2021
「狭山市・入間市と東京家政大学との地域住民の運動習慣と身体機能に関する実態調査研究」報告書

CommuLiC
Community Liaison Center

東京家政大学ヒューマンライフ支援機構
地域連携推進センター

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「狭山市・入間市と東京家政大学との地域住民の運動習慣と身体機能に関する実態調査研究」報告書

刊行にあたって

東京家政大学地域連携推進センター所長
池森　隆虎

この調査研究報告書は、東京家政大学地域連携推進センターの 2019 年度から 2021 年度に渡る調査研究事業として、狭山市・入間市と東京家政大学との連携により、行われました『地域住民の運動習慣と身体機能に関する実態調査研究』を報告するものです。この調査研究は、地域社会における課題解決のための取り組みの一つとして、狭山市（長寿健康部健康づくり支援課）、入間市（健康推進部地域保健課）との共同研究プロジェクトとして実施されたものとなります。

本プロジェクトの調査は、2019 年 7 月より開始され、2021 年 9 月まで「運動能力を測定」、「食習慣と運動習慣に関するアンケート」として行われました。当初予定になかった「コロナ対応」という難題もありましたが、データの集計・分析・検討を経て、報告書作成に至りました。なお、調査計画策定にあたっては協定書を交わし、研究計画・内容については、東京家政大学研究倫理委員会に審査請求を行い、承認されております。

本事業は、地域住民の運動能力や認知能力を横断的及び縦断的に調査するものですが、調査研究に参加した方々が自分自身の心身機能を把握し、健康意識を高めることにつながることも期待しています。また、この調査結果が行政関係者のみならず、広く市民の方々にも見て頂くことで、市民の健康への意識を考えるきっかけとしていただければ幸いです。

なお、この調査結果は、市内公共施設等の各測定会場において、参加者個人（任意）にも配布される予定となっております。さらには、この事業を継続することで健康寿命を延伸し、住民の医療費、介護保険負担料の軽減にもつながると考えられます。

最後になりましたが、調査研究委員会の清水順市委員長をはじめ、狭山市長寿健康部健康づくり支援課、入間市健康推進部地域保健課の職員の方々等関係者の皆様、調査研究委員を受けて頂いた東京家政大学健康科学部リハビリテーション学科の先生方、事務局として関わりましたセンター職員に感謝申し上げますとともに、調査にご協力いただきました狭山市「すこやか推進員」、入間市「健康づくりボランティア」「トレーニング室利用者」「入間市母子愛育会」の皆様にも、この場を借りて厚くお礼申し上げます。

令和 4 年 3 月 31 日

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序章　研究の意図と方法

序章　研究の意図と方法

清水　順市

1. はじめに

本プロジェクトは入間市および狭山市在住の高齢者を対象として、自分自身の心身機能を把握し健康意識を高め、身体の健康維持および健康改善を目的に、地域住民の運動能力や認知能力を横断的および縦断的に調査する狭山市・入間市共同研究事業である。

高齢者の人口は増え続け、団塊世代の人口が 2025 年にピークへ達するがその後も高齢社会が続くことになる。一方、健康意識が高まり、食生活に気遣いながら、運動等を実践している人たちが多くなってきている。行政においては、地域住民が自分自身の健康度（生化学的データを除いた運動能力や認知能力）をどこまで正確に把握しているかは不明なところが多分にある。また、厚生労働省は「地域包括ケアシステム」の政策を掲げ、介護対応から介護予防に転換し、その運営を市区町村単位で実施することを促している。

本プロジェクトで得られた個人の運動能力のデータを行政と把握することにより、今後の地域での課題を見出し、健康寿命を延伸し、ひいては住民の医療費、介護保険料の負担軽減へつなげることが可能であると予測される。

2. 研究の経過

本研究プロジェクトは、以下のようなプロセスで進められた。（委員会の会場は、第 1 回・2 回共に東京家政大学狭山校舎内会議室、その他についても同会場にて行われた。）

1. 平成 30 年 12 月 3 日（月）10:00～　事前打ち合わせ
   連携自治体の代表との事前打ち合わせを行い、具体的な測定方法・手段、データの保管、自治体への貢献詳細、学科での使用許可、共同プロジェクトの立ち上げ自治体との協定等の確認をした。
2. 平成 30 年 12 月 20 日（木）10:00～11:40　打ち合わせ（第 1 回目）
   意見交換を経て、共同研究プロジェクトを実施し、協定の方向性について確認をした。
3. 平成 31 年 2 月 6 日（水）11:00～12:20　打ち合わせ（第 2 回目）
   調査研究事業計画の内容についての検討と事業計画書、協定書（案）、調査研究委員会発足について確認をした。
4. 平成 31 年 4 月 3 日（水）15:30～18:00　第 1 回調査研究委員会
   調査研究委員会の構成と役割分担、調査研究事業の計画・内容と調査日程、協定書（案）等について検討をした。
5. 平成 31 年 4 月 3 日（水）「狭山市・入間市と東京家政大学との連携事業に関する協定書」を締結した。

6. 平成 31 年 4 月 10 日（水）研究倫理委員会規程に基づき、東京家政大学倫理委員会に「倫理審査申請書」を提出した。
7. 平成 31 年 4 月 24 日（水）研究計画・内容について、東京家政大学研究倫理委員会より、倫理審査結果通知書（条件付承認）を受けた。
8. 平成 31 年 4 月 25 日（木）東京家政大学倫理委員会からの質問に回答をした。
   （「倫理審査結果に対する回答書」を提出）
   同日、承認を受けた。（承認番号　狭 2019-1　承認日　平成 31 年 4 月 25 日）
9. 令和元年 7 月～令和 2 年 3 月　狭山市・入間市の指定会場（健康福祉センター・公民館・体育館等）にて、測定調査を実施した。
10. 令和 2 年 8 月 20 日（木）新型コロナウイルス感染症拡大の影響により、両市の調査対象となる団体組織の活動中止に伴う測定実施不可のため、研究期間を 1 年延期とした協定書「狭山市・入間市と東京家政大学との連携事業に関する協定書」の一部を変更する協定書を締結した。
11. 令和 2 年 9 月 10 日（木）研究倫理委員会規程に基づき、東京家政大学倫理委員会に、承認済研究課題（平成 31 年 4 月 25 日　狭 2019-1）についての「研究変更申請書」を提出した。
12. 令和 2 年 9 月 11 日（金）一部変更とする研究計画・内容について、東京家政大学研究倫理委員会より倫理審査結果通知書の承認を受けた。
13. 令和 3 年 11 月 11 日（木）11:00～12:00　第 2 回調査研究委員会
    調査研究中間報告、調査研究報告書の作成について検討をした。
14. 令和 3 年 11 月～令和 4 年 1 月　報告書執筆

3. 調査の対象・方法

1）方　法　①市内公共施設等に於いて、運動能力を測定する。
　　（狭山市：狭山市元気プラザ　入間市：地区公民館等）
　②食習慣と運動習慣に関するアンケートを実施する。

2) 対　象　狭山市：「すこやか推進員」（狭山市の健康づくり推進事業の一環として市内の各自治体から推薦され、市長が委嘱した方が、自治体と連携して様々な活動をする団体組織）等。
　入間市：「健康づくりボランティア」（入間市開催の養成講座を受講し、各地区の特徴に合わせた活動を展開）また、健康福祉センター内のトレーニング施設利用者等を対象とする。

※測定者延べ数 164 名　　1 回目のみ測定者数 125 名
　　2 回目測定者数　39 名

第 1 回測定者の日時と地域（令和元年）

地域	日時	会場	対象	測定者数
入間市	7 月 9 日（火）	健康福祉センター	トレーニング室利用者	19
入間市	7 月 16 日（火）	健康福祉センター	トレーニング室利用者	21
入間市	7 月 29 日（月）	西武公民館	地域住民	12
入間市	9 月 10 日（火）	東金子公民館	東金子元気になんべぇ会	5
入間市	9 月 13 日（金）	二本木公民館	ボランティア団体	6
入間市	10 月 8 日（火）	金子公民館	入間市母子愛育会	15
入間市	11 月 14 日（木）	藤沢公民館	健康ふじの会	6
狭山市	7 月 10 日（水）	狭山元気プラザ体育館	すこやか推進員	41
			計	125

3）測定項目
①形態測定（身長）
②体組織（体組成）
③骨粗鬆症の程度(骨密度測定)
④手指筋力（握力・つまみ力）
⑤下肢筋力（膝伸展筋力）
⑥歩行能力（5m歩行. Timed up go Test）
⑦呼吸機能（肺活量等）
⑧平衡機能（片脚立位時間）
⑨体幹の柔軟性（長座体前屈）
⑩反応時間（視覚反応速度）

4. 研究組織

研究組織は、以下のとおりである。

調査研究委員会

清水　順市	東京家政大学リハビリテーション学科	教授	委員長
後藤　寛司	東京家政大学リハビリテーション学科	教授	委　員
磯　直樹	東京家政大学リハビリテーション学科	准教授	委　員
岡部　拓大	東京家政大学リハビリテーション学科	講師	委　員
趙　吉春	東京家政大学リハビリテーション学科	助教	委　員
平田　恵介	東京家政大学リハビリテーション学科	助教	委　員
内野　美恵	東京家政大学ヒューマンライフ支援センター専門員	准教授	委　員
小池　真介	狭山市長寿健康部健康づくり支援課	課長	委　員
庄司　晴彦	狭山市長寿健康部健康づくり支援課	主任	委　員
神谷　慶太	狭山市長寿健康部健康づくり支援課	主事	委　員
書間　拓哉	入間市健康推進部地域保健課	課長	委　員
吉川　真奈美	入間市健康推進部地域保健課	主幹	委　員
菅野　優美子	入間市健康推進部地域保健課	副主幹	委　員
織田　文代	東京家政大学地域連携推進センター	次長	事務局
西川　美枝子	東京家政大学地域連携推進センター	嘱託	事務局

5. 謝辞

本研究プロジェクトの実施にあたっては、多くの方々からご教示・ご協力をいただきましたことにお礼申し上げます。

まず、本研究プロジェクトの趣旨をご理解いただきました狭山市長寿健康部健康づくり支援課、入間市健康推進部地域保健課の担当者様をはじめ、東京家政大学地域連携推進センターの関係者には、企画の段階から多くの情報や対象者の選出、そして測定時の日時・場所の手配等を頂いたことにより実施できたと感謝申し上げます。

また、測定会に参加いただきました市民の皆様にもお礼申し上げます。今回は、予定した 2 回の測定回数を完遂できませんでしたが、1 回の測定会で得られたデータは地域在住者および個人のデータとして有効に活用されることと期待しております。

新型コロナウイルス感染が収束できました際には、再度企画して地域住民の健康調査を実施する予定でありますので、ご協力をよろしくお願い申しあげます。

第１章　測定結果

第１章　測定結果

１　対象者の年齢分布

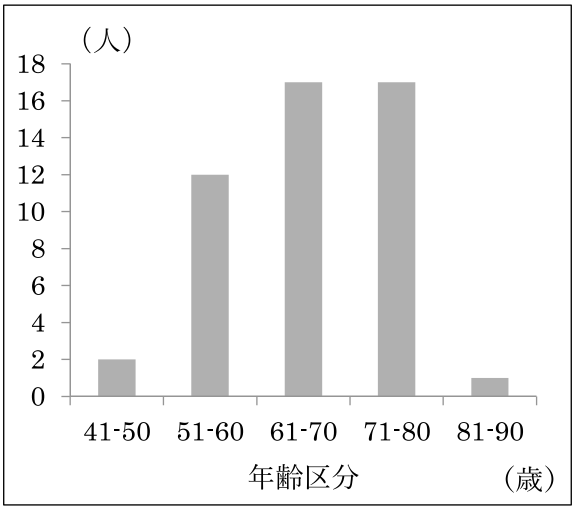


図 1-1　入間市（女性）

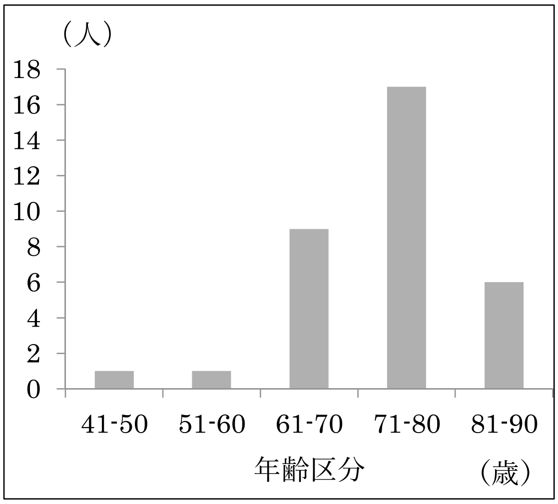


図 1-2　入間市（男性）

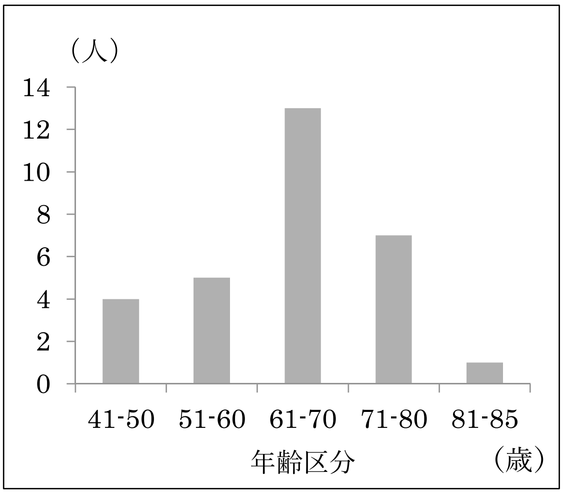


図 1-3　狭山市（女性）

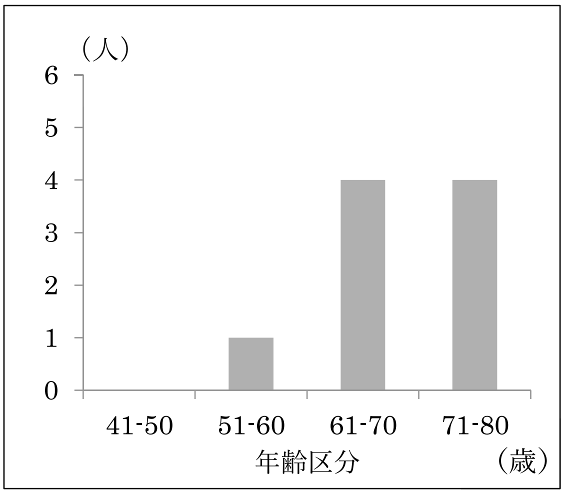


図 1-4　狭山市（男性）

平均年齢

	女性	男性
入間市	66.6±8.77 歳	72.8±9.14 歳
狭山市	65.0±9.22 歳	68.6±5.85 歳

2　体組織

1．体組織の仕組み

　体組成とは人の身体を構成する組成分のことであり、大きく分けて「筋肉」「脂肪」「骨」「水分」に分けられる。筋肉が少なく、脂肪が多いと生活習慣病や肥満のリスクとなる。本報告書では体組成でも筋肉量や脂肪量の代表値となる骨格筋量や体脂肪率について分析する。骨格筋量は身体を動かすための筋肉であり、運動や食生活などの生活習慣によって増減する。つまり、骨格筋は運動の成果が出ているかどうかを判断する指標となり、骨格筋を増やして基礎代謝が増加すれば、エネルギーを消費しやすい体質、つまり、太りにくい体質になり、筋力も高まって活動的な生活を送ることができる。骨格筋量は一般的に女性よりも男性の方が多い。一方、脂肪量は運動量の低下や不適切な栄養摂取によって増大し、体脂肪が過剰に蓄積された状態が肥満である。体脂肪率は一般的に男性よりも女性の方が高い。

2．体組成の結果

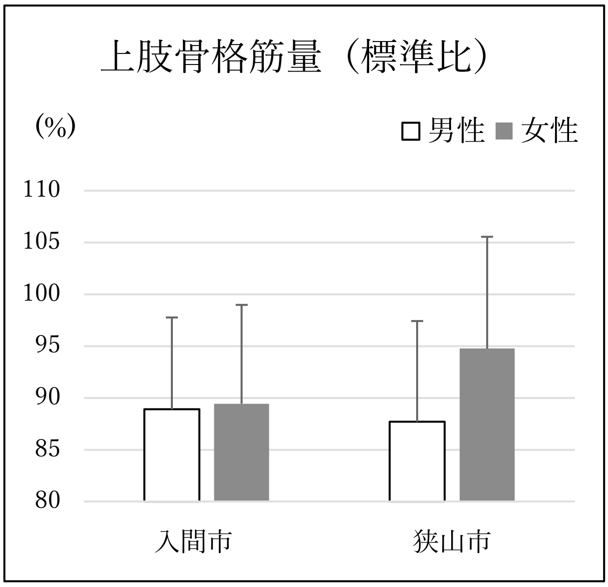


図 2-1

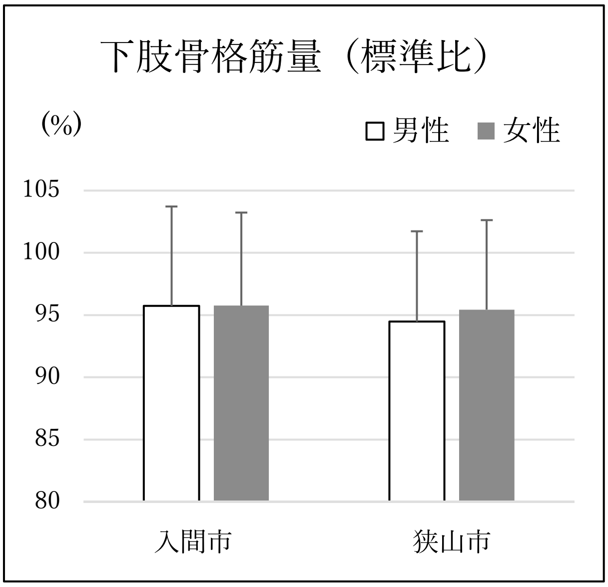


図 2-2

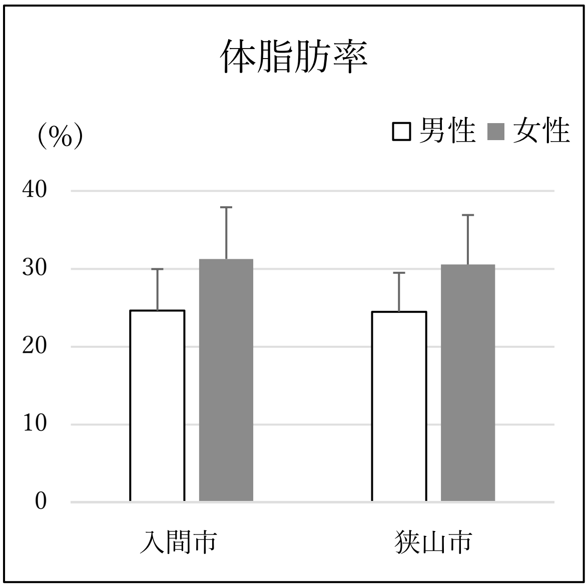


図 2-3

3．特徴・概要

上肢の骨格筋量（記載している図 2-1.2 は体重に対する標準的な筋肉量との比）では入間市においては男女差が無かったが、狭山市では女性の上肢骨格筋量が多い傾向であった。下肢の骨格筋量では両市において男女差は無く、両市間で差は認められなかった。

一方、体脂肪率において、両市ともに、女性の方が男性と比較して体脂肪率が高かった。（図 2-3）この結果は一般的な男女差と同様であった。体脂肪率においては両市間で差は無かった。

3　骨密度

1．骨密度の仕組み

骨密度とは骨を構成するカルシウムなどのミネラル成分のつまり具合であり、骨の単位面積当たりの骨塩量で算出される。骨は強固な体を作りあげるとともに、内臓を保護する役割がある。血液を作り出す骨髄組織も存在し、体内のカルシウムの貯蔵庫としての役割もある。

骨は絶えず吸収（破骨細胞が骨を溶かす）と形成（骨芽細胞が新しい骨を作る）を繰り返し、約 10 年をかけてすべて入れ替わるといわれている。この生まれ変わりは特に骨の再構築（リモデリング）といわれる。ホルモンなどによってこのバランスが崩れ、骨の吸収が骨の形成を上回ると、骨は次第に弱くなる。骨密度は骨梁面積率によって評価され、骨梁面積率は骨の単位面積(㎠)当たりの骨塩量(g)で算出され、骨粗鬆症の診断基準としても利用されている。骨密度は男女とも加齢によって減少することが確認されており、その減少率は男性よりも女性の方が大きいといわれている。特に女性の場合は 20 歳頃にピークを迎えて骨密度が最大となり、以後は骨密度が徐々に減少し閉経を迎える 50 歳頃から骨密度の減少は加速する。

2．骨密度の結果

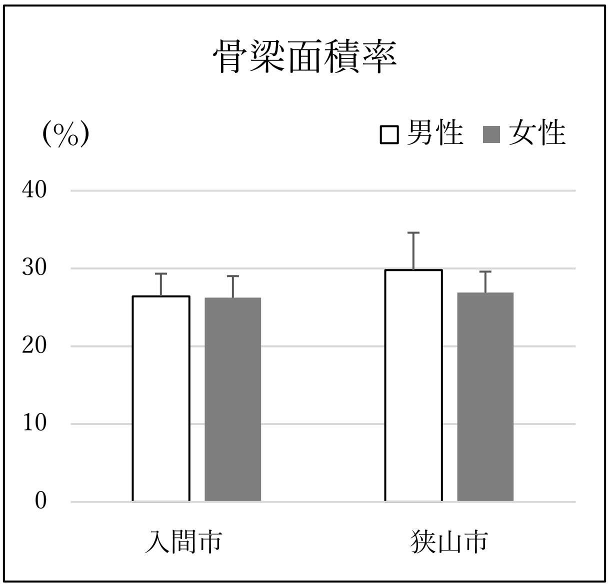


図 3 -1

3．特徴・概要

骨梁面積率では入間市では男女差は無く、狭山市において、男性の方が女性よりも高値であり、男性の方が女性と比較して骨密度が高かった。(図 3-1)

4　握力・つまみ力

この項では、握力・つまみ力と、その特徴および概要について記載する。最初に、それぞれの項目における測定意義について記載する。

1. 握力・つまみ力の測定意義

握力とは、物体を握る時に発揮される手の力のことを指す。握力の測定は難しい方法を必要とせず、且つ安全に短時間で実施することができるため、中高齢者の筋力の程度を把握するための指標として多く用いられている。

つまみ力とは、物体を挟んだり掴んだりする時（蛇口の栓を捻る、蓋を開けるなど）に発揮される手指の力のことを指す。つまみ力は、ピンチ力計やピンチメータなどと呼ばれる専用の器具で測定する。

握力・つまみ力は主には上肢の筋が働くことによって発揮されるが、下肢の筋力を始めその他全身の筋力とも関連がある。

そのため、定期的に握力・つまみ力を測定することで、筋力を含めた全身の体力変動が加齢によるものなのか、それ以外の要因によるものなのかを検討することができる。

2. 握力・つまみ力の測定結果

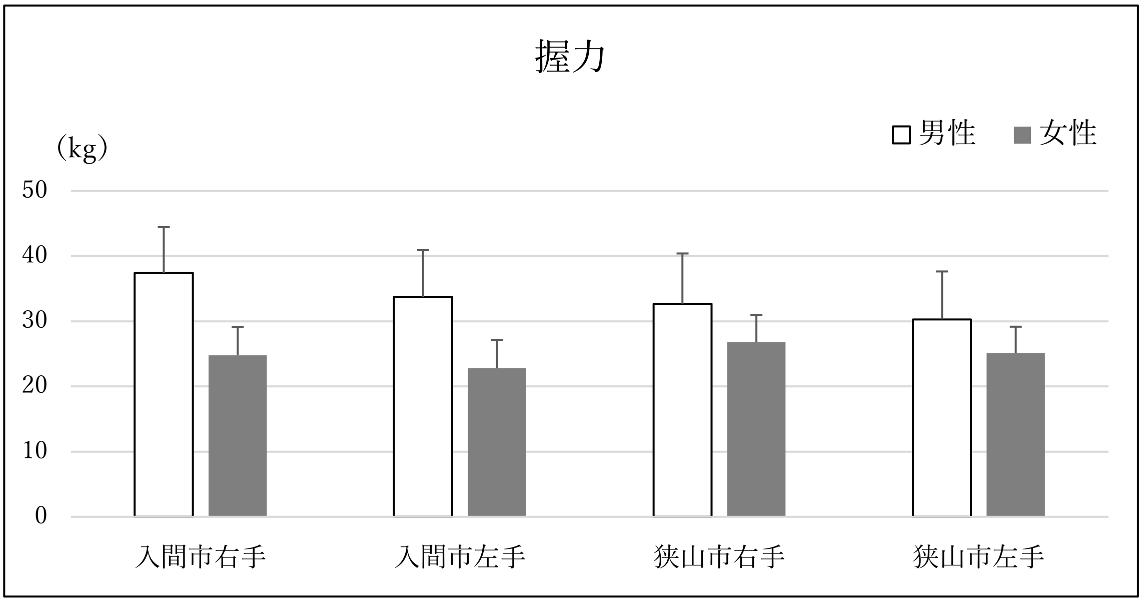


図 4 -1　握力

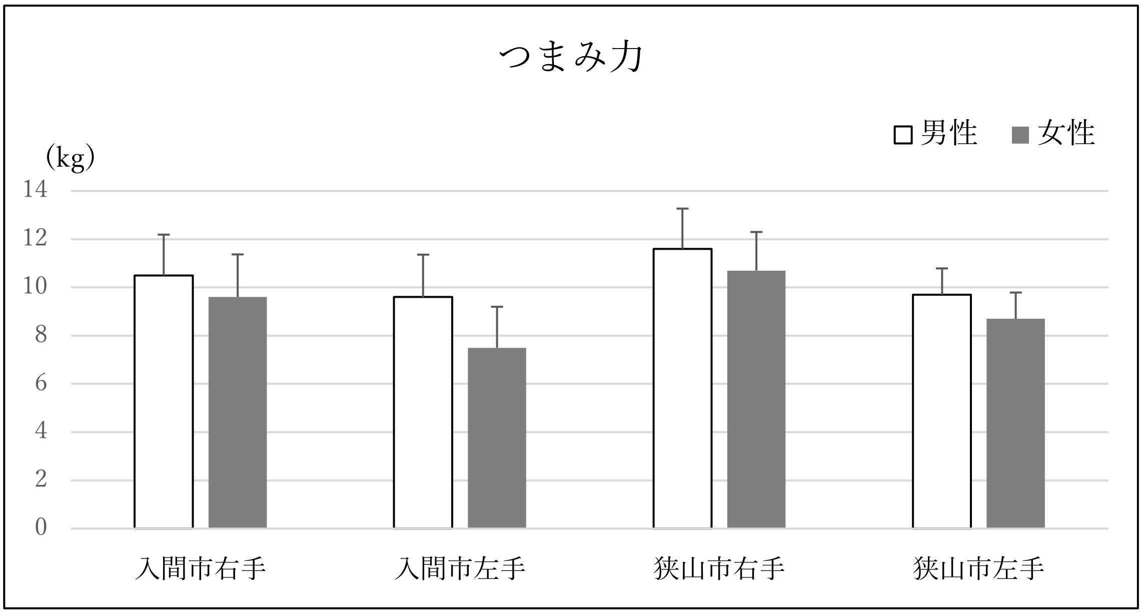


図 4 -2 つまみ力

3. 特徴・概要

握力・つまみ力ともに、女性よりも男性の方が高値であった。左右差については、左手よりも右手の方が高値であった。狭山市と入間市のいずれにおいても同様の傾向が見られた。(図 4-1.2)

5　膝伸展筋力

膝伸展筋力は以下の通りであった。入間市では男性に比べ、女性で膝伸展筋力が弱い傾向が見られた。狭山市では男女に違いは見られなかった。（図 5‒1）
※筋力は体重に依存するため、被験者の体重で正規化を行なった結果

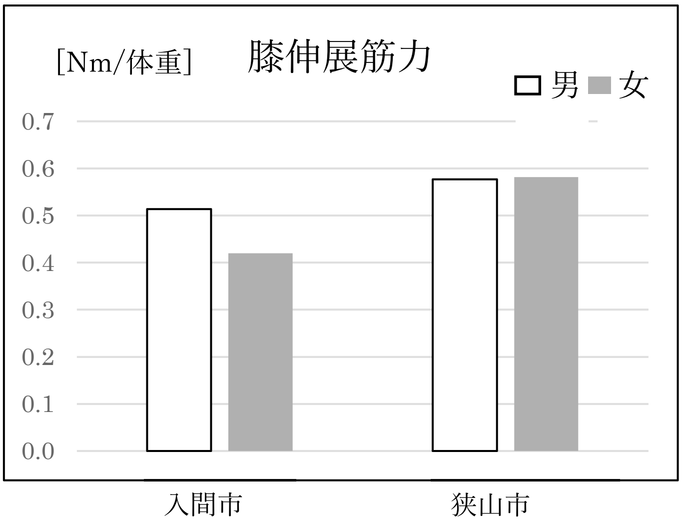


図 5 -1 膝伸展力の男女別結果

6　歩行機能

5m 歩行

最大速度での 5m 歩行の所要時間は以下の通りであった。入間市では男性に比べ、女性で所要時間が長く、狭山市では女性に比べ、男性で所要時間が長かった。（図 6-1）

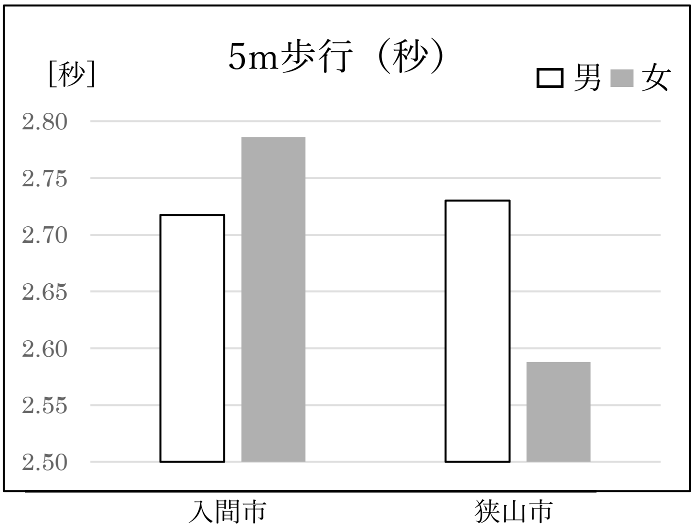


図 6 -1　5m 歩行の男女別結果

Timed Up and Go Test

最大速度での Timed Up and Go Test（TUG）の所要時間は以下の通りであった。入間市では男性に比べ、女性で所要時間が短かった。狭山市では男女に大きな違いは見られなかった。（図 6-2）

※TUG： 椅子から立ち上がり、3m 先のコーンまで歩いてターンし、歩いて戻って椅子に着座するまでの時間

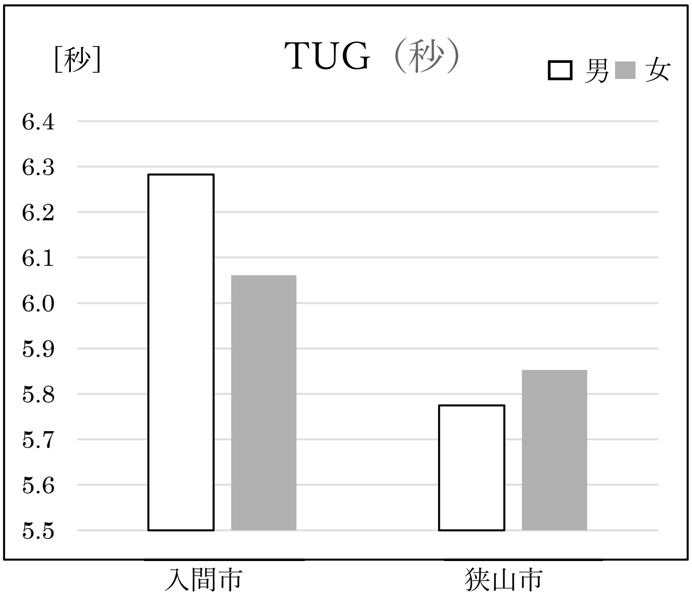


図 6-2　TUG の男女別結果

7　呼吸機能（肺活量・1 秒率）

1. 肺活量・1 秒率とは

肺機能の状態や呼吸器疾患の有無とその重症度を調べる検査として呼吸機能検査がある。呼吸機能検査は、呼吸をとおして口から出入りする空気の量を専用機器により測定する。この検査結果の代表的な項目として、肺活量と 1 秒率がある。

肺活量とは、最大吸気位（最大努力で吸い込む状態）から最大呼気位（最大努力ではき出す状態）までの容量（思い切り吸って、思い切りはき出したときの空気の量）のことをいう。肺活量は、性別、年齢や体格に影響を受けると言われているが、目安として、男性は 3,500cc、女性は 2,500cc が基準値とされている。肺活量が少ない場合は、間質性肺炎や肺線維症などにより肺が十分に拡がらないことから、肺に空気を入れる容量が少なくなっている可能性がある。

1 秒率とは、肺にいっぱい息を吸い込み、最大の速さ（思い切って）一気にはき出した時の空気の量のうち、最初の 1 秒間にはき出した空気の量が全体の空気の量に対してどの程度の割合があるかのことをいう。1 秒率は、70%以上が基準値とされており、1 秒率が低い場合は、慢性閉塞性肺疾患や気管支喘息などにより気道が狭くなって息が吐きにくい状態になっている可能性がある。

2. 肺活量

肺活量は、入間市と狭山市ともに、男性に比べ、女性の方が少ない傾向を示した。また、両市を比べると、男性では同程度の肺活量であったが、女性では、狭山市の方が、約 100cc 程度多い傾向を示した。（図 7-1）

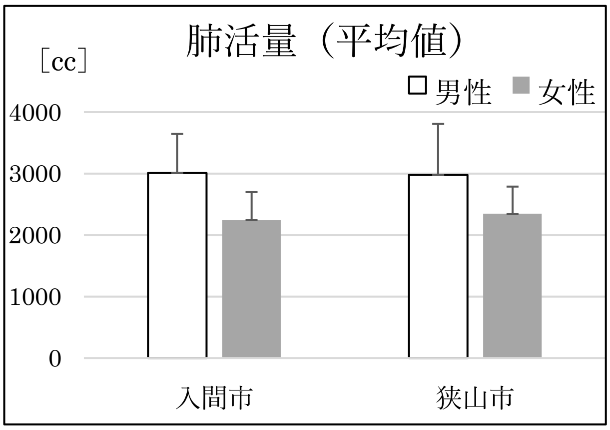


図 7-1　入間市と狭山市における男女別の肺活量

入間市の場合、年齢区分別に分析すると、男性では、65 歳以上 75 歳未満で最も高い肺活量を示していた。女性では、65 歳未満が最も高い肺活量を示していた。各年齢区分別においては、男性に比べ、女性の方が少ない傾向を示した。（図 7-2）

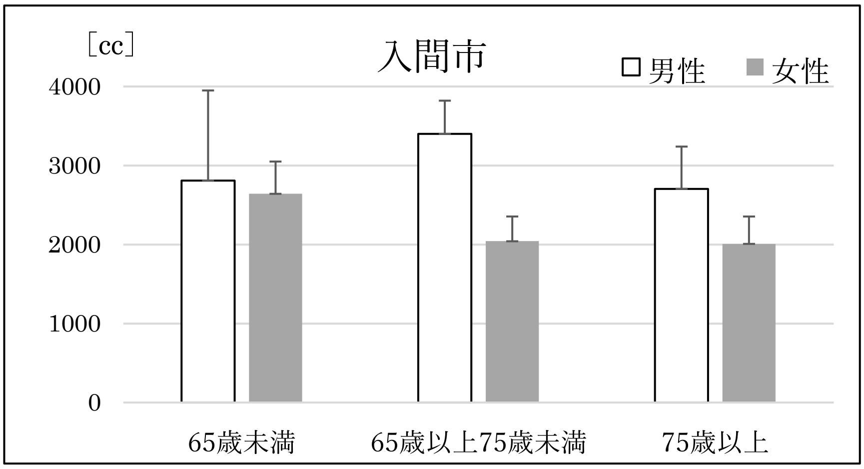


図 7-2　入間市における年齢区分別男女別の肺活量

狭山市の場合、年齢区分別に分析すると、男性では、65 歳以上 75 歳未満で最も高い肺活量を示していた。女性では、65 歳未満が最も高い肺活量を示していた。各年齢区分別においては、男性に比べ、女性の方が少ない傾向を示した。（図 7-3）

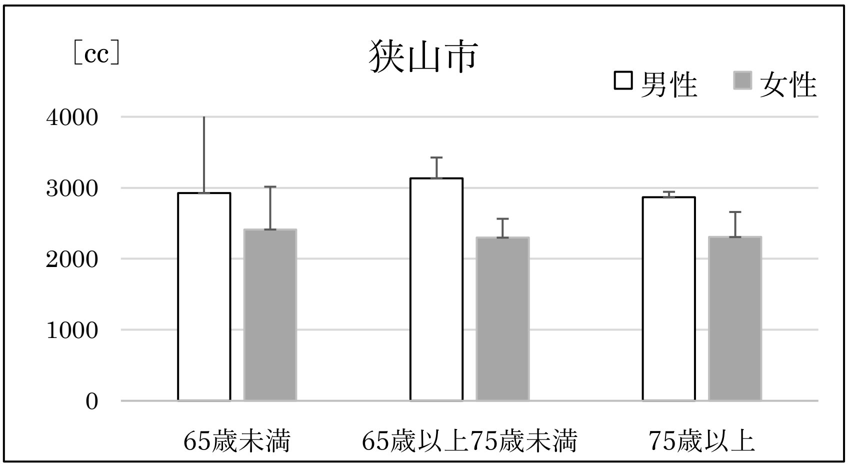


図 7-3　狭山市における年齢区分別男女別の肺活量

年齢区分別に分析すると、入間市と狭山市ともに、男性では、65 歳以上 75 歳未満で最も高い肺活量を示し、女性では、65 歳未満が最も高い肺活量を示し、同様の特徴が認められた。（図 7-2・3）

3. 1秒率

1秒率は、入間市では、男性に比べ、女性の方が高い傾向を示した。狭山市では、男性に比べ、女性の方が低い傾向を示した。(図 7-4)

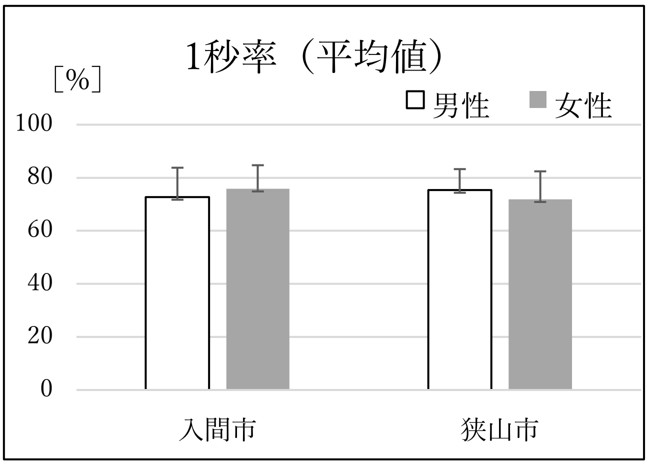


図 7-4　入間市と狭山市における男女別の肺活量

入間市の場合、年齢区分別に分析すると、男性では、75 歳以上が最も高い 1 秒率を示し、65 歳未満と 65 歳以上 75 歳未満では同程度の値を示していた。一方で、女性では、65 歳未満が最も高い 1 秒率を示し、65 歳以上 75 歳未満、75 歳以上と加齢に伴い、低下する特徴が認められた。また、75 歳未満では、男性に比べ、女性の方が高い値を示していたが、75 歳以上になると、男性に比べ、女性の方が低い値を示していた。(図 7-5)

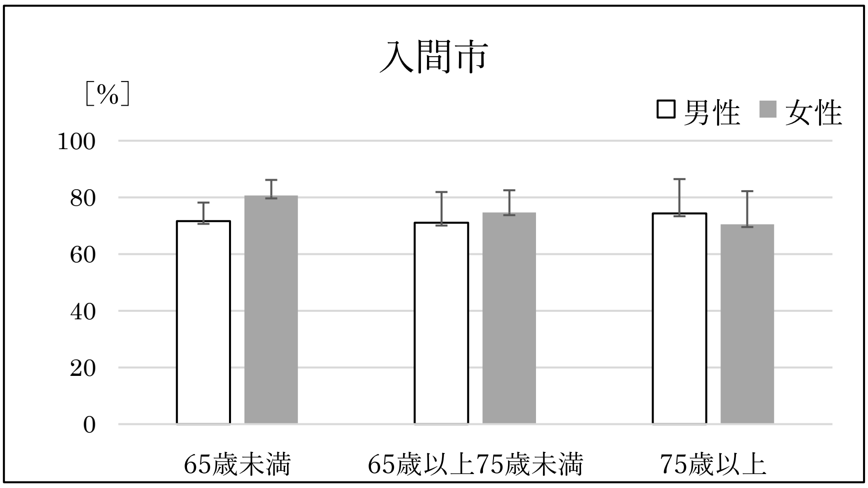


図 7-5　入間市における年齢区分別男女別の 1 秒率

狭山市の場合、年齢区分別に分析すると、男性では、65 歳以上 75 歳未満で最も高い 1 秒率を示し、65 歳未満と 75 歳以上では同程度の値を示していた。女性でも、65 歳以上 75 歳未満で最も高い 1 秒率を示し、75 歳以上で最も低い値を示していた。また、65 歳未満では、男性に比べ、女性の方が高い値を示していたが、65 歳以上になると、男性に比べ、女性の方が低い傾向を示していた。(図 7-6)

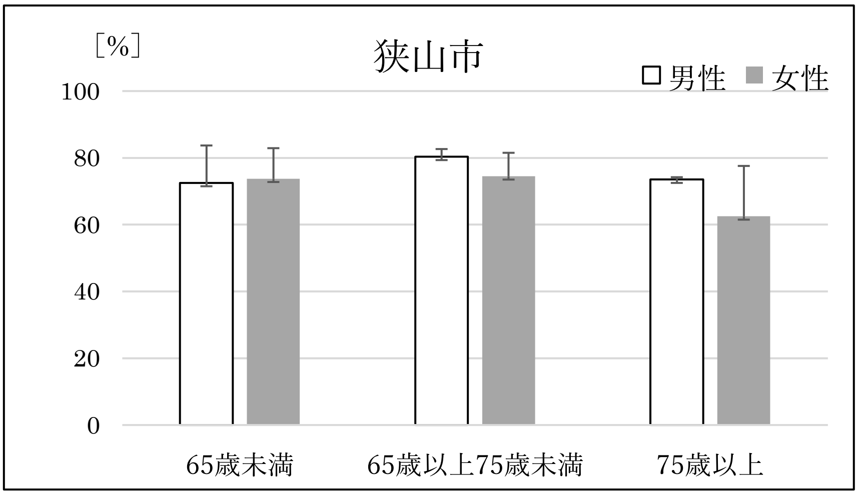


図 7-6　狭山市における年齢区分別男女別の 1 秒率

年齢区分別に分析すると、男性では、入間市は 75 歳以上の方が高く、狭山市は 75 歳未満の方が高い傾向を示していた。女性では、入間市と狭山市ともに、75 歳未満に比べ、75 歳以上の方が低い傾向を示していた。(図 7-5・6)

8　片脚立位時間（開眼・閉眼）

1. 片脚立位時間とは

片脚立位時間とは、片脚立ちの姿勢を保持できる時間のことをいい、簡易に測定することができ、代表的なバランス能力の検査方法である。片脚立位時間の測定方法には、目を開けて測定する「開眼片脚立位」と目を閉じて測定する「閉眼片脚立位」の 2 種類がある。両者の違いは、視覚情報の有無である。人は姿勢を保持するためには、平衡機能などに加え、視覚情報を中心とした感覚情報が重要であると言われている。そのため、閉眼により視覚情報が遮断された閉眼片脚立位では難易度が高くなると言われている。なお、保持時間が長いほど、バランス能力が高いことを示している。また、片脚立位時間は、転倒などのリスク指標としても活用され、開眼片脚立位時間が 20 秒以下、閉眼片脚立位時間が 5 秒以下で、転倒リスクが高まるとされている。

今回の測定では、安全性を考慮し、測定上限時間を 30 秒とした。そして、左脚・右脚のそれぞれを支持脚とする片脚立位時間を各々測定したが、以下に示す結果は、左脚支持と右脚支持の結果を平均した代表値を報告する。

2. 開眼片脚立位時間

開眼片脚立位時間は、入間市と狭山市ともに、男性に比べ女性の方が保持時間が長く、女性はバランス能力が高い傾向を示した。また、両市を比べると、男性と女性ともに、狭山市の住民は保持時間が長く、バランス能力が高い傾向を示した。（図 8-1）

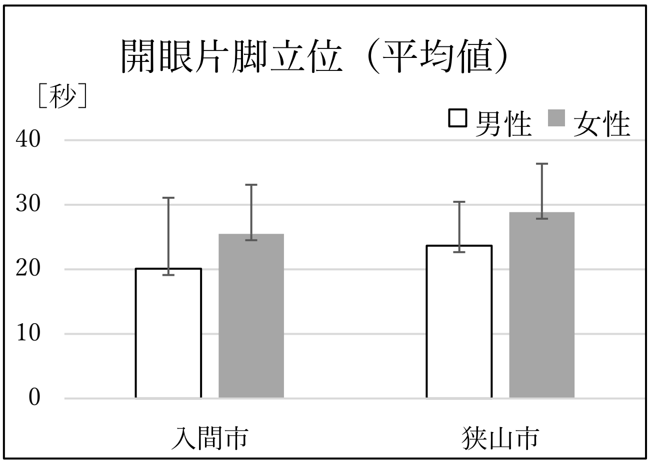


図 8-1　入間市と狭山市における男女別の開眼片脚立位時間

入間市の場合、年齢区分別に分析すると、男性では、65 歳未満が最も保持時間が長く、年齢区分が増すとともに、保持時間が短くなる傾向を示した。一方で、女性でも、男性と同様の傾向を示し、65 歳未満と 65 歳以上 75 歳未満が同程度で最も保持時間が長く、75 歳以上が最も保持時間が短かった。男性と女性ともに、年齢が増すにつれて、保持時間が短くなり、バランス能力が低下する特徴が認められた。（図 8-2）

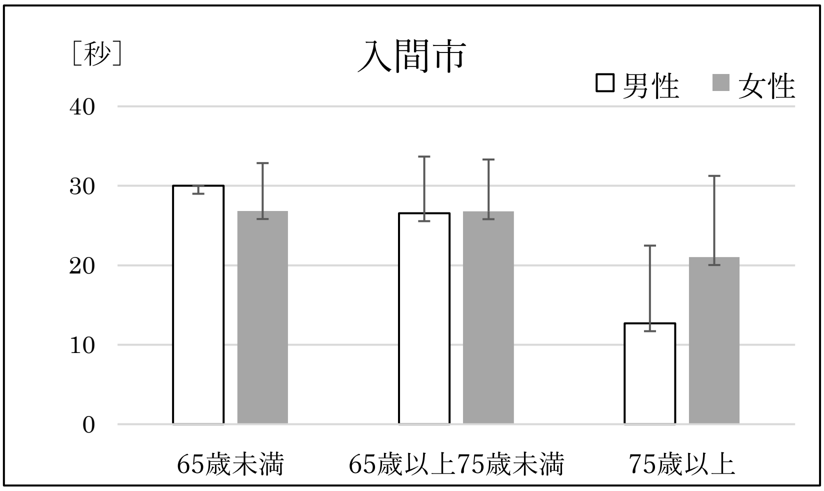


図 8-2　入間市における年齢区分別男女別の開眼片脚立位時間

狭山市の場合、年齢区分別に分析すると、男性では、65 歳未満が最も保持時間が長く、65 歳以上 75 歳未満と 75 歳以上では同程度の保持時間を示していた。女性では、75 歳以上で保持時間が最も長く、65 歳以上 75 歳未満で保持時間が最も短かった。また、どの年齢区分においても、男性に比べ、女性の方が保持時間が長く、バランス能力が高い特徴が認められた。(図 8-3)

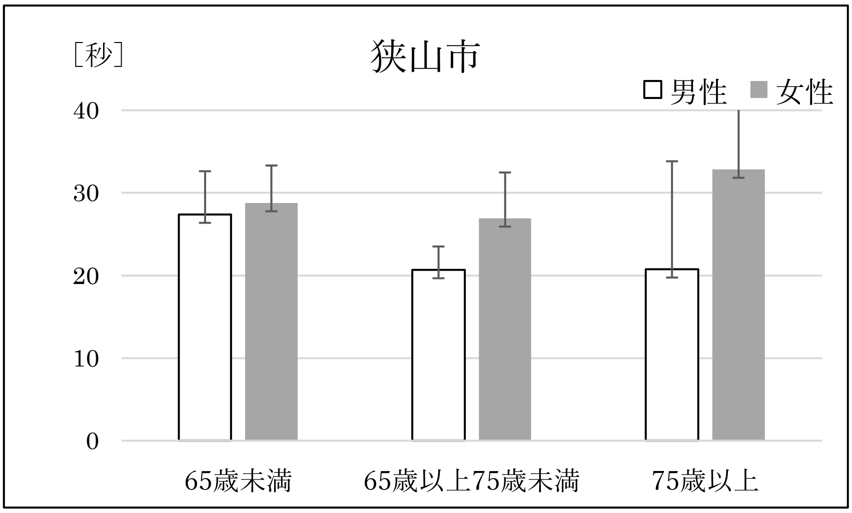


図 8-3　狭山市における年齢区分別男女別の開眼片脚立位時間

年齢区分別に分析すると、男性では、入間市と狭山市ともに、65 歳未満が最も保持時間が長く、バランス能力が高い傾向を示し、年齢区分が増すごとに保持時間が長くなり、バランス能力が低下する傾向を示していた。女性では、入間市は、75 歳未満で最も保持時間が長く、バランス能力が高い傾向を示した。一方で、狭山市では、75 歳以上で最も保持時間が長く、バランス能力が高い傾向を示した。開眼片脚立位時間において、両市では、加齢の影響に関して異なる特徴が認められた。（図 8-2・3）

3. 閉眼片脚立位時間

閉眼片脚立位時間は、入間市と狭山市ともに、男性に比べ、女性の方が保持時間が長く、女性の方がバランス能力が高い傾向を示した。両市を比べると、男性と女性ともに、狭山市の方が保持時間が長く、閉眼片脚立位時間においても、狭山市の方がバランス能力が高い傾向を示した。また、両市ともに、閉眼片脚立位時間は、開眼片脚立位時間（図 8-1 参照）と比べ、保持時間が短く、高齢者における開眼片脚立位と閉眼片脚立位の保持時間の一般的な傾向と同様の特徴が認められた。（図 8-4）

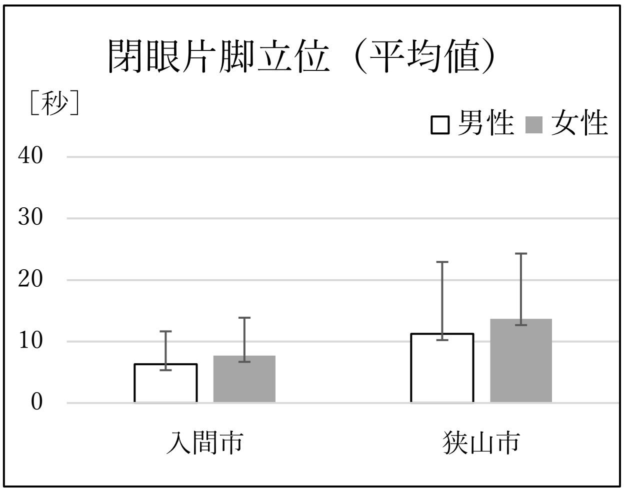


図 8-4　入間市と狭山市における男女別の閉眼片脚立位時間

入間市の場合、年齢区分別に分析すると、男性と女性ともに、65 歳未満が最も保持時間が長く、年齢区分が増すとともに、保持時間が短くなる傾向を示し、加齢とともに、バランス能力が低下する特徴が認められた。そして、75 歳未満では、男性の方が保持時間が長く、75 歳以上では、女性の方が保持時間が長い傾向を示していた。また、年齢区分別にみても、開眼片脚立位時間（図 8-2 参照）とおおむね同様の傾向を示していた。（図 8-5）

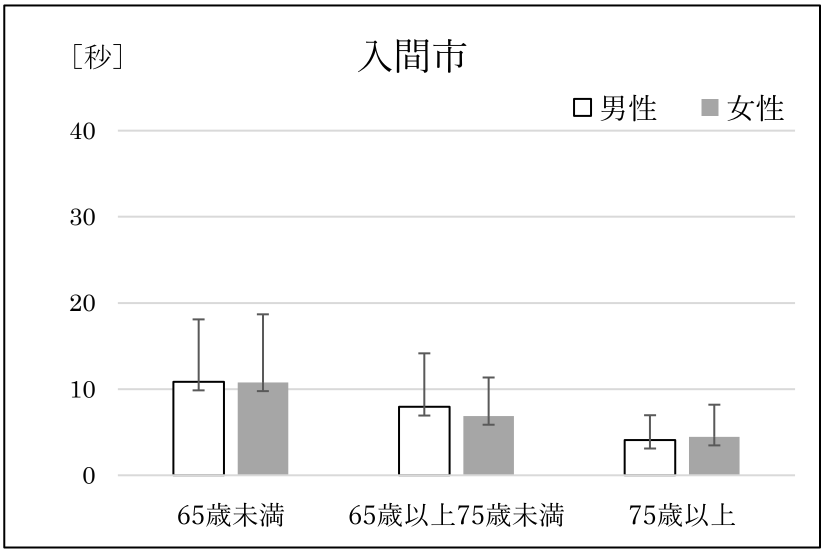


図 8-5　入間市における年齢区分別男女別の閉眼片脚立位時間

狭山市の場合、年齢区分別に分析すると、男性では、65 歳未満が最も保持時間が長く、年齢区分が増すとともに、保持時間が短くなる傾向を示し、加齢とともに、バランス能力が低下する特徴が認められた。女性では、65 歳未満で保持時間が最も長く、65 歳以上 75 歳未満で保持時間が最も短かった。また、開眼片脚立位時間（図 8-3 参照）と比較すると、共通した特徴として、男性では、年齢区分別でも同様の傾向を示し、女性では、65 歳以上 75 歳未満が最も短くなる傾向を示していた。（図 8-6）

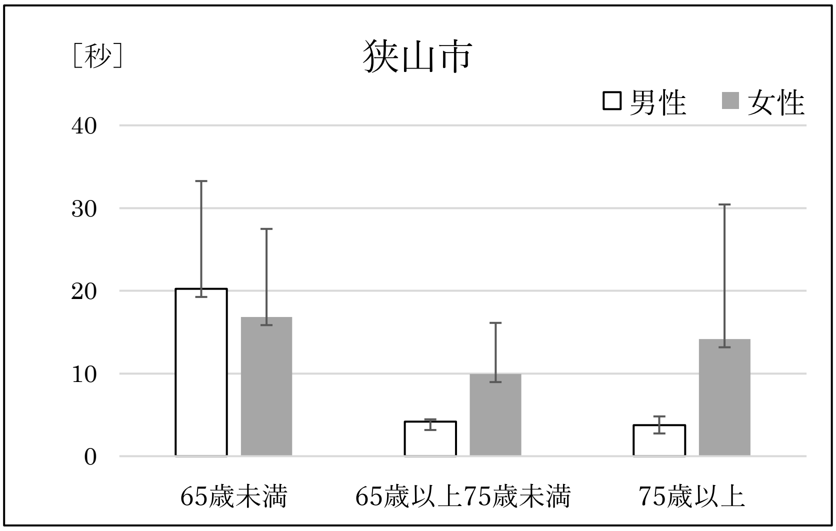


図 8-6　狭山市における年齢区分別男女別の閉眼片脚立位時

年齢区分別に分析すると、入間市と狭山市ともに、男性も女性も 65 歳未満が最も保持時間が長く、バランス能力が高い傾向を示していた。加えて、男性では、年齢区分が増すごとに保持時間が短くなり、バランス能力が低下する傾向を示していた。また、どの年齢区分においても、男性と女性ともに、開眼片脚立位時間（図 8-2・3 参照）に比べて、保持時間が短く、閉眼することにより、バランス能力が低下する特徴が認められた。（図 8-5・6）

9　長座体前屈

長座体前屈は下肢の柔軟性の評価として使用されている。特に大殿筋、ハムストリングス、腓腹筋の柔軟性を評価し、これらの筋の柔軟性が低下することにより腰痛や膝関節痛などを生じやすくなることが報告されている。また、下肢の柔軟性の低下は転倒へも関連しているため、下肢の柔軟性がどの程度であるかを評価しておくことは重要である。長座体前屈は長座姿勢をとり、壁に背中と臀部を接地し、手のひらを測定器に置き、両肘を伸ばして背筋を伸ばし、つま先の方向へ測定器を手でどこまで移動させられるかを計測する。

結果

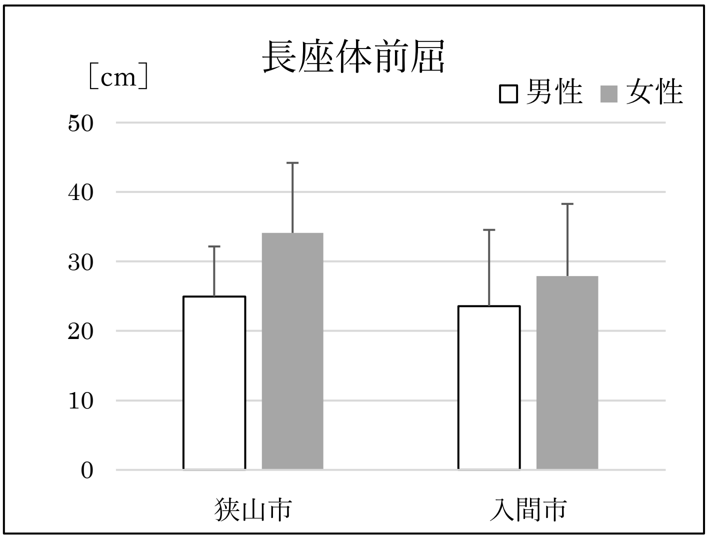


図 9-1　長座体前屈（単位：cm）

特徴と概要

狭山市・入間市ともに男性に比べて女性において柔軟性が高い結果を示した。これは一般的な結果とも一致しており、男性に比べて女性がより柔軟性が高いまま維持される傾向にあった。狭山市においては、男性と女性との差が大きく、特に女性の柔軟性が高い値を示した。（図 9-1）

10　視覚反応時間

視覚反応時間とは、光刺激を合図としたヒトの自発運動時に生体内での処理に要する時間のことであり、俊敏性や運動能力の指標として使用されている。反応時間が低下することにより、刺激に対する素早い反応ができず、特に高齢者においては転倒にも繋がることが報告されている。今回の調査で用いたのは、自動車運転をイメージして作製した視覚反応時間の測定器具である。自動車運転に関しても、高齢者の運転操作で問題となるのは刺激に対する反応の遅れである。今回は、視覚刺激としてモニター上に提示される信号機のアニメーションに対して、自動車のアクセルに見立てたスイッチを右下肢で素早く踏む課題として実施した。モニター画面上の信号機が点灯し、それに合わせて右下肢でスイッチを踏むまでの時間を視覚反応時間として今回は測定した。

結果

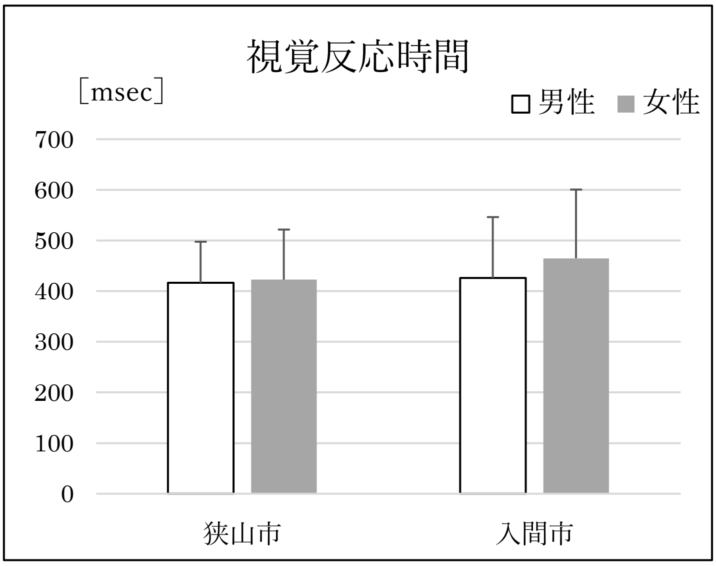


図 10-1　視覚反応時間（単位：msec）

特徴・概要

狭山市では男女間で反応時間にほとんど差がない結果であった。入間市においては、男性に比べて女性の結果において俊敏性の低下が疑われる結果となった。但し、今回の反応時間の測定は自動車運転の経験も影響すると考えられ、女性の反応時間の遅延は自動車運転経験の有無が影響した可能性もある。（図 10-1）

測定結果の総括

1．年齢構成

狭山市と入間市の対象者数に違いは存在するが、女性では平均年齢に差がなかった。男性の平均年齢は入間市が高かった。（80 歳以上が 6 名）

2．体組成

上肢骨格筋量は狭山市の女性群に高い比率が見られたが、下肢骨格筋量には差が見られなかった。同様に体脂肪率も差が見られなかった。

3．握力とつまみ力

手指の力の指標である握力とつまみ力は男性群が大きい値が得られた。
上肢骨格筋量の比率が高かった狭山市の女性群は握力・つまみ力においても大きい値を示した。このことから、骨格筋量は力と関係することが示唆された。

4．膝伸展筋力

膝伸展筋力の平均値は狭山市の男性群と女性群では差が見られなかった。すなわち男性群と同じ力を有していた。歩行との関係を比較すると狭山市の女性群は歩行速度が速いことを示した。

5．呼吸機能

肺活量は男女の差が存在した。しかし、年齢間においては大きな差が見られなかった。一秒率は男女間には差が見られなかった。

6．片脚立位時間

開眼片脚立位時間は最大 60 秒間としたことから、平均時間は短縮されているが、女性群が長い傾向が見られた。入間市の 75 歳以上の男性において短い傾向が見られた。

閉眼片脚立位時間は 65 歳を超えると低下する傾向が見られた。しかし、標準偏差が大きいことから、個体差があることがわかった。

7．長座体前屈

女性群は柔軟性が高いことがわかった。

8．視覚反応時間

男女間で差が少なかった。視覚と下肢運動の連携が保持されていると示唆された。

まとめ

今回の測定から下記のことが示唆された。

①上肢骨格筋量が多い人は握力・つまみ力が大きい。
②膝関節伸展筋力が大きい人は歩行速度が速い。
③膝関節伸展筋力が大きい人は片脚立位時間が長い。
④視覚反応時間は男女差が少ない。

第２章「食習慣と運動習慣に関するアンケート」及び結果

第2章「食習慣と運動習慣に関するアンケート」及び結果

食習慣と運動習慣に関する調査

（農林水産省 平成 28 年度 新たな食環境に対応した食育活動モデル推進事業、食生活の実態・意識調査 アンケートより抜粋）

氏名：

1. あなたの日頃の食事において、以下のことはどれくらいあてはまりますか。

	あてはまる	どちらともいえない	あてはまらない
食品や調味料の摂取量が制限されている			
食事姿勢や食べる動作に不自由を感じている			
食物は細かくしたり、刻んだり、柔らかくしないと食べられない			
歯や口腔、飲み込みに問題がある			
食べる意欲や楽しみがある			

2. 次の食事に関する行為のうち、日頃は主にどなたが担当されていますか。

	ご自身	家族	友人	ホームヘルパー	その他
店舗での買い物					
インターネットでの買い物					
調理					
配膳					
食器洗い					

3. あなたは普段、食事を誰ととることが多いですか。（1つだけ）
   1） 1人でとることが多い
   2）家族ととることが多い
   3）友人・同僚等ととることが多い

4. あなたの普段のそれぞれの食事の摂取状況についてお知らせください。

	ほぼ毎日	週に1回以上	月に1回以上	月に1回未満	全く食べない全くしない
自宅で調理された、一般的な家庭料理(主食・主菜を含む)					
自宅外のお店で購入してきた、お弁当やお惣菜など					
上記以外の簡単な食事(菓子、パン、おにぎり、カップ麺など)					
外食					
食事にとろみをつけたり刻んだりするなど食べやすくしたもの					
友人や近所の方との会食					
食べない（食事を抜く）					

5. あなたの日頃の食事における、以下の品目の摂取状況についてお知らせください。

	ほぼ毎日	週に1回以上	月に1回以上	月に1回未満	全く食べていない
肉類					
魚介類					
卵類					
牛乳(ヨーグルト・チーズ 含む)					
大豆・大豆製品(みそ・しょうゆ除く)					
緑黄色野菜					
海藻類					
いも類					
果実					
油脂類（揚げ物を含む）					
ごはん類					
パン類					
めん類（うどん，そば，ラーメン，スパゲッティ）					
菓子類					
酒類					
清涼飲料水					
栄養補助食品					

6. あなたの日頃の食事において、以下のことはどれくらいあてはまりますか。

	とてもあてはまる	ややあてはまる	どちらともいえない	あまりあてはまらない	全くあてはまらない
栄養バランスを考慮した 食事を心がけている					
美味しい食材・食事であれば値段は高くても構わない					
食材・食事を選ぶ際は、とにかく安いものを選ぶようにしている					
食材・食事を選ぶ際は、安全性に気をつけている					
地場産の食材を意識的に選んでいる					
国産食材を意識的に選んでいる					
旬の食材を意識的に選んでいる					
調理済み食品をよく活用している					
ごはん、みそ汁、お漬物があればよい					
野菜中心で肉、魚、卵はあまり食べない					
乳製品(牛乳、ヨーグルト など)は好きではない					
脂っぽいものや揚げ物は避けている					
間食をとることが多い					

7. あなたは普段どのような運動をどのくらいしていますか。

	ほぼ毎日	週に1回以上	月に1回以上	年に数回	ほとんどしない
散歩					
ラジオ・テレビ体操					
水泳					
ストレッチング					
筋力トレーニング（マシーンの使用）					
ヨガ					
ダンス（各種）					
フラダンス					
ジョギング					
登山					
その他（　　　　　　　　　　　　　　　　）					

ご協力をありがとうございました.

今回、実施したアンケート項目は、農林水産省 平成 28 年度 新たな食環境に対応した食育活動モデル推進事業、 食生活の実態・意識調査 アンケートより抜粋して作成したものである。

アンケートの回答者女性:50 名、 男性:32 名

1. あなたの日頃の食事において、以下のことはどれくらいあてはまりますか。

項目	あてはまる		どちらともいえない		あてはまらない	
	女性	男性	女性	男性	女性	男性
食品や調味料の摂取量制限されている	3	2	2	5	45	25
食事姿勢や食べる動作に不自由を感じている	1	0	0	2	49	30
食物は細かくしたり、刻んだり、柔らかくしないと食べられない	0	0	2	3	48	29
歯や口腔、飲み込みに問題がある	3	1	2	2	45	29
食べる意欲や楽しみがある	35	23	7	4	8	5

・飲食に問題を有している回答者は 4 名であった。
・食べることに意欲や楽しみを持っていない回答者は女性で 16%、男性で 15.6%がいた。

2. 次の食事に関する行為のうち、日頃は主にどなたが担当されていますか。

	ご自身		家族		友人		ホームヘルパー		回答なし	
	女性	男性	女性	男性	女性	男性	女性	男性	女性	男性
店舗での買い物	46	11	4	21	0	0	0	0	0	0
インターネットでの買い物	9	8	12	5	0	1	0	0	6	8
調理	46	6	4	26	0	0	0	0	0	0
配膳	46	8	4	23	0	0	0	0	0	0
食器洗い	43	14	7	17	0	0	0	0	0	0

・インターネットで買い物をしている回答者は、女性で 18%、男性で 25%がいた。
・男性群において、調理は 18.8%、配膳は 25%、食器洗いは 43.8%が行っていた。

3. あなたは普段、食事を誰ととることが多いですか。(1 つだけ)

	女性	男性
1 人でとることが多い	8	3
家族ととることが多い	39	28
友人・同僚等ととることが多い	0	1

・孤食は女性が 16%、男性が 9.4%であった。

4. あなたの普段のそれぞれの食事の摂取状況についてお答えください。

	ほぼ毎日		週に 1 回以上		月に 1 回以上		年に数回		ほとんどしない	
	女性	男性	女性	男性	女性	男性	女性	男性	女性	男性
自宅で調理された、一般的な家庭料理(主食・主菜を含む)	47	32	1	0	0	0	1	0	1	0
自宅外のお店で購入してきた、お弁当やお惣菜など	3	0	13	7	18	14	10	11	5	0
上記以外の簡単な食事(菓子、パン、おにぎり、カップ麺など)	3	3	13	8	15	8	14	9	2	3
外食	0	0	11	2	10	14	22	11	7	4
食事にとろみをつけたり刻んだりするなど食べやすくしたもの	0	2	1	3	1	0	4	3	42	24
友人や近所の方との会食	1	0	2	1	16	11	22	11	9	8
食べない(食事を抜く)	1	1	0	0	0	3	5	2	39	24

・自宅で調理しての食事が多く、外食は年に数回と少なかった。
・食事を抜くということは男女ともに 1 名いたが、一日 2 食という食習慣であった。

5. あなたの日頃の食事における、以下の品目の摂取状況についてお答えください。

	ほぼ毎日		週に１回以上		月に１回以上		年に数回		ほとんどしない	
	女性	男性	女性	男性	女性	男性	女性	男性	女性	男性
肉類	19	7	26	21	0	4	2	0	2	0
魚介類	19	7	28	24	1	0	2	0	0	0
卵類	24	12	20	19	6	0	0	1	0	0
牛乳(ヨーグルト・チーズ 含む)	42	22	5	9	3	0	0	0	0	0
大豆・大豆製品(みそ・しょうゆ除く)	34	22	14	9	2	0	0	1	0	0
緑黄色野菜	42	20	8	12	0	0	0	0	0	0
海藻類	15	9	33	18	2	2	0	1	0	0
いも類	8	8	36	16	5	7	0	1	1	0
果実	21	18	24	11	3	3	0	0	1	0
油脂類（揚げ物を含む）	15	5	22	25	10	1	3	0	0	0
ごはん類	44	25	6	6	0	0	0	0	0	0
パン類	25	20	18	11	7	1	0	0	0	1
めん類（うどん、そば、ラーメン、スパゲッティ）	7	6	30	23	9	2	3	0	0	0
菓子類	25	13	14	16	8	0	2	0	1	2
酒類	7	10	9	4	3	8	6	2	25	7
清涼飲料水	10	7	10	11	7	2	8	7	15	4
栄養補助食品	11	5	2	7	4	2	5	2	26	16

・パン食おいて、女性は 50%、男性は 62.5%が毎日食べていた。
・飲酒において、女性は 32%、男性は 45%が習慣的飲酒をしていた。
・栄養補助食品において、女性は 44%、男性は 50%が使用していた。

6. あなたの日頃の食事において、以下のことはどれくらいあてはまりますか。

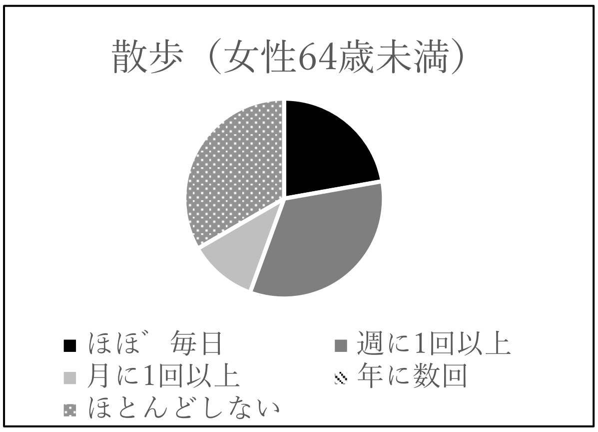
	とてもあてはまる		ややあてはまる		どちらともいえない		あまりあてはまらない		全くあてはまらない	
	女性	男性	女性	男性	女性	男性	女性	男性	女性	男性
栄養バランスを考慮した 食事を心がけている	15	9	27	16	9	6	1	1	1	0
美味しい食材・食事であれば値段は高くても構わない	6	1	24	13	13	12	5	4	1	2
食材・食事を選ぶ際は、とにかく安いものを選ぶようにしている	3	0	10	10	23	13	9	6	3	3
食材・食事を選ぶ際は、 安全性に気をつけている	20	14	24	13	4	5	1	0	0	0
地場産の食材を意識的に選んでいる	10	5	24	13	13	11	3	2	0	0
国産食材を意識的に選んでいる	28	10	14	17	6	5	1	0	0	0
旬の食材を意識的に選んでいる	16	5	27	20	7	7	0	0	0	0
調理済み食品をよく活用している	1	1	12	9	22	12	11	8	4	1
ごはん、みそ汁、お漬物があればよい	3	1	6	9	18	10	15	9	8	3
野菜中心で肉、魚、卵はあまり食べない	4	0	4	7	8	5	23	12	10	7
乳製品(牛乳、ヨーグルト など)は好きではない	4	2	2	0	3	7	7	8	34	15
脂っぽいものや揚げ物は避けている	3	4	21	9	14	9	7	6	5	4
間食をとることが多い	14	2	9	7	8	10	12	8	7	5

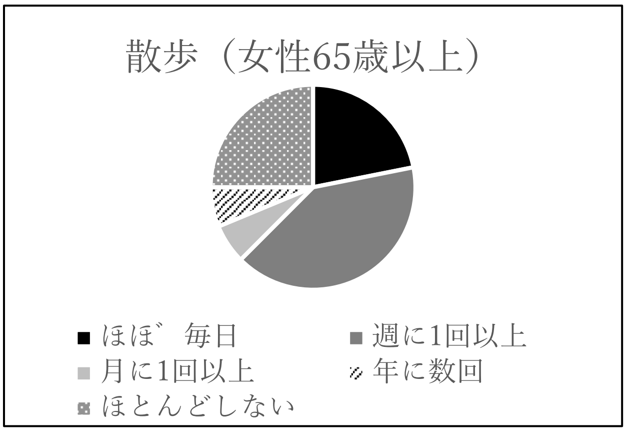
・食事は栄養バランスや食材の安全に気遣いをしていることがわかった。
・旬の食材や国産食材を選択していることがわかった。
・たんぱく質不足による低栄養のリスクを示唆する質問において、「ごはん、みそ汁、お漬物があればよい」は 23%、「野菜中心で肉、魚、卵はあまり食べない」は 19%、「乳製品（牛乳、ヨーグルトなど）は好きではない」は 10%であった。
・脂っぽいものや揚げ物は避けている割合は 45%みられ、男性より女性に多かった。

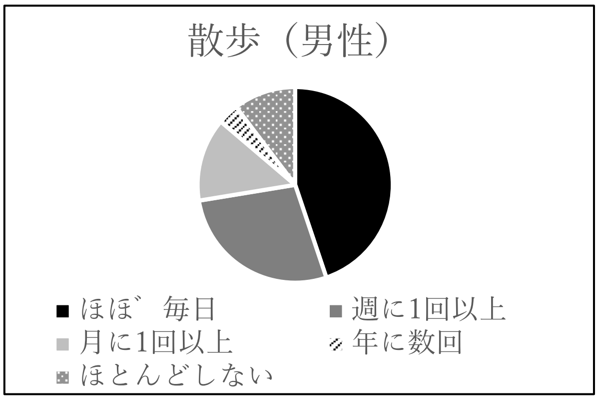
7. あなたは普段どのような運動を、どのくらいしていますか。

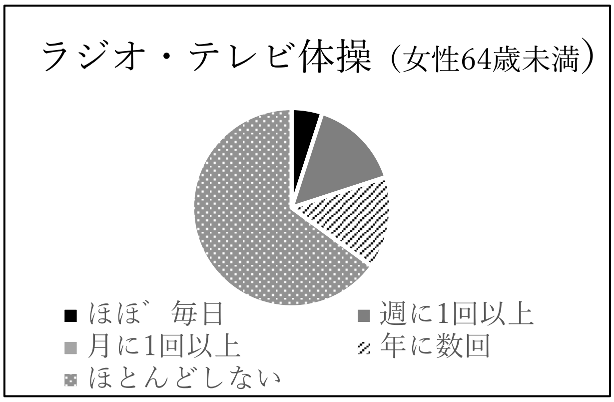
	ほぼ毎日		週に１回以上		月に１回以上		年に数回		ほとんどしない	
	女性	男性	女性	男性	女性	男性	女性	男性	女性	男性
散歩	11	14	19	9	4	5	2	1	12	0
ラジオ・テレビ体操	5	3	9	4	2	4	6	3	27	15
水泳	0	0	0	0	1	0	3	2	43	28
ストレッチング	10	10	17	12	7	1	1	0	14	7
筋力トレーニング（マシーンの使用）	2	6	16	12	0	1	2	0	28	11
ヨガ	3	0	3	0	0	0	2	1	37	29
ダンス（各種）	1	0	2	0	1	0	2	0	40	30
フラダンス	0	0	0	0	1	0	0	0	46	30
ジョギング	1	2	1	2	3	0	2	2	40	23
登山	0	0	0	1	0	2	9	5	37	23
その他	3	2	5	6	1	0	1	0	4	3

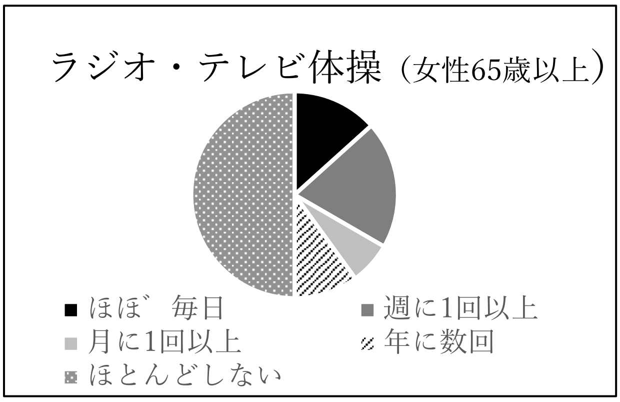
女性の年代別および男性の運動習慣

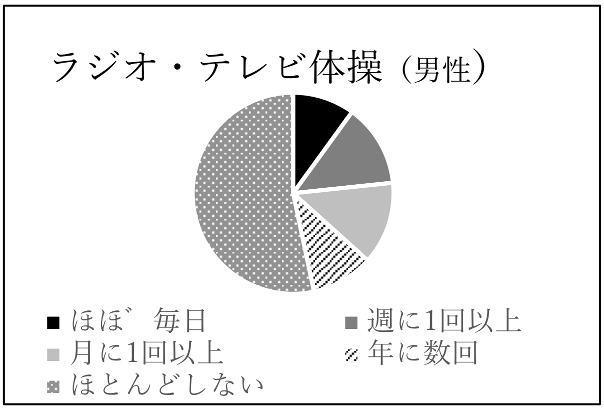


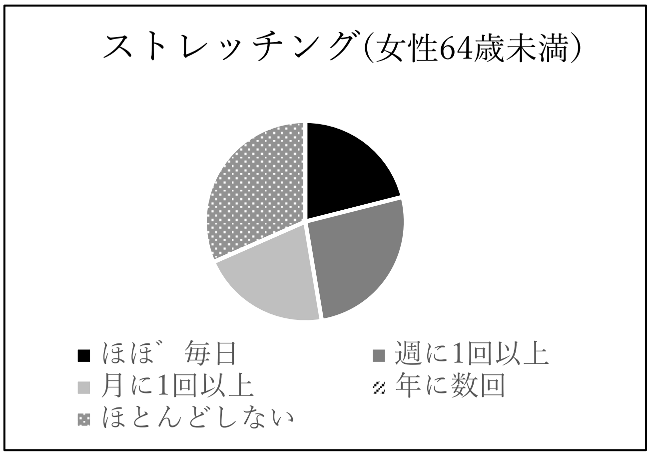


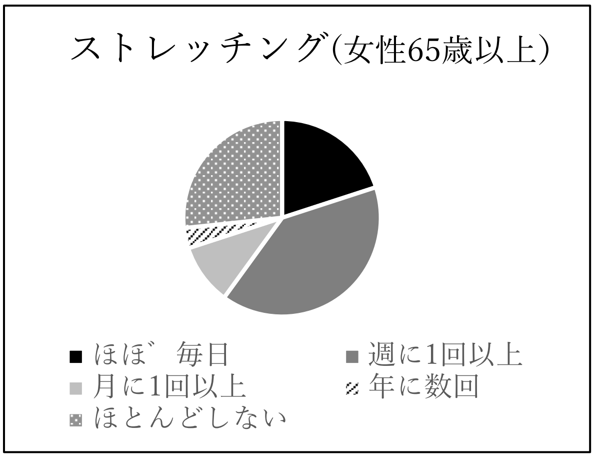


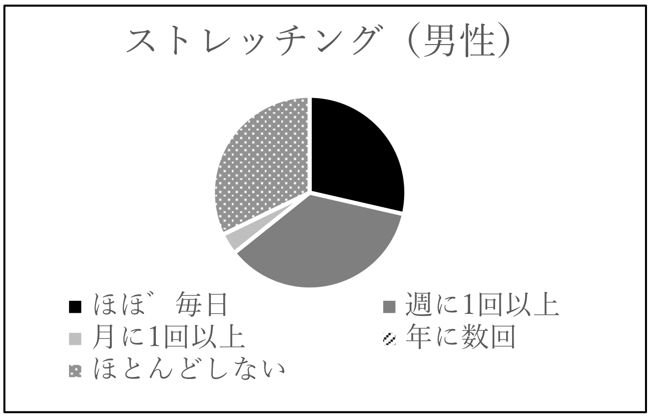







ストレッチング(女性64歳未満)
ほぼ　毎日
週に1回以上
月に1回以上
年に数回
ほとんどしない


ストレッチング(女性65歳以上)
ほぼ　毎日
週に1回以上
月に1回以上
年に数回
ほとんどしない


ストレッチング（男性）
ほぼ　毎日
週に1回以上
月に1回以上
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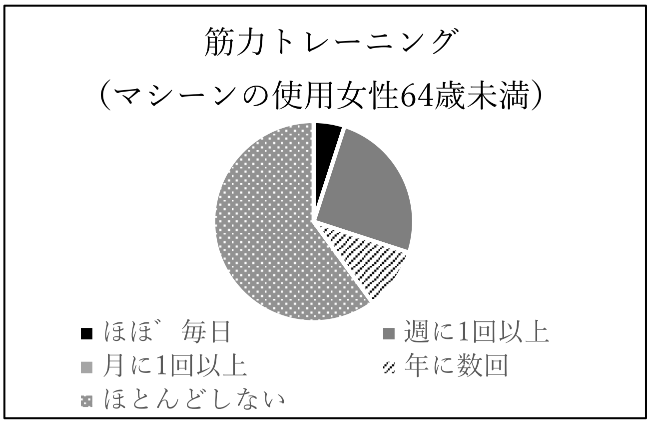
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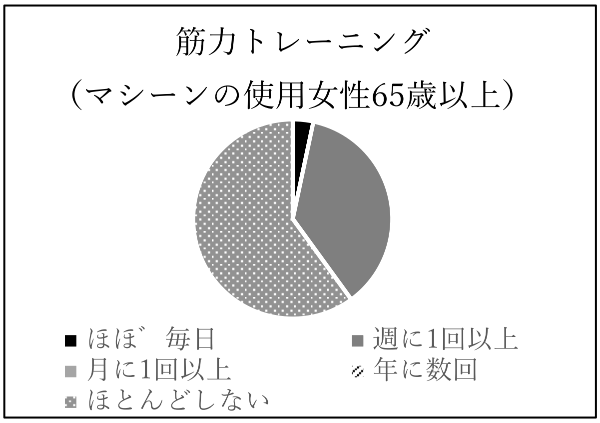
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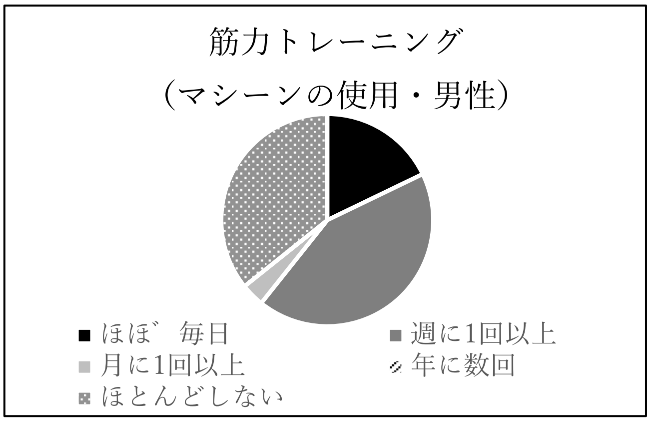
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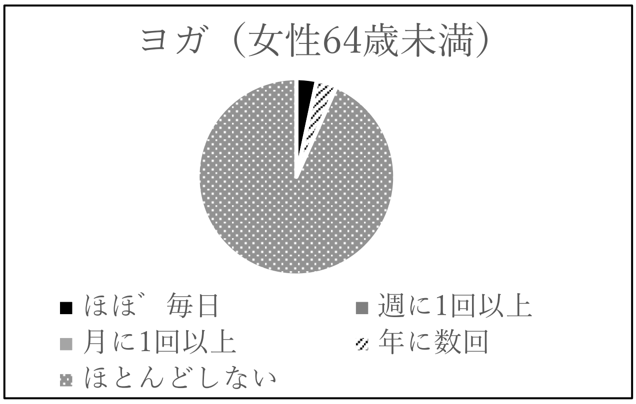
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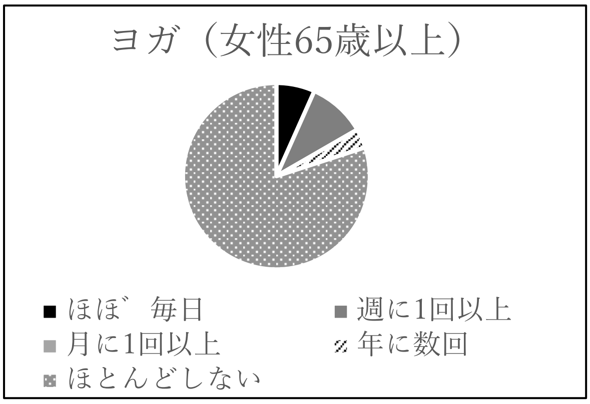
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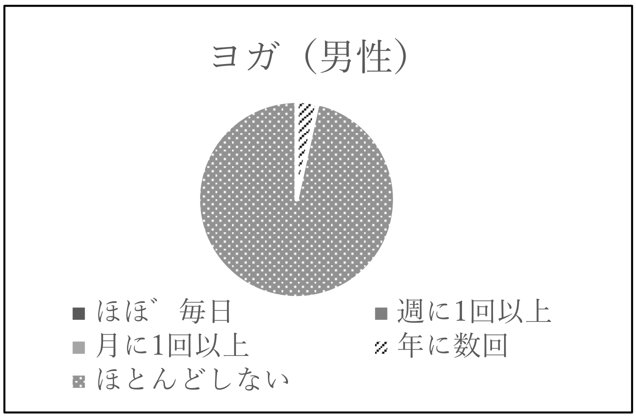
ヨガ（男性）
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第３章　研究論文

第３章　研究論文

①　Using machine learning to investigate the relationship between domains of functioning and functional mobility in older adults
PLoS ONE 16(2): e0246397, 2021

高齢者の機能と移動能力の関係性に関する人工知能による機械学習を用いた調査

機能的移動能力（functional mobility）は加齢と共に低下し、寝たきりのリスクや健康寿命の短縮のリスクファクターであることは既知の事実である。人間の機能は大きく3つに分類されている。1つは身体構造で、例えば筋肉量の低下や体脂肪率といったものである。2つ目は身体機能で、肺活量や筋力といったもの、そして3つ目は活動で、歩行速度や連続片脚立ち時間といったものに代表される。Timed Up and Go Test（以下、TUG）は、椅子に座っている姿勢から立ち上がり、歩行してコーンを回り、再び歩行して戻り椅子に座る一連の動作を可能な限り速く遂行するテストである。立ち座り動作能力と歩行能力、そしてバランスの要素が入り、機能的移動能力を測定できる有用なテストとして、高齢者の健康測定では世界的に用いられている。

TUGのスコアが高齢者の身体能力と相関することや、転倒リスクの予測因子になることなどが既に示されている。しかし、高齢者において機能的移動能力がヒトの機能の要素である身体構造、身体機能、活動のどれを最も反映するかは未だ不明である。研究が難しい要因は、加齢とともにこれらの要素は全体に低下をしていくため、その中で最も関連する要素を検出するには、単純な相関分析や因子分析には限界がある（多重共線性）。

そこで本研究では、地域在住高齢者のデータを用いて、除脂肪量（身体構造）、呼気1秒率（身体機能1）、膝伸展筋力（身体機能2）、片脚立ち時間（活動）のそれぞれと全組み合わせの結果からTUGスコアを予測した際の精度を検証した。これにより機能的移動能力を最も反映する機能の要素を明らかにすることを目的とした。

地域在住高齢者121名分の結果をデータの特徴を温存したまま5000データに拡張し、先行研究を参考に5つのランクに分け、各結果から機械学習手法の一つであるサポートベクターマシーンによってTUGの結果の予測を行なった。サポートベクターマシーンは変数同士の関連性を多次元空間に拡張して分析可能な手法で、今回の高齢者の身体に関わるデータのように、全体的に低下するなど同様の傾向を持った変数同士の分析を行うことができる。

その結果、当然予測に関わる要素の数が大きいほど予測精度は高かったが、中でも身体機能の膝伸展筋力が高くTUGのランクを予測する要素であることがわかった。

これにより、膝筋力のトレーニングが加齢に伴う機能的移動能力に最も直結する運動であり、移動能力低下の可能性を検出するには膝筋力を注視すべきであることが示唆された。本研究は全体的に低下を示す高齢者の身体に関わるデータの中で最も移動能力に関わる要素の検出を、機械学習手法で克服することで明らかにした最初の研究と言える。

PLOS ONE

RESEARCH ARTICLE

Using machine learning to investigate the relationship between domains of functioning and functional mobility in older adults

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Abstract

Previous studies have shown that functional mobility, along with other physical functions, decreases with advanced age. However, it is still unclear which domains of functioning (body structures, body functions, and activities) are most closely related to functional mobility. This study used machine learning classification to predict the rankings of Timed Up and Go tests based on the results of four assessments (soft lean mass, FEV_1/FVC, knee extension torque, and one-leg standing time). We tested whether assessment results for each level could predict functional mobility assessments in older adults. Using support vector machines for machine learning classification, we verified that the four assessments of each level could classify functional mobility. Knee extension torque (from the body function domain) was the most closely related assessment. Naturally, the classification accuracy rate increased with a larger number of assessments as explanatory variables. However, knee extension torque remained the highest of all assessments. This extended to all combinations (of 2–3 assessments) that included knee extension torque. This suggests that resistance training may help protect individuals suffering from age-related declines in functional mobility.

1. Introduction

Fractures account for approximately 10% of all cases in which older individuals become bedridden [1]. As Japan is the most rapidly aging society in the world, it is a matter of social concern to help prevent falls among older adults. One solution is to predict the probability of functional mobility decline by assessing physical function [2]. Moreover, declines in functional mobility and balance are related to falls [3, 4]. Therefore, previous studies have identified the predictors of results for the Timed Up and Go (TUG) test [2], maximum walking speed test [5], one-leg standing time test [6], functional reach test [7], Berg balance scale [8], functional balance scale [9], and four square step test [10]. Among these, the TUG test is highly recommended as a screening tool for identifying whether older individuals are at risk of falling [11]. The TUG test is also useful for predicting functional mobility, especially balancing and gait maneuvers used in everyday life (e.g., standing up, sitting down, walking, and turning) [2].

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A clinical review by Brown et al. [12] found that the predictors of mobility limitation could be aggregated into five factors: age, physical activity, BMI, muscle strength, and disease. Therefore, in older adults, mobility has a complex relationship with various domains of functioning. Further, previous studies have found that poor TUG ranks are associated with the affected domain of body structures (e.g., body composition [13]), body functions (e.g., respiratory function [14], muscle strength [15]), and activities (e.g., balance ability [16]). Thus, relevant literature shows that there are correlations between each domain of functioning (body structures, body functions, and activities) in healthy older adults [17–19]. The domains of functioning were defined in the International Classification of Function, Disability, and Health (ICF) by the World Health Organization (WHO) in 2015. However, regarding older adults in Japan, it remains unclear which functioning assessments are most closely related to functional mobility. Additionally, it is difficult to interpret functioning assessments of certain older individuals due to the increased frequency of multiple chronic diseases [20] and general declines in overall functioning [21, 22]. Moreover, frailty consists of several interrelated factors, including age-associated declines in lean body mass, strength, endurance, balance, and walking performance [23]. In sum, it remains unclear which domain of functioning is most related to TUG rank, which makes it difficult to determine the priority of results when attempting to interpret multiple assessments for a given individual.

To bridge the aforementioned gaps in the literature, we used support vector machines (SVMs) of machine learning classification algorithm (commonly used for estimating multivariate patterns) [24]. SVMs are suitable for finding relationships by high-dimensional mapping using support vectors from small sample data with complex relationships. Moreover, the prediction accuracy of machine learning prediction methods (e.g., Random Forest, Artificial Neural Network), including SVMs, are not affected by multicollinearity [25]. When dealing with multivariates that are correlated with each other such as in the present study, one of the reasonable methods to employ is SVMs [26]. The purpose of our study was clarified assessment patterns for each domain reflecting functional mobility rankings according to the TUG test. As such, we employed a machine learning classification by using TUG rank as an objective variable, while the assessment values of each domain (body structures, body functions, and activities) relative to the averages of the same generations were set as explanatory variables. From the viewpoint of structure of ICF, our hypothesis is that the prediction accuracy increases in the order of the domain from the bottom to the top, and the activities similar to TUG is the highest. Based on this classification, we attempted to clarify which assessments were most closely related to functional mobility among older adults. To the best of our knowledge, no previous studies have investigated this issue in Japan. Our study on Japanese older adults is relevant because Japan has one of the highest life expectancy rates in the world.

2. Materials and methods

2.1 Eligibility criteria

The East Japan Community Study of Aging (EJCSA) is an ongoing longitudinal survey that targets home-dwelling, healthy older adults in eastern Japan. The number of data recorded in the database of the EJCSA from 2018 to 2020 was 121. A total of 112 subjects were extracted as the target data for analysis according to the criteria of aged over 50 years and without physical disabilities.

The sample size was determined following a previous study finding knee extension torque/bodyweight of 1.91 ± 0.58 Nm/kg (average ± standard deviations) among 24 middle age and 1.55 ± 0.47 Nm/kg among 24 old adults [27]. Sample size was calculated based on a desired 80% statistical power to detect a 0.35 Nm/kg difference (standard effect size, 0.60) in knee extension torque. We confirmed that the sample size was satisfied after being estimated using G*Power 3.1 software (Franz Faul, University of Kiel, Kiel, Germany), with an effect size 0.30, a minimum power 0.80, and $\alpha = 0.05$. All participants provided written informed consent prior to participation. Furthermore, all procedures adhered to the Declaration of Helsinki. The experimental procedures were specifically approved by the Research Ethics Committee of Tokyo Kasei University.

2.2 Classifications: Five groups and four assessments

Participants performed the TUG test at a comfortable speed. We then used their results to classify them into five groups, following the guidelines that the Tokyo Metropolitan Institute of Gerontology established based on a study by Obuchi et al. [28]. These were labeled Group 1 (males $\geq$ 7.2; females $\geq$ 8.9), Group 2 (males 6.1–7.1; females 7.5–8.8), Group 3 (males 5.5–6.0; females 6.5–7.4), Group 4 (males 5.0–5.4; females 5.8–6.4), and Group 5 (males $\leq$ 4.9; females $\leq$ 5.7). All units indicate seconds.

The assessments were used as follows.

1. *Soft lean mass (SLM)*
   Body composition was assessed through direct segmental multi-frequency bioimpedance analysis (DSM-BIA) using the InBody770 (InBody Co., Ltd., Korea), which uses a multi-frequency segmental measurement method with an eight-point tactile electrode. Multi-frequency measurements were taken using frequencies of 1, 5, 50, 250, 500, and 1000 kHz for each body segment. The data were normalized according to generation and sex, based on Lee's work [29].

2. *FEV_1/FVC of respiratory function*
   FEV_1/FVC ratios were measured using a digital spirometer (AS-407, MINATO Medical Science Co., Ltd., Japan). Participants were asked to take deep breaths using a mouthpiece attached to the spirometer, while sitting. They were then asked to hold their breath long enough to seal their lips tightly around the mouthpiece. Afterwards, they were asked to hold their noses tightly and exhale the air out as forcibly and quickly as possible, until all the air was expelled. Participants were verbally encouraged to continue exhaling during this phase.

3. *Knee extension torque (KET)*
   Participants were tested for isometric maximal voluntary contraction of the knee extensor muscles on the dominant lower limb using a dynamometer (μ Tas-01, Anima Co., Ltd., Japan). During the test, participants were seated comfortably in a chair with their trunks erect, while knee and hip angles were maintained at 90 degrees. The task consisted of a quick increase to the maximum force exerted by the leg. The higher data of each leg was divided by the participants' weight and normalized according to generation and sex, based on Bohannon's work [30].

4. *One-leg standing time (OLST)*
   The OLST test measures participants' ability to continue standing on one leg with their eyes closed. The test ended when participants moved their supporting legs, lost balance, or opened their eyes. The upper threshold was 30 seconds. We registered the mean times for each supporting leg and normalized them according to generation and sex, based on Springer's work [31].

The FEV_1/FVC, KET, and OLST were adopted higher result in two trials. The participants had enough rest time between each trial, which involved resting for at least about 3 minutes between each trial, taking into account the effects of muscle fatigue [32]. The participants completed the assessments randomly. All assessments were normalized by each maximum value and expressed as 0–1.

2.3 Data analysis

We performed a one-way ANOVA for age differences among the TUG groups. Correlation coefficient was estimated the relationship between data of each assessment before normalizing and result of TUG.

All five TUG groups were used as objective variables in the SVM. To avoid group variability, data from each group included four assessments: (1) SLM, (2) FEV_1/FVC, (3) KET, and (4) OLST. The data of each group were randomly expanded to 1,000 data to overcome the limitation of a small sample size and difference in sample sizes among groups. Therefore, a total of 5,000 data measurements from all groups were maintained for the distribution of actual data using the bootstrap method. This bootstrap resampling method is often used in demographic studies [33].

The data were randomly divided as 90% training data and 10% testing data. The training data were submitted to the SVM; that is, the SVM algorithm was constructed as a prediction model using the training data. After the training, the resultant SVM prediction model with the 90% training data (4500 data) was used to predictively classify the remaining 10% testing data (500 data) into either of the five TUG groups or the four assessments for cross-validation. To verify the effect of the number and/or combination of assessments on predictive accuracy, SVM prediction was performed for all 15 combinations of the four assessments (${}_4C_1 + {}_4C_2 + {}_4C_3 + {}_4C_4$), and randomly divided into training and testing data for each prediction.

Predictive accuracy was calculated as the total number of successful predictions in each group divided by the total number of predictions in all groups. This ensured that a trained SVM with a Gaussian kernel could prospectively be generalized ($G(x_j, x_k) = \exp(-\|x_j - x_k\|^2)$). In the current investigation, we used "templateSVM," available in MATLAB software (The MathWorks Inc., Natick, MA, USA), which utilizes the algorithm defined by Schölkopf et al. [34]. The relationship between the accuracy rate and number of assessments was tested using AIC (Akaike's information criteria) as a non-linear regression equation.

3. Results

Table 1 shows participants' characteristics for each group. As seen, participants' ages in Group 1 were significantly higher than for participants in Groups 2, 3, and 4 ($p < 0.05$). There were significant differences between Groups 1 and 4 regarding SLM, KET, and OLST. Except for the SLM measurements between Groups 1 and 3 ($p < 0.05$), there were no significant intergroup differences for the other assessments. S1 Fig shows the relationships between the TUG test and other assessments (only KET showed a low negative correlation coefficient; $p < 0.05$), while Table 2 shows the average accuracy rates of SVM prediction. Combinations of three to four assessments had high rates. The relationship between the accuracy rate and number of assessments was highly correlated (S2 Fig, R = 0.89, $p < 0.001$). Notably, all top accuracy rates for single assessment and each combination of two and three assessments included KET (SLM + FEV_1 / FVC + KET 89.2%, and SLM + KET 82.2%, only KET 57.2%). Moreover, the combination of FEV_1 / FVC and KET was higher accuracy rate than the combination of SLM, FEV_1 / FVC and OLST + KET (82.0%).

Table 1. Participants' characteristics and bootstrap resampling data for each TUG group (mean ± standard deviation).

	Group 1		Group 2		Group 3		Group 4		Group 5	
	Male TUG ≧ 7.2		6.1 ≧ Male TUG > 7.1		5.5 ≧ Male TUG > 6.0		5.0 ≧ Male TUG > 5.4		4.9 ≧ Male TUG	
	Female TUG ≧ 8.9		7.5 ≧ Female TUG > 8.8		6.5 ≧ Female TUG > 7.4		5.8 ≧ Female TUG > 6.4		5.7 ≧ Female TUG	
Participants (n = 112)	30		32		28		18		4	
Age (years)	74.7 ± 7.4 *2, 3, 4		68.8 ± 6.1 *1		65.3 ± 7.5 *1		66.9 ± 8.0 *1		69.8 ± 8.0	
Sex (male / Female)	25 / 5		13 / 19		2/26/2021		0 / 18		1 / 3	
	Actual	**Bootstrap**	**Actual**	**Bootstrap**	**Actual**	**Bootstrap**	**Actual**	**Bootstrap**	**Actual**	**Bootstrap**
1) Soft lean mass (kg)	24.05 ± 3.93 *3, 4	24.07 ± 3.85	21.86 ± 5.15	21.89 ± 5.03	20.26 ± 2.92 *1	20.24 ± 2.83	19.68 ± 1.56 *1	19.67 ± 1.50	21.78 ± 4.94	21.81 ± 4.03
2) FEV_1 / FVC (%)	69.70 ± 11.86	69.63 ± 11.59	75.18 ± 9.99	75.19 ± 9.75	74.57 ± 8.64	74.59 ± 8.39	76.28 ± 9.77	76.25 ± 9.26	74.75 ± 4.65	74.76 ± 3.78
3) Knee extension Torque (Nm / kg)	0.91 ± 0.31 *4	0.92 ± 0.30	0.99 ± 0.26	0.99 ± 0.25	1.13 ± 0.30	1.12 ± 0.29	1.24 ± 0.22 *1	1.24 ± 0.22	1.07 ± 0.36	1.07 ± 0.30
4) One leg standing time (sec)	19.75 ± 9.34 *3	19.86 ± 9.14	22.41 ± 10.06	22.41 ± 9.85	26.53 ± 5.04 *1	26.58 ± 4.91	26.10 ± 7.32	26.12 ± 6.95	28.25 ± 3.50	28.24 ± 2.53

* $p < 0.05$; n = 112 older Japanese adults.

The number of next to * is the group number with a significant difference.

https://doi.org/10.1371/journal.pone.0246397.t001

4. Discussion

We conducted SVM prediction for TUG ranks based on all 15 combinations of four assessments in each domain (body structures: soft lean mass; body functions: FEV_1 / FVC, knee extension torque; activities: one-leg standing time). KET still had the highest accuracy rate in any single assessment, and all combinations (of 2–3 assessments) that included KET were the highest. To the best of our knowledge, this is the first study to identify the most closely related functioning assessment to functional mobility using a machine learning classification method.

The accuracy rate increased depending on the number of explanatory variables as assessments (S2 Fig). This result is natural because all assessments are known to contribute to the TUG. Next, in combinations of three assessments, the OLST, FEV_1 / FVC and SLM assessments were omitted in order. The accuracy rate of the combination of SLM, FEV_1 / FVC, and

Table 2. List of average accuracy rates (highest to lowest).

1) Soft lean mass	2) FEV_1 / FVC	3) Knee extension torque	4) One leg standing time	Accuracy rate (%)
○	○	○	○	94.4%
○	○	○	-	89.2%
○	-	○	○	88.4%
-	○	○	○	87.8%
○	-	○	-	82.2%
○	○	-	○	82.0%
-	-	○	○	79.4%
○	-	-	○	75.0%
-	○	○	-	73.6%
-	○	-	○	66.8%
○	○	-	-	64.8%
-	-	○	-	57.2%
○	-	-	-	56.6%
-	-	-	○	50.8%
-	○	-	-	46.2%

Note: Open circles indicate adopted assessments, while minuses indicate non-adopted assessments.

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OLST were lower than that of the combination of two assessments including KET. However, this accuracy rate did not depend on the number of assessments. Moreover, the bottom three in the single assessments were SLM, FEV_1 / FVC, and OLST. From these points, the difference in the explanatory variables can be seen between SLM, FEV_1 / FVC, and OLST compared to KET. However, since the chance of predicting the TUG's five ranks by simply thinking is 20%, it cannot be said that the predictive accuracy of these evaluations is low (SLM: 56.6%; FEV_1 / FVC: 50.8%; KET: 46.2%). This may be due to the fact that the evaluation is related with TUG.

4.1 Significance as an analytical method for the support vector machine

Among four assessments, our results showed that knee extension torque was the most closely related to each participant's TUG rank. The various abovementioned parameters of functioning typically decrease with age [20]. Personal data obtained from older adults often include high-correlation (multicollinearity) data, such as age-dependent parameters [23]. Using a multivariate analysis method precludes the analysis of data unless the other explanatory variables are removed. However, machine learning prediction can make it possible to analyze data with multicollinearity [35]. One of the methods of machine learning prediction is SVMs with kernel function. Therefore, results achieved through SVM projection are not affected by collinearity [36]. In other words, this machine learning prediction method enabled us to avoid removing important information about participants. Moreover, the input data are first projected onto a higher dimensional space before they are employed in the estimation process. Thus, this method allowed us to conduct a complex factor analysis by multiple variables. Other studies have used SVMs to analyze the relationships between outcomes and multiple complicating factors, as to individually predict each participant's prognosis [37]. An SVM with high discrimination accuracy was suitable for this study due to its usefulness in selecting evaluations with complicated correlations. However, the classification function obtained through the SVM is a black box that outputs only the classification results. This makes it difficult to interpret the contributions of each variable. In this study, all explanatory variables (SLM, KET, FEV_1/FVC, and OLST) were already known contributors to the objective variable (TUG), as mentioned above. For this reason, the study was able to use machine learning to demonstrate a relationship between knee extension muscle strength as a body function domain and the TUG test, which analyses of variance and correlations cannot reveal.

4.2 The most related domain of functioning assessment is body function: Knee extension torque

In our study, KET as the evaluation of knee extension muscle strength was the assessment most related with functional mobility. It should be noted that our results differed from those of previous studies. In older adults with functional limitations, previous studies have found that neither muscle strength nor power in the lower extremities were correlated with walking distance [38]. In older adults with high activity, another study reported that leg muscle strength and leg lean tissue mass are not outcomes for predicting mobility, because both are similarly weakly correlated with gait performance [39]. The results of the aforementioned studies likely differed from ours due to differences in methodology (short-term interventions and correlation coefficients analysis vs. machine learning).

Changes to the neural system and muscle fibers, which naturally occur with age, lead to declined neuromuscular function [40]. This is associated with a reduced ability to generate both muscle strength and power, consequently impeding daily living activities [41, 42]. In our study, body structure comparisons between SLM and FEV_1/FVC showed that SLM was significantly higher in Group 1 (low rank), while there were no significant intergroup differences for

FEV_1/FVC. Compared to cardiorespiratory fitness, knee muscle torque is significantly associated with overall physical activity, postural transitioning, walking, and stair climbing [27]. Similarly, it is conceivable that the relationship between gait performance and leg muscle strength is stronger than that between gait performance and leg muscle mass [39]. The European Working Group on Sarcopenia in Older People suggests a conceptual staging that includes presarcopenia, sarcopenia, and severe sarcopenia. The presarcopenia stage is characterized by decreased muscle mass without significant effects to muscle strength or physical performance. This stage can only be identified using techniques that accurately measure muscle mass and reference standard populations [43]. As it is possible that many of this study's participants also had presarcopenia, they may have had a reduction in SLM, but not reductions in TUG ranks or knee muscle strength.

The functional reach test is another common activity assessment when evaluating dynamic balance. However, a previous study found that knee extension muscle strength was a more important independent factor than functional reach [44]. Therefore, we conducted comparisons between activities via the one-leg standing test. Since the TUG test reflects walking speed, it may also be associated with activity tasks, such as the 10 m walking test. In a previous study, approximately 50% of older adults who had no difficulties when turning achieved nearly the same results as younger adults with similar characteristics. In said study, researchers used a pivot strategy involving one or two steps to accomplish turns in 2.49 seconds or less with no signs of imbalance [45]. For both young and old participants without walking difficulty, the ratio of walking time to total time in the TUG test was nearly the same. This indicates that both the TUG test and KET are related to walking speed, suggesting a strong relationship between the TUG test and KET.

5. Conclusions and limitations

This study had some limitations. As previously mentioned, we could not include the causality between each domain/assessment and functional mobility through this study's machine learning method. Specifically, it focused only on four assessments throughout the three domains of functioning. Therefore, SVM prediction could not exclude the possible influences of other domains (e.g., environmental and individual factors) or assessments (e.g., cardiopulmonary function or outdoor activity) and/or any interactions between these factors. In addition, there are various machine learning classification methods such as random forest and artificial neural network available today. It is necessary to verify the optimal method for such assessments in future studies.

Although this study assessed limited domains of functioning, it strongly suggests that evaluations of body function are helpful when implementing preventive rehabilitations aimed at functional mobility. As resistance training can be used to maintain muscle strength, our results also suggest that it can help prevent age-related decline in functional mobility, thereby reducing the fall risk. If physiotherapists investigate the possibility of falling among highly active elderly people, prioritizing the monitoring of items related to physical function, especially muscle weakness could be valid. In making a rehabilitation program to reduce fall risk among the elderly, increasing the proportion of strengthening or maintaining muscle strength could be valid as part of rehabilitation therapy.

As the Japanese population continues to age, it is even more important to ensure that citizens maintain knee extension muscle strength at above-average levels for their respective age groups. This may help prevent the risk of older adults becoming bedridden, while also reducing nursing care requirements and lowering overall medical expenses. For these reasons, the same measures are also important in other countries, and require further investigation, especially in countries with aging populations.

Supporting information

S1 Fig. Relationships between TUG times and assessments. (A) soft lean mass; (B) knee extension torque; (C) FEV_1 / FVC; (D) one-leg standing time. Images show correlation coefficients (r) and linear regression lines.
(TIFF)

S2 Fig. Relationships between accuracy rate and number of assessments. The circles show the accuracy rate of each combination of assessments and the dashed line represents the non-linear regression line.
(TIFF)

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② Impact of different bilateral knee extension strengths on lower extremity performance.
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目的

下肢筋力が歩行、立ち上がりなどの下肢パフォーマンスに影響を及ぼすことが広く知られているものの、両側の下肢筋力がどのように下肢パフォーマンスに寄与しているのかについては明らかになっていない。そこで本研究では、非線形と線形モデルを用いて両側下肢筋力と下肢パフォーマンスの関連性を検討することを目的とした。

方法

地域在住の中高齢者 121 名を対象とした。下肢パフォーマンスを評価するための測定項目は、下肢筋力、最大歩行時間、Timed and Up Go Test（TUG）とした。両側の膝伸展筋力体重比を説明変数、最大歩行時間と TUG 所要時間を目的変数として線形モデルと非線形モデルを作成した。そして、両モデルにおける各肢の寄与率を-2 から 0 まで変化させ Akaike Information Criterion（AIC）が最小になる寄与率の組み合わせを探索した。

結果

歩行時間については、対数モデルよりも直線モデルの AIC の方が小さく、強い側の下肢筋力が歩行速度に大きく寄与していた。TUG については、直線モデルよりも対数モデルの AIC の方が小さく、弱い側の下肢筋力が TUG に大きく寄与していた。

結論

本研究による知見は、中高齢者のトレーニングを行う際の基盤的能力と両下肢における具体的な目標値を推定することに寄与できる。

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Impact of different bilateral knee extension strengths on lower extremity performance

Kilchoon Cho, MS*, Makoto Suzuki, PhD, Naoki Iso, PhD, Takuhiro Okabe, PhD, Hiroshi Goto, PhD, Keisuke Hirata, PhD, Junichi Shimizu, PhD

Abstract

Despite the impact of leg muscle strength on lower extremity motor performance—including walking and sit-to-stand transfer—it remains difficult to predict the relationship between bilateral leg muscle strength and lower extremity performance. Therefore, this study was designed to predict lower extremity function through the differential modeling of logarithmic and linear regression, based on knee extension strength.

The study included 121 individuals living in the same community. The bilateral strengths of the knee extensors were measured using a handheld dynamometer, and the Timed Up & Go test (TUG) performance time and 5-m minimum walking times were assessed to predict lower extremity motor functions. Bilateral normalized knee extension muscle strengths and lower extremity motor function scores, including walking or TUG performance times, were assessed on the logarithmic and linear models. The Akaike information criterion (AIC) was used to evaluate the coefficient compatibility between the logarithmic regression model and the linear regression model.

The AIC value for the linear model was lower than that for the logarithmic model regarding the walking time. For walking time estimation in the linear model, the coefficient value of knee extension strength was larger on the strong than on the weak side; however, the AIC value for the logarithmic model was lower than that for the linear model regarding TUG performance time. In the logarithmic model's TUG performance time estimation, the coefficient value of knee extension strength was larger on the weak than on the strong side.

In conclusion, our study demonstrated different models reflecting the relationship between both legs' strengths and lower extremity performance, including the walking and TUG performance times.

Abbreviations: AIC =Akaike information criterion, SD = standard deviation, TUG = Timed Up & Go.

Keywords: knee extension strength, lower extremity motor performance, rehabilitation, sit-to-stand, walking

1. Introduction

Walking and sit-to-stand progression are considered essential lower extremity motor functions in daily life[1–5]; however, motor performance declines with aging[6–8] and is associated with daily dysfunction,[9–12] falls,[13] cognitive disorder,[14–16] decreasing quality of life,[17] hospitalization,[18,19] and mortality.[20–22] Previous studies have reported that weakness in both legs is an important risk factor for the inability to perform lower limb motor functions, such as sitting-to-standing movement and walking.[1,11,23–26] Therefore, a decline in the muscle mass of both legs is considered a major factor for the development of muscle weakness in older adults and is obvious in regions, such as Japan, the United States, and Europe, where society is dramatically aging.[1,6,26,27] Heterogeneous reductions in both legs' muscle strengths in particular may be clinically relevant to determine the relationship between lower extremity motor performance and leg muscle strength.[7]

The association between strength and performance has been estimated by both linear and non-linear models. Cross-sectional studies[28] on motor performance and strength have traditionally used linear regression modeling; however, a previous study[29] suggested that the association between motor performance and strength may be curvilinear. Exceeding or increasing the intensity of this threshold level cannot improve task performance; below the threshold, a stronger relationship between change in strength and change in performance should be evident. Nevertheless, it remains difficult to predict the relationship between lower extremity motor performance and leg muscle strength. Several aspects should be addressed, such as which side of the leg (i.e., weak or strong) as well as which model based on muscle strength (logarithmic or linear regression) can predict lower extremity motor performance. By predicting lower limb function in community-dwelling people according to knee strength, training to restore lower limb function will be more evidence-based in an

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The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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aging society. Thus, accurate prediction of lower extremity motor performance would provide crucially important information for both health care administrators and individual patients.

Therefore, this study was designed to assess the relationship between lower extremity motor performance and knee extension strength, and to predict lower extremity motor performance via the differential modeling of logarithmic and linear regression, based on knee extension strength. To the best of our knowledge, this is the first study to demonstrate the balance of leg strength needed to perform functional tasks. Considering the findings of previous studies regarding lower extremity function, we hypothesized the following: there is a suitable balance between both legs' muscle strengths, allowing the prediction of lower extremity motor performance; and lower extremity motor performance may be accurately predicted by linear or logarithmic regression models based on both legs' muscle strengths. Here, we predicted balance of muscle strength in both legs for lower limb motor function by applying linear or logarithmic regression modeling.

2. Methods

The research procedure was approved by the Research Ethics Committee of Tokyo Kasei University and performed in accordance with the principles of the Declaration of Helsinki. All participants were fully informed of the purpose and procedure of the study prior to participation. Written informed consent was obtained from each participant.

2.1. Eligibility criteria

The eligibility criteria included the following: community-dwelling individuals; absence of palsy, knee pain, and injury; and no use of assistive devices for walking and sit-to-stand. The target sample size was based on a desired 90% statistical power to detect changes in lower extremity motor performance and muscle strength, with a 0.90 effect size and a 2-sided α-level of 0.05. Inputting these parameters into the Hulley matrix[30] yielded a sample size of 113; accordingly, we planned to retrospectively recruit 113 patients from a database of survey for Tokyo and Saitama regional area for the analysis of muscle strength and lower extremity motor performance.

2.2. Muscle strength measurements

A handheld dynamometer (mTas-F1, Anima Corp., Tokyo, Japan) was used to evaluate bilateral isometric knee extension strength as an indicator of overall lower limb strength. Each participant sat upright in an elevated chair with the hips and knees bent at approximately 90 degrees, the feet over the floor, and the palms resting on their thighs. The dynamometer was placed perpendicular to the leg, just above the ankle. During all tests, the dynamometer was stabilized by the examiner's hands and a belt. The participants were instructed to straighten their knees, push the dynamometer, and gradually increase force with maximum voluntary effort; this was maintained for an additional 5 seconds.

During the session, each participant was given consistent verbal encouragement. The dynamometer was stabilized by the examiner using both hands during all tests, and the extension of each limb was evaluated. The starting limb was randomized. Leg strength was measured twice, and the mean was used as a parameter.[1,26] Bilateral knee extension forces (kgf) were normalized against body weight (kgf/kg), and muscle strength measurements were used to predict lower extremity motor performance.

2.3. Walking time assessment

To assess the minimum walking time, participants were asked to walk 5 m straight at their maximum speeds[11]; the run-up distance was set to 3 m, and the time required for the patient to cross 5 m (determined from the start reference line, to crossing the goal reference line) was measured. The participants were instructed to stand still with their feet behind a taped starting line and walk in a straight line at their maximum speed, without stopping at the goal reference, following the examiner's "Go!". Timekeeping started at the first foot fall and ended when the participant's first foot completely crossed the 5 m end line.[31]

2.4. Timed Up & Go test

The participants started in the chair sitting position, while the distance to the pole was 3 m. They walked as fast as possible, went around the pole, and sat back in the chair. The examiner measured the time required to return to the chair sitting position from the start; the use of walking aids, such as a cane, handrail, walker, or orthosis, was not permitted.

2.5. Data analysis

We predicted that lower extremity motor performance would be linearly or logarithmically affected by bilateral lower muscle strength.[32] Therefore, a functional model based on strength and performance was constructed as follows:

$$fx(x) = \beta_s x_s + \beta_w x_w + \alpha + \varepsilon \quad (1)$$

$$fx(x) = \beta_s \ln x_s + \beta_w \ln x_w + \alpha + \varepsilon \quad (2)$$

where β is the contribution ratio for the weak (w) or strong side (s) of the leg; x is the normalized knee extension strength; α is the potential effect of confounding factors; and ε is the residual error. Each participant's data were fitted to the model via the least-squares method. The Akaike information criterion (AIC) matrix was used to assess the compatibility of the α- and β-values of the model on the weak and strong sides of the leg. The AIC was calculated as follows:

$$AIC = n\,log\left(\frac{SSR}{n}\right) + 2k \quad (3)$$

where n is the number of data entries, SSR is the sum of squared residuals between the model's predictions and actual data, and k is the number of parameters. A lower AIC value indicates better α- and β-values of the model.[33] If the model was applicable, the series of values for ε in Eqs. (1) and (2) would be uncorrelated to each other (i.e., independent); therefore, we assessed the applicability of the model with the Ljung–Box test to measure the independence of ε as a white noise and residuals process. The following equation was used for the Ljung–Box test:

$$Q(h) = n(n+2)\sum_{i=1}^{h} \frac{\hat{\rho}_l{}^2}{n-i} \quad (4)$$

where n is the sample size, $(\hat{\rho}_l)$ is the sample autocorrelation at lag i, and h is the number of lags being tested. Thus, the data permitted the evaluation of whether lower extremity motor performance is linearly or logarithmically affected by bilateral lower muscle strength. We defined statistical significance as $P < .05$; all statistical tests were performed using R 3.4.0 software (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

In total, 121 community-dwelling individuals (sex, 46 male and 75 female individuals) were recruited (Table 1). The participants' age ranged from 32 to 86 years (average, 67.1 years; standard deviation [SD], 10.8 years). Their body weight ranged between 36.9 and 82.5 kg (average, 57.3 kg; SD, 9.4 kg), and the body mass index was between 15.6 and 31.8 (average, 22.8; SD, 2.8). The normalized knee extensor strength on the strong side for the 121 participants in this study ranged from 1.40 to 8.56 kgf/kg (average, 5.39; SD, 1.30 kgf/kg); the normalized knee extensor strength on the weak side ranged from 1.21 to 8.26 kgf/kg (average, 4.89; SD, 1.27 kgf/kg).

Table 1

Characteristics of the study population.

	Participants (n = 121)
Age (years)	67.1 ± 10.8
Sex (male/female)	46/75
Body weight (kg)	57.3 ± 9.4
Body mass index (kg/m^2)	22.8 ± 2.8
Normalized knee extensor strength on the strong side (kgf/kg)	5.39 ± 1.30
Normalized knee extensor strength on the weak side (kgf/kg)	4.89 ± 1.27

Values are presented as means ± standard deviations.

Figure 1 shows the AIC matrix calculated to determine optimal α-, β_s-, and β_w-values for the linear and logarithmic models. The smallest AIC value for the linear model (–182.71) was lower than that for the logarithmic model (–156.06) regarding the walking

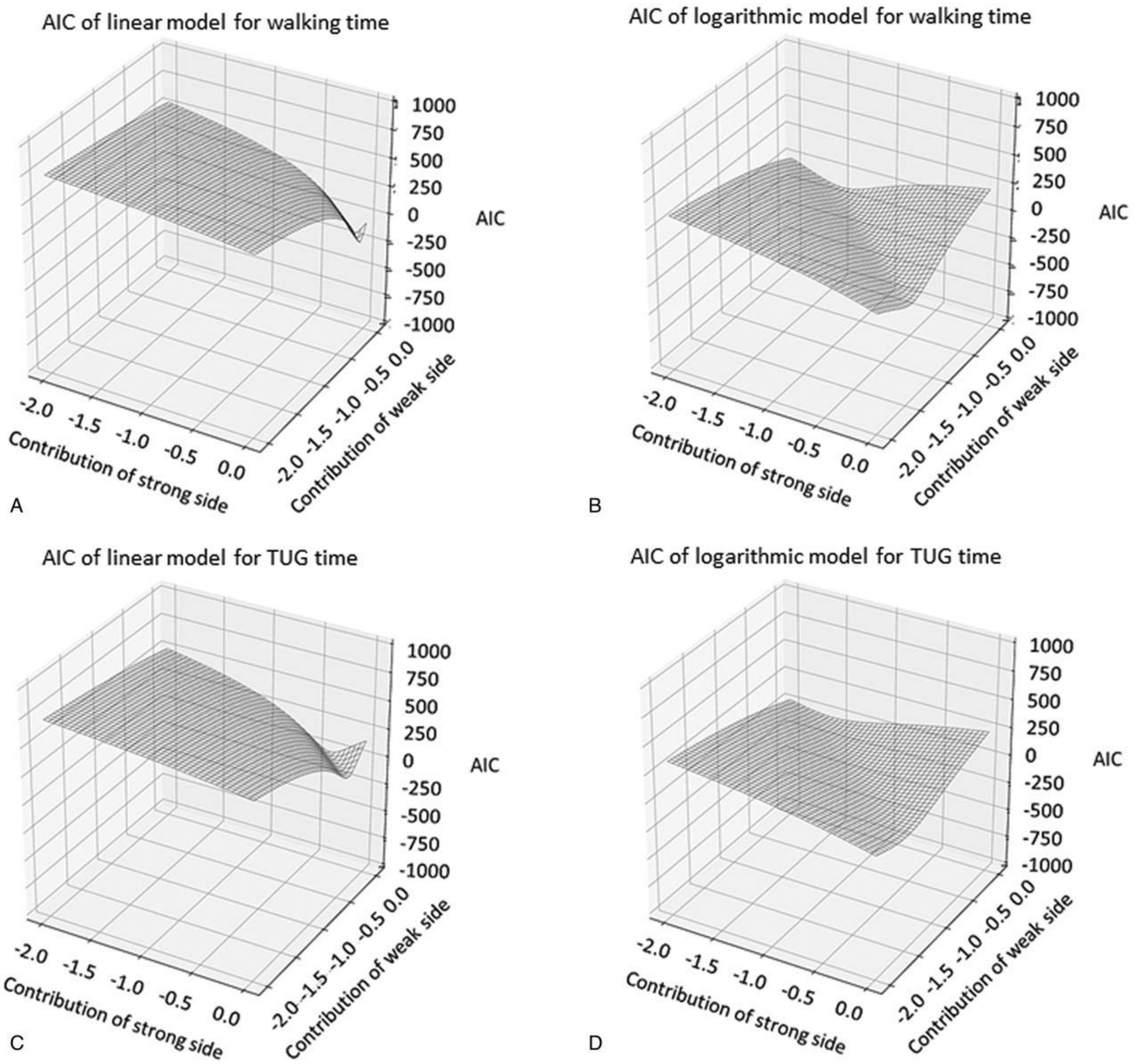

Figure 1. The AIC matrices for walking (A and B) and TUG performance (C and D) times were determined to ascertain the optimal α-, β_s-, and β_w-values for the linear and logarithmic models. AIC = Akaike information criterion, TUG = Timed Up & Go.

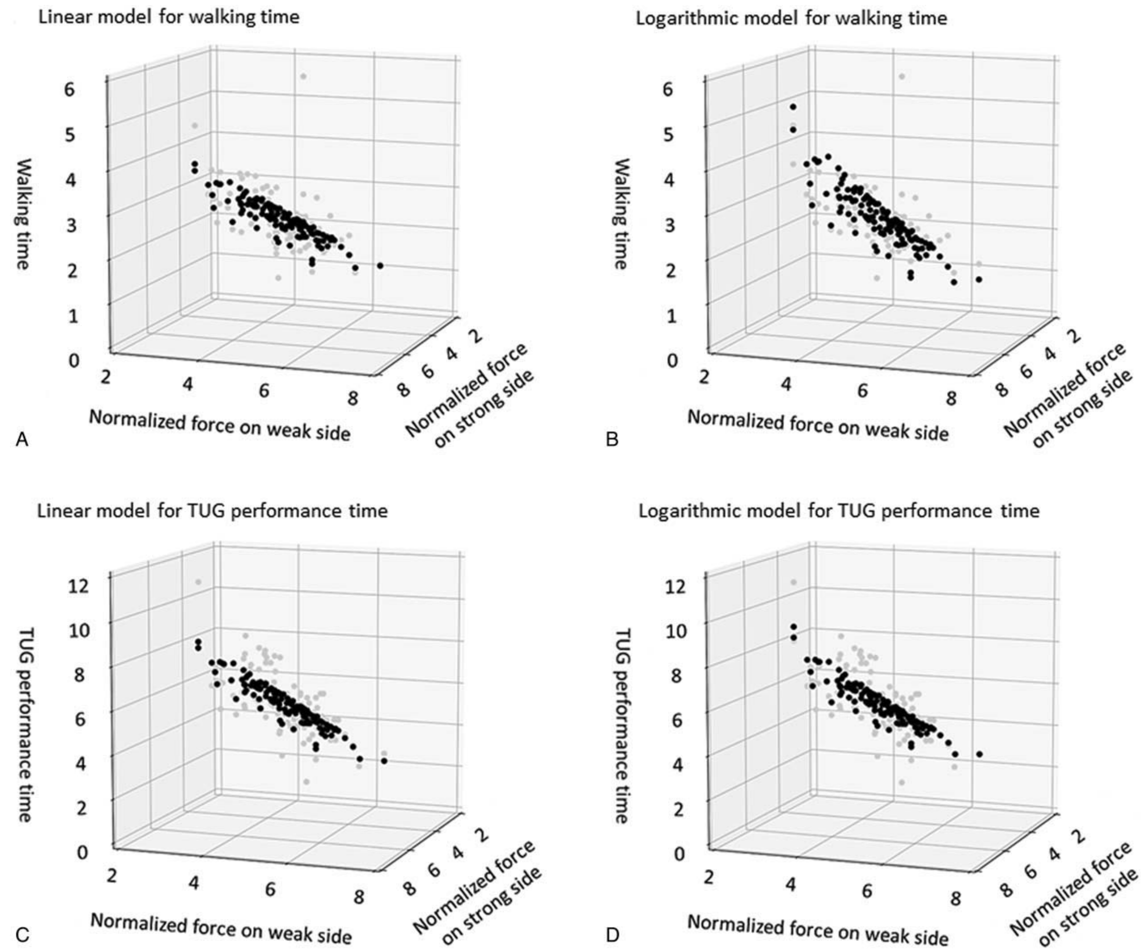

Figure 2. Scatter plot showing the relationship between the measured and predicted walking times (A and B) and the TUG performance time (C and D). The predicted values were derived from linear and logarithmic model equations using optimal α-, β_S-, and β_W-values. Gray and black circles represent actual and predictive data, derived from the linear and logarithmic models, respectively. TUG = Timed Up & Go.

time; however, the smallest AIC value was lower for the logarithmic (–19.0.6) than for the linear model (–16.49) regarding the Timed Up & Go (TUG) performance time. Figure 2 shows the scatterplots for the relationship between the actual and predicted walking times, and the TUG performance time. The predicted values for the walking and TUG performance times were derived from the linear and logarithmic model formulae using optimal α-, β_s-, and β_w-values; the linear and logarithmic models were similar to both the actual walking and TUG performance times obtained. The Ljung–Box test showed that the series of ε-values for the model with the lowest AIC was independent in the linear and logarithmic models, indicating that both models were efficient ([walking time] linear model: $P = .329$, logarithmic model: $P = .220$; [TUG performance time] linear model: $P = .165$, logarithmic model: $P = .104$).

In the linear model for walking time estimation, the $|\beta_s|$-value (0.11) was larger than the $|\beta_w|$-value (0.00). This finding indicated that the muscle force on the strong side of the leg contributed more to the walking time compared to the weak side of the leg. In the logarithmic model's TUG performance time estimation, $|\beta_w|$-value (1.00) was also larger than $|\beta_s|$-value (0.52), indicating that muscle force on the weak side of the leg contributed more to the TUG performance time compared to that on the strong side of the leg.

4. Discussion

In this study, a correlation between both legs' muscle strengths and lower extremity motor performance—including walking and TUG performance times—was discovered by applying linear and logarithmic regression modeling. The results indicated that the correlation between the knee extension strength and the walking time was linear on the strong side, whereas that between the TUG performance time and the knee extension strength was logarithmic on the weak side.

The slowing of lower extremity motor functions, such as walking and sit-to-stand transfer, is likely to cause a decline in activities of daily living performance capacity,[34] and may increase fall risk[35] and mortality.[24] Previous studies have noted that the knee extension strength was associated with better lower extremity motor performance.[28,29,36] Cross-sectional studies on strength and function have focused on correlational analysis using linear regression modeling[28,29,36,37]; however, some reports have demonstrated that lower extremity muscle strength was linearly related to the walking speed[37] and the TUG performance time,[38] whereas others have reported that no correlation was found.[37] The lack of a linear relationship between lower extremity motor performance and strength likely contributes to the discrepancies regarding the correlation between lower limb muscle strength and lower extremity motor performance in the literature.[37]

A previous study regarding the relationship between function and strength noted that the knee extension strength was correlated to non-linear function with a threshold for lower extremity functions[29]; the threshold level was 0.6 Nm/kg for walking and 0.8 to 1.2 Nm/kg for transferring to the bed/toilet/shower.[39,40] In our study, the correlation between the walking time and strength resembled linear modeling, whereas the relationship between the TUG performance time and strength resembled logarithmic modeling. Different models for walking and TUG may have been caused by the lower threshold level for walking than for sit-to-stand transfer. In our work, the participants' knee extension strengths were slightly high, as they were community-dwelling people without palsy or injury; therefore, many participants' knee extension strengths may be above the threshold level for walking. While this leads to the linear relationship between walking and strength, the threshold level for sit-to-stand transfer may be higher than many participants' knee extension strengths; therefore, the relationship between the TUG and knee extension strength resembled the logarithmic model. Correspondingly, our results showed that knee extension strength on the strong side predicted walking time more accurately than the weak side; conversely, that on the weak side predicted TUG performance time more accurately than the strong side because of the lower threshold level for walking than for sit-to-stand transfer.

Interestingly, a previous study reported that 88% of the variability in walking speed was not explained by isometric strength; therefore, strength is an important—but not comprehensive—determinant of walking.[41] In fact, the mode of isometric evaluation was not the same as for lower extremity performance; thus, the use of isometric measurements using a handheld dynamometer seems to be limited by the lack of specific rhythmic (walking) and isotonic (sit-to-stand transfer) performance. Future studies are needed to evaluate whether changes in isometric and isotonic muscle strength values are reflected in the ability of the participants to walk and transfer from a sitting to standing position. Additionally, a previous study noted that hip extensor strength predicted walking performance, whereas ankle plantar flexion strength predicted older adults' maximal walking speed and stride length[7]; further research is needed to investigate the relationship between strengths of multiple muscle groups and lower extremity performance, which may yield a more comprehensive assessment of total body strength than a single joint assessment.

In conclusion, this study presented a different model that reflects the relationship between muscle strength of both legs and lower limb performance times, such as gait and TUG performance. Resistance training based on normalized knee extensor strength is necessary to improve muscle strength and prevent functional decline. The findings of this study may contribute to an evidence-based approach to resistance training for lower extremity motor performance.

Author contributions

Study concept and design: Kilchoon Cho, Makoto Suzuki. Acquisition of participants and data: Kilchoon Cho, Naoki Iso, Takuhiro Okabe, Hiroshi Goto, Keisuke Hirata, Junichi Shimizu. Analysis and interpretation of data: Makoto Suzuki, Kilchoon Cho. Preparation of manuscript: Makoto Suzuki, Kilchoon Cho.

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Formal analysis: Kilchoon Cho, Makoto Suzuki.
Visualization: Kilchoon Cho, Makoto Suzuki.
Writing – original draft: Kilchoon Cho, Makoto Suzuki.
Writing – review & editing: Kilchoon Cho, Makoto Suzuki, Naoki Iso, Takuhiro Okabe, Hiroshi Goto, Keisuke Hirata, Junichi Shimizu.

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③　Sex Differences in Age-Related Physical Changes among Community-Dwelling Adults
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地域在住中高年者における身体機能変化様式の性差

【背景と目的】
加齢により筋力（Rothman et al, 2008）、柔軟性（Wilk et al, 2019）、歩行能力（Guralnik et al, 2000）、バランス機能（Shinkai et al, 2000）、呼吸機能（Sharma et al, 2006）、骨代謝（Russo et al, 2003）などの身体機能が低下することが知られているが、性別による低下様式の相違は明らかではない。そのため、中高年者に対する予防的介入において、性別によって、どの時期にどのような介入をすべきかいまだ明確な答えが得られていない。加齢に伴う身体機能低下の性差を特定することができれば、性別に配慮した効果的な介入に寄与できるものと思われる。本研究の目的は中高年における身体機能の変化様式の性差を明らかにすることである。

【対象・方法】
本研究の主旨を説明し、書面にて参加の同意が得られた 30 歳以上の健常中高齢者 124 名（男性 46 名、女性 78 名、平均年齢 66.0 ± 12.0 歳）を対象とし、9 項目の身体機能（骨格筋量、1 秒率、骨梁面積率、5 m 最大歩行速度、Timed and Up Go Test [TUG]、長坐体前屈、握力、膝伸展筋力、閉眼片脚立位時間）を測定した。加齢に伴う身体機能の男女における変化様式を検証するため、男女それぞれの 30 歳代の平均スコア（Masaki et al, 2015、他）を用いて各身体機能のスコアを正規化した上で、一般化最小二乗法を用いて式 1 の線形モデルを近似させ、β の絶対値を比較した。

$$f(t)=\alpha+\beta t \qquad \text{式 1}$$

$t=$ 年齢、 $\alpha=$ 30 歳代の身体機能水準、 $\beta=$ 変化率

【倫理的配慮】
東京家政大学の研究倫理委員会の承認（狭 2019-1）を得て実施した。

【結果】
9 項目中 6 項目の身体機能において、男女ともに線形モデルが近似した（$p < 0.01$）。長坐体前屈は男性のみ、1 秒率と骨梁面積率は女性のみにおいて線形モデルが近似した（$p < 0.001$）。β の絶対値（男性 vs 女性）は、閉眼片脚立位時間（0.017 vs 0.018）、長坐体前屈（男性のみ 0.0089）、膝伸展筋力（0.0071 vs 0.0069）、骨格筋量（0.0072 vs 0.0066）、1 秒率（女性のみ 0.0043）、5 m 最大歩行速度（0.0043 vs 0.0035）、TUG（0.0054 vs 0.0037）、握力（0.0064 vs 0.0037）、骨梁面積率（女性のみ 0.0039）であった。

【考察】
本研究の結果、男女に共通して中年以降は、バランス、筋機能、歩行能力のモニタリングとトレーニングを開始することが望ましいことが示唆された。また、男性では柔軟性に対する早期介入、女性では呼吸機能に対する早期介入と骨密度のための継続的な介入が必要であると考えられた。

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Sex Differences in Age-Related Physical Changes among Community-Dwelling Adults

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Abstract: The prevalence of physical functioning limitations is positively correlated with age in both men and women. However, whether the appearance of deterioration differs depending on physical function and sex remains unclear. This study aimed to clarify the modes of age-related changes in physical function and sex differences in middle-aged and older adults. This study comprised 124 (46 men and 78 women) healthy adults aged 30 years or older and examined gender differences in physical function. The results of this study showed that one-leg standing time had the highest rate of age-related decline in both men and women, followed by knee extension strength, skeletal muscle mass, the 5 m walking test, and the timed up and go test. The sex-specific points showed a high rate of decline in trunk forward bending in men and a high rate of decline in forced expiratory volume (1 s) and gradual rate of decline in the bone area ratio in women. After middle age, it is desirable to start monitoring and training balance, muscle function, and walking. Men require early intervention for flexibility, and women require early intervention for respiratory function and continued intervention for bone mineral density.

Keywords: aging; physical function; sex; middle-aged and older adults; rehabilitation

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1. Introduction

Age-related decline in physical functioning is a major factor in life disorders common in men and women. Physical functioning is an important marker of healthy aging and is a dynamic aspect of health. In Japan, the baby boomer population will reach its peak in 2025, and Japan will become a super-aging society in which one in four people is 75 years old or older. From the viewpoint of preventive medicine, under such circumstances, various fields, such as medical care, long-term care, and welfare aim to prevent age-related deterioration of physical functions, such as muscular strength, balance ability, and walking ability and extend healthy life expectancy.

Physical functions, such as muscle function [1,2], walking ability [2,3], flexibility [3], balance ability [4], respiratory function [5], and bone density [6], have been reported to decline with age.

Skeletal muscle mass begins to decrease from approximately 50 years of age and has been reported to decrease markedly more in the lower limbs than in the upper limbs [1,7]. Muscle strength peaks in middle age and by 90 years of age, declines by up to 50% [8]. Rapid walking speed decreases with advancing age, especially after 70 years [9], while balance ability is reported to decrease after the age of 40 [10]. The lung matures by 20–25 years of age (maximum lung function is reached at approximately 25 years in men and 20 years in women), after which aging is associated with a progressive decline in respiratory function [5]. In addition, peak bone mass is reached in early adulthood and decreases with age from approximately 50 years [11]. These age-related functional declines are factors in sarcopenia, frailty, and locomotive syndrome and cause inhibition of social participation, due to falls, fractures, and inactivity. However, the order in which each physical function declines is unclear.

Skeletal muscle decline due to aging has been reported as a sex difference in physical functioning, with age-related skeletal muscle mass loss in men twice as fast as in women [12]. In contrast, previous studies have reported that women have a longer life expectancy than men but often live longer with disabilities [13]. Compared to men, women have poorer levels of physical functioning [14,15] and experience a more rapid decline in functioning [16,17]. The prevalence of physical functioning limitations is positively correlated with age in both men and women. However, whether the appearance of deterioration differs depending on physical functioning and sex remains unclear. Therefore, it is not clear what preventive interventions should be administered to middle-aged and older adults. If we can identify the mode of change in physical functioning decline with age and sex, we may be able to contribute to effective interventions to prevent physical function decline. Therefore, regarding muscle strength, lower limb muscle strength may show a sharper decrease than upper limb muscle strength, and walking ability affected by these factors may show a gradual decrease. In addition, regarding sex differences, we hypothesized that men with more basic physical strength, but a shorter lifespan, might exhibit a more rapid decline. This study aimed to clarify the modes of changes in physical functioning and sex differences in middle-aged and older adults.

2. Materials and Methods

2.1. Research Design and Subjects

A cross-sectional study design was utilized in which samples were retrospectively extracted from the survey database for the Tokyo and Saitama regional areas from 2018 to 2020. This study comprised 124 healthy middle-aged and older adults aged 30 years or older (46 men, 78 women; mean age, 66.0 $\pm$ 12.0 years), who received an explanation of the purpose of this study and provided written consent to participate. The eligibility criteria were as follows: community-dwelling individuals; absence of palsy, knee pain, and injury; and no use of assistive devices for walking and sit-to-stand. The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the Research Ethics Committee of Tokyo Kasei University (SA2019-1, date of approval: 24 April 2019).

2.2. Physical Functioning Measurement

Height and weight were measured with the subjects wearing light clothing and no shoes. Body mass index (BMI) was calculated from height and weight as follows: weight/height squared (kg/m^2). Physical functions, including skeletal muscle mass, vital capacity, bone area ratio, the 5 m walking test, timed up and go (TUG) test, trunk forward bending, grip strength, knee extension strength, one-leg standing time with eyes closed, and visual reaction time, were measured.

2.2.1. Skeletal Muscle Mass

Skeletal muscle mass was measured using a bioelectrical impedance analyzer. Height was measured using a stadiometer (PA-200, UCHIDA YOKO Co., Ltd., Tokyo, Japan), and body weight and skeletal muscle mass were measured, using a body composition analyzer (InBody470; InBody Japan Inc., Tokyo, Japan). The bioelectrical impedance analysis (BIA) method is suitable for screening body composition, including muscle mass, because it is safe, simple, reliable, valid, and transportable, compared to computed tomography, magnetic resonance imaging, and dual-energy X-ray absorptiometry methods [18]. Each subject was barefooted, stood on the left and right metal plates, and grasped the metal conductor with both upper limbs for measurement. Quantitative evaluation of the skeletal muscle mass by the BIA method using Inbody is reliable and valid [19,20].

2.2.2. Forced Expiratory Volume (1 Second)

Forced expiratory volume (1 s [FEV_1]) was measured using a digital spirometer (AS-407, MINATO Medical Science Co., Ltd., Osaka, Japan). The subject held their nose and tried to exhale as forcefully and quickly as possible until all the air had been expelled. Subjects were instructed to continue exhaling during this stage. FEV_1 is associated with physical activity [2,21,22], is a predictor of the risk of cardiovascular disorders and mortality [23], and is used to evaluate respiratory and circulatory functions.

2.2.3. Bone Area Ratio

Bone density was examined along the heel bone, using quantitative ultrasound to measure the bone area ratio (Benus evo; Nihon Kohden, Tokyo, Japan). The ultrasound pulse reflection and transmission methods were used together. This method does not use X-rays, making it ideal for examining pregnant women and young people. Each subject sat in a chair, and measurements were taken on the right heel. Quantitative measurement of bone density using ultrasound is used as a valuable tool for osteoporosis screening [24,25].

2.2.4. 5 m Walking Test

For the 5 m (meter) walking test, a distance of 3 m was set for the run-up, and the measurement started 3 m before the 5 m test distance. The measurement started when a part of the body crossed the 5 m start line and ended when the body crossed the 5 m goal line. The 5 m walking test was performed once at maximum walking speed and recorded in seconds. The 5 m walking test is a reliable evaluation tool used in large-scale surveys to evaluate walking ability [26].

2.2.5. Timed Up and Go Test

For the TUG test, the subject stood up from an armless chair, walked 3 m, made a turn around a placed cone, walked back, and sat down again. The time from getting up from the chair to sitting down was measured. Subjects tried to walk as quickly as possible without shoes. The test was performed once and recorded in seconds. TUG is recommended as a regular screening test for falls in the American Geriatrics Society and the British Geriatrics Society guidelines [27], and is a reliable and valid assessment tool [28].

2.2.6. Trunk Forward Bending

The purpose of the trunk forward bending measurement is to determine the degree of flexibility. The subject was placed in a long-sitting posture with the hips, back, and head close to a wall and arms outstretched front horizontally with the floor; the lumbar joint was bent forward, and measurement was recorded at the point reached by the fingertips. Measurements were taken once, without bending or recoiling the knees or extending one hand more than the other. The recorded unit was centimeters. Trunk forward bending is an index of flexibility and is a highly valid evaluation tool applied in physical fitness tests by the Ministry of Education, Culture, Sports, Science and Technology of Japan [29].

2.2.7. Grip Strength

Grip strength of the dominant hand was measured, using a Smedley-type (mechanical) handgrip dynamometer (Smedley; Matsumiya Ika Seiki Seisakujo, Tokyo, Japan). To measure the grip strength, the dynamometer was held in a standing position with the pointer facing outward, and the width of the grip was adjusted so that the interphalangeal joint of the index finger was bent 90°. In an upright position with the feet hip-width apart, the arms were lowered naturally, and the dynamometer was grasped with maximum force without touching the body or clothing. Measurements were taken twice on the dominant side, and the average value was used for the analysis. The measurements were recorded in kilograms. Grip strength is a highly reliable and valid evaluation tool used in national surveys as a representative value of individual muscle strength [29–31].

2.2.8. Knee Extension Strength

Knee extension strength was measured using a dynamometer (μTas-01, Anima Co., Ltd., Tokyo, Japan) for isometric maximal voluntary contraction of the predominant lower limb knee extensor. Subjects comfortably sat in a chair with their torso upright, maintaining a knee-to-hip angle of 90°. The task involved maximum knee extension while maintaining posture. Measurements were taken twice on the dominant side, and the average value was used for the analysis. The measurements were recorded in kilograms.

2.2.9. One-Leg Standing

One-leg standing time was measured as an evaluation of balance. The time from the signal of "Please raise your foot" to one of the following conditions was measured: the position of the standing foot shifted, the raised foot touched the floor, or the raised foot touched the supporting leg. The upper threshold was set at 30 s. The measurement was performed once on each side with the eyes closed, and the average value was used for the analysis.

All tests were performed by an occupational or physical therapist and a trained research assistant.

2.3. Statistical Analyses

The *t* test was performed to compare each physical function between men and women. To verify the mode of change in physical function with aging, the score of each physical function was normalized, using the average score in the 30 s [29,32–38], and the linear model of Equation (1) used the generalized least squares method, where "t" denotes each person's age, "α" denotes the physical function level of 30 s, and "β" denotes the rate of decline for each physical function:

$$f(t) = \alpha + \beta t \quad (1)$$

We approximated the measured normalized data, and the absolute values of β were compared. Statistical analyses were performed using the Statistical Package for the Social Sciences (S IBM SPSS Statistics for Windows, Version 26.0, Armonk, NY, U.S.A.) and R 3.5.2 software (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Table 1 shows the characteristics of the study subjects. Men had significantly higher skeletal muscle mass and stronger grip and knee extension strength than women. Women had significantly higher forward trunk bending measurements than men. There were no significant differences in age, BMI, FEV_1, bone area ratio, the 5 m walking test, TUG test, or one-leg standing time between men and women.

Tables 2 and 3 show the rate of decline in each physical function. In all subjects, the normalized data for each physical function approximated a linear model, except for trunk forward bending ($p < 0.0001$, Durbin–Watson ratio = 1.579–2.288). The absolute values of β were, in descending order, −0.0174, −0.0076, −0.0076, −0.0053, −0.0044, −0.0041, −0.0030, and −0.0026 for the one-leg standing time, knee extension strength, skeletal muscle mass, grip strength, TUG test, 5 m walking test, FEV_1, and bone area ratio, respectively. In contrast, in men, the absolute values of β were, in descending order, −0.0170, −0.0089, −0.0072, −0.0071, −0.0064, −0.0054, and −0.0043 for the one-leg standing time, trunk forward bending, skeletal muscle mass, knee extension strength, grip strength, TUG test, and 5 m walking test, respectively. In women, the absolute values of *β* were −0.0180, −0.0069, −0.0066, −0.0043, −0.0039, −0.0037, −0.0037 and −0.0035 for the one-leg standing time, knee extension strength, skeletal muscle mass, FEV_1, bone area ratio, TUG test, grip strength, and 5 m walking test, respectively. The normalized data did not approximate the linear model in FEV_1 and bone area ratio for men or trunk forward bending for women. Figures 1–3 show the standardized distribution of each physical function and its linear model for all subjects, men, and women. Figure 4 shows a comparison of the rate of decline in each physical function.

Table 1. Characteristics of the study subjects.

	All n = 124	Men n = 46 (37.1%) Mean ± SD	Women n = 78 (62.9%)	p †
Age (years)	66.0 ± 12.0	68.0 ± 13.7	64.9 ±10.7	0.159
Body mass index (kg/m^2)	22.8 ± 2.8	23.1 ± 2.1	22.6 ± 3.1	0.284
Skeletal muscle mass (kg)	22.1 ± 4.6	26.5 ± 4.3	19.6 ± 2.4	*
FEV_1 (%)	74.4 ± 10.0	74.3 ± 10.5	74.4 ± 9.9	0.993
Bone area ratio (%)	27.0 ± 3.1	27.6 ± 3.5	26.7 ± 2.8	0.117
5 m walking test (m/sec)	1.93 ± 0.27	1.97 ± 0.30	1.91 ± 0.25	0.188
Timed up and go test (sec)	5.9 ± 0.9	5.9 ± 1.0	5.9 ± 0.9	0.976
Trunk forward bending (cm)	28.2 ± 10.7	25.0 ± 10.5	30.0 ± 10.5	0.012
Grip strength (kg)	28.1 ± 8.0	35.1 ± 8.0	26.4 ± 7.3	*
Knee extension strength (kg)	29.7 ± 8.8	34.7 ± 8.7	26.7 ± 7.3	*
One-leg standing time (sec)	10.1 ± 8.9	9.5 ± 9.4	10.4 ± 8.6	0.558
				t-test

SD: standard deviation, ns: not significant. † Significant difference between men and women in each physical function, * $p < 0.001$.

Table 2. Comparison of the rate of decline in each physical function in all subjects.

	All						
	β	α	DW	p	R^2	p	R
One-leg standing time	−0.0174	1.51	2.031	*	0.427	*	1
Knee extension strength	−0.0076	1.24	1.769	*	0.149	*	2
Skeletal muscle mass	−0.0076	1.65	1.579	*	0.208	*	3
Grip strength	−0.0053	1.16	2.119	*	0.171	*	4
Timed up and go test	−0.0044	1.25	2.288	*	0.201	*	5
5 m walking test	−0.0041	1.28	1.97	*	0.114	*	6
FEV_1	−0.0030	1.07	1.93	*	0.085	*	7
Bone area ratio	−0.0026	0.98	1.877	*	0.096	*	8
Trunk forward bending	−0.0038	0.91	1.792	0.060	0.025	0.043	

β: rate of decline, α: physical function level of the 30 s, DW: Durbin–Watson ratio, R: rank based on β, * $p < 0.001$.

Table 3. Comparison of the rate of decline in each physical function between men and women.

	Men							Women						
	β	α	DW	p	R^2	p	R	β	α	DW	p	R^2	p	R
One-leg standing time	−0.0170	1.49	2.141	*	0.493	*	1	−0.0180	1.54	1.971	*	0.375	*	1
Knee extension strength	−0.0071	1.10	2.303	*	0.466	*	4	−0.0069	1.25	2.046	0.002	0.105	0.002	2
Skeletal muscle mass	−0.0072	1.52	2.17	*	0.381	*	3	−0.0066	1.64	2.111	*	0.227	*	3
Grip strength	−0.0064	1.19	2.502	*	0.382	*	5	−0.0037	1.08	2.143	0.011	0.071	0.010	7
Timed up and go test	−0.0054	1.34	2.033	*	0.249	*	6	−0.0037	1.20	2.545	*	0.165	*	6
5 m walking test	−0.0043	1.26	1.814	0.010	0.120	0.011	7	−0.0035	1.25	2.135	0.008	0.072	0.010	8
FEV_1	−0.0021	1.03	2.079	0.105	0.019	0.179		−0.0043	1.13	1.952	*	0.152	*	4
Trunk forward bending	−0.0089	1.20	2.419	*	0.288	*	2	0.0020	0.57	1.821	0.484	0.001	0.613	
Bone area ratio	−0.0016	0.94	1.907	0.192	0.021	0.168		−0.0039	1.06	2.214	*	0.253	*	5

β: rate of decline, α: physical function level of the 30 s, DW: Durbin–Watson ratio, R: rank based on β, * $p < 0.001$.

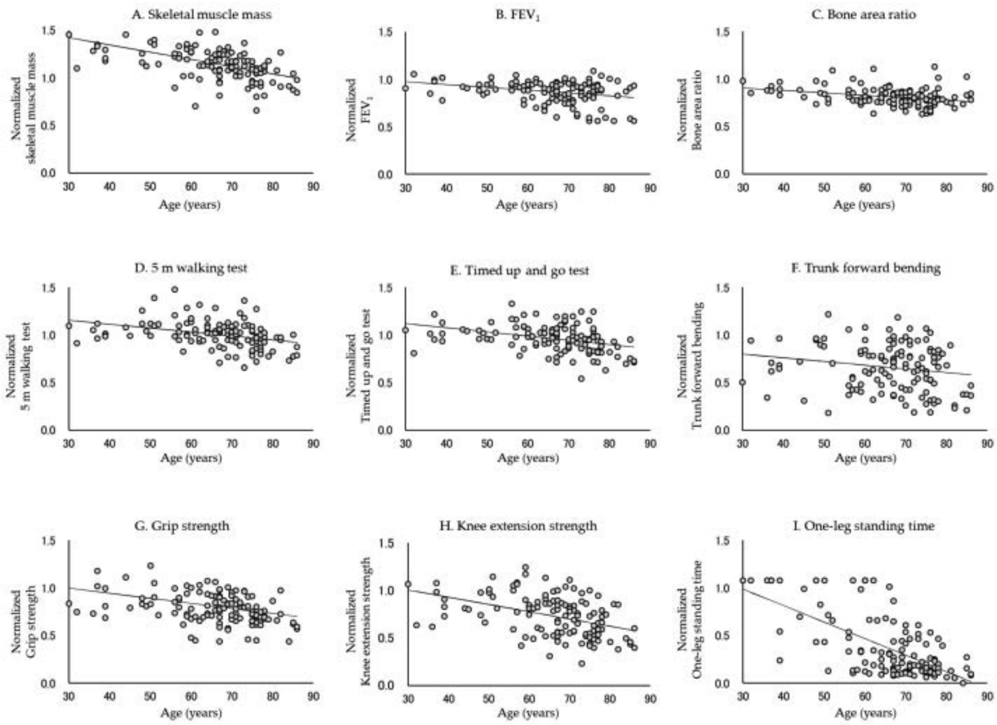

Figure 1. Normalized distribution and linear model of each physical function in all subjects. Each physical function declines with age. In particular, the rate of decrease in one-leg standing time, knee extension strength, and skeletal muscle mass was high.

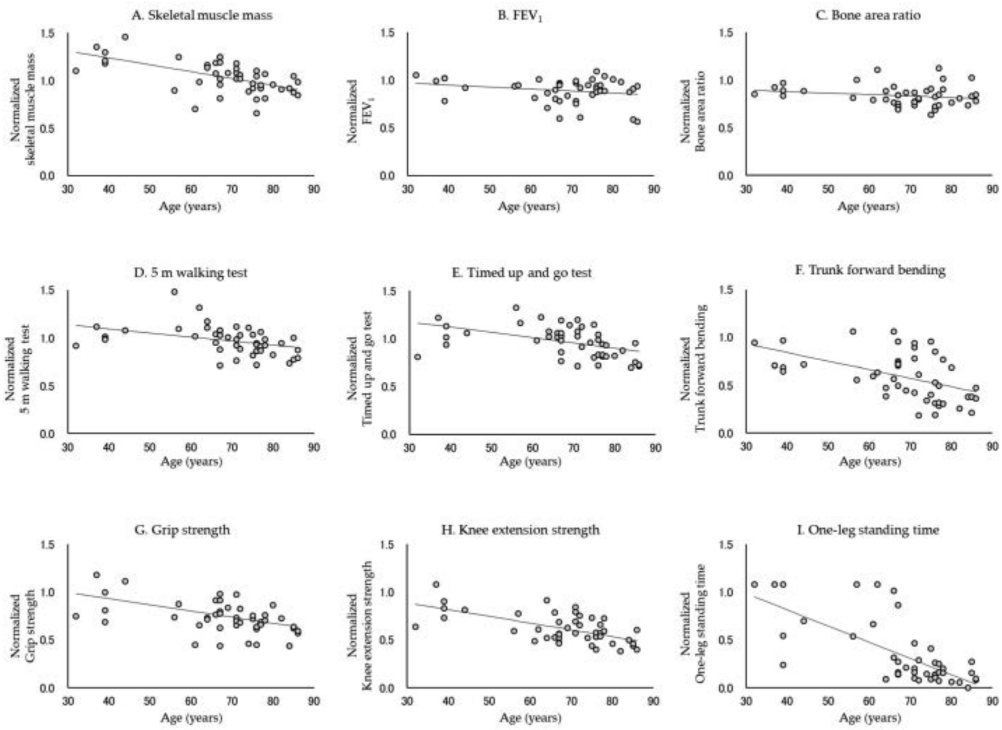

Figure 2. Normalized distribution and linear model of each physical function in men. Each physical function declines with age, except for FEV_1 and bone area ratio. In particular, the rate of decrease in one-leg standing time, trunk forward bending, skeletal muscle mass, and knee extension strength was high.

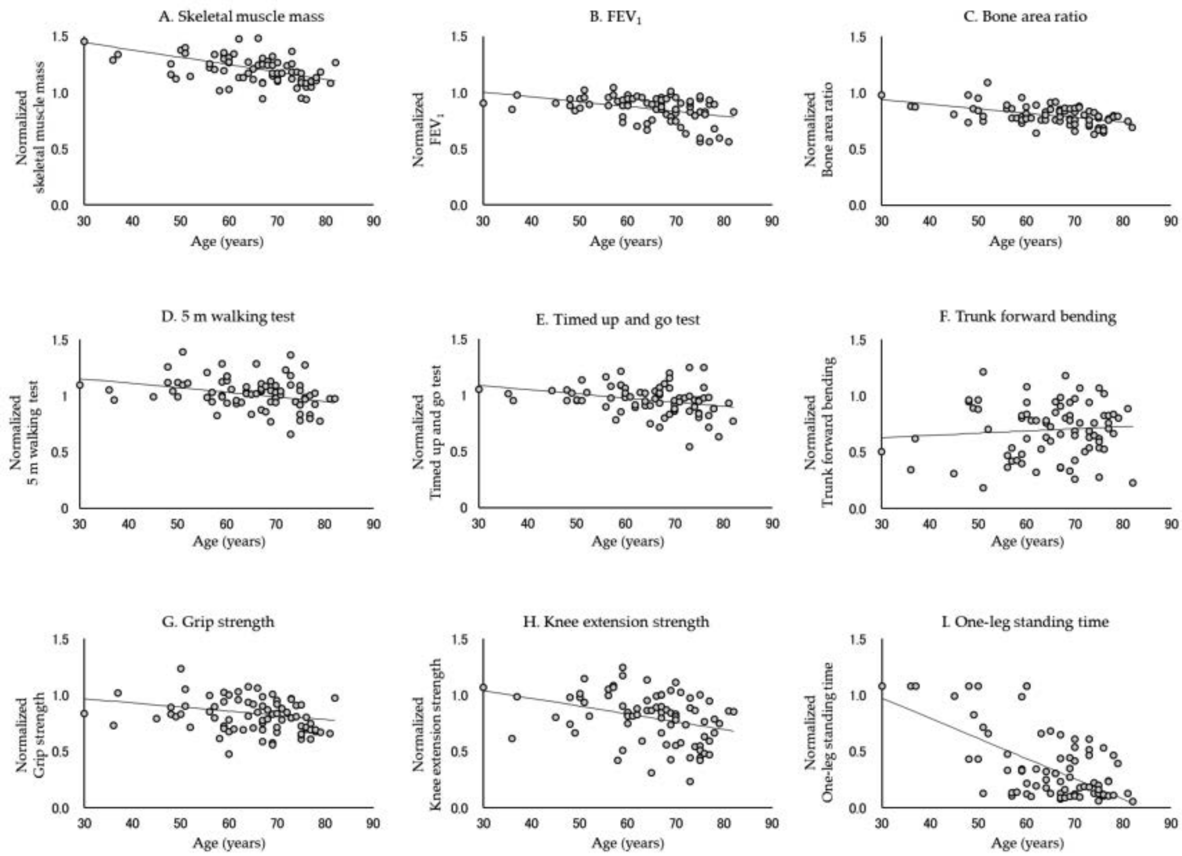

Figure 3. Normalized distribution and linear model of each physical function in women. Each physical function declines with age, except for trunk forward bending. In particular, the rate of decrease in one-leg standing time, knee extension strength, and skeletal muscle mass was high.

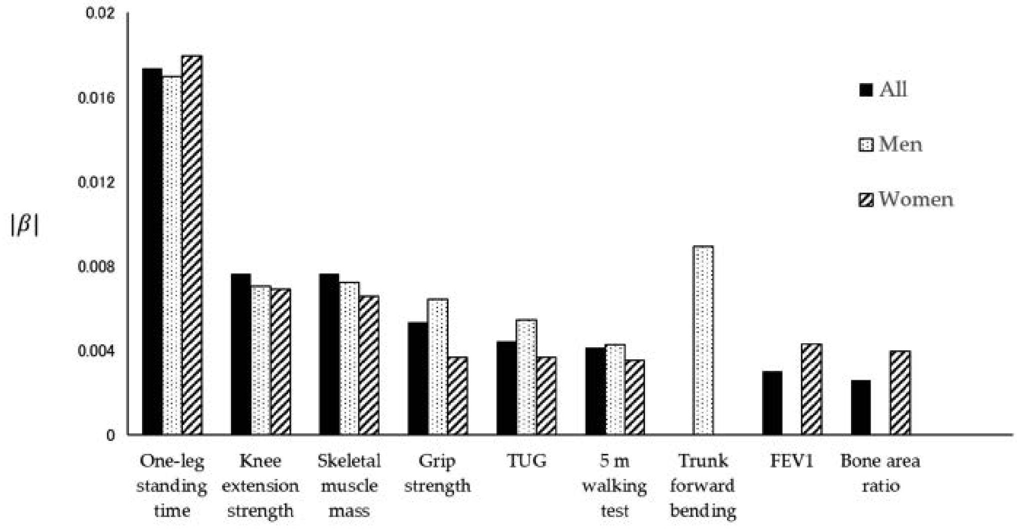

Figure 4. Comparison of the rate of decline in each physical function between all subjects, men, and women. Each bar shows the rate of decline in each physical function. The black bars represent all subjects, the dotted bars represent men, and the diagonally striped bars represent women.

4. Discussion

This study showed that an age-related decrease in some physical functions was similar between men and women. In both men and women, the balance ability (one-leg standing time) had the highest rate of decline, followed by muscle function (knee extension strength, skeletal muscle mass) and walking ability (5 m walking test and TUG test). The sex-specific points were a high rate of decline in flexibility (trunk forward bending) in men and a high rate of decline in respiratory function (FEV_1) and gradual rate of decline in bone mineral density (bone area ratio) in women.

The physiological and functional problems of muscles and the decrease in walking ability are related in a complex manner, and it seems that they have a significant effect on the decrease in balance ability. Muscle strength peaks in middle age and declines by up to 50% by 90 years [8]. The level of change with age may vary, due to several factors. For example, grip strength decline begins at age 40 [29], whereas rapid walking speed decreases significantly after 70 years [9]. These declines in physical function are expected to affect activities and participation levels, such as mobility, falls, and going out. The rate of decrease in one-leg standing time with eyes closed was the highest in both men and women. Balance ability is associated with muscle weakness [39] and flexibility [40] and is considered a comprehensive index of physical function. Age-related declines in physical function occur with diminished neuromuscular and musculoskeletal function, diminished muscle strength, and diminished coordination and motor control. Changes in sensory receptors and peripheral nerves associated with decreased visual acuity and vestibular function affect the lower extremities' postural control and muscle output, resulting in decreased postural balance [39,41]. It has been reported that the one-leg standing test is useful for screening the risk of falls [42] and is an important evaluation for both young [43,44] and older adults [45]. It was suggested that one-leg standing time with eyes closed is useful as a factor that can detect early deterioration of physical function, even in middle-aged or healthy older adults.

Furthermore, both muscle strength and balance ability were reported to be significant predictors of walking disability [46], and balance ability, lower limb muscle strength, and walking ability were reported to be associated with fall risk and activities of daily living disorders [47,48]. Multimodal exercise, a complex program, has been reported to be more effective with multiple outcomes, including strength, balance, walking speed, and falls, compared to a single exercise. [49]. It is desirable to start training muscle strength and walking centering as balance training from middle age onward.

A comparison between men and women showed that trunk forward bending decreased in men, and FEV_1 and bone area ratio decreased in women, which was sex specific. The flexibility of the trunk is lower in men than in women, and the decrease in flexibility seems to be faster in men than in women. It was reported that women are more flexible than men in both young and old age [50,51], and this study showed similar results. In addition, the fact that the decrease in bone mineral density was more pronounced in women than in men was consistent with the results of previous studies [6]. Previous studies have reported age-related declines in respiratory function in both men and women [52], and lung capacity values of women were significantly lower than those of men [53]. The lungs reach maturity by the age of 20 and achieve maximum function at about 25 years in men and 20 years in women. Lung function changes minimally and stabilizes between the ages of 20 and 35, after which it begins to decline [5]. However, Sharma et al. reported that the effects of aging on lung function vary significantly. In addition, age-related decline in FEV_1 may have a non-linear phase with an accelerated rate of decline after the age of 70 [5]. In the future, we would like to examine the appropriate intervention timing and method to prevent these declines in physical function.

Notably, although there was no difference between men and women in the univariate analysis (FEV_1, bone area ratio), there was a difference in the rate of decrease (β). Therefore, when comparing sex differences, it was suggested that not only cross-sectional numerical comparisons, but also changes due to aging should be investigated. Based on our results, balance ability and muscle function in both men and women, flexibility in men, and respiratory function in women should be evaluated and addressed from an early stage.

This study has several limitations. First, the individual physical functions were measured cross-sectionally. Therefore, changes in these individual parameters over time could not be considered. In addition, the subjects of this study were healthy, middle-aged, older adults. Therefore, the results of this study cannot be generalized to frail, older adults.

The result of this study clarified that physical function showed a sex-specific decrease. This result contributes to appropriate timing and sex-based interventions for middle-aged and older people.

5. Conclusions

Balance ability had the highest rate of age-related decline followed by muscle function and walking ability in both men and women. The sex-specific points showed a high rate of decline in flexibility in men and a high rate of decline in respiratory function and gradual rate of decline in bone mineral density in women. After middle age, it is desirable to start monitoring and training balance, muscle function, and walking. In addition, men require early intervention for flexibility, and women require early intervention for respiratory function and continued intervention for bone mineral density. The findings from this study provide useful information for the development of effective early interventions that aim to extend the healthy life expectancy of men and women in an aging society.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Research Ethics Committee of Tokyo Kasei University (SA2019-1, date of approval: 24 April 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. All subjects provided written informed consent prior to participation.

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