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Age and gender differences in relationships between physical activity and sense of coherence in community-dwelling older adults

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和文抄録

目的：地域在住高齢者における身体活動（余暇活動，家庭内活動，仕事関連活動）とストレス対処力（sense of coherence; SOC）との関連を性・年齢層別に検討した．

方法：2011年および2012年の7～8月に茨城県笠間市に在住する65～85歳の地域在住高齢者のうち，体力テストに参加意思を表明した508名に記名自記式調査を実施した．調査票は体力テスト参加日に回収し，欠損回答のない394名（男性194名，女性200名：有効回答率77.6%）を分析対象とした．調査項目は属性（性，年齢，教育年数，世帯構成，既往症の有無），身体活動（Physical Activity Scale for the Elderly日本版；余暇活動，家庭内活動，仕事関連活動の各実施量），SOC（13項目5件法版Sense of Coherence Scale），ソーシャルネットワーク（家族，友人）であった．身体活動とSOCとの関連を，教育年数，世帯構成，既往症の有無，ソーシャルネットワークを統制した重回帰分析により検討した．分析は，性別，年齢層別（前期高齢者：65～74歳，後期高齢者：75～85歳）に分けて実施した．

結果：前期高齢者の男性では，余暇活動量とSOCとの間に有意な正の関連を認めた（$\beta=0.233$, $p<0.05$）．また，後期高齢者の男性において仕事関連活動量がSOCと有意な正の関連（$\beta=0.273$, $p<0.05$）を認めた一方，前期高齢者の女性では，仕事関連活動量とSOCとの間に有意な負の関連（$\beta=-0.285$, $p<0.01$）を認めた．

結論：比較的健康な地域在住高齢者において，身体活動とSOCとの関連性は性や年齢層によって異なり，男性では，前期高齢者は余暇活動が，後期高齢者は仕事関連活動が多いほどSOCが高い一方，女性では年齢層に関わらずSOCを高める身体活動はなかった．本研究は，地域在住高齢者に対する一次予防として有効な身体活動の内容を具体的に示した点で，重要な意義をもつと考えられる．

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地域在住高齢者の歯の状態と身体機能および転倒経験との関連性

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目的 地域在住高齢者の歯の状態（残存歯数と義歯の使用の有無）と身体機能および転倒経験との関連性を明らかにすることを目的とした。

方法 2013年に茨城県笠間市で開催された健診事業に参加した地域在住高齢者205名（平均年齢74.1±4.5歳；男性49.8％）を対象とした。自記式質問紙により残存歯数と義歯（入れ歯やインプラント等）使用の有無を調査し，「残存歯数20本以上」「残存歯数19本以下かつ義歯有り」「残存歯数19本以下かつ義歯無し」の３群に分けた。握力，５回椅子立ち上がり時間，開眼片足立ち時間，Functional Reach，重心動揺軌跡長，Timed Up & Go，５ｍ通常歩行時間により身体機能を評価した。また，過去１年間の転倒経験の有無を調査した。主たる統計解析には，従属変数に各身体機能評価項目または転倒経験の有無，独立変数に歯の状態を投入した共分散分析およびロジスティック回帰分析を用いた。各分析の共変量には年齢，性，教育年数，経済的な暮らし向き，Body Mass Indexを使用した。

結果 「残存歯数19本以下かつ義歯無し」群は「残存歯数20本以上」群に比べ重心動揺軌跡長が有意に長かった（$p<0.05$）。Timed Up&Goにおいては，「残存歯数19本以下かつ義歯無し」群は「残存歯数20本以上」群および「残存歯数19本以下かつ義歯有り」群に比べ有意に遅い値を示した（$p<0.05$）。「残存歯数19本以下かつ義歯無し」群は「残存歯数19本以下かつ義歯有り」群に比べ５ｍ通常歩行時間が有意に遅い値を示した（$p<0.05$）。「残存歯数20本以上」群と比べ，「残存歯数19本以下かつ義歯が無し」群は，過去に転倒歴を有している割合が有意に高かった（オッズ比=5.80，95％信頼区間=1.74-19.37）。

結論 地域在住高齢者の身体機能は歯の状態によって異なり，さらに歯の状態と転倒経験に関連があることが示唆された。特に「残存歯数19本以下かつ義歯が無い」高齢者はバランス能力，歩行能力の低下が生じていることや，転倒リスクが高い可能性がある。

キーワード　地域在住高齢者，口腔機能，残存歯数，義歯，転倒，身体機能

Ⅰ　緒　言

日本は高齢化率25.9％（平成26年９月時点）の超高齢社会であり，高齢者の介護予防は喫緊の課題である。高齢者が要介護状態に陥る主な原因として，身体機能低下や転倒があげられており[1]，それらの発生を抑制するためにその関連要因や原因を追究する研究が散見される[2-5]。

近年，身体機能低下や転倒の関連要因として口腔機能が注目されており，主に残存歯数および義歯（入れ歯やインプラント等）装着に着目して検討されている[6,7]。残存歯数に関しては，

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平均寿命や要介護リスクとの関連[8)-11)]や認知機能との関連[12)]などが報告されている。しかしながら，加齢にともなう歯の喪失は避けられない現象であり[13)]，多くの高齢者は喪失した歯を補うために義歯を装着する。渡辺は無歯顎者において義歯使用時の重心動揺距離および歩行周期が義歯不使用時と比べて，良好な値を示したことから義歯の使用によってバランス能力が向上することを示唆している[14)]。Shimazakiら[6)]は６年間のコホート研究によって，歩行障害は残存歯数が少ない者で生じやすく，残存歯数が同じ者同士を比べると，義歯を使用していない者はより歩行障害発生リスクが高いことを報告している。以上より，残存歯数が少ない者における義歯の不使用は身体機能低下リスクが高いとされる。身体機能が低い者ほど転倒リスクが高いことは周知の事実であるため，残存歯数が少なく義歯の不使用者は転倒リスクも高い可能性が考えられる。これまでに，高齢者の歯の状態と転倒経験に関する報告は少なく[7)]，高齢者の歯の状態と身体機能および転倒経験の関連性については不明な点が多い。さらに歯の状態と身体機能および転倒経験との関連について，同一対象者で包括的に検討した報告はされていない。高齢者にとって歯の喪失は避けられない現象であることから，残存歯数や義歯の使用の有無といった歯の状態と身体機能や転倒経験との関連性を検討することで，義歯の使用といった即効性のある手段による新たな介護予防方策の開発・発展に貢献することができると考える。したがって，本研究は地域在住高齢者の歯の状態による身体機能および転倒経験の差異を検討することを目的とした。

Ⅱ 方　　法

（１） 対象者

本研究の対象者は2013年７月に茨城県笠間市で実施した，健診事業「かさま長寿健診」に参加した65～85歳の地域在住高齢者279名を対象とした。「かさま長寿健診」は2009年から始まった健診事業であり[15)]，住民基本台帳から無作為抽出された65～85歳の地域在住高齢者900～1,200名に対して，毎年健診の案内を送っている。本研究で分析に用いた2013年の参加者は，これまでに「かさま長寿健診」に１度でも参加したことのある追跡参加者を対象とし，本研究の分析に必要な調査項目に欠損のあった74名を除外した205名（74.1±4.5歳，男性49.8%）を最終的な分析対象者とした。笠間市は茨城県の中央に位置する人口79,010名（2013年10月現在）の市であり，高齢化率は25.8%と全国の高齢化率（2013年10月現在）と比して同等である。

（２） 調査項目

1） 歯の状態の調査

歯の状態は，残存歯数および義歯（入れ歯・インプラント等）使用の有無を回答する自記式質問紙[7)]を用いて調査した。残存歯数は「20本以上，10～19本，５～９本，１～４本，０本」の５件法を用い，義歯の使用状況は「上下両方のあごで使用，上のあごだけ利用，下のあごだけ利用，使っていない」の４件法により評価した。その後，先行研究[7)]にしたがって，対象者を「残存歯数20本以上」「残存歯数19本以下かつ義歯有り」「残存歯数19本以下かつ義歯無し」の３群に分類した。なお，自記式質問紙による残存歯数の確認方法は実際の残存歯数に対する妥当性が認められている[16)]。

2） 身体機能評価

身体機能は握力，５回椅子立ち上がり時間，開眼片足立ち時間，Functional Reach（以下，FR），重心動揺軌跡長，Timed Up & Go（以下，TUG），５ｍ通常歩行時間により評価した。重心動揺軌跡長を除く各身体機能項目の測定方法については，Tsunodaら[15)]と同様である。重心動揺軌跡長は，フォースプレート（TANITA社製，BM-101，サンプリング周波：80Hz）を用いて測定した。重心動揺軌跡長は，平衡機能障害を伴う目まい患者の診断に用いられるなど平衡機能を評価する指標とされている。重心動揺軌跡長の測定方法は，両足は対象者が立ちやすい幅に開き，両上肢を下垂した直立姿勢を測定肢位とした。測定中は前方の目の高さにある注視点を見るよう指示し，30秒間の重心動揺軌跡長を測定した。

3） 過去１年間の転倒経験

転倒経験の調査は，「この１年間に転んだことがありますか」の問いに対し，「はい」もしくは「いいえ」のいずれかで回答を求めた。想起期間を１年間とする転倒経験の調査は，先行研究において日本人高齢者を対象とした場合の妥当性が確認されている[17)]。

4） 基本属性

対象者の基本属性として，年齢，性，教育年数，経済的な暮らし向き，Body Mass Index（kg／(m)^2）（以下，BMI）を調査した。経済的な暮らし向きは「現在の経済的な暮らしの状況を総合的に見て，どのように評価しますか」という問いに対し，「大変余裕がある，やや余裕がある，普通，やや苦しい，大変苦しい」の５件法を用いた。

（３） 分析方法

歯の状態による基本属性の群間比較には一元配置分散分析，χ^2検定，フィッシャーの直接確率検定を用いた。一元配置分散分析およびχ^2検定の多重比較検定にはBonfferoni法を用いた。

歯の状態による身体機能の群間比較には，従属変数に各身体機能評価項目，独立変数に歯の状態を投入した共分散分析およびBonferroni法による多重比較検定を行った。歯の状態と転倒との関連性の検討には，従属変数に転倒経験の有無，独立変数に歯の状態を投入したロジスティック回帰分析を用いた。各分析では共変量として年齢，性，教育年数，経済的な暮らし向き，BMIを投入した。すべての分析において，統計学的有意水準は５%とした。

（４） 倫理的配慮

なお，本研究は筑波大学体育系研究倫理委員会（承認番号：体23-36）の承認の下で実施された。対象者には研究の目的，研究への協力は個人の自由であり研究に協力しなくても個人の不利益につながらないこと，同意書にサインをした後でも不利益を受けずに随時撤回できることを口頭で説明した。その後，同意書にサインを行うことで同意を得られたものとした。

Ⅲ 結　　果

表１に対象者の基本属性を示した。３群間で有意差を認めた基本属性は年齢，教育年数，過去１年間の転倒経験であった（p<0.05）。「残存歯数19本以下かつ義歯無し」群の年齢は「残存歯数20本以上」群および「残存歯数19本以下かつ義歯有り」群と比べ有意に高齢であった。「残存歯数20本以上」群の教育年数は「残存歯数19本以下かつ義歯有り」群と比べ有意に長かった。「残存歯数19本以下かつ義歯無し」群は「残存歯数20本以上」群と比べ，過去１年間の転倒を経験している者の割合が有意に多かった。

表２に歯の状態による身体機能の比較の結果を示した。重心動揺軌跡長においては，「残存

表１　対象者の基本属性

	全体（205名）	残存歯数20本以上（Ⅰ）（123名）	残存歯数19本以下かつ義歯有り（Ⅱ）（67名）	残存歯数19本以下かつ義歯無し（Ⅲ）（15名）	p値	多重比較検定
	平均値±標準偏差	平均値±標準偏差	平均値±標準偏差	平均値±標準偏差		
年齢（歳）†	74.1±4.5	72.9±4.1	75.7±4.5	76.9±4.6	<0.001	Ⅰ,Ⅱ<Ⅲ
男性，人（%）‡	102(49.8)	61(49.6)	33(49.3)	8(53.3)	0.958	
教育年数（年）†	12.1±2.5	12.5±2.4	11.3±2.6	11.9±2.6	0.011	Ⅱ<Ⅰ
経済的な暮らし向き#，人（%）						
大変苦しい／やや苦しい	27(13.2)	15(12.2)	8(11.9)	4(26.7)	0.601	
普通	157(76.6)	94(76.4)	53(79.1)	10(66.7)		
大変余裕がある／やや余裕がある	21(10.2)	14(11.4)	6(9.0)	1(6.7)		
Body Mass Index（kg／(m)^2）†	23.1±2.6	23.3±2.4	22.7±2.8	22.9±2.9	0.278	
過去１年間の転倒経験，人（%）‡	43(21.0)	19(15.4)	17(25.4)	7(46.7)	0.011	Ⅰ<Ⅲ

注　†一元配置分散分析，‡χ^2検定，#フィッシャーの直接確率検定

表２　歯の状態における身体機能の比較

	残存歯数20本以上（Ⅰ）			残存歯数19本以下かつ義歯有り（Ⅱ）			残存歯数19本以下かつ義歯無し（Ⅲ）			共分散分析†		多重比較検定
	人数	調整済み平均値	標準誤差	人数	調整済み平均値	標準誤差	人数	調整済み平均値	標準誤差	F値	p値	
握力（kg）	122	28.2	0.5	66	29.3	0.6	15	28.3	1.3	0.870	0.420	
５回椅子立ち上がり時間（秒）‡	121	7.5	0.2	65	7.4	0.2	14	8.6	0.5	2.566	0.079	
開眼片足立ち時間（秒）	121	35.0	2.0	66	37.3	2.7	14	30.9	5.8	0.552	0.577	
Functional Reach（cm）	121	29.7	0.5	66	29.7	0.6	15	27.2	1.3	1.603	0.204	
重心動揺軌跡長（cm）‡	100	35.7	1.5	58	39.8	1.9	11	50.0	4.3	5.253	0.006	Ⅰ＜Ⅲ
Timed Up & Go（秒）‡	122	6.0	0.1	66	5.5	0.2	15	7.1	0.4	8.347	＜0.001	Ⅰ,Ⅱ＜Ⅲ
５m通常歩行時間（秒）‡	122	3.6	0.1	65	3.4	0.1	15	4.0	0.2	4.361	0.014	Ⅱ＜Ⅲ

注　1）†調整済み平均値，標準誤差，p値は性，年齢，教育年数，経済的な暮らし向き，Body Mass Indexで調整した。
　　2）‡値が低い程良好な値を示す。
　　3）各項目の分析は欠損がある者を除いて分析をした。

歯数19本以下かつ義歯無し」群は「残存歯数20本以上」群と比べ有意に不良な値を示した（$p<0.05$）。TUGでは，「残存歯数19本以下かつ義歯無し」群は「残存歯数20本以上」群および「残存歯数19本以下かつ義歯有り」群と比べ有意に遅い値を示した（$p<0.05$）。５m通常歩行時間においては，「残存歯数19本以下かつ義歯無し」群は「残存歯数19本以下かつ義歯有り」群と比べ有意に遅い値を示した（$p<0.05$）。その他の項目では有意な群間差は確認されなかった。

表３に示したとおり，歯の状態と過去１年間の転倒経験との関連性を検討した結果，「残存歯数20本以上」群と比べ，「残存歯数19本以下かつ義歯無し」群は有意に転倒を多く経験していた（オッズ比=5.80，95%信頼区間=1.74-19.37）。

表３　歯の状態における転倒経験との関連

	オッズ比（95%信頼区間）	p値
残存歯数20本以上	1.00	
残存歯数19本以下かつ義歯有り	2.06（0.94- 4.52）	0.073
残存歯数19本以下かつ義歯無し	5.80（1.74-19.37）	0.004

注　共変量：性，年齢，教育年数，経済的な暮らし向き，Body Mass Index

Ⅳ　考　　察

（１）　歯の状態と身体機能および転倒経験との関連性

歯の状態による身体機能の比較の結果，重心動揺軌跡長，TUG，５m通常歩行時間が歯の状態が悪いほど不良な値を示した。重心動揺軌跡長，TUGや５m歩行時間は，それぞれバランス能力や歩行能力の評価指標として使用される。重心動揺軌跡長では，残存歯数19本以下かつ義歯が無い者は残存歯数20本以上の者に比べ有意に不良な値を示した。先行研究では，同一の対象者における義歯使用前後の重心動揺軌跡長を検討しており，義歯の使用によって重心動揺距離，重心動揺振幅，重心動揺面積などのバランス能力評価指標が改善する傾向を確認している[14)18)]。しかし，本研究では，残存歯数19本以下かつ義歯無しの者は，残存歯数20本以上の者に比べて有意に長い重心動揺軌跡長を示したが，残存歯数19本以下で義歯が有る者と義歯が無い者とでは身体機能に有意な差は認められなかった。この結果から，バランス能力の維持・増進には義歯の使用が効果的であることに加え，歯の喪失を防ぎ，残存歯数を保つことで当該身体能力を維持することができる可能性が考えられる。また，本研究では重心動揺軌跡長と同様にバランス能力の評価に用いられるFRや開眼片脚立ち時間では，歯の状態による有意な違いが認められなかった。FRや開眼片脚立ち時間は動的バランス能力や支持基底面が狭い中での姿勢制御能力を要し，筋力（筋骨格系）の影響を受けるといわれている[19)]。一方で，重心動揺軌跡長は静止立位で行われ，中枢神経系の姿勢制御の影響を受けやすい。ヒトは主に緊張性頸反射，緊張性迷路反射といった中枢神経系の働きによって姿勢制御を行っている。これらの反射は義歯使用により下顎系の抗重力筋，および周囲の筋の緊張変化が生じた場合に影響を受けると考えられる[20)]。歯の状態によるバランス能力の差異は，筋骨格系よりも中枢神経系の機能を反映する測定方法により確認できる可能性が高く，義歯使用前後によるバランス能力の向上を確認する際には，重心動揺を評価する必要があると考えられる。歩行能力に関しては，先行研究において同一対象者において，義歯使用による歩行速度および歩幅の増加が認められている[18)]。本研究では，残存歯数19本以下かつ義歯が無い者のTUGや５m通常歩行時間は，残存歯数19本以下かつ義歯が有る者と比べて有意に不良な値を示しており，先行研究を支持した。このことから，義歯やインプラント等を使用することで良好な歩行能力を維持できる可能性があるといえる。

歯の状態と過去１年間の転倒経験との関連性を検討した結果，残存歯数が19本以下かつ義歯が無い者は残存歯数20本以上の者と比べ，転倒経験者の割合が有意に高かった。本結果は，先行研究[7)]の結果を支持しており，転倒予防の観点からも残存歯数を20本以上に保つことや，義歯を装着することの重要性が示唆された。

（２）　地域における介護予防支援事業への提案

高齢者において義歯の不使用は不良なバランス能力や低い歩行能力と高い転倒経験率と関連した。現在，わが国の介護予防支援事業は「運動器の機能向上」「栄養改善」「口腔機能の向上」「認知機能の低下予防・支援」などに焦点を当てたプログラムが提供されている。このなかでも「運動器の機能向上」プログラムが最も多く実施されており（実施率68.1%），通所型介護予防事業全体の約半数近くを占めている[21)]。一方，「口腔機能の向上」プログラムの実施率は32.6%であり，現状では，高齢者の口腔問題に比して口腔指導の実施率が低いとされる。しかし，本研究の結果より，今後，高齢者の身体機能維持・向上，および転倒予防を目指したプログラムを提供する際は，高齢者の「運動器の機能向上」のみならず「口腔機能の向上」プログラムを併せて提供し，口腔指導を行うことが望まれる。

（３）　研究の限界および今後の課題

本研究では以下の２つの限界があげられる。１つ目は，対象者のサンプリングバイアスについてである。今回の対象者は大学からの案内状によって健診事業への参加意思を示した高齢者であり，健康意識が高い者に偏った可能性があることは否定できない。

２つ目は，横断研究であるために歯の状態と身体機能および転倒経験との因果関係について明らかにできていないことである。本研究では，歯を喪失した後に身体機能低下が生じたのか，身体機能低下が生じてから歯を喪失したのかを調査できていない。今後，追跡調査を行い，歯の状態が身体機能および転倒発生に与える影響を検討していく必要がある。

Ⅴ　結　　語

本研究では，地域在住高齢者を対象に歯の状態（残存歯数と入れ歯やインプラント等の使用の有無）によって残存歯数20本以上の群，残存歯数19本以下かつ義歯有りの群，残存歯数19本以下かつ義歯無しの群に分類し，歯の状態と身体機能および転倒経験の差異を検討した。その結果，残存歯数19本以下かつ義歯が無い者は，他の２群と比べ，身体機能が低水準であることや転倒経験の割合が高い可能性が示唆された。

今後，高齢者の身体的健康状態を維持・増進するためには，身体機能の維持・向上を目的とした筋力トレーニングやバランストレーニングのみならず，残存歯数の有無および入れ歯やインプラントの使用状況を把握し，適切な口腔指導を実施・介入していくことが重要であることが示唆された。

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投稿

女子高校生の子宮頸がん予防ワクチン接種行動に関する心理社会的要因

－修正版HBMに基づくパス解析による検討－

小林（コバヤシ） 優子（ユウコ）＊１　朝倉（アサクラ） 隆司（タカシ）＊２

目的　女子高校生の子宮頸がん予防接種行動を予測するHBM（Health Belief Model）の心理社会的な構成要因を測定する尺度開発を行い，その上でそれらを組み入れたHBMに基づいたパスモデルを用いて接種行動のメカニズムを明らかにすることを目的とした。

方法　神奈川県内の女子高校生１～３年生を対象に自記式質問紙調査を行った。因子分析の対象は項目に欠損値のない１～３年生2,463名であり，パス解析の対象は子宮頸がん等ワクチン接種緊急促進事業の対象学年であった１～２年生1,606名に限定した。子宮頸がん・予防接種に対する態度32項目に対し探索的因子分析を行い，８因子を抽出した。その後，確認的因子分析により８因子モデルの妥当性，各因子の構成概念妥当性を検討した。８因子および家族背景などの変数を用いて，まずHBMに基づくパスモデルを統計ソフトM-plusにより構築した。次いで思春期の保健行動を説明するためには，この時期に特徴的な要因である「調整力」が重要であると判断したため，「接種に向けた調整力」を加えてHBMに修正を加えたパスモデルを解析した。

結果　子宮頸がん・予防接種に対する態度としては，「家族の健康意識」「ワクチン接種の話題との接触」「接種に向けた調整力」「子宮頸がんの脅威」「ワクチン接種への肯定感と関心の高さ」「ワクチン接種への消極的態度・困難感」「ワクチンに対する不安」「ワクチン接種の時間と費用のバリア」の８因子が抽出された。HBMに基づく解析の結果，HBMの仮定どおりワクチン接種へのバリアが高いほどワクチン非接種の確率が高く，逆にワクチン接種への肯定感が高いほどワクチン接種の確率が高かった。そして，HBMの理論に反し「子宮頸がんの脅威」はワクチン接種を抑制していた。また，「ワクチンに対する不安」を説明する要因は特定できなかった。そこで，「接種に向けた調整力」を組み込んだ修正版HBMでは，HBMで特定されなかった「ワクチンに対する不安」の要因が明確になった。「子宮頸がんの脅威」は，直接的に接種行動を抑制する関連にあるが，「接種に向けた調整力」が媒介変数となり間接的に接種行動を促進するパスもあり，抑制と促進の両方の関連が明らかになった。なお，接種行動の説明率は25.2％から26.0％と「接種に向けた調整力」を加えたことによる大きな改善はみられなかった。

結論　オリジナルHBMに「接種に向けた調整力」を追加したことにより，女子高校生のワクチン接種行動をより明確に説明することができた。

キーワード　女子高校生，子宮頸がん予防ワクチン，接種行動，HBM，自律性

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Gender differences of foot characteristics in older Japanese adults using a 3D foot scanner

Mahshid Saghazadeh*, Naruki Kitano and Tomohiro Okura

Abstract

Background: Knowledge of gender differences in foot shape assists shoe manufactures with designing appropriate shoes for men and women. Although gender differences in foot shapes are relatively known among young men and women, less is known about how the older men and women's feet differ in shape. A recent development in foot shape assessment is the use of 3D foot scanners. To our knowledge this technology has yet to be used to examine gender differences in foot shape of Japanese older adults.

Methods: This cross-sectional study included 151 older men (74.5 ± 5.6 years) and 140 older women (73.9 ± 5.1 years) recruited in Kasama City, Japan. Foot variables were measured in sitting and standing positions using Dream GP Incorporated's 3D foot scanner, Footstep PRO (Osaka, Japan). Scores were analyzed as both raw and normalized to truncated foot length using independent samples t-test and analysis of covariance, respectively.

Results: In men, the measurement values for navicular height, first and fifth toe and instep heights, ball and heel width, ball girth, arch height index (just standing), arch rigidity index and instep girth were significantly greater than the women's, whereas the first toe angle, in both sitting and standing positions was significantly smaller. However, after normalizing, the differences in ball width, heel width, height of first and fifth toes in both sitting and standing and ball girth in sitting position were nonsignificant. According to Cohen's d, among all the foot variables, the following had large effect sizes in both sitting and standing positions: truncated foot length, instep, navicular height, foot length, ball girth, ball width, heel width and instep girth.

Conclusion: This study provides evidence of anthropometric foot variations between older men and women. These differences need to be considered when manufacturing shoes for older adults.

Keywords: Anthropometry, Elderly, Footwear, Shoe design, Three-dimensional shape

Background

Knowledge of gender differences in foot shape and anatomy helps shoe manufacturers design appropriate shoes for men and women [1]. For instance, knowledge of the location of the metatarsophalangeal joint can help when deciding which areas of the shoe should be flexible or stiff [2]. Although information on foot shape differences between young men and women is available, there is much less information on how older men and women's feet differ. One study compared the length and width of the feet of 668 older adults and concluded that more than two thirds of the feet were broader than the shoes available in their sizes [3]. Most shoe manufacturers utilize young adults' feet data for their shoe designs [4]. Moreover, women's shoes have traditionally been designed as a smaller version of men's shoes with all dimensions proportionally scaled according to foot length. However, if women's feet differ in shape from men's feet, this is an inappropriate model for a woman's shoe and could lead to improper shoe fit in women [5].

According to the literature, younger people tend to have smaller foot circumferences compared to older people [6]. Although, the elderly are reported to have flatter, longer, and wider feet than young adults [5, 7], we found only two

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studies, in Brazil and Australia, relating to such gender-related differences in older adults [4, 8]. However, in the Brazil study, all the foot measurements were obtained by caliper and goniometer [4]. In that study, women had significantly greater ball width and toe perimeters, while the heel width was significantly smaller relative to the height of the dorsal foot after normalizing the data to foot length. In addition, the first and fifth metatarsophalangeal angles were smaller in the men [4].

In the study conducted in Australia, the researchers measured foot anthropometrics using a calibrated 3D foot scanner. In that study, men had significantly larger measurements than the women for all dimensions with the exception of first toe angle. Men had significantly higher normalized first and fifth toe heights and a larger fifth toe angle, whereas women had a significantly longer normalized medial ball length and larger first toe angle [8]. In addition to gender differences, ethnic origin can also influence foot shape [9]. Therefore, studying older adults' foot characteristic in each nation is indispensable [10].

The opportunity for podiatric research has improved in recent years with the new laser scanner technologies available for various applications [11]. This new technology with adequate speed of data capture provides the opportunity to quickly measure the three-dimensional shape of the foot in large populations. This can improve our ability to analyze gender differences more accurately. To the best of our knowledge, this technology has yet to be used for examining gender differences in foot shape of Japanese older adults.

Unfortunately, although inappropriate footwear is a known risk factor for falls of the elderly [12], little is known about what actually constitutes safe footwear for this age group [13]. Knowing the characteristics of older adults' feet, including gender and ethnic differences, could improve footwear design and may reduce the risk of falls in the elderly. The main objective of this study was to determine gender differences in foot characteristics in a large community sample of older Japanese adults using the recently launched technology of 3D foot scanning. We could find no previous studies on this topic in Japan; this is the first such study.

Methods

Participants

We conducted this cross-sectional study in August 2012 in Kasama City (population 79,266, proportion of older adults 24.0 %), a rural region in Ibaraki prefecture, Japan.

A total of 349 older adults participated in this study conducted in the Kasama City health center. Of these participants, we excluded 58 due to incomplete data, their reliance on walking sticks during the measurement or among women because of refusing to remove their pantyhose preventing us from collecting foot characteristic.

Table 1 Participant characteristics

Variables	Men = 151		Women = 140	
	Mean or %	SD or Number	Mean or %	SD or Number
Age (years)	74.54	5.58	73.89	5.14
Height (cm)	162.62	5.73	148.94	5.67
Weight (kg)	61.28	8.25	51.38	7.4
BMI (kg/m^2)	23.15	2.15	23.14	2.97
Diabetes	14.6 %	N = 22	12.1 %	N = 17
Osteoporosis	0.7 %	N = 1	16.4 %	N = 23

There were 151 men (74.5 ± 5.6 years) and 140 women (73.9 ± 5.1 years) participants for final data analysis. Medical histories and demographics variables are shown in Table 1. All participants provided a signed, informed consent. This study was approved by the Ethical Committee of University of Tsukuba.

Measurements

Foot characteristics

We measured foot characteristics using the recently launched 3D foot scanner, Footstep PRO by Dream GP Company, Osaka, Japan (Fig. 1). Modern 3D surface scanning systems can obtain accurate and repeatable digital representations of the foot shape and have been used successfully in medical, ergonomic and footwear development applications [14]. An example of 3D image by Footstep PRO is shown in Fig. 2.

Subjects individually sat with bare feet on the end of a table so their lower legs were non-weight bearing and their ankles were slightly plantar-flexed [15]. They placed their right feet onto the factory-delineated center of the scanner as the measurer assured proper positioning. To prevent ankle dorsiflexion, the subjects were instructed not to forcibly push the platform of the 3D machine [15]. Prior to starting the machine, light blocking material attached to the rim of the scanner was secured to subjects' lower legs.

When the scanner is started, a laser rotates on the rail around the foot measuring about 30,000 positions, including instep, heel, sole and toe, which allows the software to reproduce exactly the shape of the foot. Each measurement is completed in about 13 s.

After completing measurement in a sitting position, participants stood up without changing their foot position inside the machine, set their left foot on an adjacent wooden platform next to and level with the platform inside the scanner and placed equal weight on each foot. This placed 50 % of their body weight on the foot being assessed. The measurer checked the foot positioning in the scanner prior to starting the machine. Participants were also encouraged to use the handrail placed in front of them for balance, to relax their feet and to ensure equal loading on each extremity. The handrail was placed at a level which they could

Fig. 1 3D foot scanner, Footstep PRO by Dream GP Company, Osaka, Japan

easily reach without needing to raise or lower their arms too much. The participants looked straight ahead and stood as still as possible.

Once we obtained readings for the right foot in both sitting and standing positions, we repeated the measurements for the left foot. We collected 4 measurements on each person, right and left leg in both sitting and standing positions and then sanitized the instruments with 70 % alcohol prior to measuring the next person. Foot characteristics are shown in Fig. 3.

In this study, we used the following two methods for calculating arch height:

Navicular height (NH) and navicular drop (ND)

We measured navicular heights as described in the literature [16]. The subject sat on a chair with bare feet. The most prominent portion of the navicular tuberosities on both feet were palpated and marked with a small, round, black sticky point while the participants maintained a relaxed sitting position. The 3D scanner software located these black points as the point of the navicular.

One investigator (MS) performed all markings of the navicular tuberosity. This investigator was a licensed athletic trainer with 2 years' experience in foot and posture assessment at the time of testing. In this study, navicular height

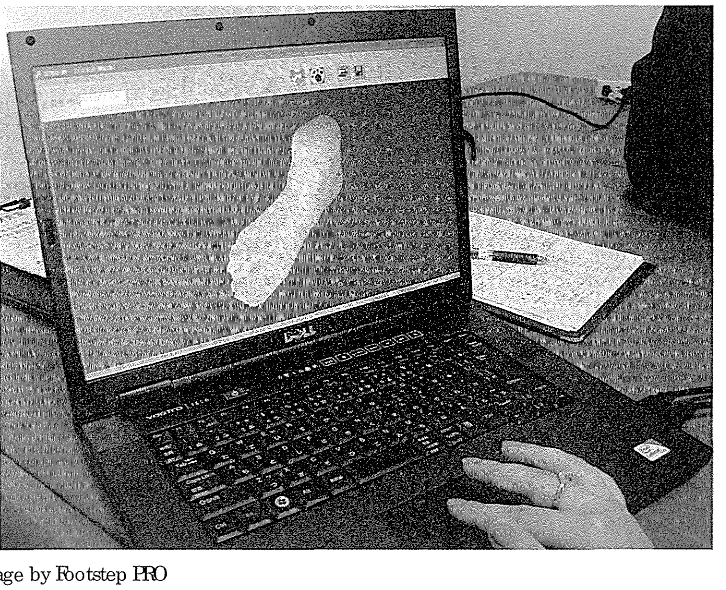
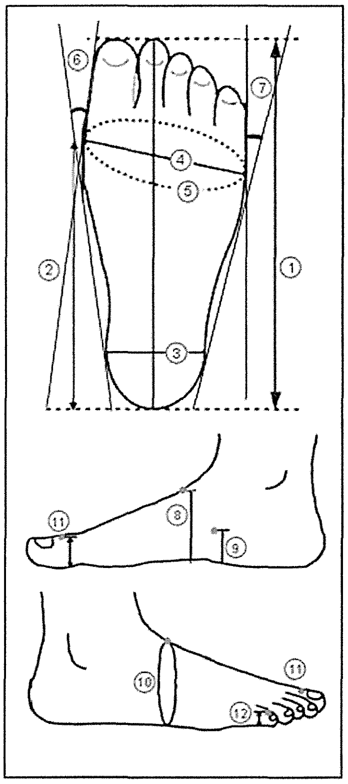


Fig. 2 An example of 3D image by Footstep PRO



1	Foot length
2	Truncated foot length
3	Heel width
4	Ball width
5	Ball girth
6	Hallux valgus degree
7	Degree of little toe
8	Instep height
9	Navicular height
10	Instep girth
11	Height of first toe
12	Height of little toe

Fig. 3 Foot characteristics

was defined as the linear distance (mm) from the most medial prominence of the navicular tuberosity to the supporting surface while sitting and while standing with 50 % body weight on each foot [17].

We defined navicular drop or foot mobility as the amount of vertical navicular excursion (mm) between the positions of the subtalar joint while neutral in sitting position and relaxed in bilateral standing (navicular drop) [18].

Arch height index (AHI) and arch rigidity index (ARI)

Since skin markers over the navicular tuberosity have been shown to not track the actual position of the bone with complete accuracy [19], AHI was also used.

In this study, AHI was defined as the linear distance (mm) from the instep as defined by the foot scanning machine, to the supporting surface while sitting and while standing with 50 % weight bearing on each foot, divided by the truncated foot length [20].

Arch rigidity index (ARI) is defined as the ratio of standing AHI divided by seated AHI (AHI stand/AHI sit). Values nearer to 1 indicate a stiffer (less flexible) foot [21].

All the foot data were collected automatically by the Footstep PRO. However, some of the data such as foot length, navicular height, ball width and angle of first and fifth toes were adjustable by defining their points in the software. For instance, we defined foot length in this study as a linear distance from the most prominent point of the calcaneal tuberosity to the tip of the longest toe. The first or second toe was chosen as the longest after viewing the 3D foot shape with the software.

Statistical analysis

Scores were analyzed as both raw and normalized to truncated foot length using independent samples t-test and analysis of covariance, respectively. Williams and McClay [22] indicated that using the truncated foot length, the perpendicular distance from the first metatarsophalangeal joint to the most posterior aspect of the heel, reduces the impact that toe deformities, such as claw toes and hallux valgus, may have on heel to longest toe foot length. Therefore, truncated foot length was used to normalize the data.

A P value of less than 0.001 was considered statistically significant. For each subject, we averaged the right and left foot measurements for the analyses. Cohen's d is interpreted as a very small effect at less than 0.2, as a small effect between 0.2 to 0.5, as a moderate effect between 0.5 to 0.8, and as a large effect greater than 0.8. Statistical analyses were performed using SPSS version 18.0.

Results

In men, the measurement values for navicular height, first and fifth toe and instep heights, ball and heel width, ball girth, AHI (just standing), ARI and instep girth were significantly greater than the women's, whereas the first toe angle, in both sitting and standing positions was significantly smaller. However, after normalizing, the differences in ball width, heel width, height of first and fifth toes in both sitting and standing and ball girth in sitting position were nonsignificant. According to Cohen's d, among all the foot variables, the following had large effect sizes in both sitting and standing positions: truncated foot length, instep, navicular height, foot length, ball girth, ball width, heel width and instep girth (Table 2).

Discussion

This study demonstrates important anatomical differences of the foot between genders. Women have narrower feet in the heel and forefoot, and their instep, first and fifth toes and navicular height are also lower than men's. Women also showed a greater first toe angle and lower ARI and AHI (just standing) compared to men. However, some of these differences were nonsignificant after normalizing to truncated foot length suggesting that the original findings were simply due to the fact that male feet tend to be larger than female feet. Furthermore, according to Cohen's d, some differences were very small, and as a practical manner, the usefulness for shoe manufacturers to incorporate those differences is questionable.

Table 2 Independent sample t-test, ANCOVA (adjusted to truncated foot length) & Cohen's d effect size

Foot characteristics	Men (N = 151) Mean ± SD	Women (N = 140) Mean ± SD	t test P value	ANCOVA P value	Effect size (ES)	Guide of ES
Sitting truncated foot length (mm)	179.81 ± 7.46	165.25 ± 6.92	P < 0.001	–	2.03	Large
Sitting instep (mm)	66.18 ± 4.30	59.65 ± 3.87	P < 0.001	P < 0.001	1.60	Large
Sitting NH (mm)	48.23 ± 6.21	42.15 ± 5.14	P < 0.001	P < 0.001	1.07	Large
Sitting AHI	0.37 ± 0.03	0.36 ± 0.03	.021	–	0.27	Small
Sitting foot length (mm)	243.19 ± 9.07	224.69 ± 8.86	P < 0.001	–	2.07	Large
Sitting ball girth (mm)	244.28 ± 11.65	227.95 ± 10.66	P < 0.001	.002	1.47	Large
Sitting ball width (mm)	98.93 ± 5.08	92.55 ± 5.24	P < 0.001	.490	1.24	Large
Sitting heel width (mm)	64.51 ± 4.22	59.93 ± 3.22	P < 0.001	.291	1.22	Large
Sitting first toe angle (degree)	10.42 ± 4.64	13.64 ± 6.92	P < 0.001	P < 0.001	0.55	Moderate
Sitting little toe angle (degree)	13.80 ± 4.00	13.35 ± 4.87	.393	.782	0.10	Very small
Sitting first toe height (mm)	18.03 ± 2.31	16.45 ± 2.16	P < 0.001	.057	0.71	Moderate
Sitting little toe height (mm)	12.88 ± 2.25	11.94 ± 1.85	P < 0.001	.564	0.46	Small
Sitting instep girth (mm)	248.93 ± 11.54	227.70 ± 10.85	P < 0.001	P < 0.001	1.90	Large
Standing foot length (mm)	246.20 ± 9.05	227.57 ± 9.13	P < 0.001	–	2.06	Large
Standing truncated foot length (mm)	182.16 ± 7.81	168.45 ± 7.01	P < 0.001	–	1.85	Large
Standing instep (mm)	61.68 ± 4.51	55.02 ± 3.88	P < 0.001	P < 0.001	1.58	Large
Standing NH (mm)	41.77 ± 6.32	35.76 ± 5.32	P < 0.001	P < 0.001	1.03	Large
Standing ball girth (mm)	247.09 ± 11.23	230.55 ± 11.41	P < 0.001	P < 0.001	1.47	Large
Standing ball width (mm)	101.53 ± 4.85	95.39 ± 5.74	P < 0.001	.251	1.16	Large
Standing heel width (mm)	65.89 ± 4.05	60.64 ± 4.67	P < 0.001	.006	1.21	Large
Standing first toe angle (degree)	10.73 ± 4.95	14.90 ± 7.60	P < 0.001	P < 0.001	0.63	Moderate
Standing little toe angle (degree)	13.84 ± 4.11	13.62 ± 5.00	.687	.725	0.05	Very Small
Standing first toe height (mm)	17.39 ± 1.91	16.02 ± 2.29	P < 0.001	.465	0.65	Moderate
Standing little toe height (mm)	12.76 ± 2.05	11.74 ± 1.87	P < 0.001	.084	0.52	Moderate
Standing instep girth (mm)	249.20 ± 11.05	228.30 ± 10.94	P < 0.001	P < 0.001	1.91	Large
Standing AHI	0.34 ± 0.03	0.33 ± 0.03	P < 0.001	–	0.46	Small
Arch drop (instep difference) (mm)	4.51 ± 1.70	4.65 ± 1.62	.464	.008	0.09	Very small
ND (mm)	6.46 ± 2.53	6.39 ± 2.53	.814	.610	0.03	Very small
ARI	0.92 ± 0.03	0.91 ± 0.03	P < 0.001	–	0.43	Small

According to Wunderlich et al., these small differences may not even be perceptible when incorporated into footwear [10]. In our study, the first toe angle was significantly greater in women. The presence of hallux valgus can explain the larger values found among the women, because it occurs more frequently in women [23–25].

Our results were different in some respects to the gender difference studies in Brazil and Australia. In Brazil, unlike the results of our study, the width and perimeter of the toes and the width of the heel in the women were significantly greater than the men's measurements. However, similar to our results, women had a significantly lower instep than men after normalizing the data to foot length, and the first and fifth metatarsophalangeal angles were smaller in the men [4]. Like our study, the Australian study used a 3D foot scanner and found men to have significantly larger values than the women for all dimensions with the exception of the first toe angle. However, men had significantly higher first and fifth toe heights and a greater fifth toe angle, and women had a significantly longer truncated foot length normalized within two common foot length categories, which is different than our results [8]. The inconsistencies between the Brazil and Australian studies and our study may be due to different measuring methods or foot categorization, or these may be true ethnic differences.

Our study results are consistent with previous studies on young or mixed-age populations. Krauss et al. showed that, for the same shoe size, young women had lower insteps than young men [1]. In addition, they found that women had smaller widths of the heel and the forefoot [1]. Aml et al. also compared foot measurements in the same foot-length category and observed that foot width and perimeter were greater in males than in females [26]. Furthermore, Wunderlich et al. normalized their data to the foot length and reported women's feet had smaller values for the height of the first toe and the perimeter of the instep [10].

When comparing arch height between men and women, results vary between studies. The results of our study are consistent with the study by Frey [5] who reported that women presented with flatter feet than men did. Hashimoto et al. [27] who used radiography, a more reliable measurement method, to verify arch height in young adults also noted that the women had lower arches than the men. Structural changes in the female body may lead to pronation of the foot. Compared to men, women have narrower shoulders, hips are in a more varus position, and knees are in a more valgus position, which induces a pronation of the rear feet [5].

On the other hand, our results are different from 2 other studies: a survey of 441 individuals 1–80 years of age by Staheli et al. [28] that used the arch index and indicated that males have flatter feet, and a study by Zifchock et al. [29] of 145 individuals 18–65 years of age that reported that standing AHI was not significantly different but ARI was significantly different between men and women. These inconsistencies may be related to ethnic, cultural, measurement tool and age differences.

It is acknowledged that, even though subjects were instructed to distribute their body weight equally when standing so that the assessed foot supported 50 %, we could not control this with accuracy. Therefore, there may be variations in percentage of weight bearing, and as a result, different standing NH and AHI in standing position. Tessem et al. previously reported that the amount of asymmetry in weight distribution between extremities during relaxed standing is 4 % or less in healthy subjects [30]. Moreover, the sample used in this study was possibly more active or mobile due to excluding people reliant on walking sticks during the measurement.

Conclusion

Overall, the current study provided evidence of anthropometric foot variations of older men and women. The dissimilarities are primarily in instep height, instep girth, ball girth and navicular height. Shoe manufacturers should consider the gender differences in feet when designing shoes for older adults to accommodate the greater ball and instep girth and the instep and navicular height of men's feet and the greater first toe angle in women. Since the P value for standing heel width is also near 0.001, we recommend shoe designers also consider this difference. It remains to be seen, however, whether a shoe designed for the elderly based on gender differences suggested here would be perceived subjectively as being a better fit and, therefore, more comfortable. Further research should investigate how footwear designed according to gender differences affects fall risk.

Abbreviation

NH: Navicular height; ND: Navicular drop; AHI: Arch height index; ARI: Arch rigidity index.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MS carried out conception and design, data acquisition, analysis and interpretation, and drafting of the manuscript. NK participated in acquisition of the data, interpretation of the data, and manuscript development. TO participated in data interpretation, supervision and coordination of the study, and manuscript development. All authors read and approved the final manuscript.

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Original Article

Ground Reaction Force in Sit-to-stand Movement Reflects Lower Limb Muscle Strength and Power in Community-dwelling Older Adults*

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Background: Ground reaction force parameters in a sit-to-stand (STS) movement can be used to evaluate lower extremity function. Few reports, however, are available on whether the ground reaction force parameters in an STS movement reflect dynamic knee and ankle strength or power. The aims of this study were to examine associations among ground reaction force parameters in an STS movement and isokinetic knee and ankle strength and power in healthy older adults, and to compare associations with the five-times STS test.
Methods: The following five ground reaction force parameters were measured in 19 men and 28 women: peak reaction force, two rate of force development (RFD) parameters and two time-related parameters.
Results: RFD (D90 ms)/body weight correlated significantly with average isokinetic knee extension/flexion power in both sexes (partial-r = 0.39e 0.54) and average ankle plantar flexion and dorsiflexion power (partial-r = 0.50 and partial-r = 0.49, respectively), in women. No isokinetic parameters were significantly related to the five-times STS test.
Conclusion: Ground reaction force parameters in an STS movement can accurately reflect the dynamic strength and power in the lower limbs, which is approximately equal to or better than the strength and power reflected by the five-times STS test.

1. Introduction

Research has firmly established the importance of lower limb muscle strength during a sit-to-stand (STS) movement[1,2]. In the clinical setting of preventive nursing care for older adults, field tests of the STS movement are frequently used to indirectly evaluate the lower limb muscle strength. However, other physiological and psychological factors may also affect the execution of an STS movement, which is a daily functional movement. The STS test considers these factors and can be tailored according to the daily lifestyle of an elderly person, which sets it apart from other tests, e.g., the isokinetic test, that directly evaluate monoarticular muscle strength. However, to demonstrate the validity of the STS test, a correlation between the results of the STS test and the lower limb muscle strength is necessary, along with determination of the extent to which these results reflect such values.

The STS movement is tested either by recording the time required for a certain number of repetitions, e.g., five-times STS test[2,3], or the number of repetitions performed within a specified time frame, e.g., 30-second chair-stand test[2,4]. However, these tests do not always reflect leg muscle function because they also involve other factors, such as general endurance[5].

Recent reports[6,7] have revealed the vertical ground reaction force parameters in an STS movement to be useful for evaluating lower limb muscle strength and power in older adults. The benefits of this method are: (1) assessment of the force output during any activity of daily living (i.e., complex motor tasks), which may be more functional than measuring the muscle strength or power of a single joint; (2) ability to measure a person who is able to perform only a few STS movements; (3) relative ease of transporting the measurement instrument (simple force platform); and (4) the direct measurement of

* Conflicts of interest: All contributing authors declare that they have no conflicts of interest.

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the force output in kgf using the force platform. This approach can bring the benefits of evaluating lower limb strength and power into the clinical setting of preventive nursing care. The ground reaction force parameters have good test-retest reliability (intraclass correlation coefficients: 0.70e 0.95), and they significantly relate to isometric knee extension strength in community-dwelling older adults[7]. However, to the best of our knowledge, the associations between the ground reaction force parameters and dynamic knee strength and power, which play a more important role when performing activities of daily living[8], have not been reported. Moreover, although strength of the muscles around the ankle joint is important to decrease fall risk[9], the relationship between ground reaction force parameters and strength and power output by these has not been discussed. A kinematic study of the STS movement[10] suggests that ankle dorsiflexion strength is essential during the flexion-momentum phase (Phase I), when the body weight is shifted from the buttocks to feet immediately after movement initiation. Knee extension strength is essential during the momentum transfer phase (Phase II), when the body weight is shifted from the chair to the feet and the extension phase (Phase III), when maximum knee extensor velocity is achieved. In addition, the force output at the feet and lower limbs (i.e., around the ankle joint), which were proximally positioned to the force platform, may have an important effect on ground reaction force parameters.

This study aimed to examine associations of ground reaction force parameters of an STS movement with isokinetic knee and ankle strength and power in healthy older adults and compare these with the five-times STS results. We hypothesized that ground reaction force parameters, which can directly reflect the force output while more important phases require muscular exertion at the knees and ankles to complete the STS movements, are more significantly associated with dynamic strength and power in the lower limbs than the five-times STS test, which is an indirect time-based evaluation method.

2. Materials and methods

2.1. Participants

We used the baseline data recorded from individuals who participated in an exercise program at our university. Community-dwelling healthy older adults, aged 65e 75 years, were recruited by means of advertisements placed in the local newspaper. The Ethics Board of the University of Tsukuba in Japan approved the study. Of the 75 respondents, 17 were excluded after telephone interviews because of lack of transportation to our university, inability to attend the study orientation, dependent living status, and having any physiological disorder that precluded strenuous exercise. Of 51 randomly-chosen participants, four withdrew. Finally, 19 men and 28 women gave written informed consent and participated in the study (Fig. 1).

2.2. Testing protocol

Testing was performed on 2 days, with a 7-day interval. On Day 1, we measured ground reaction force of the STS movement and the

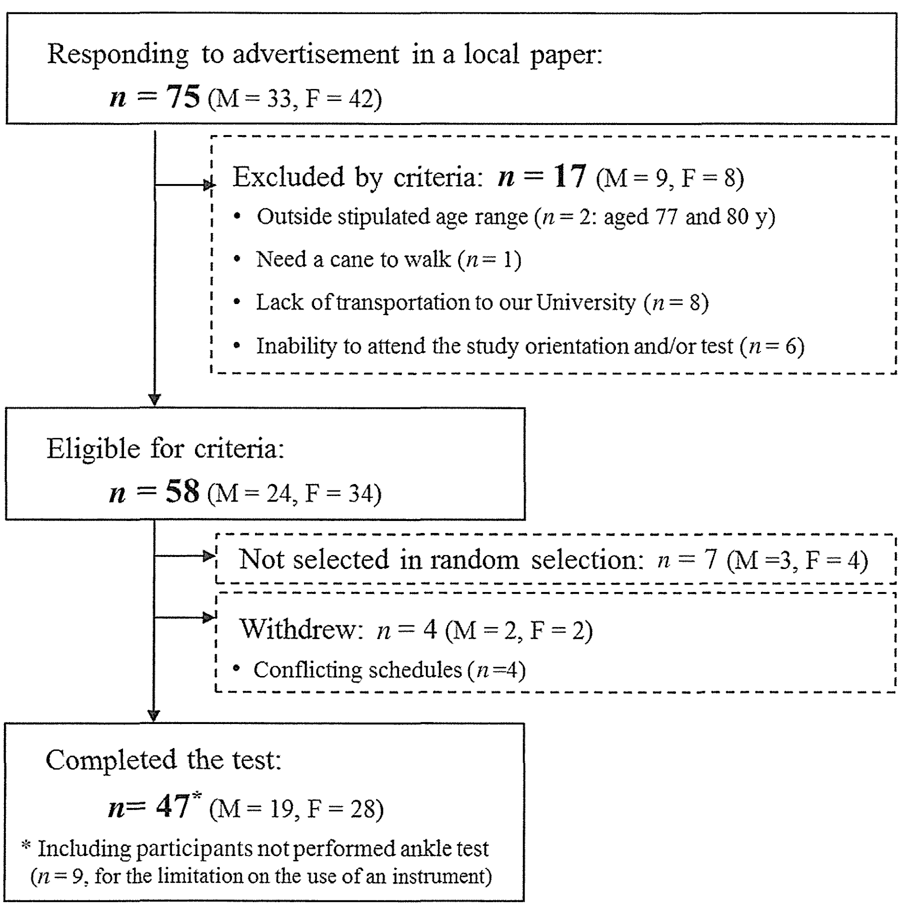

Fig. 1. Flow of participants through the study. F= female; M = male.

isokinetic knee torque and power in random order with a 20-minute interval between tests. We performed the isokinetic ankle test and the five-times STS test 7 days later. To minimize measurement errors, we held the two test sessions at approximately the same time of day. In addition, one investigator performed all ground reaction force measurements for the STS movement and five-times STS test, whereas the other investigator performed all knee and ankle torque and power tests.

2.3. Ground reaction force parameters

After explaining the sitting posture and movement pattern for the STS movement, participants sat in a chair of standard height (40 cm) with legs shoulder-width apart, the trunk stretched vertically in a straight line and their ankles held at 90° on the force plate (TKK5809, Takei Scientific Instruments Co. Ltd., Niigata, Japan). Participants stood up from the chair as fast as possible with arms folded, rested for approximately 2 seconds, and then sat down again. They performed three trials in succession with an interval of 2 seconds. The force plate provided a curve of vertical ground reaction force during the STS movement at 100 Hz (simple moving average: 10).

Based on previous studies[6,7,11,12], we collected five ground reaction force parameters (Fig. 2). The peak reaction force/body weight ($kgf\$kg^{-1}$) reflected the maximal downward force pushing the body upwards. Two maximal rate of force development (RFD) parameters were an index of the capacity for rapid muscle force production: the maximal RFD (D10 millisecond)/kg (RFD1/w, kgf/$s\$kg^{-1}$), which was defined as the steepest gradient of the force-time curve over a given 10-millisecond time frame. RFD9/w (kgf/$s\$kg^{-1}$), with a sample duration of 90 milliseconds, helps to assess the muscle exertion over a longer time frame for better reproducibility. There were also two time-related parameters: the time span of the developing force, and the chair-rise time. We evaluated these parameters as the participant's quickness of movement. The highest values of the peak reaction force/body weight, RFD1/w and RFD9/w were selected for analysis. We used the trial with the highest RFD9/w value to determine the values of the time span of the developing force and chair-rise time. The five parameters obtained from the same measurement protocol with the same force plate as the present study have good test reliability (intraclass correlation coefficients of the peak reaction force/body weight, RFD1/w, RFD9/w, the time span of the developing force and chair-rise time were 0.91, 0.51, 0.87, 0.84 and 0.82, respectively)[13].

2.4. Five-times STS test

The five-times STS test was measured according to a previous study[14]. The participants were asked to rise from a chair of standard height (40 cm) five times as fast as possible with their arms folded. The shorter time of the two trials was used for analyses.

2.5. Knee and ankle peak torque and average power

A Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) was used for testing peak torque and average power. Peak torque and average power during isokinetic (60°/s) knee extension and flexion as well as ankle plantar flexion and dorsiflexion were measured in the dominant leg. We determined leg dominance by requesting the participant to kick a ball. Calibration was performed before each test session as per the manufacturer's specifications. All isokinetic values were corrected for the effect of gravity.

Participant positioning for the isokinetic knee extension and flexion trials has been described previously[15]. The two trials were performed separately. For each trial, participants performed two submaximal and two maximal contractions before testing, and then three maximal voluntary contractions with the knee joint approximately maintained between 90° and 180°. A minimum 5-minute rest was allowed between the two trials to exclude the effect of fatigue.

For the ankle plantar flexion and dorsiflexion trials, participants were semi-reclined with knees at 15° flexion, and the back of the seat tilted to approximately 80°. The participants were stabilized with two shoulder straps, a waist strap, a thigh strap, and an auxiliary pad fixed under the calf. The foot was attached to a footplate and fixed with two belts. The ankle joint was aligned with the axis of the dynamometer. Isokinetic plantar flexor and dorsiflexor trials were performed separately. For each trial, the participant performed two submaximal and two maximal contractions before testing. For the actual test, the participant performed four maximal voluntary contractions through the full active range of motion of the ankle joint, resting at least 5 minutes between the two trials.

Isokinetic peak torque and average power were calculated using the Biodex System 3 Advantage software (version 3.03; Biodex Medical Systems, Shirley, NY, USA), and the highest value from each trial was recorded. Torque and power data were normalized/kg of body weight (Nm/kg and W/kg, respectively).

2.6. Statistical analyses

We initially calculated descriptive statistics for participant characteristics. We used Student *t* test for continuous variables and Chi-square test for categorical variables to detect sex differences. We conducted partial correlation analyses according to sex and adjusted for age, to examine the relationships among the ground reaction force parameters in an STS movement, the five-times STS results and lower limb muscle strength and power values. We calculated 95% confidence intervals for all partial correlation coefficients. All analyses were conducted using SPSS Statistics for Windows, Version 17.0 (SPSS Inc., Chicago, IL, USA). A p value <0.05 was considered significant.

3. Results

3.1. Descriptive data of participants

Table 1 contains the descriptive details of participants. The mean age was 69.0 ± 2.9 years. Significant sex differences were found in height, body weight, the peak reaction force per body weight, all knee extension and flexion variables, and ankle dorsiflexion peak torque.

3.2. Relationships among ground reaction force parameters, five-times STS test, and lower limb torque and power

Table 2 shows partial correlations among the ground reaction force parameters in an STS movement, the five-times STS results and knee and ankle torque and power values. In men, RFD9/w correlated significantly with isokinetic knee extension and flexion average power (partial-r = 0.51 and partial-r = 0.54, respectively; $p < 0.05$). In women, the peak reaction force per body weight and RFD9/w correlated significantly with all four isokinetic knee parameters and ankle plantar flexion average power (partial-r = 0.39e 0.50; $p < 0.05$). RFD9/w, the time span of the developing force and chair-rise time also correlated significantly with isokinetic ankle dorsiflexion parameters (partial-r = 0.44e 0.59; $p < 0.05$). No isokinetic parameters, however, were significantly related to any five-times STS measurements in either sex

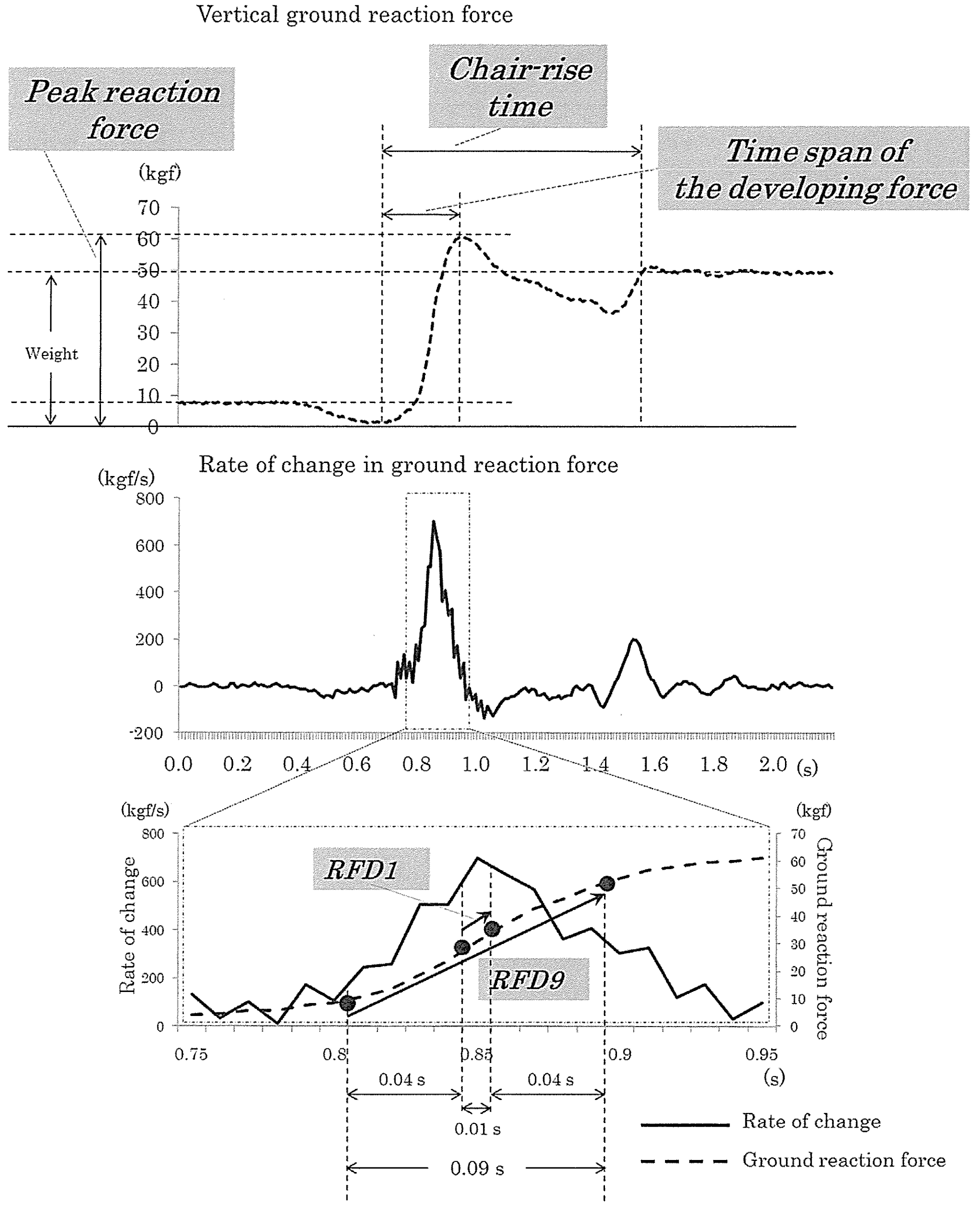

Fig. 2. Ground reaction force parameters. RFD1 = maximal rate of force development (D10 ms); RFD9 = maximal rate of force development (D90 ms).

(partial-jrj = 0.03e 0.31). There was a linear relationship between RFD9/w and isokinetic knee extension average power in both sexes (Fig. 3).

4. Discussion

The present study is the first to investigate associations among vertical ground reaction force parameters in an STS movement and lower limb dynamic strength and power. The ground reaction force parameters (especially RFD9/w) in an STS movement were associated with isokinetic knee and ankle strength and power. However, the five-times STS results had little association with isokinetic strength or power. This suggests that ground reaction force parameters in an STS movement can accurately reflect the isokinetic strength and power in the knees and ankles, which is approximately equal to or better than the strength and power reflected by the five-times STS test. Therefore, this measurement method can be a novel field test for evaluating lower limb muscle strength and power in the clinical setting of preventive nursing care for older adults.

Until recently, the relationship between lower limb muscle strength and the ground reaction force in an STS movement was unclear. Yamada and Demura[7] reported that ground reaction force parameters showed a moderate correlation (jrj = 0.29e 0.64) with isometric knee extension muscle strength in older women. In the present study, RFD9/w was related to dynamic knee extension and flexion power in both sexes. Moreover, dynamic ankle plantar flexion and dorsiflexion power were also related to RFD9/w in women. In previous studies[16,17], RFD during isometric knee extension was used to evaluate the ability to develop force rapidly, which

Table 1
Descriptive data of participants.

	All (n = 47)		Men (n = 19)		Women (n = 28)	
	Mean	SD	Mean	SD	Mean	SD
Characteristics						
Age (y)	69.0 ± 2.9		69.6 ± 2.9		68.6 ± 2.9	
Height (cm)	157.6 ± 7.2		164.4 ± 3.8		153.0 ± 4.8*	
Body weight (kg)	57.2 ± 9.3		63.8 ± 7.7		52.7 ± 7.5*	
Body mass index (kg/m^2)	23.0 ± 2.8		23.6 ± 2.6		22.5 ± 2.9	
Systolic blood pressure (mmHg)	139 ± 20		142 ± 16		137 ± 1	
Diastolic blood pressure (mmHg)	81 ± 10		84 ± 9		79 ± 10	
Medication use (piece)	1.4 ± 1.7		1.6 ± 2.3		1.2 ± 1.2	
Lower limb pain^y, yes %(n)	12.8 (6)		15.8 (3)		10.7 (3)	
Lower back pain^y, yes %(n)	10.6 (5)		10.5 (2)		10.7 (3)	
Ground reaction force parameters						
Peak reaction force/body weight (kgf\$kg^{-1})	1.43 ± 0.11		1.49 ± 0.09		1.39 ± 0.10*	
RFD1/w (kgf/s\$kg^{-1})	16.82 ± 3.70		17.59 ± 3.48		16.29 ± 3.81	
RFD9/w (kgf/s\$kg^{-1})	11.14 ± 1.48		11.56 ± 1.43		10.85 ± 1.47	
Time span of the developing force (ms)	282 ± 68		302 ± 74		269 ± 62	
Chair-rise time (ms)	782 ± 92		793 ± 88		774 ± 96	
Lower-limb strength and power						
Knee extension						
Peak torque (0°/s) (Nm/kg)	2.15 ± 0.45		2.35 ± 0.48		2.01 ± 0.38*	
Peak torque (60°/s) (Nm/kg)	1.55 ± 0.38		1.70 ± 0.32		1.46 ± 0.39*	
Average power (60°/s) (W/kg)	0.85 ± 0.26		0.99 ± 0.25		0.76 ± 0.21*	
Knee flexion						
Peak torque (60°/s) (Nm/kg)	0.81 ± 0.19		0.93 ± 0.16		0.73 ± 0.17*	
Average power (60°/s) (W/kg)	0.56 ± 0.15		0.65 ± 0.14		0.49 ± 0.12*	
Ankle plantar flexion^z						
Peak torque (60°/s) (Nm/kg)	0.88 ± 0.29		0.93 ± 0.29		0.84 ± 0.28	
Average power (60°/s) (W/kg)	0.46 ± 0.16		0.50 ± 0.17		0.44 ± 0.15	
Ankle dorsiflexion^z						
Peak torque (60°/s) (Nm/kg)	0.24 ± 0.06		0.26 ± 0.05		0.22 ± 0.06*	
Average power (60°/s) (W/kg)	0.13 ± 0.04		0.14 ± 0.04		0.12 ± 0.03	
Timed test						
Five-times sit-to-stand (s)	7.37 ± 1.43		7.41 ± 1.21		7.35 ± 1.58	

RFD1 = maximal rate of force development (D10 ms); RFD9 = maximal rate of force development (D90 ms); SD = standard deviation; w = body weight.
* $p < 0.05$ (presence of sex difference).
^{y} c^2 test.
^{z} n = 39 (men: 17, women: 22).

plays an important role in muscle power. Moreover, our results may help in understanding the misinterpreted curve of Fleming et al[12], in which RFD in an STS movement was equated with power. This association is incorrect in terms of physics, because power is defined as the amount of work performed over a period of time or by multiplying the force and velocity. However, we observed that this variable correlated well with lower limb power. Furthermore, McGibbon et al[18] investigated the relationship between ground reaction force in an STS movement and the time to lift-off from the seat, and demonstrated that RFD9/w is probably achieved around the time of lift-off. Therefore, this appearance time of RFD9/w is the transfer phase between Phase I, where the ankle dorsiflexor strength plays an important role, and Phase II, where knee extensor strength plays an important role[10]. Because the center of balance that is transferred from the buttocks to feet and the body weight is lifted upward from sitting to standing, participants who exerted sufficient knee and ankle strength also recorded superior RFD9/w results in our study.

We found a poor correlation between the five-times STS results and lower limb strength and power. Our results are in accordance with those of Netz et al[5], who reported that the multiple-STS test did not predict isokinetic strength of knee extensors, but rather, general endurance in older adults. Furthermore, Lord et al[19] found that performance of the five-times STS test was influenced by multiple physiological and psychological processes, such as proprioception and vitality, and represented a particular transfer skill, rather than a proxy measure of lower limb strength. Thus, ground reaction force parameters may also be affected by these processes; however, measuring RFD in an STS movement may attenuate the impact of factors other than lower limb strength or power because force output can be directly measured with the force platform. Furthermore, the moderate correlation observed between RFD9/w and knee extension/flexion power in this study was greater than the correlations (partial-r, controlled for age = 0.01e 0.28) observed in previous studies[19] between STS performance and sensorimotor, balance, or psychological factors. Moreover, most studies, including the present one, included cross-sectional investigations of STS performance and its relationships with muscle strength and power. Therefore, causality based on longitudinal research cannot be determined. However, STS movement is a functionally coordinated movement of multiple joints; thus, measurements of muscle strength and power for individual joints can be considered as important independent variables. In addition, participants in the present study who recorded higher monoarticular muscle strength and power measurements could step on the ground quicker and with greater force during STS movements, and they showed superior ground reaction force parameters.

The ground reaction force parameters in an STS movement were associated with more parameters of lower limb strength and power in women than in men. One reason may be the fixed chair height (40 cm). A lower chair changes the chair rise strategy so that maintaining stability is a priority making the STS movement more difficult[20,21]. In the present study, men were taller than women; thus, the burden on the lower limbs might be greater in men. In a previous study[7] on ground reaction force parameters and knee strength, participants were older women who stood up from a 40-

Table 2
Partial correlation coefficients between ground reaction force parameters, and knee and ankle peak torque and average power.

	n	Peak reaction force/body weight (kgf·kg^{-1})	RFD1/w (kgf/s·kg^{-1})	RFD9/w (kgf/s·kg^{-1})	Time span of the developing force (ms)	Chair-rise time (ms)	Five-times sit-to-stand (s)
		partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)
Men							
Knee extension							
Peak torque (60°/s) (Nm/kg)	19	0.07 (−0.40, 0.51)	−0.20 (−0.60, 0.28)	0.08 (−0.39, 0.52)	0.14 (−0.34, 0.56)	0.16 (−0.32, 0.57)	0.18 (−0.30, 0.59)
Average power (60°/s) (W/kg)	19	0.26 (−0.22, 0.64)	0.23 (−0.25, 0.62)	0.51 (0.07, 0.78)*	−0.27 (−0.65, 0.21)	−0.25 (−0.63, 0.23)	−0.09 (−0.52, 0.38)
Knee flexion							
Peak torque (60°/s) (Nm/kg)	19	0.17 (−0.31, 0.58)	0.02 (−0.44, 0.47)	0.26 (−0.22, 0.64)	−0.00 (−0.45, 0.45)	0.01 (−0.45, 0.46)	−0.03 (−0.48, 0.43)
Average power (60°/s) (W/kg)	19	0.24 (−0.24, 0.63)	0.28 (−0.20, 0.65)	0.54 (0.11, 0.80)*	−0.38 (−0.71, 0.09)	−0.30 (−0.66, 0.18)	−0.23 (−0.62, 0.25)
Ankle plantar flexion							
Peak torque (60°/s) (Nm/kg)	17	−0.19 (−0.61, 0.32)	−0.28 (−0.67, 0.23)	−0.05 (−0.52, 0.44)	0.10 (−0.40, 0.55)	0.07 (−0.42, 0.53)	0.30 (−0.21, 0.68)
Average power (60°/s) (W/kg)	17	−0.08 (−0.54, 0.42)	−0.12 (−0.57, 0.38)	0.11 (−0.39, 0.56)	−0.11 (−0.56, 0.39)	−0.11 (−0.56, 0.39)	0.10 (−0.40, 0.55)
Ankle dorsiflexion							
Peak torque (60°/s) (Nm/kg)	17	0.25 (−0.26, 0.65)	0.08 (−0.42, 0.54)	0.28 (−0.23, 0.67)	−0.45 (−0.77, 0.04)	−0.25 (−0.65, 0.26)	−0.31 (−0.69, 0.20)
Average power (60°/s) (W/kg)	17	0.43 (−0.06, 0.75)	0.27 (−0.24, 0.66)	0.46 (−0.03, 0.77)	−0.49 (−0.79, 0.00)	−0.37 (−0.72, 0.13)	−0.23 (−0.64, 0.28)
Women							
Knee extension							
Peak torque (60°/s) (Nm/kg)	28	0.43 (0.07, 0.69)*	0.38 (0.01, 0.66)*	0.47 (0.12, 0.72)*	0.05 (−0.33, 0.42)	−0.22 (−0.55, 0.17)	−0.13 (−0.48, 0.26)
Average power (60°/s) (W/kg)	28	0.41 (0.04, 0.68)*	0.34 (−0.04, 0.63)	0.45 (0.09, 0.70)*	0.03 (−0.35, 0.40)	−0.23 (−0.56, 0.16)	−0.17 (−0.51, 0.22)
Knee flexion							
Peak torque (60°/s) (Nm/kg)	28	0.44 (0.08, 0.70)*	0.21 (−0.18, 0.54)	0.39 (0.02, 0.67)*	0.13 (−0.26, 0.48)	−0.14 (−0.49, 0.25)	−0.31 (−0.61, 0.07)
Average power (60°/s) (W/kg)	28	0.39 (0.02, 0.67)*	0.20 (−0.19, 0.53)	0.39 (0.02, 0.67)*	0.03 (−0.35, 0.40)	−0.16 (−0.50, 0.23)	−0.30 (−0.61, 0.08)
Ankle plantar flexion							
Peak torque (60°/s) (Nm/kg)	22	0.38 (−0.05, 0.69)	0.57 (0.20, 0.80)*	0.38 (−0.05, 0.69)	−0.12 (−0.52, 0.32)	−0.37 (−0.68, 0.06)	−0.20 (−0.57, 0.24)
Average power (60°/s) (W/kg)	22	0.48 (0.07, 0.75)*	0.63 (0.28, 0.83)*	0.50 (0.10, 0.76)*	−0.14 (−0.53, 0.30)	−0.46 (−0.74, −0.05)*	−0.22 (−0.59, 0.22)
Ankle dorsiflexion							
Peak torque (60°/s) (Nm/kg)	22	0.29 (−0.15, 0.63)	0.22 (−0.22, 0.59)	0.44 (0.02, 0.73)*	−0.48 (−0.75, −0.07)*	−0.59 (−0.81, −0.22)*	−0.21 (−0.58, 0.23)
Average power (60°/s) (W/kg)	22	0.38 (−0.05, 0.69)	0.24 (−0.20, 0.60)	0.49 (0.09, 0.76)*	−0.51 (−0.77, −0.11)*	−0.57 (−0.80, −0.20)*	−0.14 (−0.53, 0.30)

*$p < 0.05$.
CI = confidence interval; RFD1 = maximal rate of force development (Δ10 ms); RFD9 = maximal rate of force development (Δ90 ms); w = body weight.

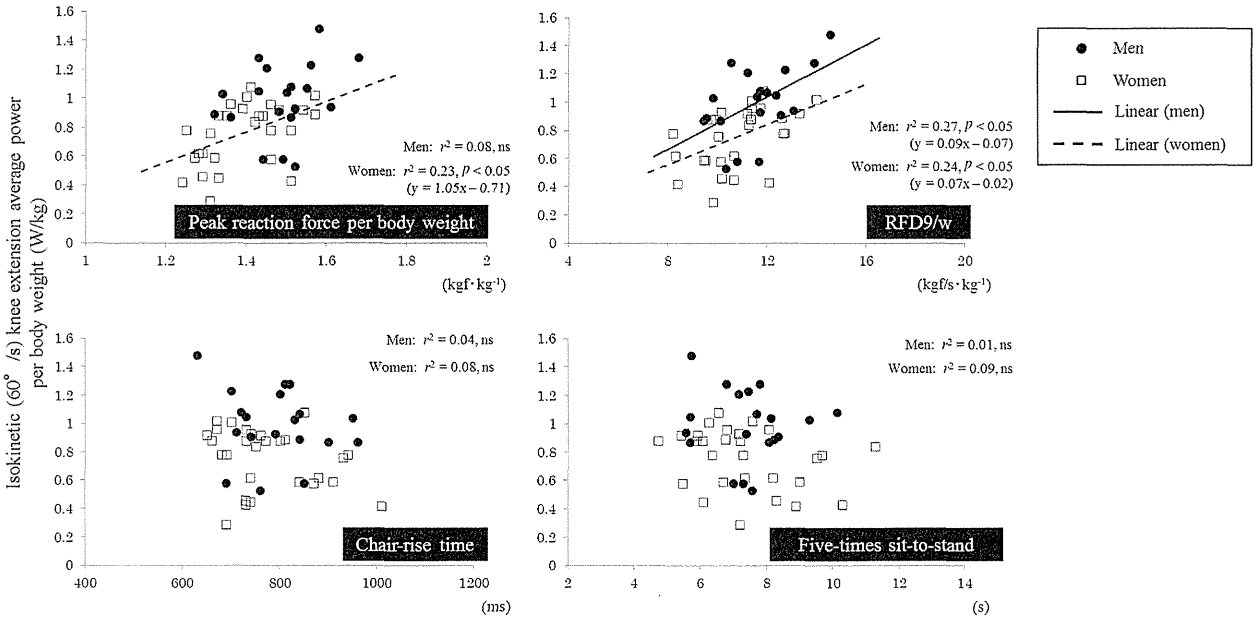

Fig. 3. Univariate regression analyses of peak reaction force/body weight, maximal rate of force development (D90 ms)/body weight (RFD9/w), chair-rise time and five-times sit-to-stand results versus isokinetic knee extension average power.

cm high chair. This suggests that a 40-cm high chair may not be appropriate for many older men; they require a taller or adjustable chair. It should be stressed, however, that only RFD9/w correlated significantly with knee extension and flexion power in men.

Unfortunately, this measurement method is not yet as practical as a field test, due to the need for specialized equipment that at present is relatively expensive. However, because several studies, including our current study, have shown this measurement method to be reliable and valid, equipment that is reasonably priced and easy to operate can be developed for general public use. For example, incorporating this measurement system into a body weight scale could lead to its widespread household use. Furthermore, individuals can use this equipment to perform measurements on themselves even in the absence of an experienced tester. The present study provides basic information that can be used to develop this novel equipment for general use.

Our study had some limitations. First, the participants may not represent all older adults because they were candidates for the training program at the university. We targeted relatively healthy older adults to ensure greater safety while performing the strenuous tests. We expect that the associations between the ground reaction force parameters and lower limb strength and power would be stronger for participants with functional limitations or severe pain because of the greater breadth of the distribution. Furthermore, in recent years, this measurement method has been used to assess asymmetry in muscle force loading in patients with knee or hip osteoarthritis[22,23]. If we measure ground reaction force from each leg separately using two force plates, we might gain more insight into participants' physical function. Second, participant physique or the characteristics of the rising strategy were not considered. However, because the ultimate objective of this study was to introduce this measurement method into the clinical setting of preventive nursing-care for older adults, we felt a fixed chair height and less precise control of a participant's STS movement were sufficient. Third, the sample size was too small to detect a statistical difference between the partial-r of ground reaction force parameters and of five-times STS test. Finally, to reduce the burden on participants and because of limitations of equipment used in the present study, we were unable to measure hip flexion/extension strength and power; this also affects the execution of the STS movement.

In conclusion, the vertical ground reaction force parameters in an STS movement can accurately reflect the dynamic strength and power in the lower limbs, which is approximately equal to or better than the strength and power reflected by the five-times STS test. In particular, the maximal RFD (D90 millisecond)/body weight variable is well correlated with knee extension and flexion power. Further progress in this measurement method may increase the accuracy and objectivity of measured data for assessment of lower limb muscle strength and power in clinical settings of preventive nursing-care and relieve testing strain on older adults.

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