Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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The effect of intensity and stroke rate on timing and coordination during ergometer rowing

Master's thesis in Human Movement Science
Supervisor: Gertjan Ettema, co-supervisor: Jørgen Danielsen
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Abstract

Purpose**:** The purpose of the present study is to examine the individual and combined effect of intensity and stroke rate on mechanical and electromyographic (EMG) output (i.e., magnitude, timing events and time profiles) during ergometer rowing. Furthermore, the analysis allows to establish whether the coordination of muscle activity is influenced by condition such as applied in competition and training (i.e., preferred intensity and stroke rate combinations), and how this is reflected in the mechanical force and power pattern of the foot-stretcher and handle.

Method**:** 12 high level rowers (age 23.8 (±1.8) years, body height 189.2 (±5.2) cm and body weight 92.3 (±8.6) kg) performed a 1.5-minute session at competition intensity with freely chosen stroke rate (HH) at the same relative intensity. The HH trail defined the moderate (75%) and low intensity (55%), subsequently establishing preferred stroke rate at the two different intensities (MM and LL respectively). The preferred conditions (HH, MM and LL) were mixed (intensity and stroke rate), leading to six more trials and a total of nine (3x3) intensity-stroke rate combinations. 3D kinematics, dynamics and EMG (of eight muscles) data were recorded to measure timing mechanical variables (i.e., amplitude and peak values), as well as the time profile of the mechanical (force and power) and iEMG pattern during ergometer rowing. Linear Mixed Model was used to determine the fixed effect of intensity, stroke rate and the interaction between them for single values, and Statistical Parametric Mapping (SPM 3x3 2-way ANOVA and t-test) was used to investigate the time profiles of the mechanical and iEMG patterns.

Results**:** Intensity and stroke rate significantly affect mechanical and iEMG outputs. When comparing the preferred conditions significantly greater magnitude variables were found with higher intensities and stroke rates for both mechanical and iEMG variables, and peak force/power tend to occur earlier in the drive phase with higher intensities and stroke rates. In the mechanical patterns for the foot-stretcher and handle, differences between the preferred conditions occurs after peak force/power for the foot-stretcher and prior to peak force/power at the handle. Six out of the eight measured muscles show small periods of significant differences between the preferred conditions during drive phase. For both mechanical and iEMG outputs the main differences were detected between the HH vs. LL and the MM vs. LL condition.

Conclusion**:** A clear effect of intensity and stroke rate were found on mechanical magnitude variables, and a more pronounced effect of intensity on mean muscle activity. For the mechanical and iEMG pattern both intensity and stroke rate influenced the patterns. Minor differences were detected between the preferred conditions, indicating that the effect of intensity and stroke rate were nullified to a certain extent, especially when investigating the iEMG patterns.

Sammendrag

Formål: Hensikten med denne studien er å undersøke den individuelle og kombinerte effekten av intensitet og ro-takt på mekaniske og elektromyografiske (EMG) utfallsvariabler (dvs. amplitude og tidshendelser) og tidsprofiler under ergometerroing. Studien ønsker å undersøke om koordinasjonen av muskelaktivitet påvirkes av ulike trening og konkurranse forhold (dvs. foretrukne intensitet og ro-takt kombinasjoner) og hvordan det gjenspeiles i det mekaniske kraft og effekt mønsteret til fot-pedalen og håndtaket.

Metode: 12 mannlige eliteroere (alder 23.8 (± 1.8) år, kroppshøyde 189.2 (± 5.2) cm og kroppsvekt 92.3 (± 8.6) kg) gjennomførte et drag på konkurranseintensitet med foretrukken ro-takt (HH) i 1.5 minutt med samme relative intensitet. HH draget definerte videre moderat (75%) og lav intensitet (55%), hvor utøveren rodde med foretrukken ro-takt (henholdsvis MM and LL). De foretrukne dragene (HH, MM og LL) ble blandet (intensitet og ro-takt) og førte til seks flere drag, totalt ni (3x3) intensitet- og ro-takt- kombinasjoner. 3D-kinematikk, dynamikk og EMG (for åtte muskler) data ble registrert for å bergene mekaniske timing variabler (amplitude- og toppverdier), samt tidsprofilen av det mekaniske (kraft og effekt) og iEMG mønsteret under ergometer roing. Lineær Mixed Model ble brukt for å bestemme den fikserte effekten av intensitet, ro-takt og interaksjonen mellom dem for enkeltverdiene, mens Statistisk Parametrisk Kartlegging (SPM 3x3 2-way ANOVA og t-test) ble gjennomført for å undersøke tidsprofilen av det mekaniske- og iEMG mønsteret.

Resultat: Intensitet og ro-takt påvirket mekaniske og iEMG utfallsvariabler og tidsprofiler. En signifikant økning i kraft, effekt og muskelaktivitet ble funnet ved høyere intensitet og ro-takt når de foretrukne dragene ble sammenlignet, i tillegg til at maks kraft og effekt inntraff tidligere i aktiv fase. I det mekaniske mønsteret forekommer forskjellen mellom de foretrukne dragene etter maks kraft/effekt for fot-pedalen og før maks kraft/effekt for håndtaket. For de registrerte musklene viser seks av åtte muskler små perioder med signifikante forskjeller mellom de foretrukne dragene under aktiv fase. For både det mekaniske og iEMG mønsteret oppdages forskjellene hovedsakelig mellom HH vs. LL and MM vs. LL dragene.

Konklusjon: En tydelig effekt av intensitet og ro-takt på mekaniske mengdevariabler og en mer uttalt effekt av intensitet på gjennomsnittlig muskelaktivitet. Både intensitet og ro-takt påvirker det mekaniske mønsteret og iEMG mønsteret. Når roerne ror med foretrukken kombinasjon av intensitet og ro-takt er forskjellen mellom de foretrukne dragene små, noe som indikerer at effekten av intensitet og ro-takt til en viss grad utlignes, særlig når man undersøker iEMG mønstrene.

Acknowledgement

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Table of content

1. Background

Rowing is an Olympic discipline consisting of repetitive cyclic movements where performance is determined by average boat velocity over a given distance (1). Boat velocity is determined by stroke power, stroke drive distance, stroke rate, propulsion per stroke and stroke velocity (2, 3). The Olympic rowing distance is 2000 m and takes about 6-7 minutes to complete (4). Competitive rowers can achieve an average power output as high as 500 watt during a race at a pace of around 30-40 strokes per minutes (5, 6). Rowing is divided into two disciplines, sculling and sweeping. In sculling the oarsmen uses two skulls (oars) each and compete in single, double or quadruple shells (boats), while sweeping means one oar for each oarsman and are rowed with 2, 4 or 8 oarsmen. Both genders are divided into heavyweight and lightweight oarsmen, where 72,5 kg is the highest weight for lightweight men, and 59 kg for women (4).

1.1 The Stroke Cycle

In rowing the propulsive phase is not continuous (7). It consist of two cyclic phases, the drive (propulsive phase) and the recovery (non- propulsive phase), separated by the catch and the finish (8). The drive phase is initiated at the catch, when the oar(s) goes into the water, and the rower moves towards the bow ending in the finish position, as shown in *Figure 1.1*. The recovery phase starts when the oar(s) comes out of the water and the rower start to move towards the stern, opposite of the rowing direction ending in catch position (9). In this phase of the rowing cycle only drag forces such as air and water resistance acts on the boat, and no propulsive force is initiated. To minimize the effect of drag forces the boat velocity should remain as constant as possible during the stroke cycle (5). The recovery phase is characterized by highest boat velocity (1, 3), with decreasing duration when stroke rate increases (3).

Figure 1.1. Illustration of the rower´s movement throughout the stroke cycle, including drive and recovery phase. Adapted and edited (10).

1.2 Performance

Because of the technical and physical demands, rowing is defined as a power-endurance sport that require a coordinated and powerful sequence of actions, utilizing as much as 70% of the total muscle mass (4, 11, 12), where hip and knee extensors are identified as the most important muscles for propulsion (13-16). However, it should be clear that applying a large foot-stretcher force does not accelerate the boat owing to it being an internal force within the rower-boat system. The supporting connection from the foot-stretcher to the water through the rigger and oar handle is therefore essential. The rower´s ability to maintain a rigid body or a stiff connection from the foot-stretcher to the handle is therefore of importance (9).

The most common style of rowing is the Rosenberg style, supported by authors to be the most power producing rowing style compared with synchronous segment movements of the legs, trunk and arms (3, 5, 17). The Rosenberg style is based on a sequential order of body segment movements initiated by the lower limbs through knee extension followed sequentially by the lower trunk, mid trunk, arms and wrist segments (17). Good command of technique, timing and power is therefore necessary to be a successful rower (11). The rower has to develop a consistent movement pattern concerning joint moment and proximal to distal sequencing of joint rotations and body angle to secure these qualities (2, 18). Studies have also highlighted the importance of force time profiles and how these can be optimized and related to performance (5, 19), whereby the timing of foot-stretcher and handle force have been emphasis in later research to be highly correlated with performance (20). However so far, no study has investigated the power time profiles in the same extent.

1.3 Training and Competition

Rowing practice is mostly done on water, but because of the environmental conditions effect on performance, indoor alternative is often used. Both stationary and dynamic ergometers is widely used in the rowing practice. This involves performance testing, crew selections, bad weather training and also to evaluate technique (5). The literature has presented some differences between ergometer and boat concerning the balancing demands and maintaining of speed, which is not present during ergometer rowing (5). Also, differences between ergometer and boat are present for the upper body pattern due to the central pully system often used (17). Despite this, studies have shown similarities in physiological demands (21) as well as dynamic and kinematic of the lower limbs when comparing dynamic ergometer with on-water rowing (22).

Maximal oxygen consumption is a key factor for performance and is coupled with efficient muscle work (4, 23). Endurance training is therefore the foundation of success in rowing, including both low and high intensity training with low intensity being the main load of exercise to enhance physiological capacity (86-94% in the winter and 70-77% during the summer) (24). This does not mean that the motor behavior in low intensity training and high intensity training, or competition, is the same. For example, Guével et al. (14) conducted two low intensity sessions and two 500 m all out starts identifying significant differences in the electromyographic amplitude and pattern of important thigh muscles and mechanical parameters (i.e., stroke rate, power and mean torque) when comparing the low intensity sessions with the 500 m all out starts on-water. Turpin et al. (16) investigated the effect of intensity on mechanical and iEMG pattern of upper and lower body muscles. Contrary to Guével et al. (14), Turpin et al. (16) found no dramatic modification in the shape of mechanical pattern (i.e., force and power) or individual EMG pattern and their timing of activation. This was despite significant changes in the level of muscle activity and in the amplitude of the mechanical variables (i.e., foot-stretcher force, handle force and external power output) for both experienced and inexperienced rowers during ergometer rowing (16). Studies investigating the effect of stroke rate also found the amplitude of mechanical variable to increase with increasing stroke rate (25, 26). Moreover, the shape of mechanical force pattern changes with increasing stroke rate where peak force occurring later in the stroke cycle (26).

1.4 Research question

Earlier studies have been focusing on the effect of intensity or stroke rate, and often not controlling for the effect of the other. The purpose of the present study is therefore to examine the individual and combined effect of intensity and stroke rate on timing and coordination. Specifically, this is done by investigating timing mechanical variables (i.e., amplitude and peak values), as well as the time profile of the mechanical and iEMG pattern during ergometer rowing. Furthermore, the analysis allows to establish whether the coordination of muscle activity is influenced by condition such as applied in competition and training (i.e. preferred intensity and stroke rate combinations), and how this is reflected in the mechanical force and power pattern of the foot-stretcher and handle.

2. Methods

2.1 Outline of the study

Based on the participants competition performance (intensity and stroke rate) two training intensities at freely chosen stroke rate were defined and then mixed, leading to nine intensity-stroke rate combinations. Data collected for the present study and used for further analysis were kinematic, dynamic and electromyographic variables in the first one and a half minute for each of the nine trials. All measurements were done unilaterally for the left side of the body. Lactate measurements were completed after each trial to ensure submaximal effort and to prevent muscle fatigue from affecting the rower´s performance.

2.2 Participants

The participants included in the study were recruited through the Norwegian National Team and the local student team in Trondheim, NTNUI. All participants were experienced rowers and had within the last year performed an all-out 2000-meter test on an ergometer. This resulted in 12 male rowers with 9 (±4) years of experience and a 2000 m time of 06:07 minutes (± 00:10), further demographics are shown in *Table 2.1*. Eight of the rowers were a part of the national team or on the national development team. Three of the participants had previously been on the national team or the national development team. Only one of the 12 rowers had no experience from the national team or national development team. At the time of the study the national level rower´s trained for approximately 20 hour per week and the NTNUI rower´s for approximately 10 hours per week. All of the participants where scullers, with one of them also being sweep oarsmen. The participants volunteered to take part in the study and were verbally informed of the experimental procedures and the possible risk and discomfort prior to giving their written consent to participate. The present study was approved by the Norwegian Social Science Data Services (project number: 689366) and conducted in accordance with the WMA Declaration of Helsinki.

Table 2.1. Mean, standard deviation (SD) and range of participants descriptive statistics.

	Age (year)	**Height (cm)**	**Weight (kg)**
Mean (±SD)	23.8 (±1.8)	189.2 (±5.2)	92.3 (±8.6)
Range	20-26	180.9-199	73.7-105.8

2.3 Procedures and instrumentation

The protocol started with a preparation part, where electrodes were attached to the rower´s body in order to collect electromyographic (EMG) data. Prior to electrode application, the skin was shaved, scrubbed and cleaned with alcohol wipes to ensure god skin impedance. Noraxon Dual Electrodes (Noraxon, Scottsdale, AZ) were attached to the skin with a fixed 20 mm interelectrode distance. Each electrode was placed longitudinally with respect to the underlying muscle fiber arrangement unilaterally on eight muscles. The recorded muscles were m. gastrocnemius lateralis (GC), m. biceps femoris (BF), m. rectus femoris (RF), m. vastus lateralis (VL), m. gluteus maximus (GM), m. erector spina iliocostalis (ES), m. latissimus dorsi (LD) and m. biceps brachii (BB). Electrode placement followed the recommendations of Surface EMG for Non-Invasive Assessment of Muscles (SENIAM) to optimize the location of the electrodes and reduce the interference of crosstalk (27). LD being the only muscle included and not referenced to by SENIAM was located in the lumbar-pelvis-costal region (28) over the muscular curve at T12 and along a line connecting the most posterior point of the posterior axillary fold and the S2 spinous process (29). To minimize movement artifacts all wires connected from the wet gel electrodes to the EMG probes (Noraxon, Scottsdale, AZ) were fixed with adhesive tape. EMG data were collected using wireless Noraxon Telemyo Direct Transmission System (Noraxon, Scottsdale, AZ).

All tests were performed on a RowPerfect 3 (RP3 model T, Netherlands) dynamic rowing ergometer. The participants included in the study had various experience with the dynamic RP3 design of the rowing ergometer. A dynamic design means that the flywheel and foot-stretcher moves freely on the slide as well as the seat, creating a dynamic movement to simulate on-water rowing (22). Simultaneous visual feedback to the participants was provided through an attached display that showed force-curves, stroke rate and external power output.

The kinematic variables were collected using reflective markers registered with the Oqus 3D motion capture system (Qualisys AB, Gothenburg, Sweden). The frame of reference was determined such that the positive x-axis was pointing to the right when facing the ergometer form the back. The positive y-axis was parallel to the horizontal seat rail and pointing from the flywheel to the back of the ergometer, and the positive z-axis was pointing upward, as seen in *Figure 2.1*. The RP3 was equipped with reflective markers in the middle of the flywheel, top of the handle, rotation point of the handle chain, seat, foot-stretcher and on the ergometer legs. Reflective markers were also placed on both ends of two Kistler force plates (see below) to record the position of the ergometer on the plates. *Figure 2.1* shows an illustration of the marker placement. Markers were also placed on anatomical landmarks for the purpose of analysis at the level of joints and body segments, which was not considered further in this study. Ten motion capture cameras (Oqus 400; Qualisys AB, Gothenburg, Sweden) were placed in a semicircle covering the left side of the participant and the RP3 ergometer to record kinematic signals. The camera system was calibrated according to the manufacturer's specification using wand calibration (Wand kit 750 mm; Qualisys AB, Gothenburg, Sweden), and were placed at different heights and angles according to general recommendations (Qualisys AB, Gothenburg, Sweden).

A tailor-made force plate with three piezoelectric force sensors with integrated charge amplifier electronics (Kistler 9602; Kistler Instrument AG, Winterthur, Switzerland) was mounted on the left foot-stretcher and recorded Y and Z forces (N). The foot-stretcher force plate was calibrated against the Kistler 9286BA plate. To measure force (N) applied at the handle, a fully calibrated, precision interface load cell (DTS Force Sensor 500 lb.-F (2200 N); Noraxon, Scottsdale, AZ) was mounted between the handle and chain. The RP3 was placed on two 600x400x30 mm Multicomponent Kistler Force Plates (Kistler Force Plate with Built-in 8 Channel Charge Amplifier; Type 9286BA; Kistler Instrument AG, Winterthur, Switzerland) measuring force (N) in X, Y and Z direction to determine force application at the seat based on Newton´s laws of motion. Power at the seat was calculated for internal validation, which was not used in further analysis.

All signals were time synchronized and registered using Qualisys Track Manager software 2019.3 (Qualisys AB, Gothenburg, Sweden). Each recording included force signals of the unloaded ergometer to allow for offset corrections. Dynamic signals were recorded at 200 Hz, via a Kistler data acquisition system (64ch DAQ system Type 5695A; Kistler Instrument AG), and the kinematic signal was recorded at 100 Hz. All forces were transformed from a local coordinate system to the global (Qualisys) coordinate system, allowing for calculation of power. Data recorded via Noraxon Telemyo Direct Transmission System (Noraxon, Scottsdale, AZ) were sampled at 1500 Hz, this include raw EMG signals and force at the handle. Data was stored for later analysis.

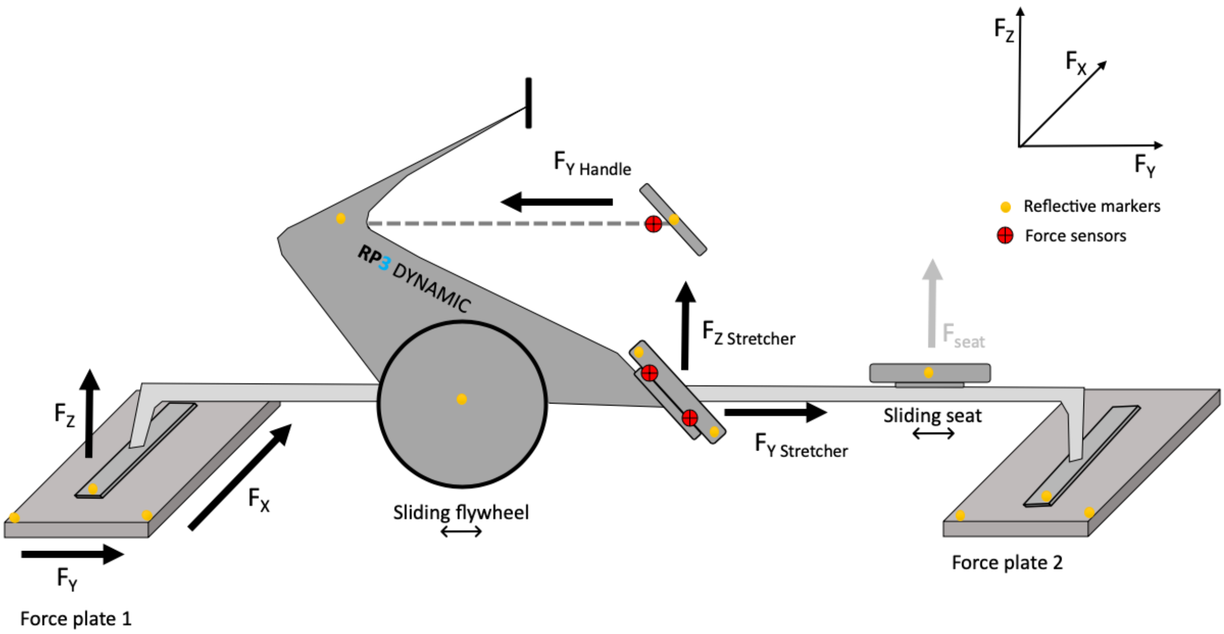

Figure 2.1. The rowing ergometer used in the study with reflective markers and measured force. Force at the seat was calculated on bases of all other forces based on Newton´s laws of motion.

2.3.1 Experimental protocol

During the 10 min low intensity warm-up on the rowing ergometer the participants individually selected the preferred flywheel damp mechanism (gear) to retain throughout the test protocol. After warm-up the participant performed a 1.5 min exercise at a simulated 2000 m competition intensity and stroke rate *(High intensity and High stroke rate = HH)*. The performance was determined as the high intensity trial (HH) and defined the intensity levels for the following trials bases on the mean external power output recorded on the feedback system. External power was thus in relationship to the athletes own level of performance. After ensuring resting lactate levels the participants were instructed to perform one 1.5-minute trial at 55% of high intensity at freely chosen stroke rate *(Low intensity and Low stroke rate = LL)*, and one 1.5-minute trial at 75% of high intensity at freely chosen stroke rate *(Moderate intensity and Moderate stroke rate = MM)*. Subsequently establishing preferred stroke rate at the different intensity, the stroke rate and intensity were mixed, leading to six more trials and a total of nine (3x3) intensity-stroke rate combinations. This means that low intensity (55%) was combined with the freely chosen stroke rate from the moderate intensity (75%) trial and from the high intensity trial (LM and LH respectively). The same was done for moderate intensity and high intensity as shown in *Figure 2.2* (MH, ML, HM and HL respectively). The order of the six last trials were partly randomized, meaning that the order of the stroke rates was mixed, but the intensity (W) followed an order, from low to high. Rest between trials were 2 min, but when the lactate levels exceeded 5 mmol/L the participants was given 5 minutes rest. Capillary blood samples were drawn from the earlobe using the hand-held portable analyzer Lactate Pro 2 (LP, Arkray KDK, Japan). As part of a larger data collection oxygen consumption was measured at the low and moderate intensity trials, thus demanded physiological steady state leading to a trial duration of actually four minutes. The overall protocol including preparation time and testing took approximately 120 min.

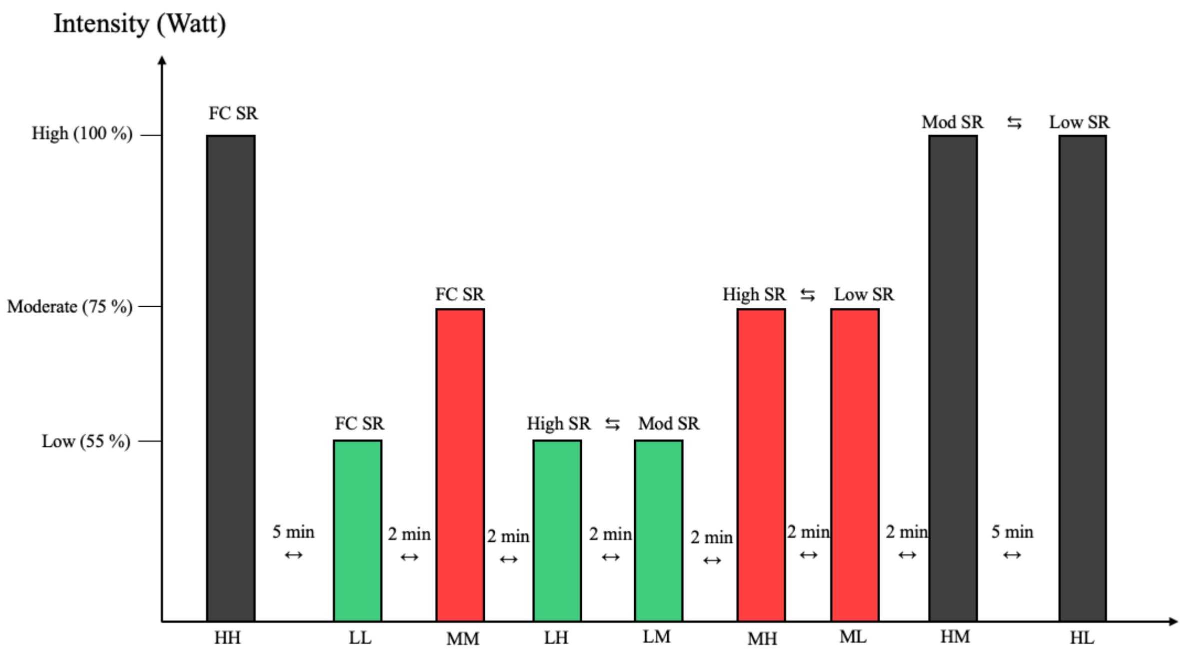

Figure 2.2. Illustration of the protocol execution. X-axis is time presenting the condition with the first letter describing intensity and second letter describing stroke rate. SR = stroke rate, FC = freely choose stroke rate.

2.4 Data analysis

The collected raw data were processed in Matlab (9.5.0 R2018b; The MathWorks, Inc; Natick, MA, USA). Dynamic and kinematic data were low-pass filtered (Chebychev "Type II, 15 Hz, 8th order). The Chebychev filter was preferred over the generally applied Butterworth filter because of a steeper roll-gradient, making it work better in the roll-off area (distinguish better between frequencies filtered out and kept). The downside of this filter is the ripple at the band pass, which amplitude was 0.003, meaning that some frequencies that should have been filtered, 0.3 % of its original amplitude remains. However, this has no substantial impact on the data. EMG signals were filtered with a bandpass filter between 20 and 300 Hz and a linear envelope (low pass 10 Hz) was applied to obtain smoothed integrated EMG (iEMG). Before inclusion, all raw EMG signals were visually inspected and evaluated, atypical signals (e.g., containing long silent periods most likely due to technical fault, obvious inconstancy among strokes, etc.) were excluded from the dataset. After filtering, the upper body EMG signals were manually checked for electrocardiographic activity, however no further filtering was necessary (30).

A set of 20 consecutive stroke cycles were extracted from a period of constant power for each condition, and averaged. The stroke cycle, drive and recovery were determined by handle position. Signals of complete stroke cycle were resampled to 200 samples before averaging to obtain the mean cycle profile. Data extracted from this process were mean muscle activity (iEMG), mean and peak force and power and relative duration of drive and recovery phase. The same was applied to the drive phase, only using 100 samples for each drive. This drive phase normalisation was used for comparison of timing specific drive events (e.g., timing of peak power), and to avoid bias due to potential different effect of rowing condition on the duration of the drive and recovery phase. For time profiles (mechanical and iEMG), signals were normalised intra-individually and for each muscle, according to the maximum amplitude of the mean profile over all nine conditions. The same procedure was done for magnitude variables of EMG, only the mean value over all nine conditions was used as reference. Thus, only the iEMG amplitude differences (of interest) between conditions remained.

Power at the handle and foot-stretcher were calculated as the dot product of velocity of the handle and foot-stretcher and their respective forces: $P = \|F\|\|v\| \cos \alpha$; α the angle between force and velocity vector. For the handle power, this angle always equal to zero. Foot-stretcher velocity was always close to horizontal (depending fully on the ergometer frame orientation), its exact direction recorded by the marker setup. The angle of foot-stretcher forces was determined according to the x and z foot-stretcher force components. The total external power, i.e., power leading to boat propulsion, was found by using the velocity of the ergometer chain extraction (speed between flywheel and handle) instead of handle speed. Thus, in relationship to the feedback from the ergometer received by the athletes while rowing.

2.5 Statistical analysis

Microsoft Excel for Mac (Version 16.34; Microsoft Corp; Redmond, WA, USA), Statistical Package for the Social Sciences (SPSS 26; IBM Corp; Armonk, NY, USA) and Matlab (9.5.0 R2018b; The MathWorks, Inc; Natick, MA, USA) were used for statistical analysis. Descriptive statistics are presented as mean ± standard deviation or median ± IQR, dependent on the distribution of the variables.

A Linear Mixed Model (LMM) was used to evaluate the effect of intensity and stroke rate on single values representing magnitude and timing events. Intensity, stroke rate and interaction of the two were determined as repeated measurements and tested for fixed effects, while subjects and intercept were included in the model as random effects. If no significant interaction between stroke rate and intensity were found, the analysis was repeated excluding the interaction for fixed effects. A pairwise post-hoc analysis, parametric or non-parametric dependent on distribution, was conducted to compare the preferred conditions (HH vs. MM vs. LL). The same procedure was used to compare all nine conditions to check if the participants executed the protocol as instructed.

To investigate the effect of intensity and stroke rate on the mechanical and iEMG pattern, Statistical Parametric Mapping (SPM) was applied using the spm1d version M.0.4.5 (2017.06.22) (31) software in Matlab. SPM is designed specifically to continuous field analysis and allows for comparing of time dependent measurements, without extracting multiple discrete variables, removing the consequences of missing or even reversing trends (32). An SPM 3x3 2-way ANOVA (3x3 ANOVA) for repeated measures was preformed to compare all conditions and a multiple t-test to compare the preferred conditions (as kind of paired post-hoc analysis). Statistical significance was accepted at $p < 0.05$. Missing data were treated differently in the LMM and SPM. Where in the LMM, missing data was replaced using Singe-value imputation method (33). For SPM analysis missing data required exclusion of all data of the participant at hand. This occurred for 1 to 3 participants, missing handle force data and EMG of some muscles.

3. Results

3.1 Task execution

3.1.1 Intensity and stroke rate

The participants were instructed to execute the protocol to the best of their ability, even if some combination of intensity and stroke rate were demanding. The measured intensity (external power) and stroke rate (stroke/min) based on instruction are presented in *Table 3.1*. The measured intensities were statistically affected by both measured stroke rate and measured intensity ($p=0.004$ and $p<0.001$ respectively), this was also true for the measured stroke rate ($p<0.001$ and $p=0.048$ respectively). Thus, the athletes did not follow instructions perfectly.

A pairwise post-hoc analysis revealed where the discrepancies between instruction and performance regarding intensity and stroke rate appeared. Comparing all combinations of high intensity (at different stroke rates) as well as all of high stroke rates (at different intensities), showed no significant differences ($p<0.05$). For moderate intensity only when comparing the high (MH) and low (ML) stroke rate the differences were significant ($p=0.03$). When comparing moderate stroke rate at different intensities both high (MH) and moderate (MM) intensity, and high (MH) and low (ML) intensity were significantly different from each other ($p=0.008$ and $p<0.001$ respectively). For the low intensity when comparing all stroke rates only the high (LH) and moderate (LM) stroke rate were significantly different from each other ($p=0.025$), while no significant differences were found when comparing low stroke rates at different intensities. The effects did not cause overlap of neither power nor stroke rate for the three levels.

Table 3.1. Mean intensity (table A) and stroke rates (table B) with standard deviation (SD) for all conditions.

A	*High SR*	*Moderate SR*	*Low SR*
High intensity	**462 (±44.4)**	454 (±47.3)	455 (±50.3)
Moderate intensity	350 (±34.0)	**346 (±33.3)**	343 (±33.7)
Low intensity	273 (±38.5)	259 (±26.2)	**259 (±31.6)**
B	*High SR*	*Moderate SR*	*Low SR*
High intensity	**35.9 (±2.4)**	31.0 (±2.4)	27.0 (±5.0
Moderate intensity	35.5 (±2.4)	**30.2 (±2.4)**	25.5 (±2.1)
Low intensity	35.0 (±2.7)	29.6 (±2.3)	**24.7 (±3.2)**

The highlighted conditions are the three conditions where stroke rate was individually chosen based on the intensity. Intensity in Watts, stroke rate (SR) in stroke/min.

3.1.2 Power and force at the foot-stretcher and handle

Mean and peak force at the handle and foot-stretcher were significantly affected by both stroke rate and intensity (p<0.001). Mean and peak power calculated from the foot-stretcher and handle were also statistically affected by both stroke rate and intensity (p<0.05 and p<0.001 respectively). Differences between the preferred conditions were significant between all comparisons for the mentioned force and power variables (p<0.05). Characteristics of the preferred condition are presented in *Table 3.2*.

Table 3.2. Mechanical variables for the foot-stretcher and handle.

Measure	**Variables**	**HH**	**MM**	**LL**
Foot-stretcher force (N)	Mean	666 (±60)	575 (±56)	503 (±53)
	Peak	1849 (±178)	1693 (±178)	1589 (±183)
Handle force (N)	Mean	220 (±13)	187 (±13)	162 (±11)
	Peak	955 (±91)	870 (±74)	822 (±95)
Foot-stretcher power (W)	Mean	227 (±39)	169 (±29)	123 (±22)
	Peak	1603 (±296)	1302 (±238)	1037 (±178)
Handle power (W)	Mean	266 (±22)	199 (±16)	151 (±16)
	Peak	1276 (±102)	1080(±79)	957 (±97)

HH=high intensity with preferred stroke rate, MM=moderate intensity with preferred stroke rate, LL=low intensity with preferred stroke rate, W=watt, N=Newton.

3.2 Stroke cycle characteristics

3.2.1 Drive and recovery time

The duration (sec) of the drive phase and recovery phase were significantly affected by both stroke rate and intensity (p<0.01). The difference between the preferred conditions for drive/recovery ratio was significant between all comparisons (p<0.05). Thus, normalizing for drive phase or stroke cycle may have implication for the analysis of timing event. *Figure 3.1* shows the effect of normalization for the power profile. The left-hand illustration in *Figure 3.1* indicates that drive/recovery ratio decreases with increased intensity and stroke rate, and are confirmed by the drive/recovery ratio, showing 1:1.23 (±0.10) for the HH condition, 1:1.38 (±0.16) for MM condition and 1:1.63 (±0.33) for LL condition.

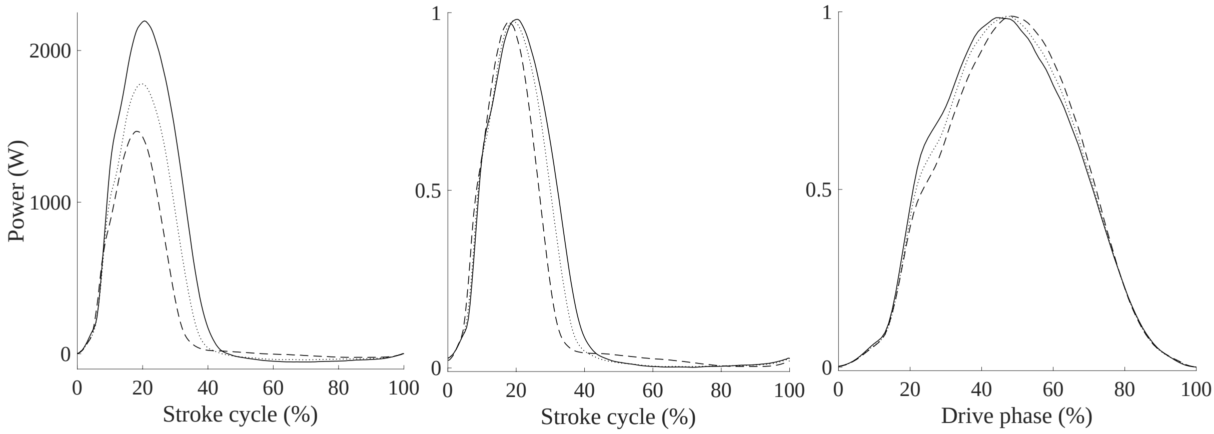

Figure 3.1. Illustration of the normalization procedure for external power output for the HH (—), MM (…) and LL (- -) condition. The left-hand figures are absolute amplitude and timescale normalized to one stroke cycle, the middle figures are also amplitude normalized, and the right-hand figures are timescale normalized to drive phase as well as amplitude normalized.

3.2.2 Timing of peak force and power

After normalizing to the duration of the drive phase, the effect of intensity, stroke rate and the interaction were tested on timing events for force and power. The interval differences between timing of peak power and force at the foot-stretcher and handle were significant different from zero ($p<0.001$), the fixed effects are presented in *Table 3.3*. When investigating the preferred conditions peak force and power tend to occur earlier in the drive phase with higher intensities and stroke rates, see *Table 3.4*. However, between the HH vs. LL and MM vs. LL significant differences are only found for timing of peak force at the handle and foot-stretcher, while all preferred conditions are significantly different from each other for timing of peak power at the handle. Details between the preferred conditions are presented in *Table 3.4*.

Table 3.3. Effect of intensity, stroke rate and the interaction between them for timing of peak force and power at the foot-stretcher and handle.

	Foot-stretcher		**Handle**		**FS-H Interval**		**Interval diff.**
Factor	*Force*	*Power*	*Force*	*Power*	*Force*	*Power*	*Power-Force*
Int.	0.390	0.241	0.002*	0.001*	0.045*	0.038*	0.042*
SR	0.002*	0.018*	0.127	0.993	0.030*	0.061	0.737
Int.*SR	0.047*	0.001*	0.019*	0.352	0.013*	0.030*	0.355

*Int. = intensity, SR=stroke rate, FS-H interval=the interval between peak foot-stretcher (FS) and handle (H) force/power. Interval diff.= interval differences between the force and power foot-stretcher and handle interval, *=p<0.05.*

Table 3.4. Mean value and standard deviation (SD) of peak timing force and power at the foot-stretcher and handle presented as % of drive phase for the preferred conditions compared.

Variables	**HH**	**MM**	**LL**	**Comparisons (p-value)** HH vs. MM	HH vs. LL	MM vs. LL
Peak force timing foot-stretcher	36.5 (±5.5)	37.4 (±5.4)	39.8 (±4.2)	0.266	0.025*	0.03*
Peak force timing handle	43.0 (±4.0)	43.0 (±4.1)	45.9 (±3.2)	1.000	0.002*	0.002*
Interval between peak force foot-stretcher and handle	6.5 (±2.6)	5.6 (±2.6)	6.1 (±3.0)	0.111	0.688	0.637
Peak power timing foot-stretcher	30.7 (±2.2)	30.8 (±2.7)	31.9 (±4.0)	0.834	0.332	0.473
Peak power timing handle	55.0 (±3.3)	56.8 (±3.6)	57.2 (±3.5)	0.004*	0.002*	0.012*
Interval between peak power foot-stretcher and handle	24.3 (±3.1)	26.0 (±5.0)	25.6 (±5.9)	0.114	0.562	0.608

HH=high intensity with preferred stroke rate, MM=moderate intensity with preferred stroke rate, LL=low intensity with preferred stroke rate. *=p<0.05.

3.2.3 Time profiles of force and power

When comparing the mechanical force and power pattern for the foot-stretcher (A and C respectively) the fixed effects (SPM 3x3 ANOVA) are clearly present in early drive phase. Nevertheless, when comparing the preferred conditions (SPM t-test), only small differences between the HH vs. LL condition are present, as seen in *Figure 3.2*. After peak force/power foot-stretcher, around the middle part of drive phase, the more pronounced differences between the preferred conditions are present. However, considering force, this could not be explained by neither of the fixed effects, as for power only intensity explained the differences.

For the handle force (B) and power (D) the fixed effects (SPM 3x3 ANOVA) are present when differences between the preferred conditions are present (SPM t-test), except in early and late drive phase for handle power, as seen in *Figure 3.2*. For handle force the main differences are detected between HH vs. LL prior to the first burst and the second burst of activation and explained by stroke rate and the interaction, and intensity respectively. For handle power the differences are detected between HH vs. LL and MM vs. LL and occur after the second burst of activation explained by intensity as seen in *Figure 3.2*.

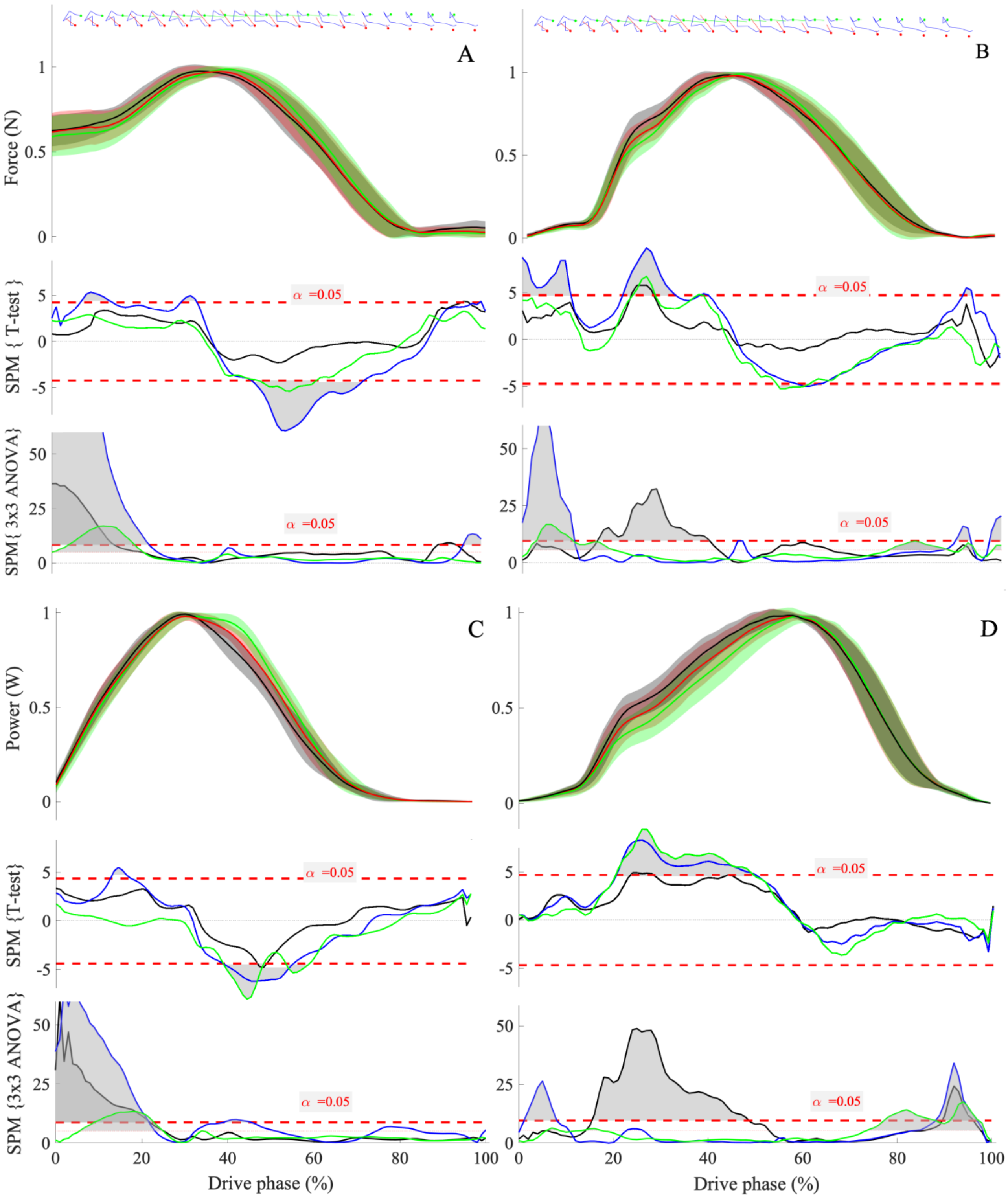

Figure 3.2. Mechanical force and power pattern of the HH (—), MM (—) and LL (—) condition for the foot-stretcher (A and C respectively) and handle (B and D respectively) with standard deviation (shaded area) and an illustration of action forces (green=handle, red=foot-stretcher) and position of the rower during drive phase. Grey shaded area represents the significant differences between HH vs. MM (—), HH vs. LL (—) and MM vs. LL (—) conditions (SPM t-test) and the fixed effects of intensity (—), stroke rate (—) and interaction (—), for all nine combination (SPM 3x3 ANOVA). Red bold dashed line represents threshold t- and f-value in the SPM t-test and 3x3 ANOVA (weak red dashed line represents threshold f-value for the interaction between intensity and stroke rate.

Figure 3.3 present the time profile (upper diagram) of external power showing what may be expected from foot-stretcher and handle power considered in isolation. Differences between the preferred conditions appears for the same range of the drive phase detected for foot-stretcher and handle power separately, see *Figure 3.2 C and D*. From the lower diagram (SPM 3x3 ANOVA) in *Figure 3.3* the differences identified between the preferred conditions in the middle diagram (SPM t-test) are mainly explained by change in intensity.

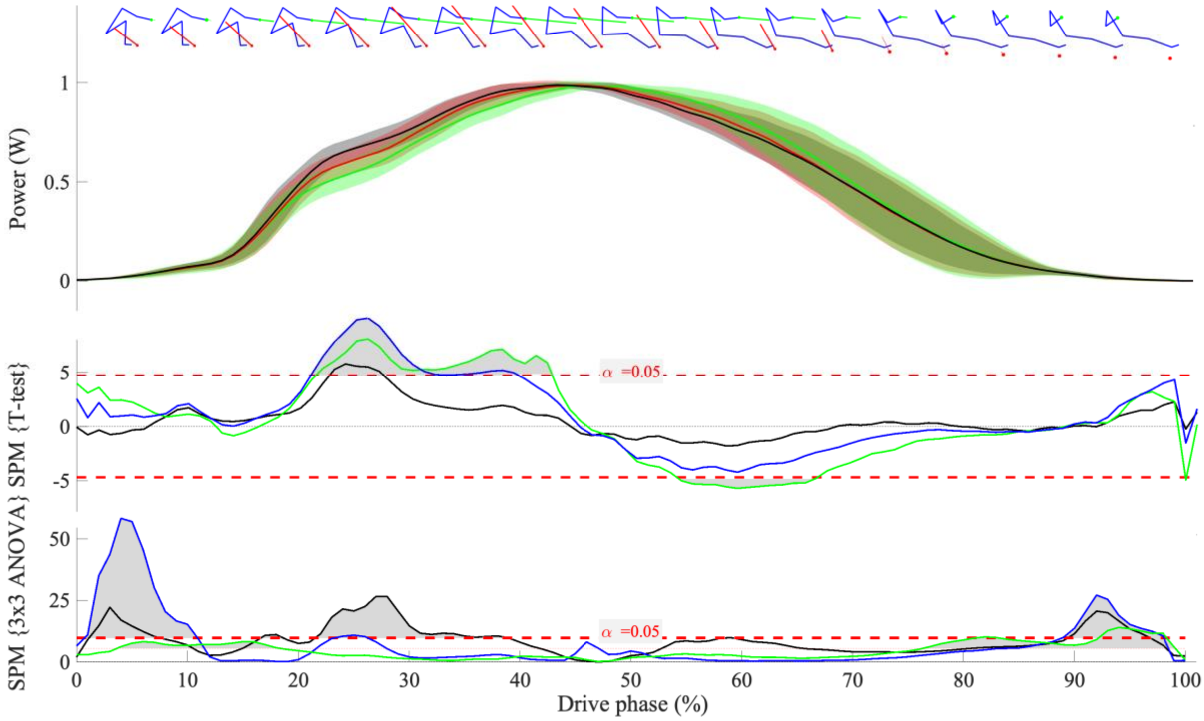

Figure 3.3. Time profile of external power pattern for the HH (—), MM (—) and LL (—) condition with standard deviation (shaded area) and an illustration of action forces (green=handle, red=foot-stretcher) and position of the rower during drive phase. Grey shaded area represents the significant differences between HH vs. MM (—), HH vs. LL (—) and MM vs. LL (—) conditions (SPM t-test) and the fixed effects of intensity (—), stroke rate (—) and interaction (—), for all nine combination (SPM 3x3 ANOVA). Red bold dashed line represents threshold t- and f-value in the SPM t-test and 3x3 ANOVA (weak red dashed line represents threshold f-value for the interaction between stroke rate and intensity.

3.3 Muscle activity

3.3.1 Mean muscle activity

Mean muscle activity is presented in *Figure 3.4* and was investigated for the effect of intensity, stroke rate and the interaction between them. The GL, BF, RF, VL, ES were only significantly affected by intensity ($p<0.05$), while the GM, LD and BB were also affected by stroke rate ($p<0.05$). GM and LD were furthermore affected by the interaction of stroke rate and intensity (p<0.05). Significant differences were found between the preferred conditions for all muscles, with increasing muscle activity with increasing intensity and stroke rate.

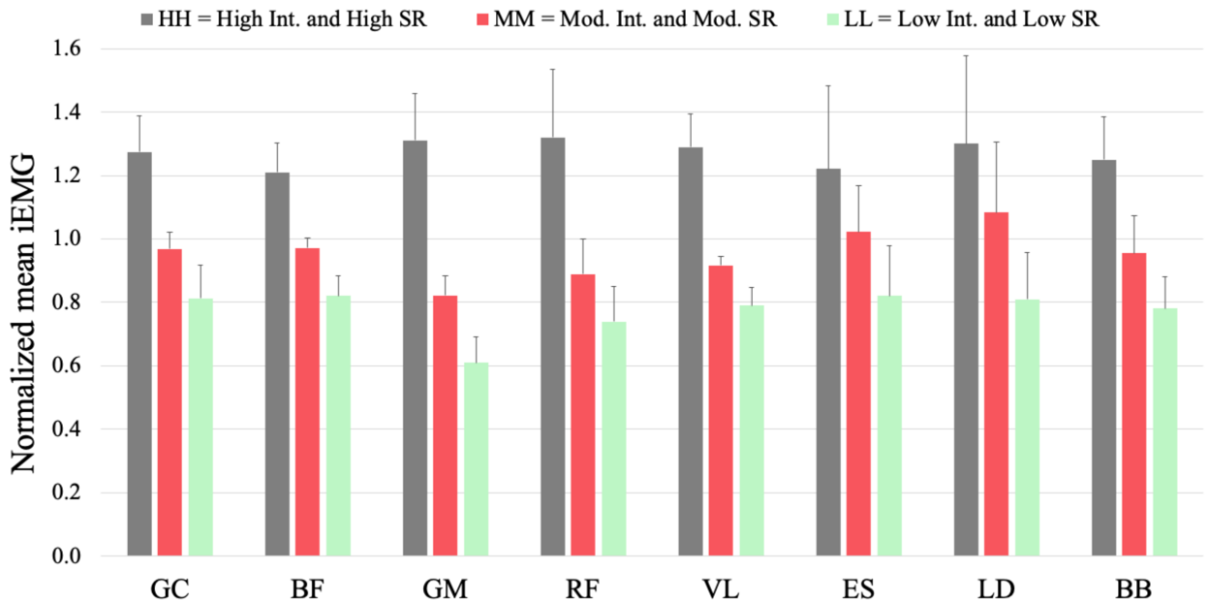

Figure 3.4. Mean muscle activity and standard deviation (SD) for all muscles at the preferred conditions (HH, MM and LL). GC=Gastrocnemius, BF=Biceps femoris, GM=Gluteus maximus, RF=Rectus femoris, VL=Vastus lateralis, ES=Erector spina, LD=Latissimus dorsi, BB=Biceps brachii.

3.3.2 Time profiles of iEMG

Figure 3.5 shows that the effect of intensity and stroke rate is significant for all muscle except GM, while the interaction between them are only significant for GM, VL, LD, RF and BB. The effect of intensity, stroke rate and the interaction (SPM 3x3 ANOVA) are rather considerable, but when comparing the preferred condition (SPM t-test), the differences are much less. The identified differences between the preferred conditions presented in *Figure 3.5* are detected during early drive, mid-drive or around the finish.

Differences detected between the preferred conditions for BF and RF are affected by change in stroke rate, while for VL and LD, the differences identified are affected by both intensity and stroke rate. The small difference detected for BB are affected by the interaction of intensity and stroke rate, while the identified difference in the activity pattern of GC are not explained by intensity, stroke rate nor the interaction between them. A time-shift (left) with increasing intensity and stroke rate is present for all muscles investigated, but only significant in small part of the drive phase in the muscles mentioned above.

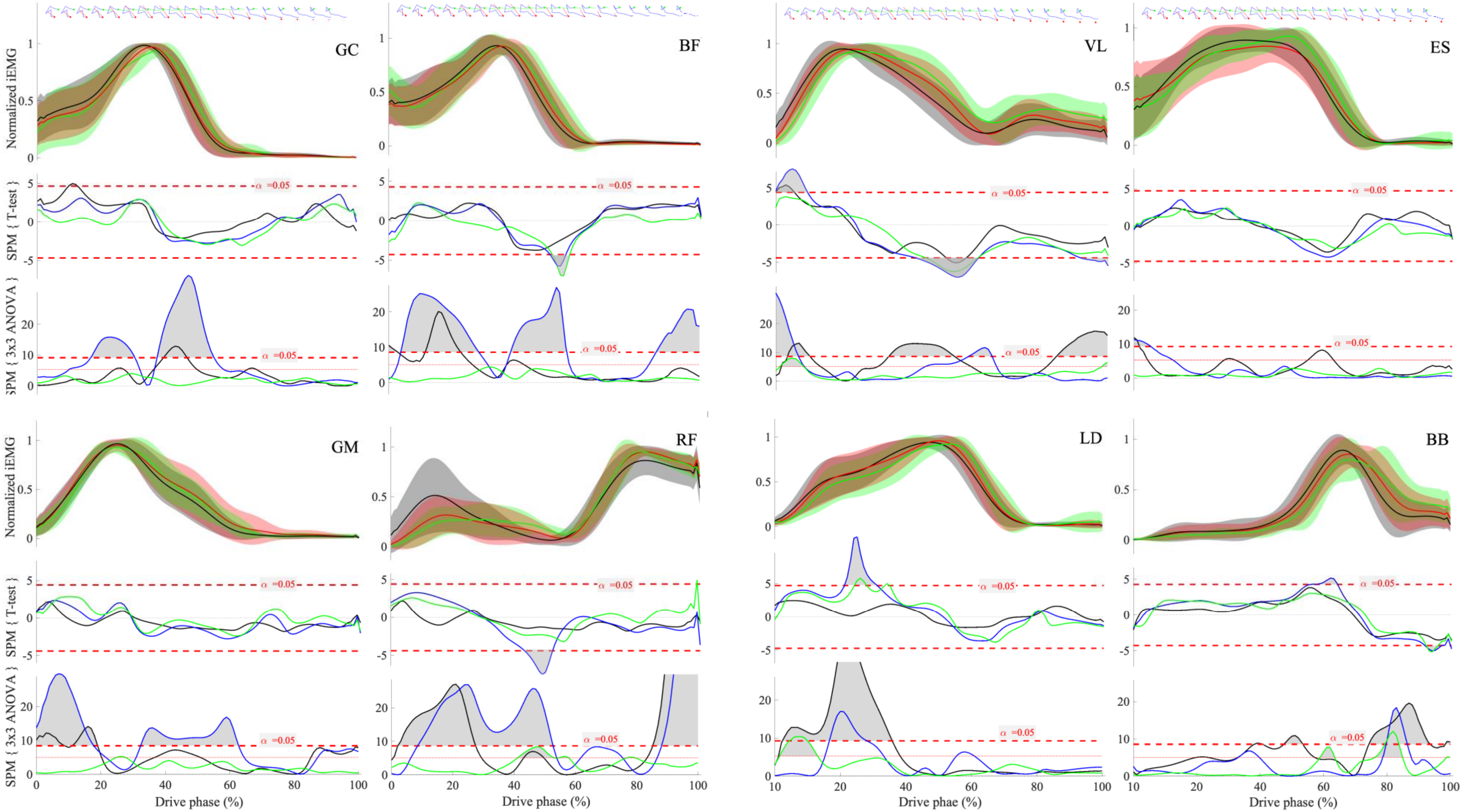

Figure 3.5. Normalized muscle activity (iEMG) pattern for all muscles with standard deviation (shaded area) at HH (—), MM (—) and LL (—) condition with an illustration of action forces (green=handle, red=foot-stretcher) and position of the rower during drive phase. Grey shaded area represents the significant differences between HH vs. MM (—), HH vs. LL (—) and MM vs. LL (—) conditions (SPM t-test) and the fixed effects of intensity (—), stroke rate (—) and interaction (—), for all nine combination (SPM 3x3 ANOVA). Red bold dashed line represents threshold t- and f-value in the SPM t-test and 3x3 ANOVA (weak red dashed line represents threshold f-value for the interaction between stroke rate and intensity). GC=Gastrocnemius, BF=Biceps femoris, GM=Gluteus maximus, RF=Rectus femoris, VL=Vastus lateralis, ES=Erector spina, LD=Latissimus dorsi, BB=Biceps brachii.

4. Discussion

The purpose of the present study was to investigate the effect of intensity and stroke rate on timing and coordination. This was done by focusing on timing mechanical variables (amplitude and peak values), as well as the time profile of the mechanical and iEMG pattern during ergometer rowing. The main result shows that both intensity, stroke rate and the interaction affect the magnitude and shape of both mechanical and iEMG pattern. However, the effect of intensity and stroke seems to be counterbalanced when comparing the preferred conditions, especially when considering the timing interval between peak force/power foot-stretcher and handle, and the iEMG pattern of the measured muscles. As expected, a significantly greater magnitude variables were found with higher intensity when comparing the preferred conditions, consequently since an increase in intensity is obtained by greater muscle activation to generate higher forces at the foot-stretcher and handle.

When investigating the timing events and shapes of the mechanical power and force pattern between the different training and competition conditions (preferred conditions), significant differences was mainly detected between the HH vs. LL and the MM vs. LL conditions. This includes both the single variables (i.e., timing of peak and interval between peak foot-stretcher and handle) and the time profiles, where peak force/power tends to occur earlier with increasing intensity (thus preferred stroke rate). In the mechanical patterns for the foot-stretcher and handle, differences between the preferred conditions occur during reduction of force/power of the foot-stretcher and during build-up of the force/power at the handle. For the measured muscles only small periods of differences between the preferred conditions for GC, BF, RF, VL, LD and BB were detected in the drive phase. Also, herein the main differences were detected between the HH vs. LL and the MM vs. LL condition.

4.1 Mechanical variables

External power output and magnitude of force at the handle and foot-stretcher are in accordance with findings from earlier studies presenting an increase in magnitude of force and power with increased intensity and stroke rate (14, 16, 26). Also, the results showed significant effect of both intensity and stroke rate on the mechanical variables indicating a combined effect of intensity and stroke rate with significant differences between the preferred conditions.

McGregor et al. (26) reported that timing of peak handle force occurred later in the stroke cycle as stroke rate increased, which is opposite from the present findings. The results indicate that the peak handle force occur earlier in the drive phase due to an increase in intensity, as presented in *Table 3.3*. The conflicting findings could be due to the methodical differences in the normalization procedure. McGregor et al. (26) time normalized to the hole stroke cycle, thus not considering the changes in the duration of the different phases of the stroke cycle as stroke rate increased, as shown in *Figure 3.1*. To avoid this limitation in this study, the drive phase was time normalized separately, as in previous studies (14, 16). The recovery phase was assumed less important, and thus removed from the analysis.

4.2 Electromyographic (iEMG) and mechanical patterns

The analysis allowed to establish whether the coordination of muscle activity was influenced by different conditions (i.e., intensity and stroke rate combinations), such as applied in competition and training, and how this was reflected in the mechanical force and power pattern of the foot-stretcher and handle.

The early drive to mid-drive was characterized with a synchronous recruitment of all muscles accept the BB. In the early drive (0-10%) differences between the preferred conditions was only detected for VL and GC, as seen in *Figure 3.5*. Wilson et al. (13) proposed that GCs role was to act simultaneously to generate plantar flexion as well as knee extension together with VL, or by acting as a stabilizer of the knee while undergoing lengthening. The biarticular function of GC suggest that power transfer between the ankle and knee. Also, unpublished data (other analyses from the same project) found large negative knee power. The effect of intensity and stroke rate was present for VL and might indicate that different intensities and stroke rates alters the demand causing a change in the recruitment pattern of this agonist contraction, Furthermore, differences between the preferred conditions for the foot-stretcher and handle force in the early drive indicates an effect on the force production caused by changes in this agonist contraction between conditions. However, no differences between the preferred conditions was detected for this specific time period in the power profiles of the foot-stretcher and handle or the external power output as seen in *Figure 3.2 and 3.3.* This suggest that the coordinative changes in this agonist contraction detected in GC and VL between the preferred conditions were performed to maintain the same mechanical power output at different training and competition conditions.

In the mid-drive, differences between the preferred conditions was detected for VL, BF and RF, when the muscle activity was close to zero with more rapid decrease in muscle activity with increasing intensity and stroke rate. Differences identified for BF and RF were described by change in stroke rate, while the change in VL was explained by both intensity and stroke rate, as seen in the SPM 3x3 ANOVA in *Figure 3.5*. Explained by the Lombard's paradox (34), which state that contraction from both quadriceps and hamstrings will result in hip and knee extension. This is explained by the biarticular RF muscles acting over the hip as a smaller hip moment arm than the hamstring, and that this moment arm is grater over the knee than the hamstring knee moment (34). Additionally, two-joint muscles can also act as stiff ropes, linking body segments, that do not share a common joint, making it possible to transfer mechanical energy between these segments (35). Fortin (18) and Wilson et al. (13) found that both GC and BF muscles engage as agonists together with VL during extension of the knee and also to stabilize the joints, while RF is shown to act during hip extension in ergometer rowing.

The differences found in the iEMG pattern of VL, BF and RF corresponds to the differences detected in the force and power profiles after peak force/power foot-stretcher and external power during decrease. The findings suggest that stroke rate affect the timing of this coordinative in-between joint function causing different mechanical pattern at different intensities (thus preferred stroke rates). Electromechanical delay (EMD) of about 80 (±20) ms (36) should be considered if mechanical and muscle activity events are to be linked to each other directly. However, in the present study the interest lies in analyzing how timing of events may have differed between conditions. Here, differences in both mechanical output as well as muscle activity profiles were found that seems to coincide.

When investigating the trunk muscles, only LD shows differences in the iEMG pattern between conditions. The ability to apply high forces is dependent on maintaining postural position (5) by keeping the lumbar spine stabilized and aligned with the pelvis to enable resultant force at the handle to be optimized (26). No difference in the iEMG pattern of ES indicates that the postural position was similar across different intensities and stroke rates. However, the differences detected for LD in early drive (20-30%) occurs around the first burst of handle power before a flattening and further increase to peak (same for force at the handle), as seen in *Figure 3.2*. Functionally, due to its humeral and widespread attachment to the spine it has been suggested that LD function as a link between the spine and shoulder (28). This could potentially indicate that the rigid body or stiff connection form the foot-stretcher to the handle was influenced by different intensities and stroke rates causing a change in the mechanical pattern (9).

Only small periods in the iEMG pattern of the measured muscles were significantly different between the preferred conditions. However, a tendency towards a shift in time (left) with increasing intensity (thus preferred stroke rate) for all of the muscles investigated was present. This in accordance with other studies (14, 16). Nevertheless, Turpin et al. (16) suggested that this time-shift in the upper body muscles was due to an increase in movement velocity because of an increase in stroke rate. The earlier muscle activation would therefore be expected to develop force in the same part of the cycle to nullify the effect of EMD when movement time is reduced at increased stroke rates. However, the same time-shift was present in parts of the mechanical patterns for both foot-stretcher and handle, indicating that this time-shift in the muscles activity pattern with increasing intensity and stroke rate would rather imply alterations in the timing of muscles activity. Furthermore, when considering the significant differences between the preferred conditions a larger time period in the mechanical pattern compared to the iEMG pattern of the investigated muscles was present. This indicates that the muscle coordination was similar across the preferred conditions and that the EMD could explain some of the differences in the mechanical pattern between the preferred conditions. This is in accordance with McGhie and Ettema (37) that showed a consistent time-shift in net muscle moment and power with increasing cadence during cycling, while the time-shift in muscle activation patterns was close to zero.

4.3 Methodical considerations

4.3.1 Protocol

The present study reported a limited number of muscles, thus changes found in the mechanical pattern could be due to alternation in the activity patterns of muscles not included in this study. However, the included muscles are the main power producing muscles (13, 15) and the most active muscles during drive phase (16).

Concerning the experimental protocol, for many participants, some of the more extreme combinations of intensity and stroke rate were demanding. When combining the high intensity with the low stroke rate the participant had to produce much higher mechanical power than they usually would do within a stroke cycle, in order to maintain the required intensity (power output). As the present findings indicates, this could potentially change the technique execution of the rowing stroke. The effect of intensity and stroke rate was present, but when comparing the preferred conditions, the effects diminishes.

The rowers were able to choose individual preferred flywheel damp mechanism (gear) at the start of the protocol to retain throughout the test protocol. Instead, the gearing could have been used to regulate for the more demanding combinations of intensity and stroke rate. However, Held et al. (25) found high positive correlations between external power output, stroke rate and gearing, indicating a difficulty controlling for the separate effect of intensity and stroke rate if gearing was adjusted as the rowers preferred throughout the different test conditions. Still, it would be an interesting next step in future research.

Also, the RP3 display used during the execution of the protocol presented the force-curve. Thus, the rowers were able to modify the execution of the stroke to maintain their own signature force-curve. This could potentially explain the relative lesser effect of intensity and stroke rate on the mechanical pattern compared to the iEMG pattern. Still, change in motor behavior was necessary to execute the protocol as instructed.

4.3.2 Statistical analysis

The statistical method used to compare the mechanical and iEMG pattern of the preferred conditions (comparison of the diagonal in the 3x3 protocol matrix) have some limitations, as it did not adjust for the number of comparisons. A one-way ANOVA (SPM) should have been conducted, but due to time constraints, three multiple t-test were used as substitute. However, the outcome would be similar as the effect indicated by the 3x3 ANOVA (SPM) was counterbalanced when comparing the preferred conditions. Also, a Bonferroni adjustment on three t-tests is modest (p=0.05/3) and areas of significance would still been present, see *Figure 3.2, 3.3 and 3.5*. Also, statistical power for some of the SPM analysis were reduced because of total exclusion of participants with missing data. This could increase the probability of making a Type II error, neglecting potential effects due to small sample size (33). Moreover, the single-value imputation method used for missing data reduces variability, thereby lowering the estimate error comparing to deletion approaches and disregards the relationship between variables (33). However, the LMM statistical analysis was performed with and without single-value imputation and showed no differences in the main result between the two datasets.

4.3.3 The influence of kinematic changes

This study was restricted to dynamics and muscle activity. Thus, potential changes of body position that could explain some of the changes detected in both the mechanical and iEMG pattern were not accounted for. However, studies have shown that high level rowers produce consistent joint torques at different stroke rates (11), and that body angles in the catch and finish do not differ between stroke rates (22). This might be a general principle in motor behavior. For example, even in ski-jumping, an open chain task when testing high level athletes in different conditions, resulted in kinematic similarities with moderate to considerable changes in muscle activity pattern and dynamics respectively (38). Also, there are limited degrees of freedom of motion when rowing on a rowing ergometer. The distal segments are stationary, and therefore the total chain has less mobility. Consequently, motion at one joint is only possible with cooperative movement at other joints creating a closed chain (39).

4.4 Practical implications

Only small differences between the preferred conditions were identified in the iEMG pattern of important muscles. This might indicate a coordinative similarity in motor behavior between the two training levels and the competition level, suggesting that technique training at low intensity (thus with preferred stroke rate) would induce the same coordinative pattern used in competition. However, the similarities were more pronounced when comparing the MM with the HH condition, indicating the importance of always focusing on technique even if the main focus is interval training to enhance physiological capacity.

Similar effect of intensity and stroke rate was present for timing of peak power and force at the foot-stretcher and handle. However, the timing of peak force and power were statistically significant from each other, revealing the importance of choosing the correct mechanical variable for the research question. Subsequently, the question at hand enquire a measurement describing the execution of the rowing stroke including both force and movement. However, as earlier research emphasis the use of force-curves, both force and power were investigated in this study, thus revealing differences between the two mechanical outputs.

4.5 Future research

As mentioned in the introduction time interval between peak force at the foot-stretcher and handle were shown to influence the velocity efficiency and correlated highly with performance (20). The present results found non-significant differences in time interval between foot-stretcher force and handle force, only a tendency towards a time-shift (left) with increasing intensity (thus, preferred stroke rate). On the other hand, the alterations in the mechanical pattern showed differences between the preferred conditions in this part of the drive phase, when foot-stretcher force/power decreases and handle power/force reaching peak. Further research should therefore focus on the interval between peak force/power foot-stretcher and handle and quantify the effect of performance by including novice rowers.

Only male rowers were included in the present study. However, earlier research has suggested differences in the force-velocity curve between male and female rowers (40). Therefore, it would be of interest to investigate if the present findings are gender specific. Also, earlier research has presented clear consistent asymmetrical pattern of the right and left side of the body in both scullers and sweepers during on-water and ergometer rowing (15). Thus, it would be of relevance to investigate if the identified effects and differences between the preferred conditions would appear in different parts of the drive phase. At least, the present findings should be confirmed during on-water rowing.

4.6 Conclusion

The present findings show a clear effect of intensity and stroke rate on mechanical magnitude variables, and a more pronounced effect of intensity on mean muscle activity. For the mechanical and iEMG patterns both intensity and stroke rate influenced the patterns. However, the minor differences detected between the preferred conditions indicated that the effect of intensity and stroke rate were nullified to a certain extent, especially when investigating the iEMG patterns. The differences detected between the two training and competition conditions (preferred conditions) in the mechanical pattern was present at time of decreasing foot-stretcher force/power and increasing handle force/power. This indicates an effect on the relative timing of mechanical output between foot-stretcher and handle.

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