NIHR | Policy Research Unit Older People and Frailty

Physical activity - life course trajectories and patterns of strength in the UK

Combined Report

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Final Report

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Contents

Introduction

This combined report outlines work conducted up to 27/01/21, followed by reporting on additional questions asked on 02/02/21. The project aims to:

(i) provide an overview of the existing evidence on the patterns and trends of the UK population levels of strength;
(ii) identify whether there are key ages and sub-populations at which intervention would be most fruitfully targeted;
(iii) identify methods used in the assessment of strength and, based on criteria to be defined during the scoping phase to make recommendations for methods to be used in future population based studies;
(iv) inform further research requirements.

Focus of the scoping searches

Following the meeting held on 7th December 2020, the Older People & Frailty Policy Research Unit has focused scoping on two specific questions:

1. How does strength change over the life-course (using CMOs' age brackets) and
2. How could we look to measure strength across the life-course?

Defining strength for the purpose of this report

Muscular strength refers to the ability to exert a force on an external object (e.g. lifting a weight), but can also refer to the ability to lift one's own body weight. The most commonly accepted method of evaluating muscle strength in a clinical physical examination is the Medical Research Council Manual Muscle Testing (MMT) scale, which involves testing key muscles from the upper and lower extremities against the examiner's resistance, and grading the person's strength on a 0 to 5 scale (1). Commonly tested muscles include upper body (shoulder abductors, elbow flexors, elbow extensors, wrist extensors, finger flexors, hand intrinsics) and lower body (hip flexors, knee extensors, dorsiflexors, great toe extensor, and plantar flexors).

In addition to the Medical Research Council MMT scale, a large number of tests of upper and lower body muscle strength exist in the public health and medical literature. Hand grip strength has been shown to be a powerful indicator of future disability, morbidity and mortality (2), in all populations (young people (3), adults (4), and older adults (5, 6)). Lower limb power is associated with functional status (7) and functional ability (8). As such, measuring, improving and maintaining lower limb strength is important for undertaking activities of daily living and thus maintaining independence. Lower limb performance tests, such as the 30-second chair stand test, five times sit-to-stand test and the Timed Up and Go test (TUG) can detect early declines in functional status, as they are able to differentiate between different levels of functional ability (9).

In this scoping exercise, we have sought to identify measures of muscle strength including, but not limited to, the tests above. We have searched in cohort studies, surveys and through using the 'tests and measures' field in the PsycInfo database.

Scoping Methods for Question 1: How does strength change over the life-course (using CMOs' age brackets)

One of our colleagues within the OPFPRU is a co-author of a 2014 paper on grip strength across the life-course, Dodds et al. (10), which we use as a starting point.

A scoping search was then conducted in MEDLINE using the following terms:

1. Thesaurus headings for muscle strength or hand strength, where these are the focus of the article, AND
2. The term 'strength' within two words of terms measure, test, assess (using truncation to pick up any variants of these terms) in the abstract, AND
3. Lifecourse OR life course OR longitudinal.

Using thesaurus headings to retrieve papers that were indexed with terms for muscle strength or hand strength ensured that we retrieved papers that were focused on these and not papers that mentioned the measures in passing.

Studies that did not use handgrip strength as a measure, or told us something about age-related nature or change over time in handgrip strength, or looked at handgrip strength in children were examined in full text (n=29).

Results of scoping for Question 1: How does strength change over the life-course (using CMOs' age brackets)

Dodds et al. (10) found that hand grip peaks in early adulthood and is maintained until mid-life, whereafter it declines. Males were on average stronger than females from adolescence onwards: males' peak median grip was 51 kg between ages 29 and 39, compared to 31 kg in females between ages 26 and 42. Weak grip strength, defined as strength at least 2.5 SDs below the gender-specific peak mean, increased sharply with age, reaching a prevalence of 23% in males and 27% in females by age 80.

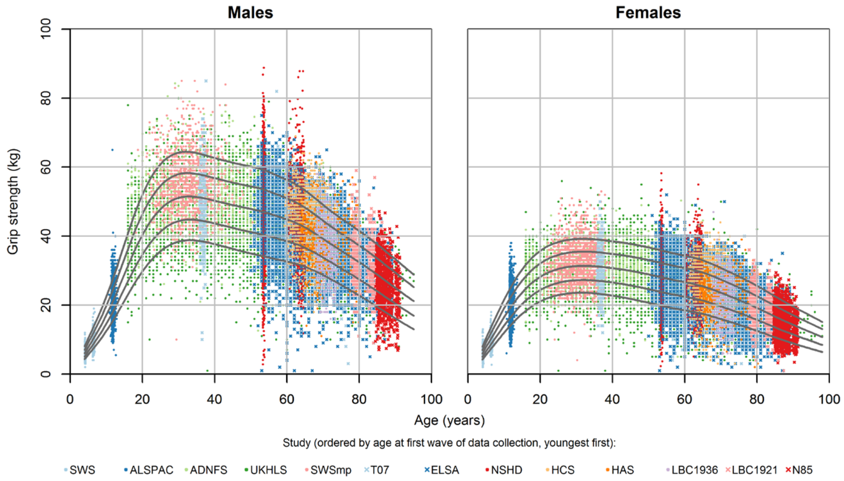

Figure 1. Cross-cohort centile curves for grip strength (10).
Centiles shown 10, 25th, 50th, 75th and 90th. ADNFS Allied Dunbar National Fitness Survey, ALSPAC Avon Longitudinal Study of Parents and Children, ELSA English Longitudinal Study of Ageing, HAS Hertfordshire Ageing Study, HCS Hertfordshire Cohort Study, LBC1921 and LBC1936 Lothian Birth Cohorts of 1921 and 1936, N85 Newcastle 85+ Study, NSHD Medical Research Council National Survey of Health and Development, SWS Southampton Women's Survey, SWSmp mothers and their partners from the SWS, T-07 West of Scotland Twenty-07 Study, UKHLS Understanding Society: the UK Household Panel Study. (Reproduced from Dodds et al (10))

Using the methods described above, our scoping searches identified *four further studies* from 29 results from the MEDLINE search. These studies include a variety of different populations, but only two included measures other than hand grip strength.

A study using data from 190 participants of the Baltimore Longitudinal Study of Aging (BLSA) aged from 32 to 93 years, showed that *deterioration in ankle function during customary walking begins in middle-age* (11). Differences in the maximum walking speed and ankle range of motion between middle-age and old-age were explained by knee strength, with *poorer performance by those with lower knee strength*.

We found one study looking at *patterns of hand grip strength and the associations with age and socio-economic position (SEP)* using the UK Household Longitudinal Study data (12). The authors concluded that the SEP differences in age and level of peak grip strength could be indicative of decline in muscle strength beginning earlier (age 33yrs as opposed to 35yrs), and from a lower base (29.3 kg as opposed to 30.2 kg), for disadvantaged groups. This could impact on the capacity for healthy ageing for those from disadvantaged backgrounds.

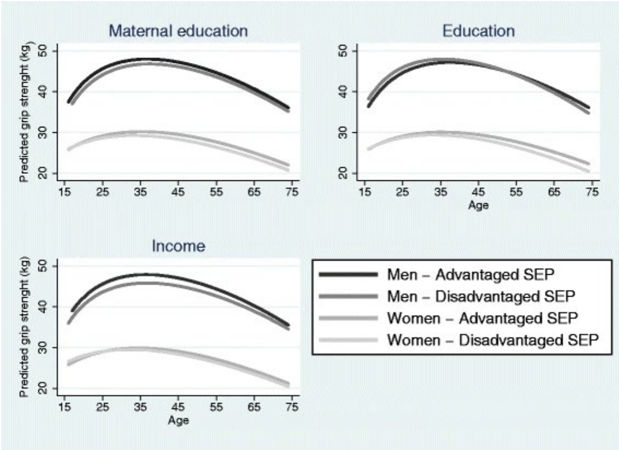

Figure 4: Trajectory of grip strength for men and women by disadvantaged or advantaged SEP (12).

Predicted probabilities from data up to age 75 for men and women obtained from regressing fractional polynomial age terms on grip strength stratified by disadvantaged and advantaged SEP on maternal education, own education and income.

A study using the German Socio-Economic Panel dataset (2006-2014) showed that *peak mean values of handgrip strength are reached in men and women in their 30s and 40s* after which handgrip strength declines in linear fashion with age (13). This aligns with the findings of the Dodds et al. study (10).

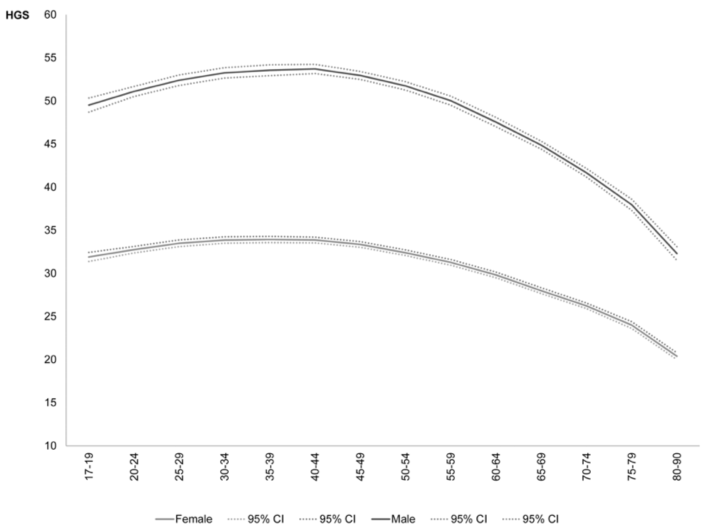

Fig 5. Life course profiles of handgrip strength for German women and men (13)

Predicted values for each age group from a regression of HGS on age, age², height, and height². The graph shows a peak mean value for men of about 54 kg and for women of about 34.5 kg. In the age group 65–69, mean values drop to 44 kg for men and 28 kg for women—values that lie about 1 SD below the peak values.

We found a study using data from 1,890 men and women aged 30 years or more at baseline, participating in the population-based Mini-Finland Health Examination

Survey (1978-1980) with *repeated handgrip strength measurement* (14). The authors found that in men aged 31-41 years, the annual decrease in handgrip strength was approximately 0.36 kg. After that, the decrease accelerated and the rate of loss stabilised around the age of 75 years, being approximately 0.74 kg per year. In women, respectively, prior to 45 years, the annual decrease was approximately 0.2 kg and after age 80 years approximately 0.41 kg per year.

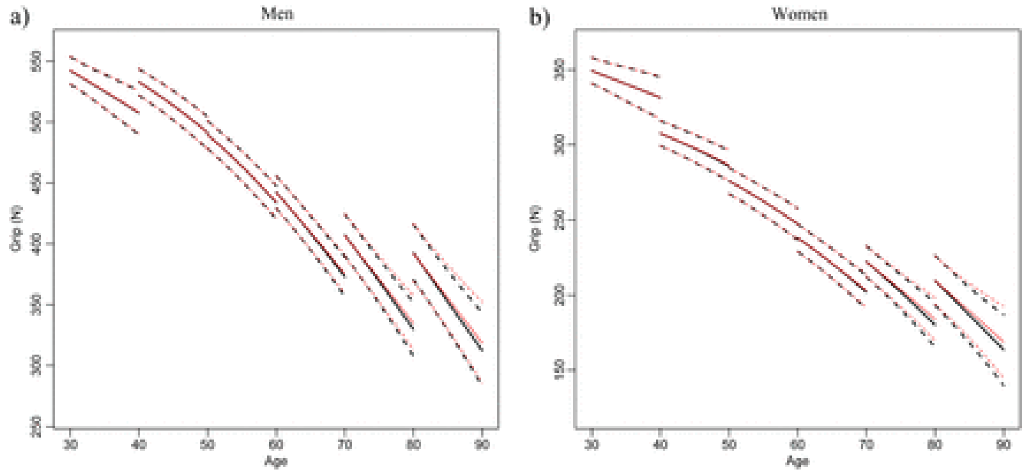

Figure 6. Posterior expectations of the longitudinal trajectories in handgrip strength according to baseline age decade (14)
*Red lines indicate crude values and black lines values in which the effect of right censoring due to deaths was accounted for and their 95% credible intervals (dashed lines). The Mini-Finland Health Survey 1978–1980, The Health 2000 Survey 2000–2001, and Mortality Data 1978–2008. (**a**) Men and (**b**) women.*

Summary: Through our scoping, we found only one study that used measured other than hand grip strength to measure change in muscle strength over time. This was a lower body measure (knee strength) (11). Three studies were found that measured changes in hand grip strength over time, with results aligning with those in the Dodds et al., 2014 study (10).

Scoping methods for Question 2: How could we look to measure strength across the life-course? Which measures may be appropriate?

To search for measures of strength we used the following sources:

- Cohort studies included in the Cohort and Longitudinal Studies Enhancement Resources (CLOSER) consortium's Discovery tool.
- Cohort studies included in the Dodds et al.(10) analysis.
- The International Journal of Epidemiology Cohort Profiles search.
- Studies and surveys identified in Moore and Hanratty, 2013 (15).
- Studies and surveys identified in Clouston et al., 2013 (16).
- Cohort identified through PRU team knowledge and expertise.
- Studies and surveys identified in the scoping for Question 1.

- PsycINFO and COSMIN systematic review databases. We used PsycINFO because it contains a 'tests and measures' field and COSMIN because it focuses on outcome measures.

For PsycINFO, we looked at the 'tests and measures' field 1987 to Jan 2021 and searched for the following to retrieve a list of tools that had been used in articles that focused on assessing strength:

1. Thesaurus heading for physical strength, where this is the focus of the article (this is the nearest equivalent to the MEDLINE headings used above)
2. The term 'strength' within two words of terms measure, test, assess (using truncation to pick up any variants of these terms) in the title.

For the COSMIN systematic review database, we searched 'strength' and screened 109 titles. Identified strength tests were de-duplicated against those identified in PsycINFO.

Results of scoping for Question 2: How could we look to measure strength across the life-course?

In total, 99 cohort studies/panel surveys were examined to search for measures of strength. Studies searched included data from children (5-18), adults (19-64) and older adults (65+). The measures of strength identified are listed below.

- Measures of strength were identified in 64/99 studies.
- The most common measure was **hand grip strength**, which was included in 53/64 studies.
- **Hand grip strength for children** was measured in three studies: The Avon Longitudinal Study of Parents and Children (ALSPAC) at age 17yrs; the Southampton Women's Survey (SWS) at ages 4yrs, 6yrs and 8yrs; the UK Household Longitudinal Study (UKHLS) at age 18+; and the Allied Dunbar National Fitness Survey from age 16+.
- Other measures of **strength for children** were **muscle mass by DXA scan, muscle mass by bioelectric impedance analyser**, **knee muscle strength** and the **Functional Strength Assessment.**
- **Quadriceps strength**, measured by the MMT strength system was measured in two studies, with adults and older adults.
- The Timed up and go test **(TUG)** was used in five studies, with adults and older adults.
- The **five times sit-to-stand** (chair rises) test was used in 17 studies, one with adolescents aged 15 and older, the others with adults and older adults.
- The **10 times sit-to-stand** (chair rises) was used in four studies, with adults and older adults.

- **Muscle mass[1] by DXA scan** was measured in four studies, one of these including children as well as adults.
- **Skeletal muscle mass** was estimated using a **bioelectric impedance analyser** in two studies, one with children and the other with adults only.
- **Lower leg extension power**, using a power rig, was measured in two studies, both including adults only.
- **Knee muscle strength** was measured in two studies, one including children and adults, and the other with adults and older adults.
- **Maximal muscle force** was measured by a two-legged counter-movement jump on a force plate in one study. This study included adults only.

Details of the strength measures and related studies are included in Table 1. The resources required to conduct these assessments of strength are included in Table 2.

[1] Note that *muscle mass* does not necessarily provide us with the same marker of muscle quality as *muscle strength*. See Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster BH, Kritchevsky SB, et al. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. J Gerontol A Biol Sci Med Sci 2006;61:72-7.

Table 1: Measures of strength from Cohort Studies / Surveys

Strength measure	Study / survey	CMO Population Group	Source
Hand grip strength	The Hertfordshire Cohort Study	19-64; 65+	https://discovery.closer.ac.uk/
	1970 British Cohort Study (BCS70)	19-64	https://discovery.closer.ac.uk/
	Avon Longitudinal Study of Parents and Children (ALSPAC)	5-18; 19-64	https://discovery.closer.ac.uk/
	Medical Research Council National Survey of Health and Development (NSHD)	19-64	https://discovery.closer.ac.uk/
	Southampton Women's Survey (SWS)	5-18; 19-64	https://discovery.closer.ac.uk/
	Understanding Society: the UK Household Longitudinal Study (UKHLS)	5-18; 19-64; 65+	https://discovery.closer.ac.uk/
	Allied Dunbar National Fitness Survey	5-18; 19-64; 65+	Dodds et al. 2014
	Lothian Birth Cohorts of 1921 and 1936	65+	Dodds et al. 2014
	Newcastle 85+ Study	65+	Dodds et al. 2014
	The English Longitudinal Study of Ageing (ELSA)	19-64; 65+	Dodds et al. 2014

	The European Prospective Investigation of Cancer (EPIC) - Norfolk	19-64; 65+	Dodds et al. 2014
	The Irish Longitudinal Study on Ageing (TILDA)	19-64; 65+	Dodds et al. 2014
	West of Scotland Twenty-07 Study	19-64	Dodds et al. 2014
	Doetinchem Cohort Study	19-64; 65+	IJE Cohort Profiles
	The Copenhagen Aging and Midlife Biobank (CAMB)	19-64	IJE Cohort Profiles
	The Framingham Heart Study (FHS)	19-64; 65+	IJE Cohort Profiles
	The Health2006 cohort	19-64; 65+	IJE Cohort Profiles
	The Hong Kong Osteoporosis Study (HKOS)	19-64; 65+	IJE Cohort Profiles
	The Integrated Women's Health Programme (IWHP)	19-64; 65+	IJE Cohort Profiles
	The Longitudinal Aging Study Amsterdam (LASA)	19-64; 65+	IJE Cohort Profiles
	The Prospective Epidemiological Risk Factor (PERF) Study	19-64; 65+	IJE Cohort Profiles
	The Study of Health in Pomerania	19-64; 65+	IJE Cohort Profiles

	The UK Adult Twin Registry (or TwinsUK Registry)	19-64; 65+	IJE Cohort Profiles
	The Whitehall II Study	19-64; 65+	Moore & Hanratty, 2013
	Ages Reykjavik	65+	Team identified
	Canadian NuAGE	65+	Team identified
	The China Health and Retirement Survey (CHARLS)	19-64; 65+	Team identified
	European Prospective Osteoporosis Study (EPOS)	19-64; 65+	Team identified
	European Vertebral Osteoporosis Study (EVOS)	19-64; 65+	Team identified
	Indonesia Family Life Survey (IFLS)	19-64; 65+	Team identified
	Japanese Study of Aging and Retirement (JSTAR)	19-64; 65+	Team identified
	Korean Longitudinal Study of Aging (KLoSA)	19-64; 65+	Team identified
	Leiden 85+	65+	Team identified
	LiLacs NZ	65+	Team identified

	The Mexican Health and Aging Study (MHAS)	19-64; 65+	Team identified
	UK Biobank	19-64; 65+	Team identified
	US Health and Retirement Study (HRS)	19-64; 65+	Team identified
	Health ABC Study (US)	65+	Clouston et al, 2013
	Survey of Health Ageing and Retirement in Europe	19-64; 65+	Clouston et al, 2013
	Hispanic EPESE (US)	65+	Clouston et al, 2013
	Chinese University of Hong Kong Study	65+	Clouston et al, 2013
	Rush Memory and Aging Study (US)	19-64; 65+	Clouston et al, 2013
	Honalulu-Asia Aging Study	19-64; 65+	Clouston et al, 2013
	Queanbeyan Community Study	65+	Clouston et al, 2013
	Swedish Adoption/Twin Study of Aging	19-64; 65+	Clouston et al, 2013
	Adult Changes in Thought Study (US)	65+	Clouston et al, 2013

	Victoria Longitudinal Study (Canada)	19-64; 65+	Clouston et al, 2013
	Women's Health and Aging Study (US)	65+	Clouston et al, 2013
	Interdisziplinäre Längsschnittstudie des Erwachsenenalters (Germany)	19-64	Clouston et al, 2013
	MacArthur Research Network on Successful Aging Community Study (US)	65+	Clouston et al, 2013
	German Socio-Economic Panel	19-64; 65+	Question 1 Scoping
	Mini-Finland Health Examination Survey	19-64; 65+	Question 1 Scoping
	Baltimore Longitudinal Study of Aging (BLSA)	19-64; 65+	Question 1 Scoping
Quadriceps strength (MMT strength system)	Hertfordshire Cohort Study	19-64; 65+	https://discovery.closer.ac.uk/
	The Geelong Osteoporosis Study (GOS)	19-64; 65+	IJE Cohort Profiles
Timed Up and Go (TUG)	Hertfordshire Cohort Study	19-64; 65+	https://discovery.closer.ac.uk/
	Medical Research Council National Survey of Health and Development (NSHD)	19-64	https://discovery.closer.ac.uk/
	The Irish Longitudinal Study on Ageing (TILDA)	65+	Dodds et al. 2014

	Newcastle 85+ Study	65+	Dodds et al. 2014
	The Geelong Osteoporosis Study (GOS)	19-64; 65+	IJE Cohort Profiles
Five times sit-to-stand	The Hertfordshire Cohort Study	19-64	https://discovery.closer.ac.uk/
	The English Longitudinal Study of Ageing (ELSA)	19-64; 65+	Dodds et al. 2014
	The European Prospective Investigation of Cancer (EPIC) - Norfolk	19-64; 65+	Dodds et al. 2014
	Healthy Aging Longitudinal Study in Taiwan (HALST)	19-64; 65+	IJE Cohort Profiles
	The Copenhagen Aging and Midlife Biobank (CAMB)	19-64	IJE Cohort Profiles
	The China Health and Retirement Survey (CHARLS)	19-64; 65+	Team identified
	Indonesia Family Life Survey (IFLS)	5-18; 19-64; 65+	Team identified
	The Integrated Women's Health Programme (IWHP)	19-64; 65+	IJE Cohort Profiles
	Korean Longitudinal Study of Aging (KLoSA)	19-64; 65+	Team identified
	The Longitudinal Aging Study Amsterdam (LASA)	19-64; 65+	IJE Cohort Profiles

	The Whitehall II Study	19-64; 65+	Moore & Hanratty, 2013
	Cognitive Function and Ageing Study (CFAS) II	65+	Team identified
	CFAS Wales	65+	Team identified
	Adult Changes in Thought Study (US)	65+	Clouston et al, 2013
	Nutrition and Successful Aging Cohort Study (Canada)	65+	Clouston et al, 2013
	Hispanic EPESE (US)	65+	Clouston et al, 2013
	MacArthur Research Network on Successful Aging Community Study (US)	65+	Clouston et al, 2013
Ten times sit-to-stand	Medical Research Council National Survey of Health and Development (NSHD)	19-64	https://discovery.closer.ac.uk/
	The European Prospective Investigation of Cancer (EPIC) - Norfolk	19-64; 65+	Dodds et al. 2014
	Doetinchem Cohort Study	19-64; 65+	IJE Cohort Profiles
	Japanese Study of Aging and Retirement (JSTAR)	19-64; 65+	Team identified
Muscle mass by DXA scan	Avon Longitudinal Study of Parents and Children (ALSPAC)	5-18; 19-64	https://discovery.closer.ac.uk/

	The Hong Kong Osteoporosis Study (HKOS)	19-64; 65+	IJE Cohort Profiles
	MrOS Osteoporotic Fractures in Men Study	65+	IJE Cohort Profiles
	The Oxford Biobank (OBB)	19-64	IJE Cohort Profiles
Lower leg extension power	The Health2006 cohort	19-64; 65+	IJE Cohort Profiles
	The UK Adult Twin Registry (or TwinsUK Registry)	19-64; 65+	IJE Cohort Profiles
Skeletal muscle mass estimated by bioelectric impedance analyser	JS High School study (JSHS)	5-18	IJE Cohort Profiles
	Yazd Health Study (YaHS)	19-64; 65+	IJE Cohort Profiles
Knee muscle strength	The Amsterdam Growth and Health Longitudinal Study (AGHLS)	5-18; 19-64	IJE Cohort Profiles
	Baltimore Longitudinal Study of Aging (BLSA)	19-64; 65+	Question 1 Scoping
Maximal muscle force two legged jump on force plate	The Copenhagen Aging and Midlife Biobank (CAMB)	19-64	IJE Cohort Profiles

Table 2: Resource requirements for assessing strength (from cohort studies/surveys)

Strength measure	Equipment	Assessor required	Clinic/lab	Home
Hand grip strength	Hand held dynamometer; chair with arms, or table, for support	Yes	Yes	Yes
Quadriceps strength (MMT strength system)	Hand held dynamometer	Yes	Yes	Yes
Timed Up and Go (TUG)	Chair (standardised height); stopwatch; 5m testing space; cone or other marker	Yes	Yes	Yes
Five times sit-to-stand	Chair (standardised height), stopwatch	Yes	Yes	Yes
Ten times sit-to-stand	Chair (standardised height), stopwatch	Yes	Yes	Yes
Muscle mass	DXA scanner	Yes	Yes	No
Lower leg extension power	Nottingham Power Rig	Yes	Yes	No
Estimated skeletal muscle mass	Bioelectric impedance analyser; scales and height measure; bed; alcohol wipes	Yes	Yes	No
Knee muscle strength	Portable dynamometer	Yes	Yes	Yes
Two legged counter movement jump	Force plate	Yes	Yes	No

Hand grip strength can be measured using a number of different types of dynamometer (17). It can be easily measured, at low cost. The Timed Up and Go test (TUG) (18) is a simple, quick and widely used clinical performance-based measure of lower extremity function. It required few resources and, with sufficient space and a suitable chair[2], can be conducted in a home environment. Similarly the Sit-to-Stand test can be conducted in the home or clinical environment, as long as a suitable chair[2] and a stopwatch are available (19). Both of these tests can also be conducted as 'instrumented' tests, using inertial sensors or smartphone technology

[2] There are methodological issues around the use of chair. A standardised chair of specified height is required [17 inches (43.2 cm) without arms] to ensure accuracy of test. There are also variations in instructions, time period, and whether test measures maximum in time period or time to complete specified number of repetitions.

(see pages 23-24 for more detail). Whilst a portable dynamometer can be used to measure knee strength, it is less feasible as a home-based test (20).

Measures of strength from PsycINFO and COSMIN searches

From the search of the ‘tests and measures’ field on PsycINFO, and the search for test in the COSMIN systematic review database, 62 different measures of strength were identified, for a variety of different population groups. These measures are often from small, experimental studies, as opposed to larger cohort studies. The measures are listed in Table 3.

Table 3: Strength measures identified in PsycINFO and COSMIN database searches

1 kg ball throw	1RM - One-Repetition Maximum
30 Seconds Chair-Stand Test	5-STS - Five times Sit-to-Stand Test [Alias: 5RT - five-repetition sit-to-stand test]
8-Foot Up and Go Test	Arm Curl Test
Arm Press	Assessment of Recruit Motivation and Strength Test
Bent-leg sit-up	Biceps curl
BIS – Bio Impedance Spectroscope	Chair Stand Test
CPE - Colorado Physical Examination scale	Crouch and walk
CS-PFP-10 - Continuous Scale-Physical Functional Performance-10 item test	Force Exertion Measure
Functional muscle power	Functional Strength Measurement
Handgrip strength	Hopping forward (L and R)
Horizontal jump	Isometric mid-thigh pull
Isometric squat	Isometric Strength Assessment
Jumping side-to-side	Lat pulldown
Leg Extension Test	Leg press
Manual Muscle Test	Maximum Voluntary Contractions Measure
Maximum voluntary isometric contraction force	Medical Research Council (MRC) Muscle Scale
MIRS - Muscular Impairment Rating Scale	MIS - Maximal Isometric Strength
MMT - Manual muscle testing	One-leg hop
One-leg/jumping/walking	Partial sit-ups
Performance of Upper Limb Scale	Pinch strength
Plantar flexion	PPB - Physical Performance Battery
PPT - Physical Performance Test (Climb stairs)	Push-ups
Right-angle push-ups	SCT - Stair Climb Test
Senior Fitness Test (Chair stand (no.); arm curl; 8ft up and go)	Sit to stand 10 times
Sit-to-Stand Height Test	Sit-ups
Stair Ascent	Standing broad jump tests

Static fatigue elbow extension and hand grip	Step-ups x 1 step (L and R)
Timed Up and Go Test	Timed Up and Go Test-Modified Version
Trunk lifts	TUDS - Timed Up-and-Down Stairs
Unified Parkinson Disease Rating Scale (Single sit-to-stand)	Unified Parkinson Disease Rating Scale-III
Vertical jump	

Additional Sources and knowledge

Public Health England

In 2018, a series of articles were published in the Journal of Frailty Sarcopenia and Falls. The Centre for Ageing Better, in partnership with Public Health England, had funded the UK CMOs' Expert Group on Physical Activity to undertake *an evidence review on muscle and bone strengthening and balance activities for health and wellbeing*. The articles reported on the work undertaken and identified *self-reported measures of strength* from four national surveys: the Health Survey for England; the Scottish Heath Survey; the Health Survey for Northern Ireland; and the Behavioural Risk Factor Surveillance Surveys conducted in Puerto Rico and Guam (21).

In the UK Home Nations' health surveys, for each sport and exercise activity that a respondent reported undertaking, they were asked "During the past four weeks, was the effort of [name of activity] usually enough to make your muscles feel some tension, shake or feel warm? Yes/No". For some potentially ambiguous sport and exercise activities, data from this question was used to confirm whether it was muscle strengthening. These nations' health surveys also include questions on how much time respondents have spent doing a range of non-sport and exercise activities that would typically be considered muscle strengthening activities including heavy housework, gardening, and DIY or building, although responses to these questions are not included when calculating the frequency of muscle strengthening activity.

In the Behavioural Risk Factor Surveillance Survey conducted in Puerto Rico and Guam, which is interviewer led, respondents were asked "During the past month, how many times per week or per month did you do physical activities or exercises to STRENGTHEN your muscles? Do NOT count aerobic activities like walking, running, or bicycling. Count activities using your own body weight like yoga, sit-ups or push-ups and those using weight machines, free weights, or elastic bands". Response options were: '(free text) times per week'; '(free text) times per month'; 'never'; 'don't know/not sure'; and 'refused'.

However, we know that there are problems with self-reporting of physical activity. Respondents tend to over-estimate the amount of physical activity they have undertaken. When correlating self-reported physical activity with objectively measured activity, evidence tells us that people tend to over-estimate both the intensity of, and the amount of time spent doing, physical activity (22-24). As such, whilst attractive for administering a health survey, self-reporting muscle strengthening activities is unlikely to provide an accurate measure of a person's muscular strength.

The review by Hillson & Foster (25) in the Journal of Frailty Sarcopenia and Falls series identified the *most common direct measure of strength as hand grip strength,* measured by dynamometer. They also found indirect measures of muscular strength, including chair rising and timed up and go. The fastest time taken to rise from a chair to a standing position and back to sitting position 5 or 10 consecutive times was the most common measure of muscular power.

In January 2021, Public Health England and the Royal Osteoporosis Society published *a rapid evidence review of muscle and bone strengthening activities for children and young people*, aged 5-18 years (26). Strength measures identified in the studies included in this review were: medicine ball throwing; jumping; the Sörensen Test; the Bench-Trunk-curl Test; a maximum one-repetition lift; and hopping.

World Health Organization

In the World Health Organization's Decade of Healthy Ageing: Baseline Report, hand grip strength is identified as a measure of intrinsic capacity, that being all of the physical and mental capacities that a person can draw upon (27). In their report, the WHO include hand grip strength as a simple but powerful predictor of declines in intrinsic capacity, onset of morbidity, and mortality (6), stating that it is most useful when multiple measurements are taken over time to track capacity of older people and chart trajectories. A recent analysis of cross-sectional data from China, Ghana, India, Mexico, Russia and South Africa documents a significant and consistent relationship between hand grip strength and other measures of intrinsic capacity across the five important domains of locomotion, psychological, cognition, vitality and sensory, and suggests that *hand grip strength is the single most important measure of intrinsic capacity* (27, 28).

Instrumented functional tests of muscle strength

Whilst not identified in our scoping searches of existing cohort studies and surveys, we know from our own work that a number of different instrumented tests of functional strength have been developed in recent years (29-31). The tests are conducted using either bespoke devices (inertial sensors), or in-built smartphone software (accelerometers and gyroscopes), to record the time taken to conduct the movements involved in the physical performance tests (32). Some research has been conducted to consider whether the iTUG (instrumented TUG) is acceptable and reliable as a self-administered test (32). In a comparison of standard and instrumented tests of physical performance (TUG and the 30-second chair stand) recorded through a smartphone, both instrumented tests were able to discriminate early functional decline in healthy adults aged 61-70 years (33) and were found to have the potential to be usable in a home setting (32).

Similarly, the instrumented Sit-to-Stand test (iSTS) uses either bespoke devices or in-built smartphone software to record the time taken to conduct the movements of the five times STS, or the 10 times STS. The iSTS has been shown to be more strongly associated with health status, functional status and physical activity than manually recorded STS tests in older adults (34).

Validity and reliability of tests of muscle strength

Whilst there is variability in the equipment and protocols for measuring hand grip strength, there is evidence of established test–retest, inter-rater and intra-rater reliability, particularly with the Jamar hand dynamometer (35). The European Working Group on Sarcopenia in Older People has developed the Southampton protocol for measuring grip strength in large epidemiological studies of older people, specifying equipment, standardised body positions and verbal instructions to overcome issues of variability (35).

The standard Timed Up and Go test and the two Sit-to-Stand tests have been found to be reliable and valid tests for measuring physical performance in populations of older adults (18, 36) and younger adults with long term conditions, such as pulmonary hypertension and COPD (37, 38).

The instrumented Sit-to-Stand test, using body-fixed inertial sensors has demonstrated strong test-retest, and absolute, reliability (39). The instrumented Timed Up and Go (iTUG) has demonstrated excellent test-retest reliability (40) and inter-rater reliability (31). iTUG has been shown to be an objective, fast, reliable and sensitive test of mobility in older populations (41).

Correlation of hand grip strength and lower limb strength

Many studies have demonstrated high correlations between hand grip strength and lower limb strength in older adults (42-44).Using data from the Health2006 study, researchers showed high correlation between hand grip strength and lower limb extension power (using a Nottingham Power Rig), in a sample of 19-72 year old men and women (45). Strong correlations between grip strength and total muscle strength (measured in the shoulder abductor, hip and ankle flexors) were found in children and young adults aged 8-20 years (46).

Conclusion and recommendations

Whilst there are long lists of different measures of strength included in Tables 1, 2 and 3, hand grip strength remains the most commonly used measure in population surveillance surveys, cohort studies and research studies. As a measure of strength, it has strong validity, reliability and correlation with lower limb strength in all three CMO populations (5-18; 19-64 and 65+).

From our scoping of life-course trajectories of strength, only one study included a measure of lower limb strength. Whilst a systematic search may identify further studies, the evidence supporting grip strength as a powerful predictor of decline in intrinsic capacity, morbidity and mortality, together with its ease of use and clear protocol, lends itself to support hand grip strength as a strong candidate for measuring strength across the life-course. If functional tests, such as Sit to Stand or Timed Up and Go, are to be added to population studies they must include clear standardised protocols. There is emerging evidence for use of instrumented versions of these tests.

Additional Questions

At the meeting held on 2nd February 2021, three additional questions were asked. The following summary presents the work undertaken to answer those questions.

Q1: What is the correlation between hand grip strength and functional tests (e.g. Timed Up and Go, Sit to Stand)?

Methods:

1. The MEDLINE and PsycInfo databases were searched for papers reporting on studies investigating correlations between hand grip strength (HGS) and:
    - Chair rise
    - Sit-to-Stand (STS)
    - Timed Up and Go (TUG)

2. Publications from the cohort studies identified in the initial scoping exercise were searched, where we had already identified that both HGS and a functional test were conducted.

3. Contact was made with colleagues in Europe working on developing and testing instrumented functional tests.

Results:

There is a very small literature on correlations between HGS and functional tests. Only 10 papers were identified through the MEDLINE and PsycInfo searches. No publications from the cohort studies reported on the correlation between HGS and functional tests. Three papers were identified through contact with colleagues in Europe.

There are no literature reviews. There are some individual studies that have investigated the correlation between HGS and TUG and/or STS, often as part of a study looking for correlations between many different factors.

Correlations between HGS and functional tests have been found for community-dwelling older adults (47-50), older adults in long-term care (51), healthy adults (52), outpatients (52), and women with hip-fracture (53). However, many of these studies have quite small sample sizes. Sample sizes in these studies ranged from 10 to 628. Only two studies included more than 125 participants. In some cases, researchers are simply correlating the two measurements, without taking into account other variables into their models (e.g. age, gender, height, weight, cognition and number of medications). One study reported negligible/low correlation in a group of older women (54).

Bottom line:

There is some evidence of correlations between HGS and functional tests, but there are few papers reporting meaningful correlations, after adjustment for confounders. However, it remains true that there is strong evidence that HGS is an indicator of total body muscle strength (42-46, 55), and that it is a strong predictor of mobility impairment, disability and mortality (5, 56, 57).

Q2: Has hand grip strength been validated in different population groups?

Methods:

Searches conducted in the initial scoping exercise were revisited to find systematic reviews or individual studies reporting the validation of hand grip strength measurement in different populations (e.g. older adults, adults, children and learning disability).

Results:

There is general agreement that there is a good relationship between HGS and total muscle strength. Although there appear to be a relatively small number of studies, hand grip strength has been shown to have high reliability in pre-school children (58), children and pre-adolescents (59), adults with learning disabilities (60, 61), older adults (62-64), healthy adults (65), and various clinical populations (65).

Bottom line:

Hand grip strength appears to be a reliable measure of muscle strength in all phases of the life course. However, it is important to follow established protocols to overcome issues of variability (35).

Q3: What is known about change across the children and young people age band (5-18). How does strength differ from a pre-puberty adolescent (10/11) and a late teen (16/17), in boys and girls?

Methods:

Searches conducted in the initial strength across the life course scoping exercise were revisited to identify evidence specific to children and young people. Our scoping searches were set up so that we examined studies that looked at measures of strength in children in full text.

Results:

Only one of the papers identified in the initial scoping exercise included reports of changes in strength within the 5-18 age band. This paper, reporting grip strength across the life course by Dodds et al. (10), included data from children aged four years and over. The sources of the data included in the paper are presented in Table 4. Dodds et al. presented normative values of hand grip strength for girls and boys at ages 5, 10, 15 and 20, shown here in Table 5.

Table 4: Data sources and study details for measures of HGS in children

Data source	N with HGS measure	Birth year(s)	Year(s) of data collection	Age range (years)
SWS (children of women cohort study, Southampton)	968	2000-2005	2004-2009	4-5
ALSPAC (children of. women attending antenatal clinics in Bristol and District Health Authority)	6701	1991-1992	2003-2005	10-14
ADNFS (random sample of English population with subsample having physical appraisal)	2602	1916-1974	1991	16-74
UKHLS (nationally representative sample of UK	1265	1908-1996	2010-2012	16-102
SWS (partner's grip strength at 19 week visit)	1563	1963-1982	2002-2005	18-58

From Dodds et al. 2014

Table 5: Normative values for grip strength in children and older adolescents

		Grip strength normative values at age shown (kg)					
Age (years)	Observations	Centiles					Mean (SD)
		10th	25th	50th	75th	90th	
Boys							
5	730	6	7	8	9	10	7.7 (2.9)
10	3222	12	15	17	20	22	17.2 (4.1)
15	288	21	25	29	33	38	29.6 (5.6)
20	354	30	35	40	46	52	41.5 (7.3)
Girls							
5	700	6	7	8	9	10	8.0 (3.1)
10	3339	12	14	16	19	21	16.7 (3.8)
15	345	17	20	24	27	30	23.9 (4.5)
20	463	21	24	28	32	36	28.4 (5.1)

From Dodds et al. 2014

From these normative values, it appears that boys' hand grip strength increases faster than girls', from a similar mean value at age 10 years. Whilst we do not have data for boys and girls at age 18, the values for age 20 are included in Table 5 to show the continued increase of hand grip strength, for both boys and girls, to later adolescence. Median hand grip strength peaks at 51kg for males between the ages of 29 and 39 years. Median hand grip strength peaks at 31kg for females between 26 and 42 years (10).

Bottom line:
The mean values for grip strength are similar for boys and girls at age 10. Hereafter, males' hand grip strength increases faster than females'; both peak in early adulthood.

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