Weight discrimination ability during an action observation task is muscle contraction dependent

Andrea Albergoni[1], Christos Paizis[2], Charalambos Papaxanthis[2], Monica Biggio[1], Marco Bove[1], and Ambra Bisio[1]

[1]University of Genoa
[2]University of Burgundy

July 16, 2024

Abstract

Concentric and eccentric contractions show different patterns of neural activity at both peripheral and cortical levels, which are thought to influence the perception of action properties such as the weight of objects moved by others. The aim of this study was to investigate how the type of muscle contraction influences weight estimation during action observation. Forty-eight volunteers completed the Main experiment and the Control experiment. In the Main experiment, they performed a weight discrimination video task in which they watched videos of an actor moving two objects, a comparison and a reference box, executing concentric or eccentric contractions and they had to indicate which box was the heaviest. Sensitivity analysis and psychometric functions were used to analyze the data. In the Control experiment, observers judged the actor's effort in moving the boxes. The results of the Main experiment showed that the weight discrimination sensitivity was higher in the Eccentric condition for the Light boxes. Conversely, for the heaviest boxes, discrimination sensitivity was higher in the Concentric than in the Eccentric condition. These results were confirmed by the psychometric function analysis. The Control experiment showed that for Light stimuli, the perceived difference in effort between the comparison and reference stimuli was greater in the Eccentric than in the Concentric condition. These results showed that the ability to evaluate the weight of the object involved in the observed action was influenced by the type of contraction and the amount of weight. The effort attributed to the actor influenced the observer's perception.

Andrea Albergoni[1,2], Christos Paizis[3,4], Charalambos Papaxanthis[3,4], Monica Biggio[1], Marco Bove[2,5,6] *, Ambra Bisio[2,5]

[1] Department of Neuroscience, Rehabilitation, Ophthalmology, Genetics and Maternal Child Health, University of Genoa, Genoa, Italy

[2] Centro Polifunzionale di Scienze Motorie, University of Genoa, Genoa, Italy

[3] INSERM UMR1093-CAPS, Faculty of Sport Sciences, Université de Bourgogne Franche-Comté, Dijon, France.

[4] Centre d'Expertise de la Performance, Faculty of Sport Sciences, Université de Bourgogne Franche Comté, Dijon, France.

[5] Department of Experimental Medicine, Section of Human Physiology, University of Genoa, Genoa, Italy

[6] IRCCS Policlinico San Martino, Genoa, Italy

Corresponding author

Prof. Marco Bove, Department of Experimental Medicine, Section of Human Physiology, University of Genoa, vial Benedetto XV, 3, 16132, Genoa, Italy e-mail: marco.bove@unige.it; tel: +39 0103538172

ORCID

Andrea Albergoni: 0000-0002-6306-6432; andrea.albergoni@edu.unige.it

Christos Paizis: 0000-0002-5070-7915; christos.paizis@u-bourgogne.fr

Charalambos Papaxanthis: 0000-0003-1955-8269; papaxant@u-bourgogne.fr

Monica Biggio: 0000-0001-5800-4643; monica.biggio@unige.it

Marco Bove: 0000-0001-8129-4298; marco.bove@unige.it

Ambra Bisio: 0000-0002-9385-1714; ambra.bisio@unige.it

Short running title: Movement-type and weight discrimination

Acknowledgments

Data Availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Funding statement

The authors declare no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest disclosure

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics approval statement

The studies involving human participants were reviewed and approved by the Comitato Etico per la Ricerca di Ateneo, (n° 2021/42), University of Genoa. The participants provided their written informed consent to participate in this study.

Authors contribution

Andrea Albergoni: conceptualization, methodology, data curation, investigation, formal analysis writing – original draft preparation**.**

Christos Paizis: methodology, writing – review & editing, resources.

Charalambos Papaxanthis: writing – review & editing, supervision.

Monica Biggio: software, writing – review & editing, methodology.

Marco Bove: writing – review & editing, resources, supervision**.**

Ambra Bisio: conceptualization, methodology, formal analysis, writing – original draft preparation**.**

Abstract

Concentric and eccentric contractions show different patterns of neural activity at both peripheral and cortical levels, which are thought to influence the perception of action properties such as the weight of objects moved by others. The aim of this study was to investigate how the type of muscle contraction influences weight estimation during action observation.

Forty-eight volunteers completed the Main experiment and the Control experiment. In the Main experiment, they performed a weight discrimination video task in which they watched videos of an actor moving two objects, a comparison and a reference box, executing concentric or eccentric contractions and they had to indicate which box was the heaviest. Sensitivity analysis and psychometric functions were used to analyze the data. In the Control experiment, observers judged the actor's effort in moving the boxes.

The results of the Main experiment showed that the weight discrimination sensitivity was higher in the Eccentric condition for the Light boxes. Conversely, for the heaviest boxes, discrimination sensitivity was higher in the Concentric than in the Eccentric condition. These results were confirmed by the psychometric function analysis. The Control experiment showed that for Light stimuli, the perceived difference in effort between the comparison and reference stimuli was greater in the Eccentric than in the Concentric condition.

These results showed that the ability to evaluate the weight of the object involved in the observed action was influenced by the type of contraction and the amount of weight. The effort attributed to the actor influenced the observer's perception.

Keywords

Motor resonance, weight discrimination, sensitivity, psychometric analysis, action observation, perception, muscle contraction

Introduction

Starting from the discovery of the mirror neuron system, many studies concluded that a common representation of human movement execution and perception exists (Bonini et al., 2022). The scientific literature refers to this mechanism as "motor resonance", which consists of the activation of the perceiver's motor system when observing human movement (Rizzolatti et al., 1999). In a recent review paper, crucial factors modulating the mirror neuron system activity during action observation have been identified (Kemmerer, 2021). Some of them are specifically related to the features of the observed movement and the possibility for them to be mirrored in the observer's motor repertoire. For instance, a stimulus that moves according to the biological laws of motion can be mapped into the observer's motor programs (A. Bisio et al., 2010; A Bisio et al., 2012; Ambra Bisio et al., 2014; Gavazzi et al., 2013). Also, observing a specific motor skill will activate motor resonance if it is also possessed by the observer (Aglioti et al., 2008; Calvo-Merino et al., 2005, 2006). Thus, the way humans perceive external movement is shaped by their motor repertoire. Therefore, if there are differences among types of motion, it is likely that these differences will also affect motion perception. Human movements are implemented by concentric (i.e., the muscle contracts and shortens, such as the upward phase of a biceps curl) and/or eccentric (i.e., the muscle contracts and lengthens, such as the downward phase of a biceps curl) muscle contractions. Scientific literature provides evidence concerning the difference between these kinds of contractions (Duchateau & Baudry, 2014). For example, maximal voluntary force is greater during eccentric than concentric contractions, as are force fluctuations (Christou & Carlton, 2002; Fang et al., 2001; Grabiner & Owings, 2002; G. H. Yue et al., 2000) and the risk of injury (Shellock et al., 1991), while the electromyogram amplitude is either similar or greater during concentric than eccentric contractions (Duchateau & Baudry, 2014). The differences are also related to cortical activation (Gueugneau et al., 2023; Kwon & Park, 2011; Winstein et al., 1997; G. Yue & Cole, 1992). During eccentric contractions, greater cortical activity was detected through a fMRI investigation in the right inferior parietal lobe, the pre-supplementary motor area, the anterior cingulate cortex, the right prefrontal, and the left cerebellar hemisphere (Kwon & Park, 2011). In contrast, a greater BOLD signal intensity was observed in the left primary motor cortex and the right cerebellum and vermis during the execution of concentric contractions (Howell et al., 1995). Differences between these kinds of movements were found in the primary motor cortex activity and during the preparation phase. Canepa and colleagues showed a time-specific modulation of corticospinal excitability in the preparatory phase to an eccentric muscle contraction (Canepa et al., 2021). Given all these differences between the two contraction modes, and based on the motor resonance theory, one might hypothesize that there might be differences when a person observes a movement implemented by an eccentric or a concentric muscle contraction and is then asked to judge its features, such as the weight of the object being moved. Skilled and dexterous manipulation requires the ability to estimate the weight of an object accurately. Additionally, assessing the characteristics of the objects moved by other people can be a valuable source of information for planning an accurate response (Reichelt et al., 2013). According to action observation studies, the weight of the object involved in the action and the effort of the observed individual both affected the activity of the observer's sensorimotor brain areas (Alaerts, Swinnen, et al., 2010; Meulenbroek et al., 2007). This suggests that the sensorimotor representation includes both characteristics, which are then used to plan the subsequent motor response. This has been suggested by Reichelt et al., who showed that after observing the handling and transfer of an object, the observer automatically adjusts the lift to the weight of the observed object (Reichelt et al., 2013). Previous studies by our group have shown that the ability to judge the weight of an object moved by an external agent is modulated by factors such as age-related decline in motor skills due to aging (Albergoni, Biggio, Faelli, Ruggeri, et al., 2023) and motor experience in the observed movement (Albergoni, Biggio, Faelli, Pesce, et al., 2023). In this study, in order to gain a deeper insight into how the characteristics of an observed movement influence the observer's perception, based on the known effect of the sensorimotor repertoire on action perception, the observer's discrimination ability was assessed while observing eccentric or concentric contractions. Since it has been shown that the activity of a fronto-parietal network involving areas that are part of the mirror neuron system is greater during eccentric than concentric contractions, we hypothesize that participants' discrimination ability would be the highest when observing the eccentric contraction.

Materials and methods

Main Experiment

Participants

An a priori power analysis was conducted using G_Power version 3.1.9.7 (Faul et al., 2007) to determine the minimum sample required to test the study hypothesis. The effect size was set at 0.25 considered to be medium using Cohen's criteria (Cohen, 1992). A F-test assessing the interaction between the condition (n = 2) and the measurements (weights; n = 6) was applied with a significance criterion of a = 0.05 and power = 0.95. The minimum sample size needed was N = 28 to detect differences in discrimination sensitivity between conditions and among measurements. Thirty-five volunteers (male/females: 11/24; mean age ± SE=24.7±0.8 years) participated in the experiment. Written informed consent was obtained from all participants before data collection. The study was approved by the ethical committee of the University of Genoa (Comitato Etico per la Ricerca di Ateneo, n° 2021/42) and was conducted in accordance with the Declaration of Helsinki.

Experimental procedure

The experiment consisted of a single session where participants performed a weight discrimination video task. The task was built using jsPsych 6.3.0 library and performed off-line (de Leeuw, 2015). The task was preceded by the instructions and a questionnaire collecting personal data (i.e., gender, age, weight, height) and physical activity level (i.e., activities performed, year of experience, weekly hours of training) data. The protocol is represented in Figure 1A.

Video stimuli

The stimuli consisted of videos showing an actor performing a typical everyday activity; namely, the actor (either a woman or a man, depending on the gender of the participant, Figure 1B) moving a box (weight of the empty box 390 g) from the chest to a shelf over the head (Concentric condition, given that the main muscle involved in the movement, i.e., the anterior deltoids – based on preliminary EMG acquisitions, shortens in this kind of movement) or bring it down from the shelf to the chest (Eccentric condition, given that the deltoid anterior lengthens). In both conditions, the box was filled with varying amounts of sheets of paper in such a way as to assume 7 different additional weights (0, 2.5, 5, 7.5, 10, 12.5, 15 kg). Actors were informed about the weight of the box. Videos, whose durations range from 1.3s to 3.7s, were acquired on the same day with a video-camera positioned to record the execution of the lifting movement laterally. The face of the actor was blurred to cover facial expressions, as these reflected the level of exertion during a physical task (de Morree & Marcora, 2010).

Task

Participants (hereafter 'observers') sat in front of a laptop with a 16-inch LCD screen positioned on a table, at a distance of approximately 60 cm. They were required to perform a two-interval forced-choice (2IFC) task (Duarte et al., 2018). Each trial consisted of a sequence of two videos, a reference, and a comparison stimulus/video. After observing both, the observer had to indicate in which video the box was heavier. In particular, she/he had to press the left arrow key to answer "the First" and the right arrow key to answer "the Second". The 7.5kg-video was shown in every trial as it represented the reference stimulus. The 0kg-, 2.5kg-, 5kg-, 7.5kg-, 10kg-, 12.5kg-, and 15kg-video were the comparison stimuli (the 7.5kg-video was used both as a reference and as comparison stimuli). In each trial, the order of appearance of the reference and the comparison stimuli was random. Each comparison video was displayed 12 times in random order for each condition, for a total number of trials corresponding to 168 (7 box weights, 12 repetitions, 2 conditions). The total duration of the experiment was about 30 minutes. — Figure 1 here —

Data analysis

The discrimination sensitivity (*d'*) was evaluated at each comparison stimulus (except 7.5 kg) using signal-detection theory as described in Norman et al. (Norman et al., 2009). The d' was calculated according to one-dimensional classification experiments, following the procedure adopted by Norman et al. (Norman et al., 2009). A "hit" occurred when the first weight was heavier and the observers correctly responded, "first was heavier." A "false alarm" occurred when the first weight was lighter, but the observers incorrectly responded, "first was heavier." The hit rate was computed by dividing the number of hits by the total number of trials in which the first weight was heavier; the false-alarm rate was obtained by dividing the number of false alarms by the total number of trials in which the first weight was lighter (Norman et al., 2009). The log-linear adjustment method was used to adjust for extreme values of hits and false alarms (Macmillan & Creelman, 2004). The higher the *d'* values, the better the ability to discriminate between the object's weight. Then data were classified as Light (0kg, 2.5kg, 5kg) and Heavy (10kg, 12.5, 15kg), and*LHmean d'* was obtained in the two conditions by averaging the answers to Light and Heavy weights. Finally, the *mean d'* was calculated considering all the weights. The ratio of responses in which the comparison stimulus was judged "Heavier" than the reference stimulus at each box weight was computed for each observer in the two conditions (Concentric and Eccentric) to build a Psychometric function. The observers' psychometric curves were obtained by finding the best-fitting logistic functions using*psyphy* and *quickpsy* R package (Linares & López-Moliner, 2016; Yssaad-Fesselier & Knoblauch, 2006). The lower and upper asymptotes, threshold, and just noticeable difference (JND), were estimated for each psychometric function (Knoblauch & Maloney, 2012). Lower asymptote (A_{LOW}) and upper asymptote (A_{UP}) were computed according to Oh et al. (Oh et al., 2016). The lower/higher A_{LOW}/A_{UP}, the better the ability to discriminate low/high weights. The threshold corresponds to the curve point crosses 0.5 on the y-axis and indicates the point of subject equality (Kopec & Brody, 2010). JND is considered the smallest weight that produces changing in perception and is calculated as the half difference between the weights at which the psychometric function equals 0.75 and 0.25, respectively (von Sobbe et al., 2021). A lower JND indicated a better ability to discriminate the stimuli.

Statistical analysis

Sensitivity (*d'*) at each comparison stimulus (Norman et al., 2009), mean sensitivity (*mean d'* , obtained by averaging*d'* at the different comparison stimuli except 7.5-kg) (Maguinness et al., 2013), A_{LOW}, A_{UP}, threshold, and JND, were considered as outcome parameters. Shapiro-Wilk test was applied to evaluate data distribution and Levene's test was used to evaluate the equality of variances. LH*mean d' and mean d'* were normally distributed, whilst *d'* , A_{LOW}, A_{UP}, threshold, JND, and heavier probability at each comparison stimulus (including 7.5 kg) were not. Statistical analyses were chosen based on data distribution. Concerning the sensitivity analysis, Wilcoxon tests were applied to compare *d'* values at each comparison stimulus between Concentric and Eccentric conditions. Within each condition, Friedman tests, followed by post hoc, were used to assess differences among *d'* at each comparison stimulus (0kg, 2.5kg, 5kg, 10kg, 12.5kg, and 15kg). An ANOVA was applied on *LHmean d'* with Amount-of-weight (2 levels, Light and Heavy) and Condition (2 levels, Concentric and Eccentric) as within subject factors. Bonferroni post hoc tests were applied in case of significant interaction. Then, a t-test was performed to statistically compare *mean d'* between Concentric and Eccentric conditions. Concerning the psychometric function, all parameters were statistically evaluated using the Wilcoxon test to assess differences between the two conditions. Normally distributed data are reported as mean value ± standard error (SE), while not-normally distributed data are given as median [interquartile range, IQR]. The significance level was set at 0.05, except for *d'* , where Bonferroni correction was applied due to multiple comparisons. Statistical analyses were performed with SPSS Statistics 26 software.

Control experiment

A Control Experiment was conducted to assess the role of the actor's perceived effort in the ability to discriminate the weights of moving objects.

Participants

Thirteen volunteer observers (females/males: 7/6, mean age ± SD: 29.5 ± 4.9 years), not involved in the Main Experiment, were recruited in the Control Experiment.

Experimental procedures

Observers were involved in a single session experiment during which they were required to perform a video task lasting about 30 minutes. Video stimuli were the same used in the Main Experiment (Figure 1A). In a single trial, a video was shown and then observers were asked to rate the actor's effort using a Visual Analog Scale (VAS). The VAS consisted of a line approximately 10 cm (378 pixels) long, with "No effort" and "Maximal Effort" as initial and final anchor points, respectively. The score was expressed on a scale from 0 to 100 (Delgado et al., 2018). Each video was displayed 10 times, in random order, for a total number of 140 trials (7 box weights, 10 repetitions, 2 conditions).

Statistical analysis

The difference between the perceived effort of the actor at each comparison stimulus and at the reference stimulus (i.e., 7.5kg), expressed as an absolute value (ΔVAS Effort; e.g., abs[VAS Effort(7.5kg) – VAS Effort(12.5kg)]), was calculated. Furthermore, based on the value of the comparison stimulus for which ΔVAS Effort was calculated, ΔVAS Effort values were classified as Light (0kg, 2.5kg, 5kg) and Heavy (10kg, 12.5, 15kg), and *LHmean* ΔVAS Effort was obtained for the two conditions. Shapiro-Wilk test was performed to evaluate if the parameters were normally distributed. Levene's test was used to evaluate the equality of variances. ΔVAS Effort was analyzed via a 2 x 6 ANOVA with Condition (2 levels: Concentric and Eccentric) and Box-Weight (6 levels: 0kg, 2.5kg, 5kg, 10kg, 12.5kg, and 15 kg) as within subject factors. Also,*LHmean* ΔVAS Effort was analyzed via 2x2 ANOVA with Condition (2 levels: Concentric and Eccentric) and Amount-of-weight (2 levels, Light and Heavy) as within subject factors. Bonferroni post hoc tests were applied in case of significant interaction.

Results

Main Experiment: Sensitivity analysis (d')

Table 1 shows the discrimination sensitivity at each box weight in the two conditions. These data are also plotted in Figure 2A, which shows how the difference between the two conditions was modulated by the weight of the observed box. In fact, the discrimination sensitivity was higher in the eccentric condition only when the lighter boxes were shown, whereas it was better in the concentric condition when the heavier boxes were shown. The results of the Wilcoxon test on *d'* showed significant differences between Concentric and Eccentric for 2.5kg (z=2.02, p = 0.043) and 5kg (z=2.63, p=0.008). No difference between the two conditions was observed for 0kg, 10kg, 12.5kg, and 15 kg (p>0.05). Friedman test showed a significant effect of weight in both Concentric ($\chi^2(5)=28.2$, p<0.0001) and Eccentric ($\chi^2(5)=66.8$, p<0.0001) conditions. In the Concentric condition, the post hoc analysis revealed that *d'* at 0kg was significantly higher than at 2.5kg (p=0.003), 5kg (p=0.003), 10kg (p=0.007), 12.5kg (p=0.002) and 15kg (p=0.03). In Eccentric Condition, the post hoc showed that *d'* at 0kg was significantly higher than at 10kg (p<0.0001), 12.5kg (p=0.001), and 15kg (p=0.004). Also, *d'* at 2.5kg was significantly higher than at 10kg (p<0.001), 12.5kg (p=0.004) and 15kg (p=0.002). Furthermore, *d'* at 5kg was significantly higher than 10kg (p=0.006). Lastly, *d'* at 15kg was significantly higher than 10kg (p=0.02). No additional significant differences were revealed. Data are given in **Table 1** and represented in Figure 2A. — Table 1 here — ANOVA performed on *LHmean d'* showed a significant Amount-of-weight effect (F(1,34)=24.9, p<0.001, ^{2}=0.19) and a significant interaction Condition*Amount-of-weight (F(1,34)=30.6 , p<0.001, ^{2}=0.11). In Light, observers had a higher *LHmean d'* in Eccentric than Concentric condition (Concentric: 2.59±0.11, Eccentric: 3.03±0.06; p<0.0001). The opposite was observed in Heavy where *LHmean d'* was higher in Concentric than in Eccentric condition (Concentric: 2.43±0.10, Eccentric: 2.11±0.12; p=0.014). In the Eccentric condition, post hoc analysis revealed that *LHmean d'* was significantly higher in Light than in Heavy (Light: 3.03 ± 0.06, Heavy: 2.11 ± 0.18; p<0.001). No difference was found between Light and Heavy in Concentric condition (Figure 2B). The statistical analysis on *mean d'* did not show a significant difference between Conditions (Concentric: 2.47±0.03, Eccentric: 2.53±0.03; t(34)=0.763, p=0.45).

Main Experiment: weight discrimination ability

The graphical representation of the psychometric functions of the two conditions is displayed in Figure 2C. The psychometric curves represent the probability that the observer judges the weight of the comparison box to be heavier than that of the reference in the two conditions. It can be deduced from the figure that the ability to discriminate load was better in the eccentric condition for the lighter boxes, whereas when the weights of the comparison stimulus were heavier, this parameter was better in the concentric condition. The comparison between Heavier probability at each box weight showed a significant main effect of Condition at 2.5kg (Concentric: 0.08 [0.00, 0.17]; Eccentric: 0.00 [0.00, 0.08]; z=2.72, p=0.007), and at 5kg (Concentric: 0.17 [0.00, 0.33]; Eccentric: 0.08 [0.00, 0.13]; z=2.88, p=0.004) (Figure 2A). No difference between Concentric and Eccentric was found in JND (Concentric: 1.76 [0.59, 2.63] kg, Eccentric: 1.76 [0.95, 2.60] kg), A_{LOW} (Concentric: 0.00 [0.00, 0.03], Eccentric: 0.00 [0.00, 0.03]), and threshold (Concentric: 7.46 [6.89, 7.66] kg, Eccentric: 7.54 [7.24, 8.06] kg). The result of the statistical analysis on A_{UP} showed that it was significantly higher in Concentric (0.95 [0.89, 1.00]) than in Eccentric condition (0.88 [0.80, 0.98]) (z=2.49, p=0.021) (Figure 2D). — Figure 2 here —

Control Experiment

Figure 3A shows the effort that the observer attributed to the actor when performing the action, which increased as the weight of the box increased. Figure 3B shows the difference in the perception of effort, expressed as an absolute value, between each comparison stimulus and the reference stimulus, while Figure 3C shows the same parameter but averaging the lightest and heaviest boxes with respect to the reference.

From panels B and C, it can be deduced that this difference was greatest when observing the lightest boxes in the eccentric condition. The results of ANOVA on ΔVAS Effort revealed a significant effect of Box-Weight (F(5,60)=102; p<0.0001; η^2=0.65), a significant effect of Condition (F(1,12)=10.1; p=0.008; η^2=0.09), and a significant interaction Box-Weight*Condition (F(5,60)=3.02; p=0.017; η^2=0.10). The post-hoc analysis conducted on the Condition effect showed a significantly higher ΔVAS Effort in Eccentric than in Concentric at 2.5kg (Concentric: 30.8±2.7, Eccentric: 40.1±2.1, p=0.07) and at 5kg (Concentric: 14.6±2.2, Eccentric: 29.1±2.9, p<0.001) (Figure 3B). The post-hoc analysis computed on Box-Weight revealed significantly higher values in Concentric condition at 0kg (46.6±2.3) than at 2.5 (30.8±2.7, p=0.005), 5kg (14.6±2.3, p<0.0001), 10kg (15.5±1.5, p<0.0001), 12.5kg (17.3±2.7, p<0.0001), and 15kg (20.3±2.2, p<0.0001). Likewise, at 2.5kg ΔVAS Effort was significantly higher than at 5kg (p=0.0001), 10kg (p=0.0003), and 12.5kg (p=0.003). Within Eccentric condition, ΔVAS Effort was significantly higher at 0kg (49.6±2.2) than at 5kg (29.1±2.9, p<0.0001), 10kg (14.6±2.1, p<0.0001), 12.5kg (18.4±2.9, p<0.0001), and 15kg (21.5±2.0, p<0.0001), ΔVAS Effort was also significantly higher at 2.5 (40.1±2.1) than at 10kg (p<0.0001), 12kg (p<0.0001) and 15kg (p<0.0001). In the end, significantly higher values of ΔVAS Effort were found at 5kg than at 10kg (p=0.002). ANOVA performed on *LHmean* ΔVAS Effort showed a significant Amount-of-weight effect (F(1,12)=102.8, p<0.0001, ^{2}=0.65), a significant effect of Condition (F(1,12)=8.80; p=0.012; η^2=0.13) and a significant interaction Condition*Amount-of-weight (F(1,34)=5.30, p=0.040, ^{2}=0.14). Considering Light, ΔVAS Effort was higher in Eccentric Condition than in Concentric (p=0.014). No difference between Concentric and Eccentric was found in Heavy weights. In the Eccentric condition, post hoc analysis revealed that *LHmean* ΔVAS Effort was significantly higher in Light than in Heavy (Light: 39.6±1.7, Heavy: 17.4±1.9; p<0.0001) and the same result was observed in Concentric (Light: 29.7±2.0, Heavy: 17.7±1.7; p=0.001) (Figure 3C). — Figure 3 here —

Discussion

The aim of this study was to test whether the weight estimation of an object moved in an observed action is influenced by the type of movement performed by the actor, namely a lifting movement produced mainly by a concentric contraction, or a lowering movement, requiring an eccentric contraction. Results of the Main experiment showed that, in the case of light boxes (e.g., 2.5kg and 5kg), discrimination sensitivity (*d'*) was significantly higher in Eccentric than in Concentric condition. This also appeared evident when considering the Mean d' that in Light was significantly higher than in Heavy condition. Furthermore, this result was confirmed by the analysis of the psychometric function, which showed a significantly better performance in Eccentric than Concentric condition in correspondence of 2.5kg and 5kg. Differently, when the weights of the comparison stimuli were higher than the reference, *d'* was higher in Concentric than in Eccentric condition (as shown by analysis on Mean d'), and the upper asymptote of the psychometric function (A_{UP}) was higher in Concentric than Eccentric condition. The Control experiment revealed that, in the case of Light stimuli (e.g., 2.5kg, 5kg), the difference between the effort that observers attributed to the actor when moving the comparison and the reference stimulus (ΔVAS Effort) was significantly higher in Eccentric than Concentric condition. No difference between conditions appeared when showing Heavy stimuli. At last, ΔVAS Effort in Light was significantly higher than in Heavy for both Concentric and Eccentric conditions. For the light boxes, the results of all the analyses indicated that the weight discrimination ability was better in the Eccentric than in the Concentric condition. This difference could be explained by the different perceptions of the effort reported by the observers when seeing the actor performing the eccentric movement, as shown by the result of the Control experiment. For the Light stimuli, the effort attributed by the observers to the actor when he/she moved the comparison stimuli was significantly lower from that associated to the reference box. This marked difference may have helped observers to discriminate the weight of the comparison stimuli from the weight of the reference stimulus. In a recent fMRI study by Casiraghi et al. (Casiraghi et al., 2019), the perceived effort reported by observers after watching an actress perform a grasping action at different percentages of her maximum voluntary force was shown to correlate with activity in cortical areas involved in sensorimotor and cognitive processes. In particular, a linear relationship was found between the BOLD signal evoked during action observation and the entity of the perceived effort in the postcentral gyrus, an area included in the somatomotor network and involved in processing proprioceptive and tactile representations of the manipulated object (Ebisch et al., 2008). Consistent with these results, the amount of force applied by an actor modulated the activation of the primary motor cortex of the observer (i.e., a higher level of force elicited higher cortical excitability in the observer (Alaerts, Senot, et al., 2010)). Based on these results, one could speculate that the observation of the actor's movements may have elicited activity in a fronto-parietal network that was correlated with the effort the actor exerted to move the boxes, thus influencing the ability to discriminate the weight of the comparison stimulus from that of the reference stimulus. When observers were unable to distinguish the effort exerted by the actor in moving the comparison and the reference stimuli, as was the case for the Light boxes in the Concentric condition and the Heavy boxes in both conditions, the ability to discriminate the weight of the two boxes deteriorated. In fact, d' was lower for the Light boxes in the Concentric than in the Eccentric condition. Then, considering the Heavy boxes, in the Eccentric condition, the individual d' values at 10kg, 12.5kg, and 15kg were lower than those at 0kg and 2.5kg, whereas in the Concentric condition d' at 15kg was lower than at 0kg. Again, in the Eccentric condition, the mean d' was lower for Heavy than for Light and comparable to the value in the Concentric condition, and the upper asymptote of the psychometric function was lower than in the Concentric condition. All these data pointed out the deterioration of observers' responses in Eccentric condition when observing the actor moving the heavy boxes. In a previous study of our group (Albergoni, Biggio, Faelli, Ruggeri, et al., 2023), we showed that the ability to discriminate the weight of a moved object was impaired with aging, and we discussed this result as related to the deterioration of the elderly's strength. Thus, since the motor resonance mechanisms involved in action perception depend on the individual sensorimotor repertoire (Aglioti et al., 2008; Albergoni, Biggio, Faelli, Pesce, et al., 2023; A. Bisio et al., 2010; Petroni et al., 2010), the altered motor feature negatively affected the way older people perceived the movement. Furthermore, previous studies have shown that eccentric contractions are characterized by high force fluctuations (Christou & Carlton, 2002) and continuous adjustments in force level (Perrey, 2018). One could speculate that the high force fluctuations during movement execution may have translated into high uncertainty when observers were asked to judge the actor's effort in moving the comparison versus the reference box (due to motor resonance mechanisms), and consequently into a deterioration in the ability to discriminate the weight of the two stimuli when the actor performed an Eccentric contraction involving the heavy boxes. One cannot reject the possibility that these differences resulted from the different cortical activation patterns elicited by the execution of eccentric and concentric contractions, which are transferred to motion perception. For example, higher brain activity during eccentric than concentric contractions has been described in a multimodal-associative brain network (Borot et al., 2018; Fang et al., 2001; Kwon & Park, 2011; Yao et al., 2014), which is also known to be involved in weight perception (Hamilton et al., 2006; Chouinard et al., 2009) and which may have played a role in the discrimination task. However, this explanation would not motivate the differences described here between Eccentric and Concentric contractions in Light but not in Heavy boxes. For this reason, we are inclined to discard this hypothesis. Another feature of the actor's movement that might have helped the observers in estimating the weight of the object, and thus in weight discrimination, is the velocity of the end effector, namely the velocity of the hand moving the box (Bingham, 1987; Shim & Carlton, 1997). Although statistical analysis of the actor's movement velocity cannot be done since there were only two actors, performing only one movement for each weight, it might be of interest to report that in Eccentric Condition, at the Light weights (0kg, 2.5kg and 5kg), maximum speed values (1.05 m/s, 0.88 m/s, and 0.82 m/s) were substantially different from those of the reference stimulus (7.5kg – 0.61 m/s), whereas these differences were not so pronounced in case of the Heavy weights (10kg - 0.64 m/s, 12.5kg - 0.57 m/s, and 15kg - 0.56 m/s). Therefore, the substantial difference between the maximum speed of the comparison and the reference stimuli in the Light weights may have helped observers to discriminate the box weights. In contrast, the minimal difference in the Heavy weights may have negatively affected observers' ability in the discrimination task. Following this line of reasoning, in the Concentric condition, where the discrimination ability was terrible and, for the Light weights, also lower than that in the Eccentric condition, one would expect no substantial differences between the actor's velocity in moving the comparison stimuli relative to that of the reference stimuli. Actually, data on the actor's velocity is not clear, making it difficult to explain the results in the Concentric condition in terms of differences in the actor's velocity. In conclusion, the results of this study show that the ability to evaluate the weight of the object involved in the observed action is influenced by both the type of contraction and the entity of the weight. The effort that observers attributed to the actor may partly explain these results. Future work assessing brain activation during the discrimination task when observing eccentric and concentric contractions may shed light on understanding the role of the different cortical areas in processing the information about the object involved in the different types of observed movement.

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Tables

Table 1. Discrimination sensitivity (d') at each box weight and condition. Data are expressed as median [interquartile range].

d' **values**	**0kg**	**2.5kg**	**5kg**	**10kg**	**12.5kg**	**15kg**
Concentric	3.46 [2.7, 3.46]	2.77 [2.16, 3.46]	1.93 [0.97, 3.46]	2.16 [1.73, 3.46]	2.77 [1.73, 3.46]	2.77 [2.35, 3.46]
Eccentric	3.46 [2.77, 3.46]	3.46 [2.77, 3.46]	2.77 [2.43, 3.46]	1.73 [0.97, 2.43]	2.16 [1.35, 2.77]	2.77 [1.93, 2.77]

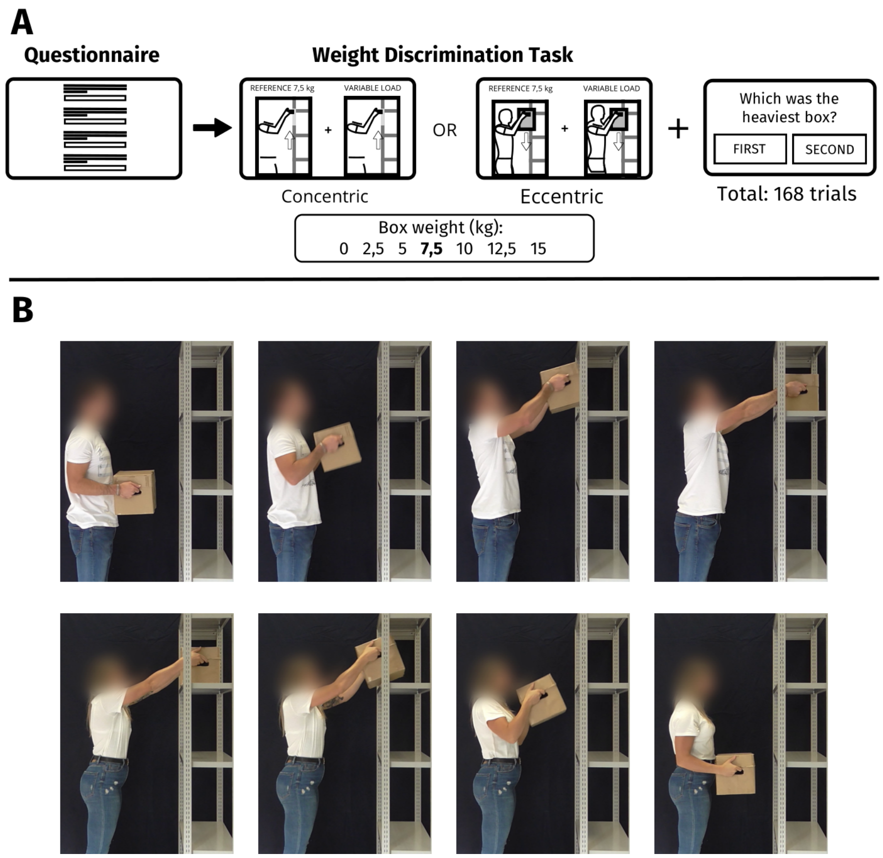
Figure legends

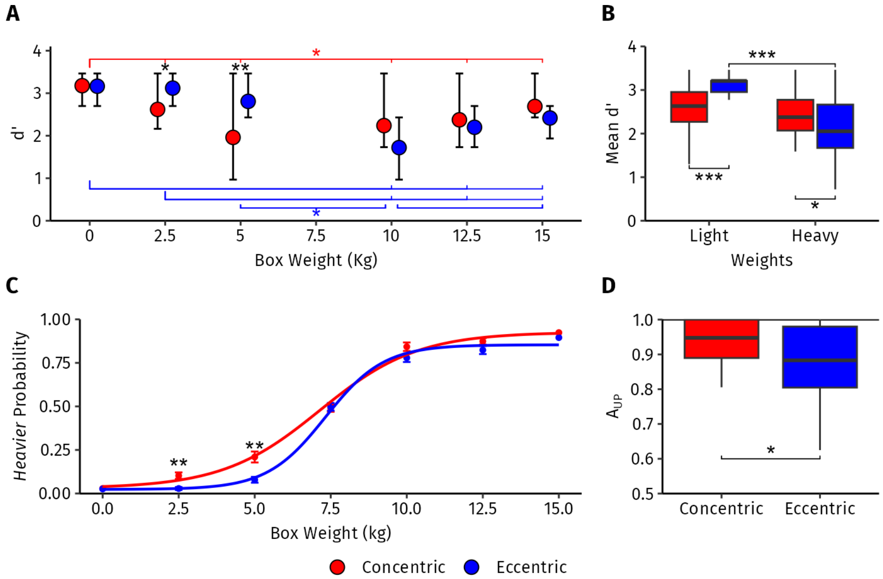
Figure 1. Experimental design . A) Task Protocol: each observer executed the task on a computer. The observers filled out a questionnaire collecting personal and physical activity-related data. Then a two-interval forced-choice (2IFC) task consisted of 84 trials. Each trial contained two videos in sequence: one was the reference stimulus (box weight: 7.5 kg) and the other was one of the seven comparison stimuli (box weights: 0, 2.5, 5, 7.5, 10, 12.5, 15 kg). In the end, a question asked in which video the box was heavier, and the observers could choose between "first" or "second". B) Frames of a video proposed to observers for male and female.

Figure 2. Results of the Main experiment . A) Discrimination sensitivity (d') in Concentric (red) and Eccentric (blue) condition at each weight. Circles represent median values, and error bars represent interquartile intervals. Black asterisks indicate significant differences between conditions (*p < 0.05, **p < 0.01). Colored brackets and asterisks indicate significant weight differences within each condition (Concentric: red, Eccentric: blue; *p < 0.05). B) Mean d' in Concentric and Eccentric conditions for Heavy and Light weights (*p < 0.05, ***p < 0.001. The box represents the inter-quartile ranges, and the bars show the maximum and the minimum values. C) Psychometric functions for Concentric (red) and Eccentric (blue) condition. Dots represent the proportion of Heavier responses at each load for each group, obtained from the average of the responses of all observers to each load. (D) Asymptotes (AUP) and for Concentric (red) and

Eccentric (blue) conditions. The box represents the inter-quartile ranges, and the bars show the maximum and the minimum. *p < 0.05.

Figure 3. Results of the Control experiment . A) Estimated Effort in Concentric (red) and Eccentric (blue) condition at each box weight. Circles represent the answer of each participant. The square represents mean value at each weight and condition, error bars represent the standard deviation. B) Δ (estimated) Effort in Concentric (red) and Eccentric (blue) condition at each weight. Squares represent mean values and error bars represent the standard error of means. Black asterisks indicate significant differences between conditions (*p < 0.05, ***p < 0.001). (C) ΔVAS Effort in Concentric and Eccentric conditions for Heavy and Light weights. The box represents the inter-quartile ranges, and the bars show the maximum and the minimum values (*p < 0.05, **p < 0.01, ****p < 0.0001).

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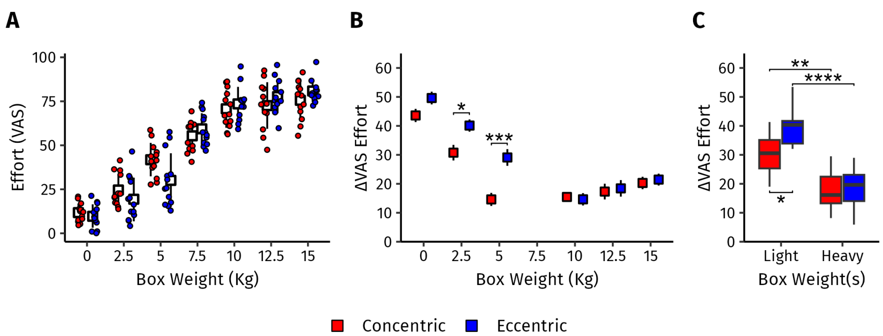
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