Magnitude of force perception errors during static contractions of the knee extensors in healthy young and elderly individuals

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Abstract The accuracy of force perception during muscular contraction has not been studied extensively, despite its importance in rehabilitation and training. The purpose of this study was to quantify the errors made by healthy young and elderly individuals in their perceptions of force produced at the knee. Four different tasks were used to evaluate the perception of force and the effect of a sensory–motor reference and simultaneous contraction on the accuracy of perception. The absolute errors were similar between groups, with values of 11.9% to 16.3%, depending on the task. The raw perception errors were greater for high levels of force (>50% of the maximal voluntary contraction, or MVC), indicating an overestimation of the forces produced for both groups. At 70% MVC, the sensory–motor reference reduced raw perception errors, and the simultaneous contraction improved the accuracy of force production. Healthy young and elderly individuals had about the same capacity to judge the muscular force of their knee extensors. Therapists involved in the training of active elderly individuals should be aware that the accuracy of force perception is not perfect and that these clients have the same ability as young individuals to perceive their knee extension strength.

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The production of graded, controlled forces is required in many activities, such as walking, rising from a chair, or grasping a fragile object. The mechanisms governing the perception of muscular force and the sense of effort have been studied using different paradigms, including bilateral force-matching tasks, in which the participant is asked to exert identical forces on both sides (Cafarelli & Bigland-Ritchie, 1979; Carson, Riek, & Shahbazpour, 2002; Jones, 1983; Jones & Hunter, 1983). Force perception can also be evaluated by examining the relationship between the force perceived and the force produced during simple unilateral contractions of different levels of intensity. Using this paradigm, some studies have shown that the perception of force increases as a positive power function, in relation to the force produced by the muscle (Eisler, 1962; Pincivero, Coelho, & Campy, 2003b; Stevens & Cain, 1970; Stevens & Mack, 1959), or as a negative power function (Jones & Hunter, 1982). Other studies have demonstrated the existence of a positive linear association between the perception of force and the production of force, with a general tendency to overestimate the force produced (Cooper, Grimby, Jones, & Edwards, 1979; Pincivero, Coelho, Campy, Salfetnikov, & Bright, 2001; Pincivero, Coelho, & Erikson, 2000; Timmons, Stevens, & Pincivero, 2009).

The lack of consensus on force perception could be attributed to between-subjects variability (Pincivero, Coelho, & Campy, 2003a; Pincivero et al., 2000) or to the different scales of perception used, as mentioned by Timmons (Timmons et al., 2009). Force perception could also vary according to the age of the participants assessed. As far as we know, the perception of force has never been compared between young and elderly participants, and

the accuracy of force perception has not been studied extensively.

Further quantification of force perception is clearly needed in order to establish the motor behavior of healthy individuals and to use this information as a reference to appreciate the difficulties of patients presenting sensory–motor deficits such as those encountered after a stroke. Since poststroke participants are often in their 60s, older adults in the same age group need to be assessed. Moreover, in order to better understand the motor control deficits of poststroke individuals and have referential values, it is important to determine whether different sensory–motor enhancements might improve their judgment. Knowing how to improve muscle force awareness would be of benefit to rehabilitation specialists retraining motor task execution.

The main objective of the present study was therefore to compare the errors in force perception made by young and elderly healthy individuals at different levels of force magnitude. Secondly, for a subgroup of participants, the objectives were to determine the effect of a sensory–motor reference on errors of force perception and to evaluate the effect of a simultaneous ipsilateral contraction on these errors. The first manipulation was selected to provide participants with information about their internal reference framework of force production, and the second to provide additional sensory–motor information, coming from a body segment richly innervated and sensitive, as revealed by the homunculus (Penfield & Boldrey, 1937; Penfield & Rasmussen, 1950). These two tasks will allow us to examine whether these manipulations provide additional information useful for improving the precision of force production.

Method

Participants

A convenience sample of 28 volunteers was recruited for this study. The inclusion criteria were that they presented no orthopaedic, neurological, or cardiac problems and no pain in the lower extremities or the trunk, and that they could sustain a period of activity for 2 h with rest intervals. The sample was divided into two age groups. The elderly group (n = 14) included 8 women and 6 men with a mean age of 65.3 ± 3.8 years, while the young group (n = 14) included 6 women and 8 men with a mean age of 29.3 ± 6.9 years. A subgroup of 15 volunteers executed two additional conditions in the same session (third and fourth tasks; see below). This subgroup (9 women and 6 men) was composed of a higher number of younger adults (n = 13) and had a mean age of 34.1 ± 13.9 years. Table 1 shows the

means and the standard deviations of the participants' characteristics. The experiment was approved by the local ethics committee and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants gave written informed consent to participate prior to their inclusion in the study.

Clinical assessment

Before the experiment, the participants were assessed by a physiotherapist. For the young group, only a general health questionnaire comprising questions about their medical status (pain, surgery, and other medical conditions) was used. For the elderly group, in addition to this general health questionnaire, a clinical evaluation was performed.

To evaluate balance, participants were asked to maintain unipodal standing for 10 s (Berg, 1989). To document their walking speed, a digital stopwatch was used to measure the time taken to cover a 5-m distance with participants walking before and beyond the recording distance to eliminate the effects of acceleration and deceleration on the time recorded. To meet the inclusion criteria, participants had to be able to walk the 5-m distance in less than 5 s. Touch-pressure sensitivity was evaluated 1 cm below the external malleolus bilaterally, using 6.65, 5.18, 4.31, and 4.17 calibrated Semmens–Weinstein filaments to determine the threshold. The proprioception of the ankle was evaluated (sense of movement and sense of position), and vibration sensitivity was determined with a 128-Hz tuning fork. Participants had to be able to feel the 4.31-calibrated Semmens–Weinstein filaments (Saltzman, Rashid, Hayes, Fellner, Fitzpatrick, Klapach, & Hillis, 2004), to identify correctly ≥5 of 6 movements and positions of articulation, and to feel the vibration for ≥10 s (Kokmen, Bossemeyer, Barney, & Williams, 1977; Richardson, 2002). To verify their ability to perceive different weights, the participants were also asked to place four identical cylinders of different weights in increasing order. Finally, the psychological status of the elderly participants was documented by the Geriatric Depression Scale (Sheikh & Yesavage, 1968). The normal value for this test is ≤5 out of 15 (Sheikh & Yesavage, 1968).

Measurement of maximal voluntary contraction (MVC)

Knee extensor strength A bilateral assessment of knee extensor strength was performed to quantify the dominant and nondominant strength difference using a Biodex dynamometer (Biodex Medical Systems, New York), recognized as a reliable and valid tool for strength measurements (Taylor, Sanders, Howick, & Stanley, 1991). To assess the maximal static strength of the knee extensors, the participants sat with their hips in a 60º

Table 1 Characteristics of the groups

	Young Group (n = 14)		Elderly Group (n = 14)		Subgroup (n = 15)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)[*]	29.3	6.9	65.3	3.8	34.1	13.9
Height (m)	1.79	0.1	1.68	0.1	1.69	0.1
Mass (kg)	67.8	8.3	77.1	17.7	66.9	8.3
Knee extensor strength (Nm/kg)[*]	3.2	0.7	2.0	0.6	3.2	0.7
Grip muscle strength (N)					327.2	113.6

[*] Significant difference between young and elderly groups (p < .05).

flexion position. Biodex straps were used to restrain the thigh, pelvis, and trunk movements. The axis of the dynamometer was aligned with the axis of rotation of the knee. The angle of the knee was set at 75º.

Grip muscle strength Measurement of the MVC of the grip muscles was necessary in order to measure performance on the task combining hand grip and knee extension (Task 4). Participants in the subgroup had to hold a static-grip dynamometer in their dominant hand (Bertrand, Mercier, Shun, Bourbonnais, & Desrosiers, 2004) with the elbow in a 90º flexion position and the arm along the trunk. A towel was placed between the arm and the trunk to be sure that participants maintained the correct position.

For all MVC conditions, participants were reminded to avoid an explosive contraction and instructed to progressively increase their effort to their maximal strength level. For each test, two trials with less than 10% difference were used, and the mean value of the two trials was calculated in order to determine the maximal strength: torque values (in newton-meters [Nm]) for knee extensors, and force values (in newtons [N]) for grip strength. Standardized verbal cues and encouragement were given to each participant during the test. A rest period of 45 s was given after each contraction (Bottaro, Russo, & Jaco de Oliveira, 2005).

Measurement of the perception of muscular force

The perception of the muscular force was assessed using four different tasks: (1) *force estimation*, (2) *force production*, (3) *force estimation* with a sensory–motor reference at 50% MVC, and (4) *force production* during a simultaneous contraction of the hand and knee. Only the subgroup of participants previously described executed the last two tasks. The tasks were always completed in the same order, but the levels of force to be produced in each condition were randomized. All tests were performed on the dominant side. Details of each task are provided below.

Force estimation For this task, participants sat on a Biodex dynamometer in front of a screen displaying visual feedback on the different relative force targets. The visual feedback was displayed as two horizontal bars. One bar was fixed and represented the target zone with a ±5% area tolerance. This bar was always presented in the middle portion of the screen. The other bar was mobile and represented the ongoing force produced by the participant. Participants were blind to the percentage of MVC that the target represented, because they saw only the two horizontal bars (the target zone and the ongoing cursor) without any other indications. Participants were asked to do a static contraction of the knee extensors in order to move the cursor into the target zone and make it stay in this zone for 2 s. The imposed percentages of force, assigned randomly, were 30%, 40%, 50%, 60%, and 70% MVC. Each percentage of MVC, composed of two successive trials, was performed twice randomly. After completing two successive trials providing the same level of force, participants rated their perceived force on a visual analogue scale (VAS) ranging from *no force*, on the extreme left of the scale (0%), to *maximal force*, on the extreme right (100%). The dependent variable was the score marked by the participants on the VAS provided on a portable computer.

Force production For this task, the evaluator verbally asked the participants to do a static contraction of the knee extensors at different percentages of their MVC (40%, 50%, 60%, and 70%). The dependent variable was the torque (in Nm) recorded by the Biodex, as described in the Data Analysis and Variables section below. Each level of MVC was performed twice randomly.

Force estimation with a sensory–motor reference This was the same as for the force estimation task, except that a sensory–motor reference corresponding to 50% of the MVC was presented to the participants beforehand. After the participants had felt this reference, they had to rate their perception of force for two targets randomly assigned,

corresponding to 40% and 70% MVC. Each level of MVC was performed twice randomly.

Force production during a simultaneous contraction In this task, participants were verbally asked to produce, on the dominant side, simultaneous contractions of the knee extensors and grip muscles of the hand according to different percentages of their MVC. No visual reference was given in this task. The different couples of MVC were 40%–40%, 70%–70%, and 70% of the MVC at the knee with 40% of the MVC at the hand (40%–70%). Each combined percentage of MVC couples was performed twice randomly.

Data analysis and variables

The levels of strength (torque or force) executed by the participants in all trials were calculated with homemade software. A mathematical algorithm determined the event corresponding to the beginning of the contraction release. The strength was then averaged over a 1-s period preceding this event (see Fig. 1). The two trials with the same level of strength were averaged, and the values were then expressed as a percentage of the participant's MVC.

To appreciate the participants' capacity to perceive their muscular force, two types of errors (absolute and raw) were calculated. The absolute error was defined as the absolute difference between the percentage of force scored on the VAS and that produced on the Biodex dynamometer (or between the force produced on the Biodex and that verbally requested by the evaluator for the force production tasks). For example, in the force perception task, if the VAS score was 38% and the actual force produced was 40%, the absolute error was 2%. This error represents the accuracy of the perception. The raw error was defined as the raw difference between the percentage of force scored on the VAS and that produced on the Biodex dynamometer (or
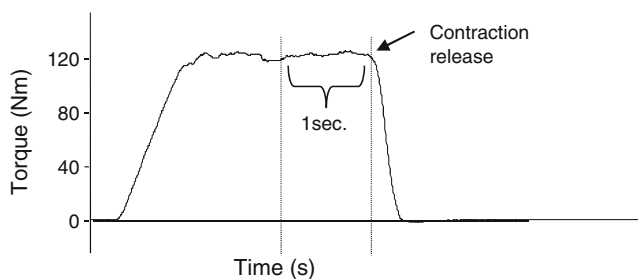
between the force produced on the Biodex and those verbally requested by the evaluator for the force production tasks). Using the same example, the raw error was −2%. This error represents the overestimation or underestimation of the perception.

Statistical analysis

Descriptive statistics were calculated for the demographic data and to summarize the variables. The normality of the sample, assessed by the Kolmogorov–Smirnov test and the equality of the variances by Levene's test, satisfied the conditions for using parametric tests. Intraclass correlation coefficients (ICCs) with a 95% confidence interval (CI), applied to the young and elderly group separately, were used to evaluate the level of the association between the real force produced (measured by the Biodex) and the perceived force (marked on the VAS) for the force estimation task, and between the force verbally specified and the force produced in the force production task. To assess the influences of age and of levels of force on the perceived force for both the force estimation and force production tasks, two-way ANOVAs were used, with age as the between-subjects factor and the levels of force perception as a repeated factor. Two separate two-way ANOVAs were used to study the absolute and raw errors of perception. When the ANOVAs were significant, the comparison between levels of force was depicted using Student's *t*tests. The latter were also used to assess the influence of a sensory–motor reference and the effect of a combined contraction on the perceived force. In all analyses with multiple comparisons, the Bonferroni correction was used to adjust the level of significance for the number of comparisons. Statistics were performed with the 13th version of the SPSS package software with the statistical significance level fixed at .05, except those corrected for the number of comparisons.

Results

Errors in force perception of young and elderly individuals during a force estimation task

The association between the force produced and that perceived on the VAS was good, with ICC = 0.658, 95% CI = 0.502 to 0.772, for the young group, and ICC = 0.661, 95% CI = 0.507 to 0.775, for the elderly group. Statistically, when the raw errors were used, Student *t*tests performed using the produced force (torque recorded on the Biodex dynamometer) and the perceived force (score on the VAS) showed that the perceived force and that actually produced were not significantly different from each other,

Fig. 1 Interval of time chosen for processing the force data. Custom software was used to calculate the mean of the torque signal over a period of 1 s, just before the beginning of the contraction release. Two trials with the same level of force were averaged, and the values were then expressed as a percentage of the participant's maximal voluntary contraction (MVC)

except at the 50% MVC level ($p < .001$) for the elderly group and at 60% MVC ($p = .002$) and 70% MVC ($p < .001$) for the young group (Fig. 2).

The two-way ANOVA for the raw errors revealed a force level effect ($df = 4$, $F = 3.493$, $p < .05$) but no group effect ($df = 1$, $F = 0.006$, $p > .05$). Interestingly, a significant group × levels of force interaction ($df = 4$, $F = 6.399$, $p < .001$) was found. Since a subsequent one-way ANOVA comparing the levels of force was significant in the young group ($df = 4$, $F = 9.288$, $p < .001$), Student t tests used for between-levels comparisons revealed that raw errors at 30% were significantly different from the raw errors at 70% ($p = .012$). Moreover, raw errors at 40% were significantly different from those at all other levels of force (see raw errors in Table 2). In the elderly group, the one-way ANOVA for the raw errors did not show a difference between the levels of force ($df = 4$, $F = 1.091$, $p > .05$). Comparisons between groups were significant only at 70% MVC (independent t test, $p < .05$). However, when absolute errors were analyzed, the two-way ANOVA revealed no effect of group ($df = 1$, $F = 1.716$, $p = .202$) or force level ($df = 4$, $F = 0.465$, $p = .761$), and no interaction ($df = 4$, $F = 0.275$, $p = .893$). Both young and elderly participants were seen to have similar errors, ranging from 8.9% to 14.3%. The raw and absolute errors of perception are presented in Table 2.

Errors in force perception of young and elderly individuals during a force production task

A very low level of association between the muscular force verbally specified and the force produced was found for both young (ICC = 0.197, 95% CI = −0.066 to 0.435) and elderly (ICC = 0.257, 95% CI = −0.003 to 0.486) groups (Fig. 3). For each group, the paired Student t tests (p value
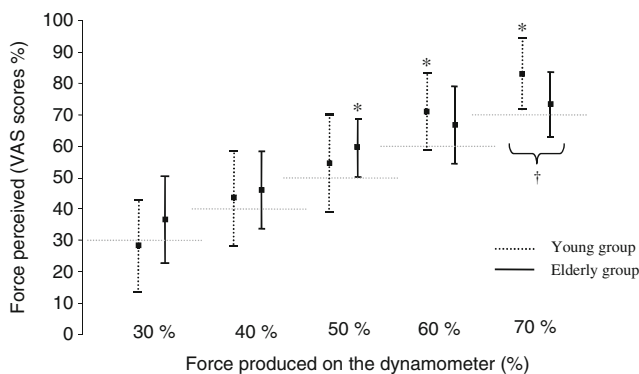

Fig. 2 Relation between the force produced and the force perceived on the visual analogue scale (VAS). The asterisks indicate the levels of MVC at which a difference was observed between the perceived and produced forces, while the dagger denotes a significant difference between groups. The short horizontal lines depict the levels of MVC. The vertical lines represent one standard deviation ($\pm SD$)

at .0125 after the Bonferroni correction) performed on the force verbally requested and that produced revealed lower values than those requested, except for the level of 40% MVC in the young group. The raw and absolute errors of perception are presented in Table 3.

Effect of a sensory–motor reference on the force estimation task

The results of the subgroup of participants in the force estimation task both without and with the sensory–motor reference are presented in order to appreciate the effect of the reference. For the subgroup, the ANOVA for repeated factors in the force estimation task without the sensory–motor reference showed a significant interaction ($p < .05$). Paired Student t tests did not reveal a difference between perceived and produced forces for 40% MVC ($p = .46$). For 70% MVC, the paired Student t tests revealed a significant difference between the force perceived and the force produced ($p = .001$). In fact, an overestimation of 13% was observed (Fig. 4). When *a sensory–motor reference* was provided, this overestimation was only 2.6%, so that no significant difference was observed between the force produced and that perceived at 70% MVC ($p = .245$; Fig. 4).

Effect of a simultaneous contraction on the force production task

The simultaneous forces produced at the hand and the knee were, respectively 42%–43%, 66%–69%, and 36%–68% MVC for the couples 40%–40%, 70%–70%, and 40%–70% MVC. Relative to the results at 70% MVC of the force production task during a simple contraction of the knee, the performance of the subgroup of participants producing a force of 70% MVC in extension at the knee was improved for the couples 40%–70% and 70%–70% ($p < .001$). In fact, the raw error of −17.9% calculated in the force production task for the subgroup of participants was reduced to −1% below the verbally requested force with the simultaneous contraction for the 70%–70% couple, and to −2.33% for the 40%–70% couple (Fig. 5). The simultaneous contraction also reduced the absolute errors of perception. In fact, the absolute error of 20.52% decreased to 10.59% for the 70%–70% couple, and to 11.15% for the 40%–70% couple.

Discussion

The principal objective of this study was to compare the capacities of young and elderly healthy participants to perceive their muscular force during different tasks of force

Table 2 Raw and absolute errors of perception in the force estimation task

Target Force	Young Group				Elderly Group			
	Raw Errors		Absolute Errors		Raw Errors		Absolute Errors	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
30%	−1.8[*]	15.4	13.5	6.9	6.5	13.8	11.8	9.3
40%	3.4[**]	14.7	11.9	8.8	6.0	12.4	9.3	9.9
50%	4.6	16.9	13.4	10.7	9.5	9.3	10.6	7.9
60%	11.3	12.0	14.3	7.6	6.7	12.4	10.9	8.5
70%	13.0	10.8	14.0	9.4	3.3	10.3	8.9	5.7
Global mean	6.1	14.0	13.4	8.7	6.4	11.6	10.3	8.3

[*]Significantly different from the 70% level. [**]Significantly different from 30%, 50%, 60%, and 70% levels.

production. Secondary objectives were to determine the effect of a sensory–motor reference and to evaluate the effect of a simultaneous contraction on the capacity of force perception.

When the absolute errors of perception were compared, no difference was found between the young and elderly groups. Thus, age did not seem to affect the ability to perceive muscular force. The very good state of health of our elderly participants could partly explain these findings. In fact, all of the elderly participants in our study reached normal values for each clinical test previously described.

Another important finding of the present study was that healthy young and elderly individuals were not perfectly accurate when they judged their force. Mean absolute errors during the force estimation and force production tasks were 12.5% and 16.3%, respectively, while the corresponding raw values were 6.3% and −12.6%. As far as we know, no previous studies on force perception have reported the absolute magnitude of errors between the forces produced and perceived. However, estimates of raw errors in young individuals could be appreciated from the mean data of previous studies. Based on Fig. 2 (p. 176) of Cooper et al.

Fig. 3 Relation between the force verbally requested by the evaluator and the force produced by the participants. The asterisks indicate significant differences between the force produced and the force verbally requested. The vertical lines represent one standard deviation (±SD). Except at 40% MVC in the young group, the raw errors of perception for all levels are substantial, with a strong tendency to produce forces lower than those verbally requested

(1979), which plotted the percentage of MVC against the percentage of relative perceived effort, mean raw errors ranged from 18% to 29% for percentages of MVC going from about 30% to 70%. These estimated errors, although higher than those of our study (−1.8% to 13%), also revealed an overestimation of the force produced. Our results and those of Cooper et al. (1979) are both greater than those estimated (−4.7% to 5%) from the mean values of Pincivero et al. (2000, Table III). This amplitude difference in the mean raw errors could be explained, in part, by the scales used to assess the perception. Pincivero et al. (2000) used a CR-10 scale instead of a VAS. As mentioned by Timmons et al. (2009), use of an ordinal scale might limit the perception of force, because the participants are instructed to select a single number from the scale. Also, the CR-10 scale has proved to be an efficient way of monitoring sensations that follow a positive acceleration (Noble & Robertson, 1996). This could also explain the linearity of the relation that Pincivero found between the forces produced and perceived in their studies (Pincivero et al., 2001; Pincivero et al., 2000; Timmons et al., 2009). Another factor to consider when explaining the error differences in the data is knee angles, which differed between the studies. Cooper et al. (1979) and Pincivero et al. (2000) assessed the MVC at 90° and 60° of knee flexion, respectively, whereas we used an angle of 75°. At the shoulder, previous studies have shown that the shoulder angle modified the perceived effort during load transfer tasks (Dickerson, Martin, & Chaffin, 2006, 2007).

Younger participants have greater raw errors at 70% MVC than do elderly participants. In fact, they seem to overestimate this level of force. The difference in maximal knee extension strength (215.8 Nm vs. 152.1 Nm) might be one explanatory factor. Since the young participants have to produce higher absolute strength than the older participants, they might perceive this as being more difficult. Dickerson et al. (2006) have shown that higher muscular strength yielded higher perception of effort during a loaded reaching task—due, in part, to an increased contribution of the
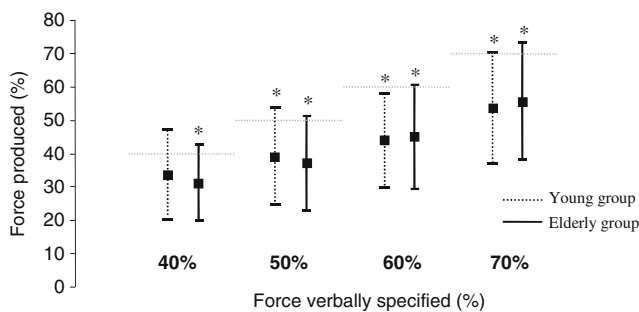
Table 3 Raw and absolute errors of perception in force production task

Target Force	Young Group				Elderly Group			
	Raw Errors		Absolute Errors		Raw Errors		Absolute Errors	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
40%	−6.4[**]	13.6	11.9[*]	8.7	−8.7[†]	11.3	12.1[*]	7.1
50%	−10.8[*]	14.5	14.9	9.9	−12.9	14.1	15.8	10.3
60%	−16.0	14.1	18.7	9.8	−14.9	15.6	18.1	11.3
70%	−16.3	16.6	19.2	13.0	−14.3	17.4	19.6	10.6
Global mean	−12.4	14.7	16.2	10.4	−12.7	14.6	16.4	9.8

[*]Significantly different from the 60% and 70% levels. [**]Significantly different from the 50%, 60%, and 70% levels. [†]Significantly different from the 50% and 60% levels.

peripheral sensitive afferences (Dickerson et al., 2006). These results in the young group also agree with the power function of the force produced, as described in previous studies (Eisler, 1962; Stevens & Cain, 1970; Stevens & Mack, 1959).

For the force production task, interestingly, no association was found between the force verbally requested and that produced. In fact, the force produced was 12.5% lower than the force verbally specified, whereas in the force estimation task, the force perceived was 6.25% over the force produced. In both tasks, an overestimation of the force produced was thus revealed. The difference in the magnitudes of the errors between the two tasks could be explained by the regression effect, which implies that a person decreases the range of a variable over which he/she has control (the score in the magnitude estimation task and force in the magnitude production task; Eisler, 1962).

As expected, the sensory–motor reference at 50% of MVC allowed improvements to the accuracy of force perception at high levels, indicating that the reference can be integrated by individuals to correct their errors in perception of muscular force. It would be interesting to

compare this result with the results for individuals who have had a stroke, to see whether they have the same capacity to correct their errors of perception.

One surprising observation in the present study was the effect of simultaneous contractions of the hand and knee. Although a dual task has been shown to be more difficult to execute than a single one (Pashler, 1994), it seems that, concerning muscular force production, simultaneous contraction of the hand and knee provides more references than one joint alone. The first hypothesis explaining this result is that a larger brain representation of the hand might allow us to better appreciate the hand force and transfer this accuracy to improve the force perceived at the knee. One could also argue that the increase in force produced at the knee during the simultaneous contraction is explained by the neural coupling between the arms and legs, showing that lower-limb muscle activation increased when an effort of the upper limb was exerted (Huang & Ferris, 2004). Finally, considering that the simultaneous contraction conditions were always performed after the sensory–motor reference at 50%, we cannot exclude the idea that the better precision was the result of a carryover effect of the previous task.
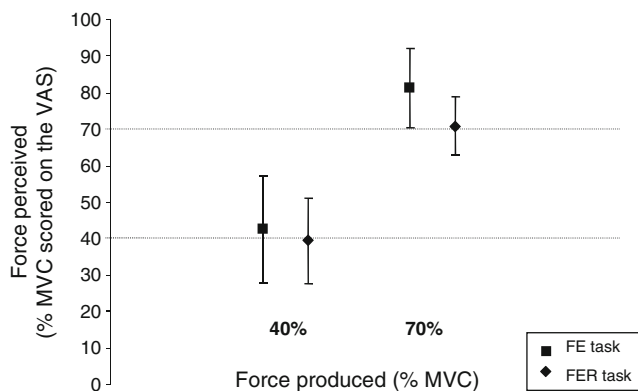

Fig. 4 Relation between the force produced and the force perceived on the VAS during the force estimation task (FE task) and during the sensory–motor reference task (FER task) for the levels of 40% MVC and 70% MVC. The vertical lines represent one standard deviation (±SD). This graph represents the data of the subgroup only
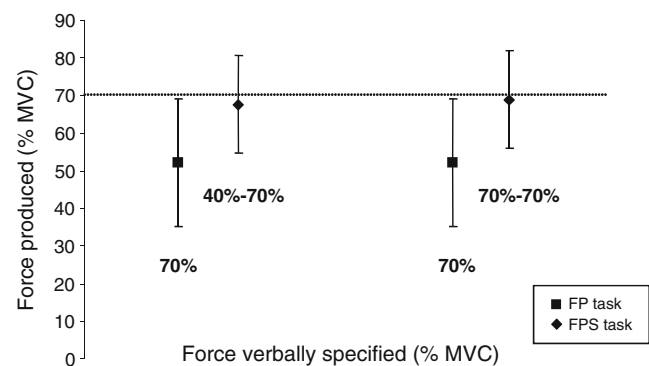

Fig. 5 Relation between the force verbally requested by the evaluator and that produced by the participants in the force production task (FP task) and during the simultaneous contraction (FPS task). The vertical lines represent one standard deviation (±SD). This graph shows the data of the subgroup only.

However, this methodological choice does not explain why the errors during the simultaneous contractions were lower than in the sensory–motor reference task. Future studies will need to assess more hand–knee couples, and possibly also examine whether contractions of other segments (such as the foot) could also improve the accuracy of perception, or whether the increase is specific to the hand.

Conclusion

This study has shown that healthy young and elderly individuals have about the same capacity to perceive their muscular force and can perceive it with absolute errors of 11.9% to 16.3%, depending on the task. Using a sensory–motor reference of 50% MVC improved the perception, and thus reduced the errors, at high levels of force. Other studies are needed to further understand the effect of simultaneous contraction of the ipsilateral hand. Future studies on both healthy and neurological populations such as poststroke individuals are needed to better understand the mechanisms underlying the perception of muscular force, to evaluate how patients perform in similar conditions, and to determine the impact of force perception deficits on functional tasks.

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