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Age-related differences in rate of power development exceed differences in peak power

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Age-related differences in rate of power development exceed differences in peak power

Abbreviations

Peak torque (pT); peak velocity (pV); peak power (pP); time to peak velocity (ttpV); time to peak power (tttP); rate of velocity development (RVD); rate of power development (RPD)
ABSTRACT

Peak power (pP) declines during aging, resulting in reduced functional performance. However, the rate of power development (RPD) takes into account the short response times available during many functional tasks and may therefore add valuable information to functional declines. This study examined the age-related effects on pP and RPD of the knee-extensors across different loads and how these are related to functional performance.

36 young (♂21, ♀15, age = 22 ± 2 years) and 56 older adults (♂26, ♀30, age = 68 ± 5 years) performed four maximal isotonic contractions against three loads (40, 20 and 60% of maximal isometric strength) on a Biodex System 3 dynamometer. pP was calculated as the highest value and RPD as the linear slope of the power-time curve. Functional performance in the older group was tested by 7.5-meter walk test, timed up-and-go and stair climbing.

pP and RPD were higher in young compared to old and this was more pronounced with lower loads. Age-related differences in RPD (range from 37-44% across loads) were higher than in pP (24-37%). Both pP and RPD showed a positive correlation with functional performance (r: .59-.64).

To conclude, percent differences in RPD exceed differences in pP between young and old. This emphasizes the inability to generate power rapidly at older age and underlines the importance of time-dependent measures to detect age-related changes in muscle function.

KEYWORDS

Rate of Velocity Development; Functional Performance; Aging; Muscle Function; Power-load relationship
1. INTRODUCTION

Human aging has been associated with declines in muscle strength and power (1, 2). These age-related declines lead to a reduction in functionality, a higher risk of falls and a slower general movement pattern, jeopardizing the independency of older adults (3). In order to prevent this loss of independence, a better understanding of aging of muscle function is required.

The majority of methodologies that evaluated muscle function in older adults focused on maximal strength, which is very important in daily tasks since this sets the reserve limit (4). However, maximal strength requires more than 500 ms to be achieved (5). This makes it less functionally relevant in situations that require quick and powerful responses of muscles, such as balance recovery following sudden perturbations (6). Parameters that reflect the ability to rapidly produce force, such as the rate of force development, correspond to the short response times that are normally available to accelerate the limbs during many functional tasks (i.e., less than ~200ms) (7-9). Previous research that focused on rapid isometric force production already demonstrated differences between young and older adults and its link to functional performance (7-12).

In comparison to isometric tests, dynamic tests have greater external validity to functional movements. More specific, power, i.e. the product of force and velocity measured during dynamic tests is more strongly related to functional performance than maximal isometric
Age-related differences in rate of power development

strength (2). In addition, power and velocity decline more than maximal strength during aging, leading to an age-related slowing of muscles (2, 13). The age-related slowing of muscles suggests that older adults need more time to develop maximal velocity or power. This emphasizes the need to study muscle function in a time-dependent way, which would more closely reflect functional movements in older adults (14). To date, few studies have focused on rapid force characteristics during dynamic actions (i.e. the rate of velocity (RVD) or power (RPD) development) and their relationship to functional capacity in older adults. Interestingly, Thompson et al. observed a greater difference in RVD compared to pV of the leg extensor muscles between young and older men (15). These findings underline the importance of the time to peak velocity (ttpV) and suggest that RVD can be more discriminatory between age-groups compared to pV.

The scarce research that investigated RVD using dynamometry focused on isokinetic and unloaded testing (15). However, most activities during daily life are variable in velocity and include loading. More similar to daily tasks, isotonic contractions include an acceleration component and a certain amount of loading (16). Therefore, isotonic measures of power could serve as a better indicator for functional movements. Accordingly, isotonic testing has been emerging as a more functional though standardized method for the evaluation of muscle function (17-20). This type of testing in the older population seems especially relevant for the knee extensors, given that these muscles are crucial in a number of functional and locomotor tasks (21). To date, research using isotonic tests for knee-extensor muscle function in older adults is limited (13, 20, 22). Even more, no research has evaluated time-dependent isotonic knee-extensor function and its link to functional movements.
Therefore, the present study aimed at determining age-related differences in pV, pP, RVD and RPD of the knee-extensor muscles using the isotonic mode on a gold standard dynamometer. These differences were evaluated across different loads. Functional performance tests were included to investigate the functional relevance of pV, pP, RVD and RPD. We hypothesized that RVD and RPD would differentiate more between young and older adults compared to pV and pP respectively. In addition, we hypothesized that RPD would be more strongly related to functional performance in older adults than pV, RVD and pP.

2. METHODS

2.1. Subjects

Baseline values of the participants of two intervention studies in our lab were used for this study (23, 24). Subjects were community-dwelling and aged between 20-30 or 60-80 years. Exclusion criteria were (i) pathologies that prohibit a maximal strength test, such as severe cardiovascular disease, artificial hip or knee, acute hernia, infection or tumor and (ii) systematic engagement in endurance (i.e. no training with progressive increases in volume and/or intensity) or resistance exercise (i.e. no participation in the prior 12 months). Occasional engagement in physical activity, such as cycling, walking and running was allowed. Thirty-six young (♂ 21, ♀ 15, age = 22 ± 2 yrs) and fifty-six older adults (♂ 26, ♀ 30, age = 68 ± 5 yrs) volunteered. Young participants were apparently healthy and free of medication use.
Based on self-reported health questionnaires, the older participants were classified into health categories following a classification system as described previously (25-27) in order to estimate the risk for complications during physical exercise. Subjects’ characteristics are shown in Table 1. All subjects gave written informed consent. The study was approved by the University’s Human Ethics Committee in accordance with the declaration of Helsinki.

2.2. Procedures

2.2.1. Dynamometry
Measurements of static strength as well as power of the knee extensors were conducted on the Biodex Medical System 3\textsuperscript{®} dynamometer (Biodex Medical Systems, Shirley, New York, United States). The tests were performed unilaterally on the right side, unless there was a medical contraindication. This was the case for four older adults, who experienced injuries at the right leg in the past (e.g. knee pain or muscle rupture). None of them reported problems during daily activities, nor during the functional performance tests. Tests were solely performed on the left side for safety reasons. Participants were seated on a backward-inclined (5°) chair. The upper leg on the test side, the hips and shoulders were stabilized with safety belts. The rotational axis of the dynamometer was aligned with the transversal knee-joint axis and was connected to the point of force application at the distal end of the tibia using a length-adjustable rigid lever arm. Range of motion was set from a knee joint angle of 90° to 160°, with a fully extended leg corresponding to a knee angle of 180°. The test protocol, which was used in previous studies in our lab (24), was conducted twice and included two standardized tests in the following order: isometric and isotonic tests. Isometric strength was assessed at a
knee joint angle of 90°. Subjects were clearly instructed by the test leader to avoid an explosive contraction, but to extend their leg as hard as possible during 5 seconds, by building up strength gradually till maximal strength was reached. Two maximal isometric knee extensions, which were separated by a 20-second rest interval, were performed. Peak torque ($pT$, Nm) was recorded. The isotonic tests included ballistic knee extensions against constant resistances in the same specific order for every subject (i.e. consecutively 40%, 20% and 60% of maximum isometric strength). The subjects were clearly instructed by the test leader to extend their leg as fast as possible and then passively return the leg to the starting position (90°). Two explosive contractions were performed at each load. The velocity (°/s) and the torque produced (Nm) during the ballistic extension were recorded. The tests with the highest peak value of torque for the isometric tests and the highest peak value of velocity for the isotonic tests were used for further analyses.

2.2.2. Functional performance tests

The following tests, which varied in terms of strength and velocity characteristics, were performed in older adults: 7.5-meter walk test (7.5MWT), timed up-and-go test (TUG) and stair climbing (STC). All tests were timed by hand. To test maximal walking capacity, participants walked a distance of 7.5m as fast as possible without running (11). The best result as the shortest total time to walk 7.5m of two performances was used. The TUG was performed by standing up from a standard armchair, walk a distance of 3m, turn, walk back and sit down again as fast as possible without running (28). Subjects were free to choose left or right turn. The time in seconds was measured and the best result from two trials was used.
To measure STC ability, participants were asked to climb a 12-step staircase as fast as possible. The best result in seconds of two performances was used.

### 2.3. Data analyses

Torque and velocity signals from all isotonic tests were sampled at 100 Hz and processed off-line using a commercial software package (Matlab R2015b, The MathWorks Inc., Natick, Massachusetts, United States). Instantaneous power (Nm/s) was calculated as the product of both torque (Nm) and velocity (rad/s). Peak power (pP, Nm/s) and peak velocity (pV, °/s) were determined as the highest values of the power and velocity curve respectively. Time to peak power (ttpP, s) and time to peak velocity (ttpV, s) were determined as the time from the start of the movement till pP and pV were reached. Rate of power development (RPD, Nm/s²) and rate of velocity development (RVD, °/s²) were calculated as the linear slopes from the start of the movement till pP and pV were reached. The start of the movement was determined as the point where the acceleration reached a threshold of 150 °/s² after overcoming the imposed load. All measures of muscle function reported in this study were found to be reliable in a group of 63 older adults (ICC: .85 - .96, SEM(%): 3.6 – 12.5) with a trend for increased reliability at lower loads (paper under revision). Time-dependent variables (RVD and RPD) showed similar relative (ICC) and absolute (SEM) reliability compared to peak variables (pV and pP).

### 2.4. Statistical Analyses

All statistical analyses were performed using R software, version 1.0.136, R Core Team (2016). Normality was analyzed with Shapiro-Wilk tests. All parameters were normally distributed at
α-level 0.01. Two-sample t-tests were used to compare the differences in muscle function between young and older adults for men and women separately. No age-group by sex interaction effect was found using two-way analysis of variance. Therefore, an age-group by load interaction effect was examined for both sexes together with two-way repeated measures analysis of variance with age-group as the between- and load as the within-subjects factor. Post hoc analyses of the difference scores between the age-groups were conducted to determine the age-related difference between the loads. Pearson’s correlation coefficients were calculated to examine the relationship of measures of muscle function with the functional performance tests. Fischer z transformation was used to statistically compare correlation coefficients. Statistical significance was set at p < 0.05 for all analyses.

3. RESULTS

Subject characteristics and functional test scores are presented in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Young Men (n=21)</th>
<th>Old Men (n=26)</th>
<th>Young Women (n=15)</th>
<th>Old Women (n=30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>21.8 ± 2.2</td>
<td>68.3 ± 5.3*</td>
<td>21.8 ± 1.9</td>
<td>67.7 ± 4.9*</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>74.2 ± 6.4</td>
<td>84.1 ± 10.5*</td>
<td>62.5 ± 13.3</td>
<td>66.4 ± 8.1</td>
</tr>
<tr>
<td>Body height (m)</td>
<td>1.82 ± 0.05</td>
<td>1.73 ± 0.05*</td>
<td>1.69 ± 0.07</td>
<td>1.60 ± 0.06*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.4 ± 1.5</td>
<td>28.0 ± 3.3*</td>
<td>21.8 ± 3.9</td>
<td>26.0 ± 3.4*</td>
</tr>
<tr>
<td>(Co)morbidity (n)</td>
<td></td>
<td>1.65 ± 1.52</td>
<td></td>
<td>2.30 ± 2.05</td>
</tr>
<tr>
<td>Medication use (n)</td>
<td></td>
<td>1.23 ± 0.95</td>
<td></td>
<td>1.93 ± 1.46</td>
</tr>
<tr>
<td>Health Category (n)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>5</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>1</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>8</td>
<td></td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>9</td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7.5MWT (s)</td>
<td></td>
<td>3.8 ± 0.6</td>
<td></td>
<td>4.5 ± 0.6</td>
</tr>
<tr>
<td>TUG (s)</td>
<td></td>
<td>5.8 ± 0.9</td>
<td></td>
<td>6.3 ± 0.9</td>
</tr>
<tr>
<td>STC (s)</td>
<td></td>
<td>3.9 ± 0.8</td>
<td></td>
<td>4.6 ± 0.9</td>
</tr>
</tbody>
</table>
Measures of muscle function are listed in Table 2. Young adults performed significantly better compared to older adults for almost all strength-, velocity- and power-related muscle variables in both sexes (p < 0.05). While pP was significantly different at every load, difference in pV was only significant when measured at low load (i.e. 20%). Next to pV and pP, the variables ttpV and ttpP were significantly lower in young compared to older adults at every load (table 2). In terms of percent difference, RVD and RPD differentiated more between young and older adults compared to pV and pP respectively. Figure 1 illustrates the difference in mean power development between young and older adults.
Table 2. Muscle function in men and women by age group.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Young Men (n=21)</th>
<th>Older Men (n=26)</th>
<th>Percent difference (YM-OM)</th>
<th>Young Women (n=15)</th>
<th>Older Women (n=30)</th>
<th>Percent difference (YW-OW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pT (Nm) at 90°</td>
<td>282 ± 48</td>
<td>203 ± 43</td>
<td>28%</td>
<td>169 ± 41</td>
<td>121 ± 27</td>
<td>28%</td>
</tr>
<tr>
<td>Isotonic test at 20% load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pV (°/s)</td>
<td>441 ± 35</td>
<td>389 ± 50</td>
<td>12%</td>
<td>390 ± 40</td>
<td>344 ± 38</td>
<td>12%</td>
</tr>
<tr>
<td>ttpV (s)</td>
<td>0.20 ± 0.01</td>
<td>0.22 ± 0.02</td>
<td>11%</td>
<td>0.23 ± 0.03</td>
<td>0.26 ± 0.03</td>
<td>12%</td>
</tr>
<tr>
<td>RVD (°/s²)</td>
<td>2252 ± 305</td>
<td>1796 ± 376</td>
<td>20%</td>
<td>1746 ± 366</td>
<td>1353 ± 258</td>
<td>23%</td>
</tr>
<tr>
<td>pP (Nm/s)</td>
<td>637 ± 83</td>
<td>430 ± 110</td>
<td>32%</td>
<td>367 ± 67</td>
<td>247 ± 54</td>
<td>33%</td>
</tr>
<tr>
<td>ttpP (s)</td>
<td>0.16 ± 0.02</td>
<td>0.18 ± 0.03</td>
<td>10%</td>
<td>0.18 ± 0.04</td>
<td>0.21 ± 0.03</td>
<td>15%</td>
</tr>
<tr>
<td>RPD (Nm/s²)</td>
<td>3991 ± 813</td>
<td>2476 ± 799</td>
<td>38%</td>
<td>2219 ± 792</td>
<td>1242 ± 397</td>
<td>44%</td>
</tr>
<tr>
<td>Isotonic test at 40% load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pV (°/s)</td>
<td>289 ± 39</td>
<td>270 ± 39</td>
<td>7%</td>
<td>282 ± 48</td>
<td>250 ± 37</td>
<td>11%</td>
</tr>
<tr>
<td>ttpV (s)</td>
<td>0.20 ± 0.02</td>
<td>0.23 ± 0.02</td>
<td>11%</td>
<td>0.23 ± 0.02</td>
<td>0.26 ± 0.03</td>
<td>12%</td>
</tr>
<tr>
<td>RVD (°/s²)</td>
<td>1433 ± 246</td>
<td>1201 ± 233</td>
<td>16%</td>
<td>1215 ± 200</td>
<td>963 ± 196</td>
<td>21%</td>
</tr>
<tr>
<td>pP (Nm/s)</td>
<td>623 ± 95</td>
<td>435 ± 106</td>
<td>30%</td>
<td>376 ± 71</td>
<td>246 ± 59</td>
<td>35%</td>
</tr>
<tr>
<td>ttpP (s)</td>
<td>0.18 ± 0.02</td>
<td>0.20 ± 0.02</td>
<td>12%</td>
<td>0.19 ± 0.02</td>
<td>0.22 ± 0.03</td>
<td>12%</td>
</tr>
<tr>
<td>RPD (Nm/s²)</td>
<td>3571 ± 785</td>
<td>2213 ± 689</td>
<td>38%</td>
<td>1957 ± 453</td>
<td>1152 ± 367</td>
<td>41%</td>
</tr>
<tr>
<td>Isotonic test at 60% load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pV (°/s)</td>
<td>176 ± 46</td>
<td>183 ± 40</td>
<td>-4%</td>
<td>201 ± 58</td>
<td>172 ± 38</td>
<td>14%</td>
</tr>
<tr>
<td>ttpV (s)</td>
<td>0.18 ± 0.03</td>
<td>0.22 ± 0.05</td>
<td>20%</td>
<td>0.23 ± 0.04</td>
<td>0.26 ± 0.07</td>
<td>14%</td>
</tr>
<tr>
<td>RVD (°/s²)</td>
<td>1015 ± 272</td>
<td>854 ± 242</td>
<td>16%</td>
<td>884 ± 209</td>
<td>681 ± 193</td>
<td>23%</td>
</tr>
<tr>
<td>pP (Nm/s)</td>
<td>512 ± 116</td>
<td>388 ± 97</td>
<td>24%</td>
<td>344 ± 88</td>
<td>216 ± 60</td>
<td>37%</td>
</tr>
<tr>
<td>ttpP (s)</td>
<td>0.16 ± 0.03</td>
<td>0.20 ± 0.05</td>
<td>19%</td>
<td>0.20 ± 0.04</td>
<td>0.24 ± 0.07</td>
<td>14%</td>
</tr>
<tr>
<td>RPD (Nm/s²)</td>
<td>3257 ± 1030</td>
<td>2049 ± 759</td>
<td>37%</td>
<td>1721 ± 488</td>
<td>979 ± 366</td>
<td>43%</td>
</tr>
</tbody>
</table>

Data are means ± SD and percent differences of peak Torque (pT), peak Velocity (pV), time to peak Velocity (ttpV), Rate of Velocity Development (RVD), peak Power (pP), time to peak Power (ttpP) and Rate of Power Development (RPD) between young and older men and women. *significantly different from young men p < 0.05; **significantly different from young women p < 0.05
Figure 1. Age-related differences in power development.
Data are expressed as mean power (Nm/s) over time (ms) of young (blue solid line) and older adults (red dashed line) performing an isotonic test at 20% load. Peak power (pP), time to peak power (ttpP) and rate of power development (RPD) as the change of (Δ) power over Δ time are presented.

The data illustrate that absolute maximal power was produced at 20-40% load (Table 2), whereas maximal RPD was clearly produced at 20% load in every age-group. In terms of percent difference, RPD at 20% load showed the greatest difference between young and older adults. Two-way repeated measures analyses of variance showed an age-group by load interaction effect for all measures of muscle function (p < 0.01). More specifically for RPD, post hoc analyses showed that the age-related difference at 20% was larger than at 40% and 60% load (p < 0.05).

All functional tests were interrelated (r: .63 - .75) and their relation to the muscle parameters was relatively similar (Table 3). Although strength and velocity capacities showed a relatively high correlation with the functional performance tests, the power-related variables seemed to correlate systematically higher, irrespective of the load. However, Fischer z transformation showed that these correlation coefficients were not significantly higher. In addition, there was a trend that isotonic muscle function showed a higher correlation with functional performance with increasing load, although this was not significant. To illustrate, correlation coefficients
Age-related differences in rate of power development ranged from .30 to .64 at 40% load and from .11 to .59 at 60% load. All correlation coefficients were significant, except for pV at 60% load. Correlation coefficients for the association of the isometric test and the isotonic test at 20% load with functional performance are presented in Table 3. In addition, Figure 2 gives a representation of the relationship between functional performance and RPD at 20% load.

Table 3. Association between measures of muscle function and functional performance tests in older adults (n=56).

<table>
<thead>
<tr>
<th>Isometric</th>
<th>Isotonic at 20% load</th>
</tr>
</thead>
<tbody>
<tr>
<td>pT</td>
<td>pV</td>
</tr>
<tr>
<td>7.5MWT</td>
<td>-.51</td>
</tr>
<tr>
<td>TUG</td>
<td>-.55</td>
</tr>
<tr>
<td>STC</td>
<td>-.59</td>
</tr>
</tbody>
</table>

Data are Pearson’s correlation coefficients (r-values) for the association of peak Torque/Body Mass (BM) (pT), peak Velocity (pV), time to peak Velocity (ttpV), Rate of Velocity Development (RVD), peak Power/BM (pP), time to peak Power (ttpP) and Rate of Power Development/BM (RPD) with 7.5-meter walk test (7.5MWT), timed up-and-go (TUG) and stair climbing (STC). All correlation coefficients were statistically significant at p < 0.001.
Figure 2. Relationship between functional performance and knee-extension rate of power development. Data represent the association of rate of power development (RPD) measured at a load of 20% of isometric maximal strength with 7.5-meter walk test (7.5MWT), timed up-and-go (TUG) and stair climbing (STC) in 56 older adults. Rate of power development was normalized to body mass (BM). All associations were statistically significant at p < 0.001 (see Table 3).
4. DISCUSSION

The current study investigated age-related differences on time-dependent measures of knee-extensor muscle function during isotonic tests against different loads. The key finding is that RVD and RPD differentiate more between young and older adults in terms of percent difference compared to pV and pP respectively. Furthermore, age-related differences were more pronounced at low load compared to at higher loads. All power-related parameters showed a strong relationship with functional performance in well-functioning community-dwelling older adults. Our results emphasize the inability to generate power rapidly at older age and underlines the importance of time-dependent measures to detect age-related changes in muscle function.

In line with previous research, our findings demonstrate that aging results in significant declines in strength, velocity and power characteristics of the knee extensors. More specifically, the older adults in this study were 28% weaker, 7-14% slower and 24-37% less powerfull than the younger adults, a decline rate of similar magnitude compared to previous reports (1, 7, 20, 29).

A particular novelty of the present study is the use of time-dependent muscle parameters determined from loaded isotonic tests to distinguish young from older adults. More specifically, RVD and RPD take into account the time needed (i.e. ttpV and ttpP) to develop pV and pP respectively. Similar to pV and pP, young performed better than old at every load with
Age-related differences in rate of power development

regard to ttpV and ttpP. The longer time needed to reach peak power in old age might be influenced by the role of the knee joint angle at which peak power is attained. However, data analyses (not reported here) showed that position at peak power was similar between young and older adults (p > 0.05) at all loads.

In terms of percent difference, RVD and RPD differentiated more between young and older adults at every load compared to pV and pP respectively. To illustrate, differences between young and older adults across loads ranged from 24-32% in men and 33-37% in women for pP and from 37-38% in men and 41-44% in women for RPD. To our knowledge, there is no statistical methodology to verify whether these percent differences are significantly different. However, RPD is calculated as the ratio of both pP and ttpP. Increases in RPD are the result of increased pP and/or decreased ttpP. Therefore, we can assume that RPD differs more than pP because of the additional difference between young and old in ttpP. This emphasizes the added value of the time-dependent nature of RVD and RPD to discriminate between age-groups.

In terms of velocity capacities, our results are similar with the reduction in pV and RVD previously reported by Thompson and colleagues (15). Yet, our older age-group was slightly younger than the oldest age-group of Thompson and colleagues. In addition, Thompson et al. investigated an unloaded test in men only. Therefore, our study adds to the current literature on RVD in old age by including different loads and both sexes. To illustrate, men were stronger, more powerful and faster than women within each age-group at every load. However, no age-group by sex interaction effect was found, meaning that age-related differences in muscle function were similar between both sexes. Next to RVD, previous research mainly focused on the rate of torque development (RTD), which has been shown to decline during aging and to
be more related to falling compared to pT (7, 30). However, to the authors’ knowledge, no previous studies have reported age-related differences in RPD. The effect of aging at a neuromuscular level includes quantitative loss of muscle mass, altered muscle fiber contractile properties, slowing of neuromuscular activation and altered architecture and compliance of muscle and tendon (2). These changes in muscle quantity and quality have an influence on both strength (31) and velocity capacities (32). Strength and acceleration (i.e. the change of velocity over time) capacities are combined in RPD, which might explain the greater age-related declines.

The age-group by load interaction effect indicates increasing age-related differences in velocity- and power-related variables with decreasing load. In addition, power at lower loads appeared to be more associated with functional performance than power at higher loads, although this could not be statistically confirmed. Furthermore, RPD was performed maximally at low load (i.e. 20%) in every age group. Therefore, RPD at low load might be considered to detect early age-related declines in muscle function, although more research is necessary to confirm this.

Previous reports showed that both muscle strength and velocity are associated with functional performance (33). Consequently, power, which is more holistic in nature because it incorporates both strength and velocity capacities, has emerged as an important predictor of functional limitations in the elderly (2, 34). Similarly, although isolated knee-extension movements were used to test muscle function, this study shows that pP during the isotonic contractions was clearly linked with functional performance (35). Stepwise regression
analyses, not reported in this study, showed that pP and RPD were the single best predictors for functional performance, which confirms their holistic nature. In line with previous research on the rate of torque development (36), we hypothesized that time-dependent muscle parameters would more closely reflect daily life functioning in older adults. However, the results did not confirm our hypothesis. This might be caused by the fact that our sample of older adults were still well-functioning (Table 1), which is shown by the high scores on functional performance tests compared to reference values (28, 37, 38). In addition, our functional tests might not be a good representation of the short response times needed to accelerate the limbs in many daily activities, such as recovery from perturbations to prevent falling. Next, it should be noted that single-joint isolated tests might not be a good representation of falling as they lack coordination of multiple joints and muscles. Therefore, we should be careful in interpreting these results.

Some limitations of this study have to be recognized. Although the tests were performed using a gold standard dynamometer (Biodex System 3), a sampling frequency of 100Hz could be rather low for time-sensitive measurements. However, previous testings in our lab show good to high reliability for all measures of muscle function reported in this study (paper under revision). A second limitation of the study is the cross-sectional design. Therefore, reductions in muscle function characteristics should be interpreted as differences between two age groups, rather than longitudinal declines. Further research should focus on differences in RPD across the adult life span with much larger study samples, in order to have a better insight in the early phase of age-related differences.
To conclude, the key finding of this study is that age-related percent differences in RPD exceed differences in pP for the knee-extensor muscles. RPD combines both maximal strength and acceleration capacities of the muscle in one parameter, which might explain the greater age-related declines. Interestingly, the age-related differences in RPD and pP increased as the load decreased. All power-related parameters were related to functional capacity in well-functioning community-dwelling older adults. Future research should investigate whether RPD could be used as a sensitive screening method for future disability.

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