Influence of emotionally affective imaginations on the Adaptive Force in young women: unpleasant imaginations reduce the holding capacity of muscles

Laura V Schaefer (lschaefe@uni-potsdam.de)
University of Potsdam
Silas Dech
University of Potsdam
Lara L Wolff
University of Potsdam
Frank N Bittmann
University of Potsdam

Research Article

Keywords: Adaptive Force, maximal holding capacity, pleasant imaginations, unpleasant imaginations, motor control

Posted Date: March 11th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1281031/v3

Influence of emotionally affective imaginations on the Adaptive Force in young women: unpleasant imaginations reduce the holding capacity of muscles

Short Title: Influence of imaginations on the Adaptive Force

Laura V Schaefer[1]*, Silas Dech[1], Lara L Wolff[1] and Frank N Bittmann[1]

[1]Division Regulative Physiology and Prevention, Department Sports and Health Sciences, University of Potsdam, 14476 Potsdam, Germany.

*Corresponding author:
lschaefe@uni-potsdam.de;
Karl-Liebknecht-Str. 24-25
14476 Potsdam, Germany
Phone: +49-(331)-977-2987

Abstract

Emotionally affective imaginations can influence the Adaptive Force (AF) in healthy participants as was recently shown in an exploratory study. The AF describes the neuromuscular holding capacity in reaction to an increasing external force, which was suggested to be especially vulnerable for interfering inputs. The present study investigated the influence of pleasant and unpleasant food imaginations on the manually assessed AF of elbow and hip flexors objectified by a handheld device in 12 healthy young women in an improved design. Baseline measurements, randomization of imagination tasks and single-blinding were implemented. The maximal isometric Adaptive Force was significantly reduced during unpleasant vs. pleasant imaginations and baseline ($p < 0.001$, $d_z = 0.98$ to 1.61). During unpleasant imaginations muscle lengthening started at 59.00 ± 22.50% of the maximal AF, which was reached during eccentric muscle action. For baseline measurements and pleasant imaginations, this ratio amounted ~97.90 ± 5.00% for both muscles, indicating that the participant was able to maintain the isometric position during the entire external force increase. For those stable adaptations, oscillations arose in force signal at a level of ~72.26 ± 12.89% of AFmax, whereby they occurred under isometric conditions. For unpleasant imaginations, the onset of oscillation was at a force of 84.28 ± 14.03% of AFmax, which in most cases was after the muscle started to lengthen.

In conclusion, healthy participants showed an impaired holding function triggered by unpleasant imaginations, which are assumed to be related to negative emotions. This muscular instability is suggested to lead to joint destabilization which can result in musculoskeletal

complaints. Therefore, the findings might support the understanding of the causal chain of linked musculoskeletal pain and mental stress. A case example (current stress vs. positive imaginations) will be presented, underpinning the hypothesis this approach might support psychomotor diagnostics and therapeutics.

Introduction

The interaction between emotions and motor control has been discussed since decades especially in psychology and behavioral science (e.g., appraisal theory [1,2]) or in psychoneuroimmunology (e.g., mind-body connection [3,4]). It is known that emotions influence different body systems, like the autonomic, endocrine and motor systems.[5] The link between emotions and motor control can be explained by the central areas involved in processing both – emotions and motor control – e.g., the cerebellum, the basal ganglia and the cingulate cortex.[5–10] A related discussion was given in Schaefer et al.[11] The topic is also of great interest in medicine. There is a large agreement that mental health issues and complaints of the musculoskeletal system are connected.[12–21] However, the detailed causal relationship of, e.g., mental stress and musculoskeletal pain, is still unknown.[12,18,19,21] Investigations regarding the influence of mental stress on muscular activity are mostly performed by evaluating electromyography (EMG).[22–24] Thereby, usually a higher muscular activity was found, e.g., for lumbar and thoracal muscles while being exposed to negative emotional pictures and music vs. positive ones [25] or during anger and sadness recall interviews vs. baseline values [12]; regarding trapezius muscle during increased self-reported stress induced by Stroop color word test and mental arithmetic [26], or while anticipating a nociceptive stimulus (uncontrollable and unpredictable).[27] This leads to the conclusion that mental stress can increase muscle tension. However, there is also evidence that mental stress can cause muscle weakness which is referred to as psychogenic or functional weakness.[28–31] Its etiology remains still unclear.[29] Therefore, it would be of interest investigating the effect of mental stress or emotions on muscle strength. There is scarce scientific literature on that particular topic. A significant strength increase was found after an 8-week intervention of weight lifting in a group with prior induced positive emotions vs. controls in elderly people, suggesting that training effects are higher by inducing positive emotions.[32] Mehta & Agnew investigated, inter alia, muscle endurance and force-related changes at 15%, 35% and 55% of the maximal voluntary isometric contraction (MVIC) during mental stress (mental arithmetic task).[33] Since force-related changes were not present, the authors concluded that the "performance measure employed may not be sensitive to capture force-related changes".[33] However, muscle endurance was significantly reduced during mental stress task.[33] This is in line with another study in which a reduced time to task failure at 20% of MVIC during a mental-math task was reported.[34] Those studies point out that there are changes in the motor output, especially during sustained isometric muscle action. It was suggested to differentiate two types of isometric muscle action: the holding (HIMA) and the pushing one (PIMA).[35,36] During HIMA time to task failure was significantly reduced compared to PIMA.[37–40] Our research group proposed that HIMA is characterized by more complex control strategies than PIMA.[11,35,36,41]. Therefore, the investigation of the holding capacity might be an interesting approach to investigate the effects of emotions and mental stress.

Recently, our research group investigated the influence of positive vs. negative emotionally affective imaginations on the Adaptive Force (AF) in an explorative study. The AF is based on HIMA, whereby the holding activity is challenged in particular due to the required adaptation to an increasing external load. This must require even more complex neuromuscular control processes than isometric actions without adaptation to varying external forces. By performing the AF the muscular length-tension control must work properly to maintain stability (isometric position) during the external force increase. Different AF parameters during one measurement are of interest. The maximal isometric AF ($AFiso_{max}$) refers to the maximal force which arise under isometric conditions. In case, the muscle starts to lengthen during adaptation to the external force, the maximal holding capacity is exceeded, but during this eccentric phase the force increases further. Then, the maximal AF of the trial refers to the maximal eccentric AF ($AFecc_{max}$). Hence, the maximal AF (AFmax) can be achieved either during isometric or eccentric muscle action. In case of a stable adaptation, the $AFiso_{max}$ is similar or considerably high related to AFmax or to MVIC, respectively.[11,41,42] In case of instability (inadequate adaptation), muscle lengthening starts on a low force level (decreased $AFiso_{max}$), whereby AFmax reaches a similar high level as for stable adaptations but then during eccentric motion.[11,41] That suggests that the holding capacity has to be clearly differentiated to other force parameters. Due to the complex control processes which were assumed to be necessary for a stable adaptation in the sense of AF,[11,41,43] it was suggested that the maximal holding capacity is especially sensitive to inputs entering the involved complex control circuitries. Therefore, its investigation might be more beneficial than, e.g., examining the (pushing) MVIC. In first pilot studies the $AFiso_{max}$ was found to be significantly reduced in healthy participants perceiving unpleasant vs. pleasant odors [41] as well as by imagining negative vs. positive food experiences [11]. Both, unpleasant odors and negative food imaginations, are related to the emotion ‘disgust’. Perceiving those negative stimuli, the participants were no longer able to adapt their muscle tension by maintaining the muscle length (isometric conditions) appropriately during the entire force increase. Additionally, slight mechanical oscillations seem to play a relevant role for stable adaptation between two interacting persons.[44,45] Oscillations occur in the form of minimal mutual swinging motions at least of both involved extremities which are in contact. They emerge usually under stable conditions at particular force levels with a frequency around 10 Hz.[44,45] The measured reaction force also shows oscillations with corresponding frequencies. In the previous pilot studies, the force signal showed an onset of oscillations (AFosc) during force increase on a significantly lower level during pleasant stimuli (imaginations/odors), compared to unpleasant ones.[11,41] Furthermore, during stable adaptation (positive odors/imaginations) the oscillations appeared still under isometric conditions, whereby for unstable adaptation (negative odors/imaginations) they appeared – if at all – after the maximal isometric holding capacity was exceeded, thus, during muscle lengthening.[11,41]

The primary findings of those exploratory studies led to the assumption, that muscular stability during adaptation to external forces might be impaired by imaginations related to the emotion disgust and possibly also by other negative emotionally affective stimuli. Since the previous study concerning the effect of imaginations on AF had some methodological limitations (no blinding, no randomization, no baseline AF), the aim of the present study was to investigate the influence of positive and negative emotionally affective imaginations on the AF in a revised and improved design including randomization of imagination tasks, single-blinding and baseline measurements.

The following main hypotheses adopted from the previous study should be verified here. (1) The $AFiso_{max}$ is significantly reduced during unpleasant food imaginations compared to pleasant ones and baseline. (2) The maximal AF (AFmax) shows no significant difference between baseline, unpleasant and pleasant imaginations. (3) Oscillations arise on a significantly higher level of AF (AFosc) during unpleasant vs. pleasant imaginations and baseline, whereby AFosc during pleasant imagination vs. baseline shows no significant difference. In addition to the group comparisons, a case example of a participant being in an actual stressful situation will be presented. The effect of positive imaginations under those circumstances will be exemplified thereby.

In case the previous findings will be positively verified, this would underpin the novel insights into the interaction of emotions and motor control. Furthermore, it could provide new indications for a better understanding of pathomechanisms of musculoskeletal diseases related to mental health issues. Perspectively, a positive verification might result in innovative diagnostic approaches for mental but also particular physical health states.

Methods

The study was performed in the Neuromechanics Laboratory of the University of Potsdam (Germany). The AF of elbow and hip flexors of one side was investigated by the manual muscle test (MMT) executed by one experienced female tester (35 years, 168 cm, 55 kg; 8 yrs. of MMT experience) objectified by a handheld device regarding its reaction to emotionally affective pleasant and unpleasant food imaginations. In addition to the tester, two assistants participated and conducted the measurements: the first assistant was responsible for handling software, controlling the handheld device, and protocolling, the second assistant guided the imagination.

Participants

A priori power analysis (G*Power 3.1.9.7) for group differences (dependent t-test, two-tailed) on the base of the parameter with the lowest effect size of the previous study (unpleasant vs. pleasant imagination; parameter $\frac{AFosc}{AFmax}$, d_z = 1.390) [11] revealed a necessary sample size of at least n = 9 (α = 0.05, β = 0.95). In the anticipation of possible dropouts and due to an assumed lower effect size because of the improved design with a presumably lower bias, n = 12 participants were measured.

A total of 12 healthy women volunteered to participate in the study (age: 24.92 ± 3.50 yrs.; body mass: 64.08 ± 7.69 kg; body height: 170.67 ± 7.63 cm) (detailed information see supplementary material S1 Table). Inclusion criteria were female sex, age between 18 and 35 years and good overall health (values > 0 on mood and physical wellbeing numeric analogue scales from -4 (worst) to +4 (best)). The participants reported their mood on the measurement day on that scale with 2.58 ± 0.79 and their physical well-being with 3.00 ± 1.22. Exclusion criteria were current or previous (last six months) diseases or health complaints, current feeling of stress and an ongoing or planned psychological treatment. Furthermore, an impaired neuromuscular function of the tested muscles assessed by the MMT prior to the measurements led to exclusion.

The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of the University of Potsdam, Germany (protocol code 35/2018; 17th October 2018).

Handheld device for Adaptive Force recordings

The reliable and valid handheld device (Fig 1A; development funded by the Federal Ministry of economy Affairs and Energy; project no. ZF4526901TS7) was already utilized in previous studies.[11,41,43] It consists of strain gauges (co. Sourcing map, model: a14071900ux0076, precision: 1.0 ± 0.1%, sensitivity: 0.3 mV/V) and kinematic sensor technology (Bosch BNO055, 9-axis absolute orientation sensor, sensitivity: ± 1%) and records the reaction force, the accelerations and angular velocity (gyrometry) between tester and participant during the MMT. The sampling rate was 180 Hz. The data were buffered, AD converted and sent by Bluetooth 5.0 to a tablet. An app (Sticky notes, comp.: StatConsult) saved the transmitted data.[11,41]

Manual muscle testing

The characteristics of the MMT were described previously.[11,41,43] The MMT is a clinical method testing the AF as a biomarker of neuromuscular functioning.[46] The so-called “break test” [43,46] was used in the present investigation, which is usually conducted in submaximal intensities. Generally, the tester applies a gradually increasing force during MMT by pushing against the participant’s limb, who should resist this force application in an isometric holding manner. The aim of the MMT is not to test the maximal strength of the participant, but the neuromuscular capability to adapt to the external force increase. In case of an optimal adaptation during force increase, the muscle length stays quasi-isometric during the entire

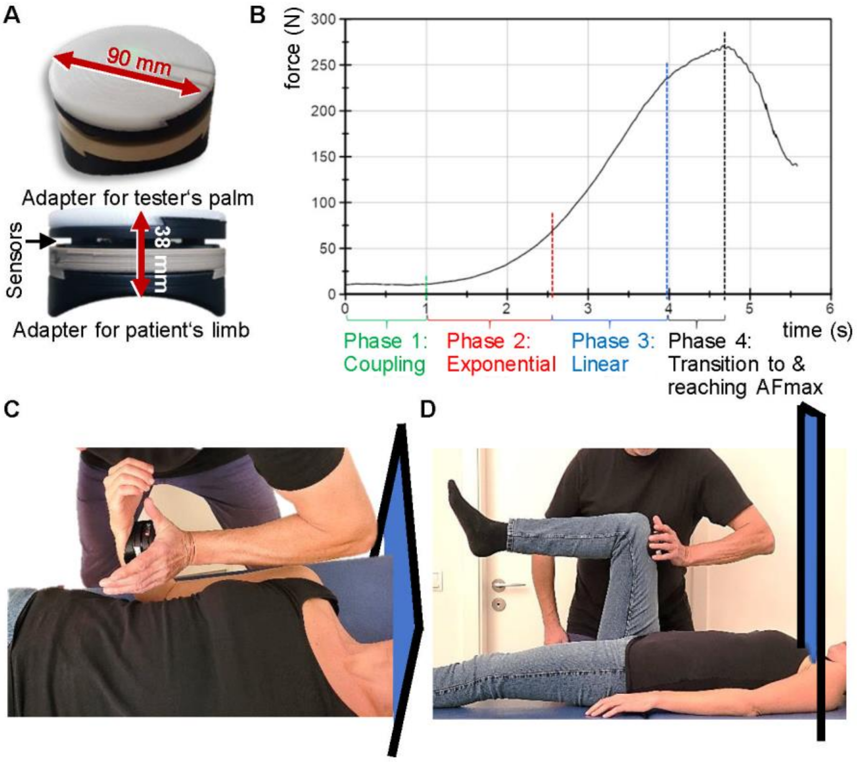

Fig 1. Handheld device, optimal force profile and setting.
(A) Handheld device. (B) Suggested optimal force profile applied externally by the tester during the MMT, which consists of the four illustrated phases (according to Bittmann et al. [43]). (C) Starting position of the MMTs of elbow flexors and (D) of hip flexors including the curtain which prevented visual contact between tester and participants during the trials.

MMT until an oscillating force equilibrium is reached between tester and participant on a considerably high force level.[11,41,43,46] If the adaptation is not optimal, the muscle starts to lengthen during the force increase (breaking point) on a considerably low force. The subjective rating of the MMT by the tester is differentiated into two qualitative states:[11,41,43,46] “Stable” – the participant`s limb maintains the isometric position during the entire force increase. “Unstable” – the participant`s limb gives way; thus, the muscle starts to lengthen and merges into eccentric muscle action during the force rise. The MMT and its interpretation are originally subjective due to the manual assessment. An objectification (force profile and limb’s position) can be achieved by utilizing the handheld device, which records the dynamics and kinematics simultaneously during the test. The characteristics of the force profile applied by the tester were described in detail previously.[11,41,43] The tester's force increase should allow the participant to adapt to the load (Fig 1B). For that, firstly, tester and participant get in contact on a low force level for ~1s; secondly, the tester starts to increase the force smoothly in an exponential way. A smooth force rise is necessary at the beginning, so that the neuromuscular system of the participant gets the chance to adapt to the rising force (for neurophysiological explanations see [43]). Thirdly, a linear force increase follows. In case an oscillating force equilibrium between tester and participant is reached, this should be sustained for a few seconds, whereby the maximal AF (AFmax) is attained. The interaction is stopped by the tester and the force decreases again. The duration of the entire force increase (phase 2 to 4) should be ~4 s (Fig 1B). The aim is not to break the participant's muscle but to check for the adaptive capacity of the participant's neuromuscular system.

A reproducible force application is a necessary precondition for valid data. Experienced testers are able to perform reliable force profiles over time.[11,41,43] The tester of this study proofed her ability to test reproducibly prior to the study by performing 10 repeated force increases against a stable resistance.[43]

Questionnaires

Two questionnaires had to be filled in, the first one online prior to the measurement appointment. It examined anthropometric data, current or planned psychological counselling, sensory perception of food consumption while eating (e.g., odor, taste, optics, texture) as well as the three most pleasant and the three most unpleasant foods. The foods had to be rated on a scale from -4 (most unpleasant) to +4 (most pleasant). Those were the base for food imaginations during the MMT and were discussed at the measurement appointment to get precise instructions for the imagination tasks (see below).

The second questionnaire was filled on-site before the measurements. The current state of mood and physical well-being were obtained (see above). General health questionnaires, such as the SCL-90 (HTS), were not applied, since the investigation does not aim at psychological well-being. Coming from the movement science, the above-mentioned scale seems to be sufficient to get an impression of the self-reported mood and well-being for the purposes of this investigation.

Food imaginations

The queried food preferences were discussed between participant, tester, and assistants on the measurement day. The participant described the food experience as detailed as possible and the tester noted the exact words used. Thereby, the tester enquired individual memorable experiences of the two most pleasant and two most unpleasant foods as, e.g., smells, tastes, associations etc. The aim was to identify triggering and exact words used by the participant to ensure a well-executed imagination during the MMT trials. Furthermore, the participant chose the most suitable picture of the respective food on a tablet (pictures of a common online search engine) provoking pleasure or disgust. Across all participants, the most pleasant foods included brownies, pasta with salmon, strawberries, chocolate, pancakes, mango, ice cream, pizza, curry with rice, sushi, BLT sandwich, lasagne, potatoes with quark, mustard eggs, yeast dumplings or hamburger; the most disgusting foods ranged from meat, fish, blood sausage, beet root, octopus, offal, bananas, Brussels sprout, spinach, tomatoes on a sandwich, aspic, licorice to pickled gherkins. This highlights the very individual food choices perceived as pleasant or unpleasant. Overall, the unpleasant foods were rated in 13 cases with -4, in 10 cases with -3 and in one case with -2; the pleasant foods were rated 19 times with +4 and five times with +3. In all cases, the foods were connected to individual experiences. For example, the participant who named “BLT Sandwiches” as one of her most pleasant foods (+4) described it reminds her of the positive situation “being on family vacation in Sweden, sitting in the winter garden and watching the lake” while “eating a BLT sandwich with fresh toast, mayonnaise, lettuce, flavorsome bacon and tomatoes”. She reported this as “experience of great pleasure”. The same participant chose aspic as her most unpleasant food (-4). She described it as “glibbery with pieces of meat inside, it wobbles in the mouth” and “you don´t know what is inside”. This example underlines the highly individual experiences connected with the food consumptions including the related positive or negative emotions.

Setting of manual muscle testing

The starting positions of the MMTs of elbow and hip flexors including the handheld device are illustrated in Fig 1 (according to [11,41]). For testing the elbow flexors, the participant lay supine on a practitioner table and flexed its elbow joint in 90° with a maximal supination (Fig 1C). The tester contacted the distal forearm of the participant with the handheld device, which was held in the tester’s palm. To avoid a probably painful pressure on the forearm, the handheld device was cushioned. For the starting position of the hip flexor test, the participant also lay supine with a hip and knee angle of 90° (Fig 1D). The tester contacted the participant’s distal end of the thigh with the handheld device. Cushion was not necessary thereby. To ensure a reproducible lever, the placement of the device was marked at the respective limb. The force vector by the tester was in direction of muscle lengthening of the participant's elbow flexors (elbow extension) or hip flexors (hip extension). The visual contact between tester and participant was prevented by a curtain on a hanging rail (Fig 1C, D). During the MMTs, the participant had the task to hold the starting position stable (isometrically) for as long as possible throughout the entire force increase applied by the tester. The handheld device simultaneously recorded the reaction force between tester and participant and the position of the limb during the MMT for objective evaluation.

Procedure

Prior to the measurement day, the participant received information on the study, the consent form, and the access to the first questionnaire via e-mail. On the measurement day, the tester introduced the participant to the procedure and the informed declaration of consent was signed before the second questionnaire was filled in. In case mood and physical well-being were rated on the scale > 0, the preliminary MMT of the elbow and hip flexors were executed on both sides. In case of regular stability, the participant was included, and the muscles of her preferred side were measured. If only one side showed regular stability, this side was used for the following measurements. Subsequently, the AF measurements followed. In total, 16 trials were performed, starting with two baseline measurements for each muscle (elbow and hip flexors). 12 single-blinded, randomized measurements including the imagination tasks followed: each muscle (elbow and hip flexors) was tested three times (M1, M2, M3) during pleasant (tasty) and unpleasant (disgusting) imaginations. The order of muscles and imaginations being tested was randomized in Microsoft Excel (Microsoft 365) prior to the measurements. A double-blinding is not possible, since the participant must actively imagine the food. To ensure single-blinding, the tester left the room for entering the imagination while the participant was instructed by the second assistant using the words noted earlier. The assistant read the words in a neutral and calm manner repeatedly for ~20 s and held the tablet with the chosen picture of the respective food straight above the participant’s eyes at the height of the hanging rail so that the participant kept a supine position without head rotation. Meanwhile, the other assistant prepared the handheld device and tablet for the new trial and protocolled any relevant details such as noises. As soon as the participant successfully imagined the respective food (~20 s; indicated by head-nodding), the tester was informed to enter the laboratory. She had no eye contact, neither to the participant (avoided by the curtain) nor to the assistants. The first assistant named the muscle to be tested and confirmed that the handheld device was ready for recording (“ok”) without making eye-contact. Any further verbal interaction was prohibited. The participant was priorly instructed to stay in her imagination during the MMT. The whole procedure of one trial lasted ~40 s. Resting periods were ~60 s. After each trial, the result of the subjective rating of the MMT (stable/unstable) was given by the tester to the first assistant by a thumb up (stable) or thumb down (unstable) sign without eye contact.

After completing all AF measurements, both muscles were tested again during each imagination without blinding, without the curtain and without the handheld device. This should check the testers’ evaluation of the MMTs during pleasant and unpleasant imaginations comparing blinded and unblinded trials. Interactions between all persons were allowed again.

Subsequently, the participant was asked for feedback. Self-reported information on the imagination process or thoughts during the measurement were of interest and were protocolled.

Data processing and statistical analysis

NI™ DIAdem 2021 (National Instruments) was used for data processing. The csv-files of the recorded measurements were transferred from the tablet to NI™ DIAdem 2021. The force and gyrometer signals were used for evaluation and were firstly checked visually, which partly led to exclusion of trials besides other reasons.

Exclusion of trials

In total, 16 trials were performed per participant (192 trials). Only 161 trials were evaluated (elbow: 78; hip: 83) due to the following reasons: the elbow flexors of two participants and the hip flexors of one participant showed a dysfunction in the preliminary MMT and, therefore, those 24 trials were excluded from evaluation. To not change the measuring procedure, they were also measured and not omitted before. Furthermore, one trial of hip flexors had to be excluded, because the tester contacted the knee with her chin during the MMT, which might have led to confusion of tester and/or participant. The visual inspection led to exclusion of further six trials. In one trial a clear pushing by the participant against the tester was visible. This was not allowed since the participant should only perform holding isometric muscle action. In further five trials the recording stopped before the end of the measurement. It is not clear, if the tester pushed the stop button too early or if the measurement stopped because of technical issues.

Data processing and relevant parameters of Adaptive Force

The force and gyrometer signals of the 161 included trials were interpolated (linear spline interpolation) for gaining equidistant time intervals (1000 Hz) and were filtered (Butterworth, cut-off frequency 20 Hz, filter degree 5) in NI™ DIAdem 2021. For those prepared signals, the following parameters of interest were extracted for each trial of baseline, pleasant and unpleasant imaginations (analogues to [11,41]):

(1) Maximal Adaptive Force: AFmax

The AFmax (N) refers to the maximal value of AF in the force curve that was reached during the entire trial, irrespective if the muscle length stayed stable or not. Thus, it can arise during isometric or eccentric muscle action. In case the muscle stayed stable during the whole measurement, AFmax was reached under isometric conditions ($AFiso_{max}$); if the muscle gave way, AFmax was obtained during eccentric muscle action ($AFecc_{max}$). AFmax does not display the participant's maximal force in general. Under isometric conditions, the AFmax depends also on the force applied by the tester, whereas in case of muscle lengthening, the AFmax is equal to the maximal eccentric force in the present circumstances and is less dependent on the tester's force application.

(2) Maximal isometric Adaptive Force: $AFiso_{max}$

This parameter is the most important one for the present investigation. $AFiso_{max}$ (N) refers to the maximal AF, which was reached under isometric conditions. In case of muscular stability, AFmax = $AFiso_{max}$. In case of instability, it marks the breaking point in which the participant's muscle merges from isometric to eccentric action. To identify the $AFiso_{max}$, the gyrometer signal (deviation of angle over time) was analyzed. It oscillates around zero under isometric conditions but increases above zero as the muscle starts to lengthen. Hence, if the gyrometer signal increased above zero, the force value at the moment of last zero crossing of the gyrometer signal refers to as $AFiso_{max}$ (breaking point). If the gyrometer signal constantly oscillates around zero throughout the entire force increase, $AFiso_{max}$ = AFmax.

The $AFiso_{max}$ was furthermore related to AFmax: $\frac{AFiso_{max}}{AFmax}$ (%). This should reflect the maximal holding capacity in relation to the maximal reached force value of the respective trial. Since the AFmax does not necessarily reflect the maximal strength of the participant, a second ratio ($\frac{AFiso_{max}}{maxAFmax}$ (%)) was calculated additionally, whereby maxAFmax refers to the highest value of AFmax across all trials of the respective muscle and participant, irrespective if it was reached under isometric or eccentric conditions. Hence, maxAFmax is closest to the participant's maximal strength.

(3) Adaptive Force at the onset of oscillations: AFosc

In the previous studies,[11,41] both interacting partners developed an oscillating force equilibrium, especially in case of muscular stability. This was accompanied by arising oscillations in the force signal, indicating a clearly distinguishable regular oscillatory behavior (swing up). Therefore, the force at the moment of onsetting oscillations (AFosc (N)) was investigated. For that, the force signal was checked for oscillations (force maxima) appearing sequentially after the exponential phase (phase 2). In case, four force maxima with a time distance dx < 0.15 s appeared consecutively, the force value of the first maxima was defined as AFosc, which marked the force at the onset of oscillations. $d_x < 0.15$ s was chosen since mechanical muscle oscillations occur around ~10 Hz.[44,45,47,48] If no such oscillations appeared during the entire trial, AFosc = AFmax. For AFosc, the ratios to AFmax (%) and to maxAFmax (%) were calculated, too. It was previously found that AFosc appeared on a lower level than $AFiso_{max}$, thus, prior to $AFiso_{max}$ in stable and on a higher level than $AFiso_{max}$, hence, after $AFiso_{max}$ in unstable MMTs. Therefore, the ratio $\frac{AFosc}{AFiso_{max}}$ (%) was additionally calculated.

(4) Slope of force rise

The force increase during the test might affect the outcome. Especially a steeper force rise could compromise the participant's ability to stabilize the limb's position. Therefore, similar slopes of force increase are a necessary prerequisite to compare the above-mentioned parameters between baseline, pleasant and unpleasant food imaginations. Hence, the slope (N/s) of force increase was considered.[11,41] For that, the arithmetic mean of the $AFiso_{max}$ values of all unstable trials of the respective muscle of one participant served as reference. The slope of each force curve (stable/unstable) was calculated by the difference quotient including the time and force values at 70% and 100% of this reference value (averaged $AFiso_{max}$ value of all unstable trials). The decadic logarithm was applied to obtain the logarithmic slope (lg(N/s)) since the force rise was exponential.[11,41] In case the reference value occurred after the linear phase (transition to force plateau), the trial was excluded from slope analysis to avoid distortion. This was the case in 19 of 161 trials.

For the subsequent statistical evaluation, the arithmetic means (M), standard deviations (SD) and 95%-confidence intervals (CIs) were calculated for each parameter separately per participant, muscle (elbow and hip flexors) and baseline or imagination (pleasant/unpleasant) and were used for statistical comparisons.

Statistical analyses

In total, ten complete data sets for elbow flexors and eleven for hip flexors were analyzed comparing baseline, pleasant and unpleasant imaginations. Statistical analyses were performed using IBM SPSS Statistics (Windows, Version 28.0. Armonk, NY: IBM Corp). The normal distribution of each parameter for each muscle in each condition (baseline, pleasant, unpleasant imaginations) was checked by Shapiro-Wilk test. In case of normal distribution, the ANOVA for repeated measurements was performed (RM ANOVA). If sphericity was not given (Mauchly test), the Greenhouse-Geisser correction was chosen (F_{Green}). For post-hoc test, Bonferroni correction was applied (adjusted p values are given by p_{adj}) . The effect size eta squared (η^2) was calculated in IBM SPSS Statistics. For pairwise comparisons the effect size Cohen's d_z was calculated by $d_z = \frac{|MD|}{SD_{MD}}$, whereby MD stands for the mean difference and SD_{MD} for its standard deviation. The effect size was interpreted as small (0.2), moderate (0.5), large (0.80) or very large (1.3).[49,50] Because the RM ANOVA is considered to be robust against violation of normal distribution,[51,52] the Friedman test to compare baseline, pleasant and unpleasant imaginations was only used if more than one group was not normally distributed. This was the case for the parameters slope and $\frac{AFiso_{max}}{AFmax}$ for elbow and hip flexors, respectively. Kendall's W was then calculated as effect size. Bonferroni post-hoc test was applied for pairwise comparisons (adjusted p values are given by p_{adj}) and effect size Pearson's r was calculated by r = $\left|\frac{z}{\sqrt{n}}\right|$. Significance level was set at α = 0.05.

Results

Rating of the MMT by the tester

The single ratings of the tester for each trial and participant are given in supplementary material Table S2. The relative shares of the qualitative ratings (stable vs. unstable) of all MMTs by the tester are visualized in Fig 2. For elbow flexors, all of the 19 baseline trials were rated as stable (100%). Regarding pleasant imaginations, 26 of 29 trials were assessed as stable (90%), three as unstable (10%). For unpleasant imaginations, 3 of 30 trials were rated as stable (10%) and 27 as unstable (90%). For hip flexors, 21 of 22 of baseline trials were rated as stable (95%), one as unclear (5%); 26 of 30 MMTs during pleasant imaginations were rated as stable (87%) and 4 as unstable (13%); 2 of 32 MMTs during unpleasant imaginations were rated as stable (6.25%), 27 as unstable (84.38%) and three as unclear (9.38%). The subsequent statistical evaluation is only based on the grouping of conditions (baseline, pleasant and unpleasant imaginations), independent of the tester's rating.

For comparison of the MMT assessment of blinded vs. unblinded trials, the unblinded MMTs after AF assessment (one trial per imagination and muscle) without handheld device, thus, only evaluated according to the subjective tester's rating were considered. In most cases they showed that the imagination led to the expected MMT outcome (stable for pleasant, unstable for unpleasant imaginations). For elbow flexors, all 20 unblinded MMTs were rated accordingly as stable during pleasant imaginations (100%). During unpleasant imaginations, the elbow

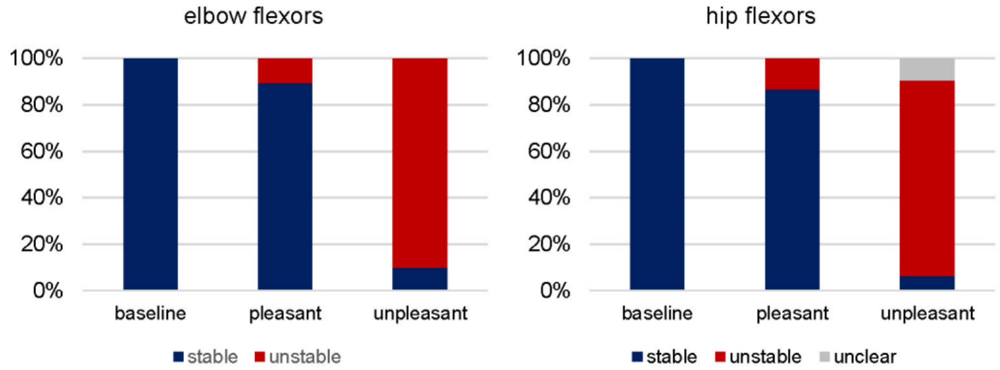

Fig 2. Rating of manual muscle tests by the tester. Displayed are the relative shares of the qualitative rating of all manual muscle tests by the tester (stable = blue, unstable = red, unclear = grey) for baseline (elbow: n = 19, hip: n = 21), pleasant (elbow: n = 29, hip: n = 30), and unpleasant (elbow: n = 30, hip: n = 32) imaginations for elbow (left) and hip flexors (right).

flexors of one participant remained stable for one of the two unpleasant food imaginations (5%), which was in contrast to the hypothesis. All other 19 unblinded MMTs during unpleasant imaginations were rated as unstable (95%), according to the hypothesis. For hip flexors, 20 of the 22 MMTs showed stability during pleasant imaginations (91%), the remaining two were rated as unclear (9%) and pertained to the same participant. During unpleasant imaginations, 21 of 22 unblinded MMTs of hip flexors were assessed as unstable (95.5%), according to the hypothesis; one was rated as unclear (4.5%).

Quality of imagination

The imagination quality was assessed via verbal report and open questions after the measurements and gave an impression on the ability to imagine the food experience. Four participants reported to have difficulties to imagine the food such as for unpleasant ones in general, with repetition of the imaginations, the alternation between pleasant and unpleasant imaginations or because of discrepancies between the assistant's instructions and own imaginations. In all of those four participants, the result of at least one trial was not according to the hypothesis that AF would be stable during pleasant imagination and unstable during unpleasant imaginations (refers to 26% of all trials of those four participants); One of those participants with the highest amount of discrepancies between expected and occurred result of MMT (50% according to hypothesis) showed insecurities during the test by, e.g., excusing herself if the muscle was not stable. It seems that she was irritated by the outcome of MMT in the course of the measurements, especially in case of instability. Two further participants had difficulties to enter the imaginations. They also showed deviations from the hypothesis in 3 of 12 MMTs for hip flexors (25%). Only in two of the remaining 6 participants who report no difficulties to imagine the food experience each one trial of the elbow flexors was not according to the hypothesis; thus, the MMT results of those six participants without imagination difficulties were according to the hypothesis in 97% of all trials. This might indicate that the trials which were not assessed according to the hypothesis could result from the imagination quality rather than from the tester's MMT performance.

Exemplary force and gyrometer signals

Fig 3 exemplifies the force and gyrometer signals of elbow and hip flexors of one participant for baseline, pleasant and unpleasant imaginations. The MMTs were rated as stable for baseline and pleasant imaginations and as unstable for unpleasant ones. The force curves show nearly identical slopes, especially at the beginning, which is considered as the crucial phase for adaptation.[11,41,43] This reflects the high reproducibility of the tester's force application.

The gyrometer signals during unpleasant imaginations (Fig 3, red) show an increase above zero. The related force values at those breaking points mark the maximal holding capacity for unpleasant imaginations ($AFiso_{max}$; elbow: 100 N, hip: 103 N), which is considerably lower than the AFmax of those trials, which were reached during muscle lengthening (AFmax = $AFecc_{max}$; elbow: 138 N, hip: 166 N). Thus, the muscle started to lengthen at 73% and 62%, respectively, of the maximal force capacity. This reflects an inappropriate adaptation. In contrast, the gyrometer signals during baseline (grey) and pleasant imaginations (blue) oscillate around zero throughout the entire force increase, reflecting the quasi-isometric muscle state until the maximum was reached (AFmax = $AFiso_{max}$; elbow: 153 N and 143 N; hip: 185 N and 190 N). Minor lift-offs are related to the slight muscle suspension during MMT, which are accepted due to the freely moveable limb.[41] Consequently, for baseline and during pleasant imaginations muscle lengthening did not occur. However, the same participant was not able to access her maximal holding capacity under the influence of unpleasant imaginations, the muscle gave way during force increase resulting in a considerably lower $AFiso_{max}$ compared to baseline and pleasant imaginations (-32% (elbow) and -45% (hip)). However, the force increases further during muscle lengthening. It is notable for this example that even the AFmax was slightly lower for unpleasant vs. baseline and pleasant imaginations (elbow: ~93 ± 5%; hip: ~89 ± 2%).

The onset of oscillations did not appear as clear as hypothesized on the base of the previous studies. The AFosc during unpleasant imaginations was 138 N and 153 N for elbow and hip flexors, respectively. For baseline and during pleasant imaginations, the AFosc amounted 133 N and 130 N for elbow and 149 N and 190 N for hip flexors, respectively. Nevertheless, for unpleasant imaginations the onset of oscillations appeared clearly after the breaking point,

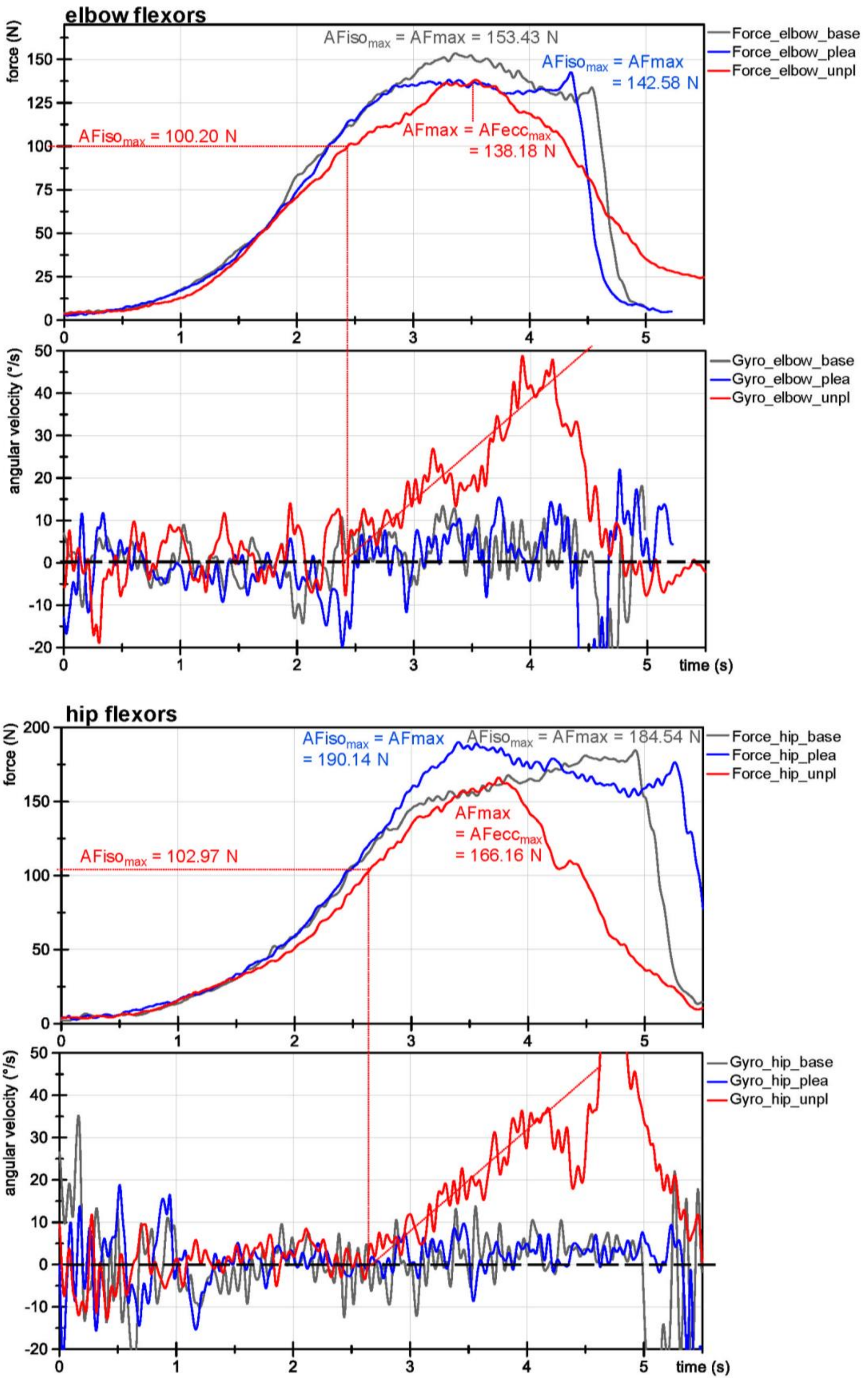

Fig 3. Exemplary signals of Adaptive Force during MMT.

Displayed are force (N) and gyrometer signals (°/s) during MMT of elbow and hip flexors of the same participant (age: 22 yrs., height: 171 cm, body mass: 63 kg) for baseline (grey, base), pleasant (blue; plea) and unpleasant (red; unpl) imaginations. Parameters AFmax, AFecc$_{max}$ and AFiso$_{max}$ are marked.

thus, during muscle lengthening; whereas for baseline and pleasant imaginations, it appeared under isometric conditions (before $AFiso_{max}$ was reached); Exempted from this is the MMT of hip flexors during pleasant imagination, whereby oscillations arose simultaneously to AFmax. This will be discussed later. The results of this example are supported by the following statistical group comparisons. The single values of all parameters of each trial, muscle and participant are given in supplementary material (S3 to S10 Tables).

Slope of force rise

The prerequisite of similar slopes of force rises for elbow and hip flexors are given indicated by a non-significant difference between baseline, pleasant and unpleasant imaginations (elbow: $\chi^2(2) = 0.722$, $p = 0.697$, $n = 10$; hip: $\chi^2(2) = 0.250$, $p = 0.882$, $n = 8$, Fig 4, Table 1, S9 and S10 Tables). Hence, the requirement of reproducible force profiles for comparing the AF parameters between the three conditions was fulfilled.

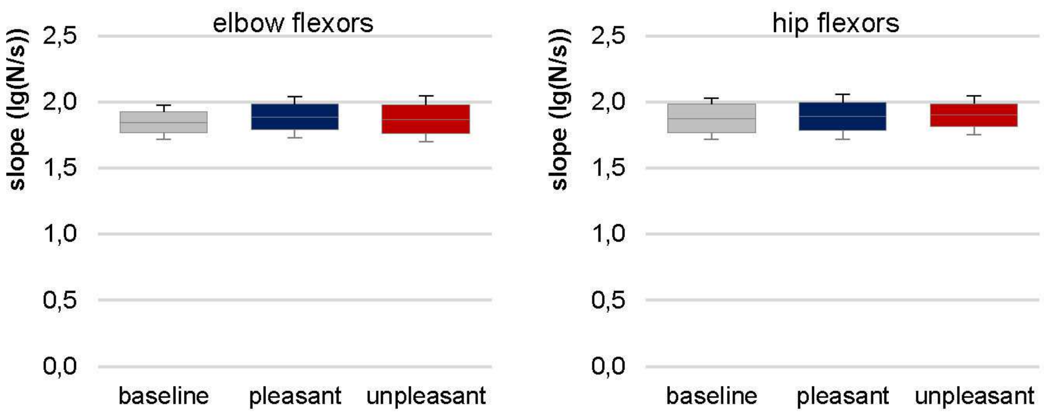

Fig 4. Slope. Arithmetic means, standard deviations (error bars) and 95%-CIs of the logarithmic slope (lg(N/s)) comparing baseline (grey), pleasant (blue) and unpleasant (red) imaginations for elbow (left) and hip flexors (right) are displayed. Statistical comparisons were non-significant (p > 0.05).

Table 1. Arithmetic means (M), standard deviations (SD), lower and upper border of 95%-confidence intervals (CI) as well as p values and effect sizes η^2 or Kendall's W of the AF parameters for baseline, pleasant and unpleasant imaginations of elbow and hip flexors are given.

Parameter	imagination	M ± SD	Borders of 95%-CI	Significance p	η^2 or Kendall's W[b]
			Elbow flexors		
	baseline	156.87 ± 31.83	137.15; 176.60		
AFmax (N)	pleasant	163.15 ± 31.39	143.70; 182.61	0.518	-
	unpleasant	169.26 ± 26.56	152.80; 185.73		
	baseline	156.87 ± 31.83	137.15; 176.60		
$AFiso_{max}$ (N)	pleasant	157.20 ± 30.38	138.38; 176.03	**< 0.0001**	0.720
	unpleasant	90.45 ± 34.20	69.25; 111.64		
Ratio $AFiso_{max}$	baseline	100 ± 0	-		
	pleasant	97.14 ± 5.00	94.04; 100.23	**< 0.0001[b]**	0.936[b]
to AFmax (%)	unpleasant	54.82 ± 21.74	41.34; 68.29		
	baseline	115.93 ± 30.33	97.14; 134.73		
AFosc (N)	pleasant	131.64 ± 34.69	110.14; 153.14	**0.003**	0.478
	unpleasant	161.54 ± 27.54	144.47; 178.62		
Ratio AFosc	baseline	73.67 ± 10.87	66.94; 80.41		
	pleasant	79.59 ± 8.88	74.08; 85.09	**< 0.0001**	0.720
to AFmax (%)	unpleasant	95.16 ± 4.63	92.29; 98.03		
Ratio AFosc	baseline	73.67 ± 10.87	66.94; 80.41		
	pleasant	83.62 ± 14.79	74.45; 92.78	**0.003[a]**	0.626
to $AFiso_{max}$ (%)	unpleasant	217.75 ± 108.72	150.37; 285.14		
	baseline	1.85 ± 0.13	1.77; 1.93		
Slope lg(N/s)	pleasant	1.89 ± 0.16	1.79; 1.98	0.836[b]	-
	unpleasant	1.87 ± 0.17	1.76; 1.98		
			Hip flexors		
	baseline	158.51 ± 18.02	147.86; 169.16		
AFmax (N)	pleasant	168.62 ± 35.01	147.93; 189.31	**0.020**	0.323
	unpleasant	187.02 ± 28.58	170.13; 203.90		
	baseline	157.38 ± 18.24	146.60; 168.16		
$AFiso_{max}$ (N)	pleasant	157.89 ± 33.13	138.31; 177.47	**<0.001**	0.512
	unpleasant	114.20 ± 45.28	87.44; 140.96		
Ratio $AFiso_{max}$	baseline	99.35 ± 2.17	98.06; 100.63		
	pleasant	95.22 ± 6.66	91.29; 99.15	**< 0.0001[b]**	0.890[b]
to AFmax (%)	unpleasant	62.80 ± 23.53	48.90; 76.71		
	baseline	105.51 ± 28.49	88.67; 122.35		
AFosc (N)	pleasant	120.41 ± 34.05	100.29; 140.53	**0.029[a]**	0.367
	unpleasant	137.99 ± 25.86	122.71; 153.27		
Ratio AFosc to	baseline	65.83 ± 13.06	58.11; 73.55		
	pleasant	70.76 ± 15.18	61.79; 79.73	0.168	-
AFmax (%)	unpleasant	74.40 ± 12.18	67.20; 81.60		
Ratio AFosc	baseline	66.40 ± 13.30	58.54; 74.26		
	pleasant	76.27 ± 17.50	65.93; 86.62	0.053[a]	-
to $AFiso_{max}$ (%)	unpleasant	161.17 ± 130.54	84.02; 238.31		
	baseline	1.88 ± 0.16	1.77; 1.98		
Slope lg(N/s)	pleasant	1.89 ± 0.17	1.79; 2.00	0.687[b]	-
	unpleasant	1.90 ± 0.15	1.82; 1.99		

[a]Greenhouse-Geisser correction; [b]Friedman test incl. Kendall's W. Significant results are displayed in bold.

Maximal Adaptive Force of elbow and hip flexors

For elbow flexors, the AFmax showed no significant difference between the three conditions ($F(2,18) = 0.683$, $p = 0.518$), reflecting that AFmax, irrespective if reached during isometric or eccentric muscle action, was similar between baseline, pleasant and unpleasant imaginations (Fig. 5a, Table 1, S3 Table). AFmax during pleasant imaginations was ~5.5 ± 16.6% and during unpleasant imaginations ~12.9 ± 30.4% higher compared to baseline. AFmax during unpleasant imaginations was ~6.6 ± 22.1% higher than AFmax during pleasant imaginations.

For hip flexors, RM ANOVA was significant ($F(2,20) = 4.777$, $p = 0.020$, $\eta^2 = 0.323$) (Fig 5D, Table 1, S4 Table). Pairwise comparisons revealed a just significantly lower AFmax for baseline vs. unpleasant imaginations ($t(10) = -2.928$, $p_{adj} = 0.045$, $d_z = 0.883$). Baseline vs. pleasant and unpleasant vs. pleasant imaginations were non-significant ($p_{adj} = 0.498$ and $p_{adj} = 0.379$, respectively). The AFmax during pleasant imaginations was ~9.46 ± 18.05% and during unpleasant imaginations ~14.84 ± 14.03% higher than the AFmax of baseline. During unpleasant imaginations the AFmax was ~4.13 ± 13.96% higher compared to pleasant imaginations. Since AFmax for unpleasant imaginations was always reached during eccentric muscle action, the decisive parameter for comparison is $AFiso_{max}$.

Maximal isometric Adaptive Force of elbow and hip flexors

For elbow and hip flexors $AFiso_{max}$ was significantly lower during unpleasant vs. pleasant imaginations and vs. baseline (Table 1, Fig 5B, E; S5 and S6 Tables,). No significant difference was found between baseline and pleasant imaginations. The $AFiso_{max}$ during unpleasant imaginations amounted 54.82 ± 21.74% of the related AFmax for elbow and 62.80 ± 23.53%

for hip flexors. During baseline and pleasant imaginations $\frac{AFiso_{max}}{AFmax}$ was 100 ± 0% and 97.14 ± 5.00% for elbow flexors, respectively, and 99.35 ± 2.17% and 95.22 ± 6.66% for hip flexors, respectively (Table 1, Fig 5C, F). Consequently, $\frac{AFiso_{max}}{AFmax}$ differed significantly in Friedman test between the three conditions for both muscles. Bonferroni post-hoc test revealed a significant difference for baseline vs. unpleasant imaginations (elbow: $z = 1.650$, $p_{adj} = 0.001$, $r = 0.52$, $n = 10$; hip: $z = 1.636$, $p_{adj} < 0.001$, $r = 0.49$, $n = 11$) and for pleasant vs. unpleasant imaginations (elbow: $z = 1.350$, $p_{adj} = 0.008$, $r = 0.43$, $n = 10$; hip: $z = 1.364$, $p_{adj} = 0.004$, $r = 0.41$, $n = 11$). Baseline vs. pleasant imaginations were non-significant (elbow: $z = 0.300$, $p_{adj} = 1.000$; hip: $z = 0.273$, $p_{adj} = 1.000$).

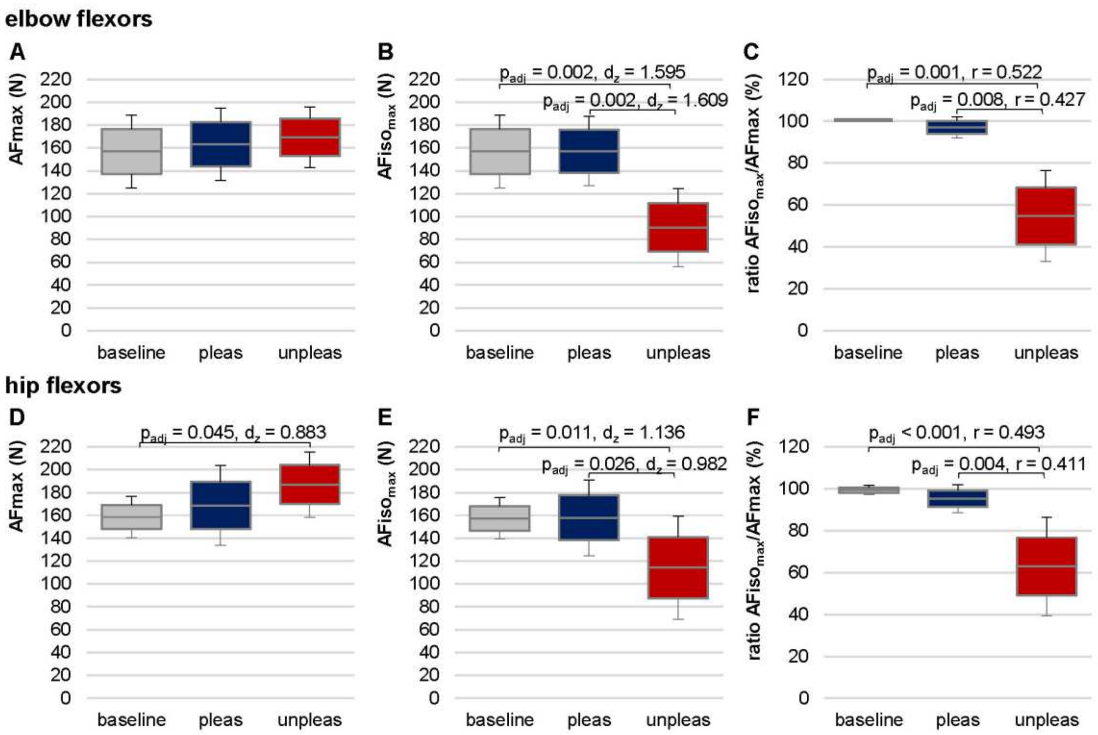

Fig 5. Maximal Adaptive Force and maximal isometric Adaptive Force.
Arithmetic means, standard deviations (error bars) and 95%-CIs of the maximal Adaptive Force (AFmax; (A),(D)), the maximal isometric Adaptive Force ($AFiso_{max}$; (B),(E)) and their ratio ((C),(F)) compared between baseline (grey), pleasant (pleas, blue) and unpleasant (unpleas, red) imaginations for elbow ((A) to (C)) and hip flexors ((D) to (F)) are displayed. Adjusted p values (Bonferroni correction) and effect sizes (Cohen's d_z or Pearson's r) are given in case of significance.

The overall maximal value of AF (maxAFmax) amounted averagely 202.43 ± 31.31 N for elbow (n = 10) and 216.82 ± 25.67 N for hip flexors (n = 11). Taking the individual maxAFmax values (S3 and S4 Tables) as references (closest to the participant's maximal strength), the $AFiso_{max}$ of elbow flexors amounted ~78.31 ± 16.50% of maxAFmax for baseline and ~77.79 ± 10.95% for pleasant imaginations, which was significantly higher than for unpleasant imaginations (~44.79 ± 16.54%; $F(2,18) = 28.105$, $p < 0.00001$, $\eta^2 = 0.757$); similar for hip flexors: $\frac{AFiso_{max}}{maxAFmax}$ = 73.34 ± 11.25%, 73.00 ± 14.35% and 52.76 ± 19.78% for baseline, pleasant and unpleasant imaginations, respectively ($F(2,20) = 11.678$, $p < 0.001$, $\eta^2 = 0.539$). For both muscles, pairwise comparisons showed significantly lower $\frac{AFiso_{max}}{maxAFmax}$ for unpleasant vs. pleasant imaginations (elbow: $t(9) = -5.684$, $p_{adj} = 0.001$, $d_z = 1.798$; hip: $t(10) = -3.471$, $p_{adj} = 0.018$, $d_z = 1.047$) as well as for unpleasant imaginations vs. baseline (elbow: $t(9) = -5.559$, $p_{adj} = 0.001$, $d_z = 1.758$; hip: $t(10) = -3.888$, $p_{adj} = 0.005$, $d_z = 1.172$), whereby it was non-significant for pleasant imaginations vs. baseline (both muscles: $p_{adj} = 1.000$).

The results clearly show that the participants were not able to appropriately adapt to the external increasing force in an isometrically holding manner by imagining unpleasant food experiences. The maximal holding capacity was reduced so that the muscles gave way at a significantly lower force level compared to baseline and pleasant imaginations. Comparing the results of $AFiso_{max}$ to the tester's MMT ratings, a high agreement is visible. The MMTs rated as stable showed a ratio of $\frac{AFiso_{max}}{AFmax}$ = 100.00 ± 0.00% for elbow and 99.74 ± 0.87% for hip flexors, whereas for unstable rated MMTs it was 51.36 ± 18.25% and 58.34 ± 21.08%, respectively. This indicates the data evaluation of the handheld device supports the tester's ratings.

Adaptive Force at the onset of oscillations

For elbow flexors, AFosc was significantly lower for baseline and pleasant vs. unpleasant imaginations (Fig 6, Table 1, S7 Table). For baseline and during pleasant imaginations, the oscillations arose at 73.67 ± 10.87% and 79.59 ± 8.88% of AFmax, respectively, which was on a significantly lower level than for unpleasant imaginations (95.16 ± 4.63%; baseline vs. unpleasant: $t(9) = -5.747$, $p_{adj} = 0.001$, $d_z = 1.817$, pleasant vs. unpleasant: $t(9) = -5.457$, $p_{adj} = 0.001$, $d_z = 1.726$). The ratio $\frac{AFosc}{AFiso_{max}}$ demonstrated that the oscillations for baseline and pleasant imaginations appeared during the force increase before $AFiso_{max}$ was reached (averaged over both groups: 78.64 ± 13.62%), whereby during unpleasant imaginations they appeared – if at all – after the breaking point for each participant (217.76 ± 108.72%).

For hip flexors, the results showed a slightly different behavior. RM ANOVA was significant in comparing baseline, pleasant and unpleasant imaginations ($F_{Green}(1.19,11.85) = 5.804$, $p = 0.029$, $\eta^2 = 0.367$). Although AFosc was highest during unpleasant imaginations, pairwise comparison of pleasant vs. unpleasant imaginations did not differ significantly (Bonferroni correction: $p_{adj} = 0.591$). Nevertheless, AFosc was significantly lower for baseline vs. unpleasant imaginations (Table 1, S8 Table; $t(10) = -3.665$, $p_{adj} = 0.013$, $d_z = 1.105$). The ratio $\frac{AFosc}{AFiso_{max}}$ amounted 66.40 ± 13.30%, 76.27 ± 17.50% and 161.17 ± 130.54% for baseline, pleasant, and unpleasant imaginations, respectively. This reflects the high variation of the oscillatory onset related to the breaking point for unpleasant imaginations, which is visible in the 95%-CIs (Fig 6F). RM ANOVA comparing $\frac{AFosc}{AFiso_{max}}$ for baseline, pleasant and unpleasant imaginations just missed significance after required Greenhouse-Geisser correction ($F_{Green}(1.019,10.190) = 4.747$, $p = 0.053$, 0.322).

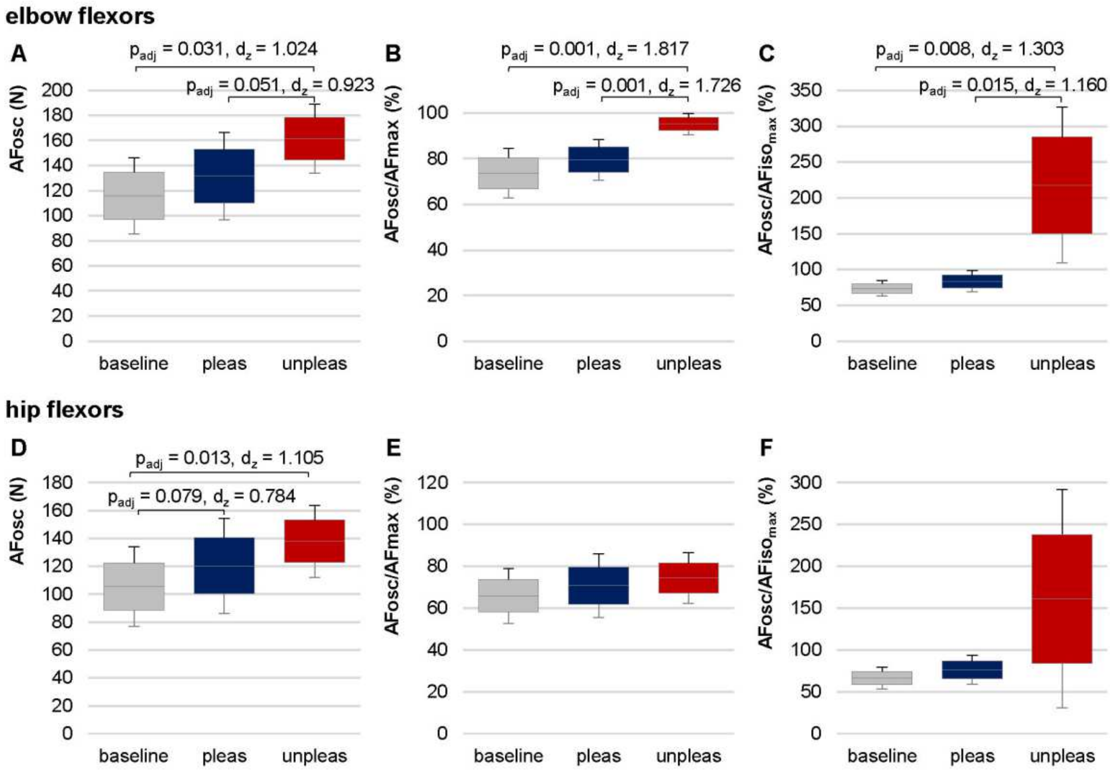

Fig 6. Adaptive Force at the onset of oscillations.

Arithmetic means, standard deviations (error bars) and 95%-CIs of the Adaptive Force at the onset of oscillations (AFosc (N); (A),(D)) and the ratios of AFosc to AFmax (%) ((B),(E)) and to $AFiso_{max}$ (%) ((C),(F)) compared between baseline (grey), pleasant (pleas, blue) and unpleasant (unpleas, red) imaginations for elbow flexors ((A) to (C)) and hip flexors ((D) to (F)) are displayed. Adjusted p values (Bonferroni correction) and effect sizes Cohen's d_z are given in case of significance.

Case example: Adaptive Force under current stress vs. positive imaginations

One female participant (28 years, 174 cm, 69 kg) initially showed an impaired neuromuscular function in preliminary MMTs. A brief talk revealed she experienced current stress (time pressure, several exams ahead). The initial instability of her muscles could be repealed immediately by positive imaginations (yoga or victory in kickboxing competition; both good feelings of relaxation and strength). Therefore, we decided spontaneously to perform the AF measurements of elbow and hip flexors using the negative imagination (exam situation) vs. the positive one (yoga/kickboxing) randomized and single-blinded (each 3x per muscle, same setting as above but without baseline). For negative imaginations, the elbow flexors showed an unstable behavior in 2 of 3 trials, in one trial the MMT was rated as stable despite of negative imagination. For positive imaginations, the elbow flexors were rated as stable for all trials. For hip flexors, all three trials during negative imagination were unstable, for positive imagination, the first two trials were assessed as stable and the last one as unstable. Fig 7 displays exemplary measuring curves of force and gyrometer signals for elbow and hip flexors during positive (blue) and negative imaginations (red). The tester's MMT ratings were again confirmed by the recorded data of the handheld device.

$\frac{AFiso_{max}}{AFmax}$ for elbow flexors was 62 ± 37% for negative and 100 ± 0% for positive imaginations. For hip flexors it amounted to 40 ± 9% (negative) and 84 ± 27% (positive). $\frac{AFosc}{AFiso_{max}}$ for elbow flexors was 189 ± 177% and 49 ± 5% for negative and positive imaginations, respectively, and for hip flexors 201 ± 25% and 93 ± 61%, respectively. Summarizing, the holding capacity ($AFiso_{max}$) was considerably reduced during negative imaginations, which was also the entry state of the participant. By imagining positive experiences, the holding capacity was immediately improved, indicating a regular neuromuscular function. The oscillatory onset in stable MMTs occurred before and for unstable MMTs after $AFiso_{max}$ was reached.

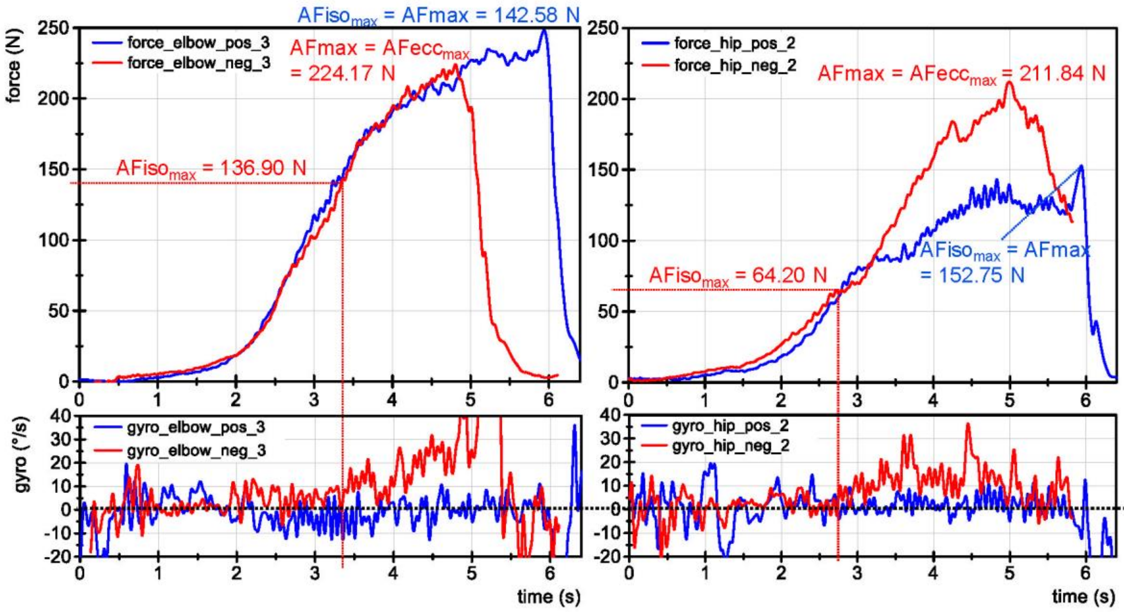

Fig 7. Exemplary signals of case example.
Displayed are the force (N) and gyrometer signals (°/s) of the manual muscle test of elbow (left) and hip (right) flexors of the same participant (age: 27 yrs., height: 174 cm, body mass: 69 kg) during positive (blue; pos) and negative (red; neg) emotionally affective imaginations. Marked are the parameters AFmax, $AFecc_{max}$ and $AFiso_{max}$.

Discussion

The aim of the present study was to verify previous findings regarding the influence of pleasant and unpleasant emotionally affective imaginations on different AF parameters of elbow and hip flexors in an improved design including randomization, single-blinding and baseline measurements. Since the force rises (slope) did not differ significantly between baseline, pleasant and unpleasant imaginations, the subsequently discussed findings are based on reproducible force rises and, thus, similar performances of the tester's force application.

It was hypothesized the MMTs would be rated as stable for baseline and pleasant imaginations and as unstable for unpleasant ones. For elbow flexors, this was the case in 100% for baseline and ~90% for pleasant as well as for unpleasant imaginations; for hip flexors, 95%, 87% and 84%, respectively, were assessed according to this hypothesis, whereby for unpleasant imaginations, three MMTs (5%) were classified as unclear. Those ratings of blinded MMTs differed not considerably compared to the non-blinded ones assessed without handheld device after the objectified AF measurements. The missing blinding was the main limitation of the previous study. However, 88% of all 121 blinded MMTs (baseline measurements are excluded) and 95% of all 84 unblinded MMTs were rated according to the hypotheses in this study. Thus, even though the tester did not know which imagination was performed, the subjective rating of MMTs supported the hypothesis in the vast majority of trials. On that base it can be stated that blinding did not lead to a considerably different MMT rating by the tester compared to non-blinding. Some limitations regarding imagination quality (mentioned above) must be considered which possibly led to the deviating results.

The main hypothesis of this study was supported by the results: the muscles started to give way on a clearly and significantly lower force ($AFiso_{max}$) during unpleasant imaginations compared to pleasant ones and baseline measurements. Since the $AFiso_{max}$ reflects the adaptive capacity of the neuromuscular system during holding isometric muscle action, this result indicates that unpleasant imaginations result in a worse adaptation capacity in healthy participants, irrespective of the regarded muscle. Under the assumption that unpleasant food imaginations are related to the negative emotion disgust, this suggests that such negative emotions might affect the motor control in the sense of isometric AF also in healthy participants. The value of this finding will be discussed later.

The second hypothesis was mainly confirmed by the results. The AFmax did not differ between baseline, pleasant and unpleasant imaginations for elbow flexors. For hip flexors, however, the

AFmax was just significantly higher for unpleasant imaginations vs. baseline. Since the limb's position was stable for all baseline measurements (AFmax = $AFiso_{max}$), the lower AF is due to the lower maximally applied force by the tester. Therefore, the adaptive capability of the participant was not challenged by higher forces. However, one outlier existed which might have led to the significant result: the baseline AFmax of one participant was clearly lower compared to the respective AFmax during unpleasant imaginations (116.66 N vs. 193.98 N). By excluding this participant, baseline vs. unpleasant imaginations differed not significantly ($p_{adj} = 0.096$). As mentioned in the methods, the tester stops the force increase if an oscillatory equilibrium between tester and participant is reached on a considerably high force level. Looking at the onset of oscillations for the baseline trials of this participant, oscillations already arose at 58.02 N, which was the lowest of all participants. Those oscillations might have caused a feeling of stability which, in turn, led to termination of force rise by the tester. The essential result is, however, that the AF under isometric conditions was significantly lower for unpleasant imaginations, despite of AFmax.

Regarding the third hypothesis (onset of oscillations), the results for AFosc of elbow flexors confirmed the first study since oscillations appeared at a significantly higher AF during unpleasant vs. pleasant imaginations and baseline; furthermore, during unpleasant imagination they appeared – if at all – after the breaking point for each participant, thus during muscle lengthening. For hip flexors a deviating behavior was found for some participants. A trend according to the hypothesis was visible, e.g., AFosc for baseline was significantly lower than for unpleasant imaginations. During pleasant vs. unpleasant imaginations, AFosc differed not significantly, however, the results were close to significance (p_{adj} = 0.079). However, three participants showed a low AFosc also during unpleasant imaginations. It was visible, thereby, that the oscillations were not as clear and as constant as for pleasant imaginations and baseline. This might highlight some methodological limitations for AFosc evaluation.

Limitations

Although the study design of the present study was improved compared to the previous one and included single-blinding, randomization and baseline measurements, some limitations especially regarding the evaluation should be considered. The evaluation of the oscillatory onset (AFosc) was adopted from the previous study and is based on the criterion that four consecutive maxima in force rise with a time distance d_x < 0.15 s must arise. This was chosen, since mechanical muscular oscillation are known to show low-frequencies around 10 Hz. The amplitude and concrete frequency of those oscillations were not considered thereby. As above-mentioned, in some cases a clear swing up was missing, although four consecutive maxima were present. Therefore, the algorithm of oscillatory onset ought to be revised. From a visual inspection, the frequency and the amplitude seem to differ between stable and unstable MMTs. Therefore, probably a power-frequency analysis could be applied in further studies.

Another limitation might be that the quality of imagination was not assessed quantitatively. The self-report after the measurements gave an impression on how good the participant interpreted their ability to imagine the food experience. Some participants had difficulties to imagine the food as above-mentioned. This might have led to deviations regarding the stability of AF.

However, the aim was not to quantify the quality of imagination but their effect on AF in healthy persons in general. Therefore, they were included.

Possible limitations concerning MMT performance were previously described,[11,41] especially regarding the maximal value and slope of force application. The hip flexors showed a slightly but still significantly lower AFmax for baseline measurements vs. unpleasant imagination trials in this study (discussed above), which was not expected. This is presumably a result from the lower maximal force applied by the tester, probably because of perceiving the mutual oscillations already on a low force level. Since the crucial parameter is the AF under isometric conditions ($AFiso_{max}$), which was still clearly and significantly lower during unpleasant imagination, the lower AFmax of hip flexors for baseline can be neglected here.

Neurophysiological considerations of muscular adaptations and practical applications

A detailed proposed explanation of neurophysiological processing during AF was previously given.[11,41,43] It is assumed that the here performed pleasant and unpleasant imaginations trigger positive (pleasure) and negative emotions (disgust), respectively. This is in accordance with other authors.[25,53]

Since several central structures are involved in processing motor control as well as emotions,[5–10] the influence of emotions on motor control are conceivable. However, as mentioned in the introduction, only few studies investigated the influence of positive and negative emotions on muscular activity in healthy participants.[12,25,32] It is suggested that the AF, especially the isometric AF (holding capacity), characterizes a particular functioning of the neuromuscular control which seems to be highly sensitive to interfering inputs. Because not only emotional states are affecting motor processing but also various afferences like, e.g., nociception, it is suggested that the AF could be also influenced by other disturbing factors.

Based on the findings, negative imaginations apparently result in a substantial muscular instability even in healthy participants. It can only be assumed how stressful situations and traumas influence the AF. If stress is persisting (at work, relationships, conditions after traumatic experiences, e.g., accidents, death of related persons or alike), we expect a permanently impaired holding function in the sense of $AFiso_{max}$. This is based on own experience of long-term clinical practice and is supported by the present findings. In daily activities and sports, the adaptive capacity of the neuromuscular system is necessary for joint stabilization. In case it is reduced, joints could suffer from inappropriate joint alignment under strain, which might result in pain and probably leads to degeneration or increased danger of injury. This could explain the still poorly understood “overuse”-injuries and might clarify the causal chain regarding the joint appearance of musculoskeletal pain and mental stress. From our point of view, mental problems lead to an impaired neuromuscular control which, in turn, can result in complaints of the musculoskeletal system. The results of the present investigation underpin this hypothesis, since already healthy participant showed a reduced muscular holding capacity even by just imagining unpleasant food experiences. This effect was only temporary and could be reversed immediately by imagining pleasant experiences. It is hypothesized that the muscular stability in the sense of $AFiso_{max}$ in persons suffering from chronic mental stress might be impaired permanently. Furthermore, we assume that a positive effect on muscular stability could be gained by imagining positive situations in those persons. The presented case example supports those hypotheses, since the participant showed a muscular instability in entry state, whereby she reported to currently perceive mental stress. Positive imaginations improved the $AFiso_{max}$ of this participant immediately. Therefore, the AF assessment seems to be suitable to evaluate this effect and to test which imagination can improve the holding capacity since this particular muscular function can instantaneously change. It can only be assumed if other bodily systems – like autonomous nervous, endocrine, immune system – behave similarly and would switch from a dysfunction into normal regulation. The underlying potential of such an approach can be imagined thereby.

Characterization of 'stable' vs. 'unstable' adaptation

In the previous studies investigating the AF behavior regarding pleasant and unpleasant imaginations/odors,[11,41] values characterizing stable and unstable adaptation were proposed. Including the findings of this study, the suggested values can be extended. In the following, the data of all three studies are included. Stable adaptation seems to be characterized by a high $AFiso_{max} \approx$ AFmax ($\geqslant$ 99% of AFmax), indicating the muscle length stays quasi-isometric during the entire force increase. Unstable adaptation, in turn, shows a significantly lower $AFiso_{max} \approx$ 56% of AFmax, reflecting that the muscle starts to lengthen on a significantly lower force during adaptation. Furthermore, during stable adaptation oscillations occur at a force level of ~74% of AFmax, in turn, for unstable adaptation they appear at ~88% of AFmax. In the previous studies and for elbow flexors in the present study, the onset of oscillations for unstable adaptation was on a higher force level (~95%). It is not clear, why the oscillations under unstable conditions for hip flexors in the present study arose on a low force level (~75%). Hereby, as above-mentioned, the evaluation or possibly the participant's regulatory state might play a role. However, it seems to be more important if oscillations arise before or after the breaking point ($\frac{AFosc}{AFiso_{max}}$). Considering the data of all three studies, 183 stable and 124 unstable MMTs were recorded during AF assessment. In 177 stable trials (96.9%) oscillations occurred before $AFiso_{max}$, thus, under isometric conditions; in 108 unstable trials (87.4%) the oscillations arose after the breaking point, thus, during muscle lengthening. Again the here presented unstable trials of hip flexors showed a different behavior, whereby in only 58.1% the oscillations occurred after the breaking point (for comparison: elbow flexors: 96.7%; both other studies: 94.7%, 100%). The previous studies also included the hip flexors, so the investigated muscle seems not to be the reason for the deviation. Speculations on other possible causes are not appropriate at this point. Nevertheless, the occurrence of oscillations might be a prerequisite for stability during muscular adaptation. Further investigations remain.

Conclusion

The present study investigated the motor adaptation in the sense of AF in reaction to emotionally affective imaginations in a single-blinded, randomized setting. The findings support the previous results: the maximal holding capacity ($AFiso_{max}$) was reduced highly significantly by imagining unpleasant food experiences. The conclusion thereof was that negative emotions such as disgust seem to lead to muscular instability. Assuming this might lead to a joint destabilization under strain, it could pave the way for explaining the causal chain regarding the link between musculoskeletal pain and mental health states. It is proposed that an impaired holding function due to mental stress could lead to musculoskeletal pain.

Investigating the adaptive holding function might be a promising innovative approach to get insights into psychomotor states and to support diagnostics of mental health conditions. The instantaneous change of stability as reaction to positive or negative stimuli might further help to determine purposeful therapies. This might open up innovative and highly beneficial possibilities regarding psychological diagnostic and treatment approaches. Further research is needed to examine this hypothesis.

Moreover, the collected data until now suppose that a proper “regular” neuromuscular adaptation might be characterized by oscillations. This provides novel insights into neuromuscular control. Further research is needed to investigate if they could be a prerequisite for reacting and adapting adequately to external forces.

Acknowledgments: We acknowledge the support of the International College of Applied Kinesiology (ICAK-US) by supporting our investigations by a donation. The above-mentioned development project of the handheld device ran in cooperation with StatConsult (Magdeburg, Germany). Furthermore, we would like to thank the second student assisting the study and all participants for the interest and contribution to our research.

References

1. Scherer KR, Moors A. The Emotion Process: Event Appraisal and Component Differentiation. Annu Rev Psychol. 2019;70: 719–745. doi:10.1146/annurev-psych-122216-011854

2. Moors A, Ellsworth PC, Scherer KR, Frijda NH. Appraisal Theories of Emotion: State of the Art and Future Development. Emotion Review. 2013;5: 119–124. doi:10.1177/1754073912468165

3. Pert CB, Dreher HE, Ruff MR. The psychosomatic network: foundations of mind-body medicine. Altern Ther Health Med. 1998;4: 30–41.

4. Pert CB. Molecules of emotion: why you feel the way you feel. 1999. Available: https://www.overdrive.com/search?q=E997839D-A022-4F0E-A653-045C182CE931

5. Vogt BA, Nimchinsky EA, Vogt LJ, Hof PR. Human cingulate cortex: Surface features, flat maps, and cytoarchitecture. J Comp Neurol. 1995;359: 490–506. doi:10.1002/cne.903590310

6. Groenewegen HJ. The Basal Ganglia and Motor Control. Neural Plasticity. 2003;10: 107–120. doi:10.1155/NP.2003.107

7. Vogt BA, Finch DM, Olson CR. Functional Heterogeneity in Cingulate Cortex: The Anterior Executive and Posterior Evaluative Regions. Cereb Cortex. 1992;2: 435–443. doi:10.1093/cercor/2.6.435-a

8. Doya K. Complementary roles of basal ganglia and cerebellum in learning and motor control. Current Opinion in Neurobiology. 2000;10: 732–739. doi:10.1016/S0959-4388(00)00153-7

9. O'Halloran CJ, Kinsella GJ, Storey E. The cerebellum and neuropsychological functioning: A critical review. Journal of Clinical and Experimental Neuropsychology. 2012;34: 35–56. doi:10.1080/13803395.2011.614599

10. Başar E. A review of alpha activity in integrative brain function: Fundamental physiology, sensory coding, cognition and pathology. International Journal of Psychophysiology. 2012;86: 1–24. doi:10.1016/j.ijpsycho.2012.07.002

11. Schaefer LV, Dech S, Bittmann FN. Adaptive Force and emotionally related imaginations – preliminary results suggest a reduction of the maximal holding capacity as reaction to disgusting food imagination. Heliyon. 2021;7: e07827. doi:https://doi.org/10.1016/j.heliyon.2021.e07827

12. Burns JW. Arousal of negative emotions and symptom-specific reactivity in chronic low back pain patients. Emotion. 2006;6: 309–319. doi:10.1037/1528-3542.6.2.309

13. Gerhart JI, Burns JW, Bruehl S, Smith DA, Post KM, Porter LS, et al. Variability in negative emotions among individuals with chronic low back pain: relationships with pain and function. Pain. 2018;159: 342–350. doi:10.1097/j.pain.0000000000001102

14. Lumley MA, Cohen JL, Borszcz GS, Cano A, Radcliffe AM, Porter LS, et al. Pain and emotion: a biopsychosocial review of recent research. J Clin Psychol. 2011;67: 942–968. doi:10.1002/jclp.20816

15. Tan G, Jensen MP, Thornby J, Sloan PA. Negative emotions, pain, and functioning. Psychological Services. 2008;5: 26–35. doi:10.1037/1541-1559.5.1.26

16. Wiech K, Tracey I. The influence of negative emotions on pain: Behavioral effects and neural mechanisms. NeuroImage. 2009;47: 987–994. doi:10.1016/j.neuroimage.2009.05.059

17. Firth J, Siddiqi N, Koyanagi A, Siskind D, Rosenbaum S, Galletly C, et al. The Lancet Psychiatry Commission: a blueprint for protecting physical health in people with mental illness. The Lancet Psychiatry. 2019;6: 675–712. doi:10.1016/S2215-0366(19)30132-4

18. Wade JB, Price DD, Hamer RM, Schwartz SM, Hart RP. An emotional component analysis of chronic pain. Pain. 1990;40: 303–310. doi:10.1016/0304-3959(90)91127-5

19. Pinheiro MB, Ferreira ML, Refshauge K, Colodro-Conde L, Carrillo E, Hopper JL, et al. Genetics and the environment affect the relationship between depression and low back pain: a co-twin control study of Spanish twins. Pain. 2015;156: 496–503. doi:10.1097/01.j.pain.0000460330.56256.25

20. Haukkal E, Leino-Arjasl P, Ojajärvil A, Takalal E-P, Viikari-Juntural E, Riihimäkil H. Mental stress and psychosocial factors at work in relation to multiple-site musculoskeletal pain: A longitudinal study of kitchen workers. European Journal of Pain. 2011;15: 432–438. doi:10.1016/j.ejpain.2010.09.005

21. Wippert P-M, Wiebking C. Stress and Alterations in the Pain Matrix: A Biopsychosocial Perspective on Back Pain and Its Prevention and Treatment. IJERPH. 2018;15: 785. doi:10.3390/ijerph15040785

22. Arsalan A, Anwar SM, Majid M. Mental Stress Detection using Data from Wearable and Non-wearable Sensors: A Review. 2022 [cited 3 Mar 2022]. doi:10.48550/ARXIV.2202.03033

23. Pourmohammadi S, Maleki A. Stress detection using ECG and EMG signals: A comprehensive study. Computer Methods and Programs in Biomedicine. 2020;193: 105482. doi:10.1016/j.cmpb.2020.105482

24. Wijsman J, Grundlehner B, Penders J, Hermens H. Trapezius muscle EMG as predictor of mental stress. ACM Trans Embed Comput Syst. 2013;12: 1–20. doi:10.1145/2485984.2485987

25. Scheer C, Kubowitsch S, Dendorfer S, Jansen P. Happy Enough to Relax? How Positive and Negative Emotions Activate Different Muscular Regions in the Back - an Explorative Study. Front Psychol. 2021;12: 511746. doi:10.3389/fpsyg.2021.511746

26. Lundberg U, Kadefors R, Melin B, Palmerud G, Hassmén P, Engström M, et al. Psychophysiological stress and emg activity of the trapezius muscle. Int J Behav Med. 1994;1: 354–370. doi:10.1207/s15327558ijbm0104_5

27. Luijcks R, Hermens HJ, Bodar L, Vossen CJ, Os J van., Lousberg R. Experimentally Induced Stress Validated by EMG Activity. Macaluso A, editor. PLoS ONE. 2014;9: e95215. doi:10.1371/journal.pone.0095215

28. Gelauff J, Stone J, Edwards M, Carson A. The prognosis of functional (psychogenic) motor symptoms: a systematic review. Journal of Neurology, Neurosurgery & Psychiatry. 2014;85: 220–226. doi:10.1136/jnnp-2013-305321

29. Stone J, Warlow C, Sharpe M. The symptom of functional weakness: a controlled study of 107 patients. Brain. 2010;133: 1537–1551. doi:10.1093/brain/awq068

30. Stone J, Warlow C, Deary I, Sharpe M. Predisposing Risk Factors for Functional Limb Weakness: A Case-Control Study. JNP. 2020;32: 50–57. doi:https://doi.org/10.1176/appi.neuropsych.19050109

31. Stone J, Warlow C, Sharpe M. Functional weakness: clues to mechanism from the nature of onset. J Neurol Neurosurg Psychiatry. 2012;83: 67–69. doi:10.1136/jnnp-2011-300125

32. Rodríguez GS, Monroy Antón AJ. Effect of induced emotions on strength in older people. Scientific Research and Essays. 2011;6: 5369–5373. doi:https://doi.org/10.5897/SRE11.1363

33. Mehta RK, Agnew MJ. Influence of mental workload on muscle endurance, fatigue, and recovery during intermittent static work. Eur J Appl Physiol. 2012;112: 2891–2902. doi:10.1007/s00421-011-2264-x

34. Yoon T, Keller ML, De-Lap BS, Harkins A, Lepers R, Hunter SK. Sex differences in response to cognitive stress during a fatiguing contraction. Journal of Applied Physiology. 2009;107: 1486–1496. doi:10.1152/japplphysiol.00238.2009

35. Schaefer LV, Bittmann FN. Are there two forms of isometric muscle action? Results of the experimental study support a distinction between a holding and a pushing isometric muscle function. BMC Sports Sci Med Rehabil. 2017;9: 11. doi:10.1186/s13102-017-0075-z

36. Schaefer LV, Bittmann FN. Two forms of isometric muscle function: Interpersonal motor task supports a distinction between a holding and a pushing isometric muscle action. 2020 Aug. doi:10.1101/2020.08.17.253633

37. Hunter SK, Ryan DL, Ortega JD, Enoka RM. Task Differences With the Same Load Torque Alter the Endurance Time of Submaximal Fatiguing Contractions in Humans. Journal of Neurophysiology. 2002;88: 3087–3096. doi:10.1152/jn.00232.2002

38. Rudroff T, Kalliokoski KK, Block DE, Gould JR, Klingensmith WC, Enoka RM. PET/CT imaging of age- and task-associated differences in muscle activity during fatiguing contractions. Journal of Applied Physiology. 2013;114: 1211–1219. doi:10.1152/japplphysiol.01439.2012

39. Rudroff T, Barry BK, Stone AL, Barry CJ, Enoka RM. Accessory muscle activity contributes to the variation in time to task failure for different arm postures and loads. Journal of Applied Physiology. 2007;102: 1000–1006. doi:10.1152/japplphysiol.00564.2006

40. Rudroff T, Justice JN, Holmes MR, Matthews SD, Enoka RM. Muscle activity and time to task failure differ with load compliance and target force for elbow flexor muscles. Journal of Applied Physiology. 2011;110: 125–136. doi:10.1152/japplphysiol.00605.2010

41. Schaefer LV, Dech S, Aehle M, Bittmann FN. Disgusting odours affect the characteristics of the Adaptive Force in contrast to neutral and pleasant odours. Sci Rep. 2021;11: 16410. doi:10.1038/s41598-021-95759-0

42. Dech S, Bittmann FN, Schaefer LV. Assessment of the Adaptive Force of Elbow Extensors in Healthy Subjects Quantified by a Novel Pneumatically Driven Measurement System with Considerations of Its Quality Criteria. Diagnostics. 2021;11: 923. doi:10.3390/diagnostics11060923

43. Bittmann FN, Dech S, Aehle M, Schaefer LV. Manual Muscle Testing—Force Profiles and Their Reproducibility. Diagnostics. 2020;10: 996. doi:10.3390/diagnostics10120996

44. Schaefer LV, Torick AH, Matuschek H, Holschneider M, Bittmann FN. Synchronization of Muscular Oscillations Between Two Subjects During Isometric Interaction. Eur J Transl Myol. 2014;24: 2237. doi:10.4081/ejtm.2014.2237

45. Schaefer LV, Bittmann FN. Two forms of isometric muscle function: Interpersonal motor task supports a distinction between a holding and a pushing isometric muscle action. Physiology; 2020 Aug. doi:10.1101/2020.08.17.253633

46. Conable KM, Rosner AL. A narrative review of manual muscle testing and implications for muscle testing research. Journal of Chiropractic Medicine. 2011; S1556370711000903. doi:10.1016/j.jcm.2011.04.001

47. Beck T. Applications of mechanomyography for examining muscle function. Editor Travis W Beck; 2010. Available: https://issuu.com/researchsignpost/docs/beck/63

48. McAuley JH. Physiological and pathological tremors and rhythmic central motor control. Brain. 2000;123: 1545–1567. doi:10.1093/brain/123.8.1545

49. Cohen J. A power primer. Psychological Bulletin. 1992;112: 155–159. doi:10.1037/0033-2909.112.1.155

50. Sullivan GM, Feinn R. Using Effect Size—or Why the *P* Value Is Not Enough. Journal of Graduate Medical Education. 2012;4: 279–282. doi:10.4300/JGME-D-12-00156.1

51. Khan A, Rayner GD. Robustness to non-normality of common tests for the many-sample location problem. Journal of Applied Mathematics and Decision Sciences. 2003;7: 187–206.

52. Blanca MJ, Alarcón R, Arnau J. Non-normal data: Is ANOVA still a valid option? Psicothema. 2017; 552–557. doi:10.7334/psicothema2016.383

53. Illouz E. Emotions, Imagination and Consumption: A new research agenda. Journal of Consumer Culture. 2009;9: 377–413. doi:10.1177/1469540509342053

Supporting information captions: S1 Table: Anthropometric data; S2 Table: Tester's ratings of manual muscle tests; S3 Table: Maximum Adaptive Force (AFmax) of elbow flexors; S4 Table: Maximum Adaptive Force (AFmax) of hip flexors; S5 Table: Maximum isometric Adaptive Force ($AFiso_{max}$) of elbow flexors, S6 Table: Maximum isometric Adaptive Force ($AFiso_{max}$) of hip flexors; S7 Table: Adaptive Force at onset of oscillations (AFosc) of elbow flexors; S8 Table: Adaptive Force at onset of oscillations (AFosc) of hip flexors; S9 Table: Slope of force rise of elbow flexors; S10 Table: Slope of force rise of hip flexors.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.pdf