digit). The single ratio (of sums) formula used for the MFFD cannot be applied logically to the rofMFFD. We adopted robust statistical methods throughout, to protect against potential violation of distributional assumptions arising from the use of ratio measures. Nonetheless, there is scope to investigate further whether the manner that the various MFFD measures are derived, influences the magnitude of association with other variables of interest.

The rofMFFD and the MFFD relate differently to the manner that the single and multifinger tasks unfold in time. It is conceivable that the phase of the action during which the level of applied force is increasing (reflected in the rate of force) is differentiated with respect to attentional demands from the phase during which the maximal level of force is achieved. Any such difference may contribute to the level of association with the MoCA being higher for the rofMFFD than for the MFFD. Since the goal is to detect individual differences in cognitive status, this possibility might be considered a feature of the rofMFFD, rather than a limitation.

5 | CONCLUSION

In this cross-sectional study, it was demonstrated that there is a negative association between the MFFD – when derived from the maximum rate at which force was generated, and scores on the MoCA, which is independent of age and level of education. The stated aspiration for the use of the MFFD in this context, is that it may provide a means of detecting individuals at risk of cognitive decline.[12] The present results suggest that the sensitivity with which it may be able to do so, is enhanced by using the maximum rate of force developed by each finger, rather than the maximum force generated by each finger, as the basis upon which the deficit is calculated.

5.1 | Statements relating to ethics and integrity policies

In respect of this work, the authors received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The authors declare that there are no conflicts of interest. Excepting recordings generated during performance of the force production tasks, all data are provided herein.

AUTHOR CONTRIBUTIONS

Richard G. Carson: Conceptualization, Data analysis, Writing - Original Draft, Writing- Reviewing and Editing. Eimíle Holton: Data collection, Data analysis, Writing- Reviewing and Editing.

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DATA AVAILABILITY STATEMENT

Excepting recordings generated during performance of the force production tasks, all data are provided herein. Upon request, the authors will provide the recordings generated during performance of the force production tasks.

ORCID

Richard G. Carson https://orcid.org/0000-0002-1190-2814

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