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Research article

Reliable Peak Power Assessment During Concentric and Flexion-Extension-Cycle Based Rowing Strokes using a Non-Modified Rowing Ergometer

Steffen Held ✉, Ludwig Rappelt and Lars Donath
Department of Intervention Research in Exercise Training, German Sport University, Cologne, Germany

Abstract

Accurate assessment of peak rowing power is crucial for rowing-specific performance testing. Therefore, within and between day reliability of a non-modified rowing ergometer was examined. 52 trained male rowers (21.0 ± 2.9 years; 1.89 ± 0.05 m; 83.2 ± 8.2 kg; 2,000-m ergometer Time Trial mean power: 369 ± 57 W) performed (two times 4) isolated concentric rowing strokes (DRIVE) and single flexion–extension cycle (FEC-type) rowing strokes (SLIDE-DRIVE) on two separate days (1 week apart). Good to excellent intraclass correlation coefficients (0.94 ≤ ICC ≤ 1.00), low standard error of measurement (≤ 2.7%), low coefficient of variation (≤ 4.9%), and suitable level of agreements (≤ 30W) for DRIVE and SLIDE-DRIVE indicated a high level of (within and between day) reliability. In addition, SLIDE-DRIVE (423 ± 157 W) revealed remarkably higher rowing power ($p \leq 0.001$; $\eta_p^2 = 0.601$; SMD = 0.34) compared to DRIVE (370 ± 154 W). The non-modified rowing ergometer is considered to be a reliable tool for the peak power assessment during isolated concentric contraction and FEC-type rowing strokes. Notably higher power outputs (compared to an isolated concentric contraction) during FEC rowing may refer to an underlying stretch shortening cycle.

Key words: Erg, oarsman, performance testing.

Introduction

The rowing cycle can be divided into a drive phase and a slide phase, whereby the catch corresponds to the start of the rowing cycle (Held et al., 2020b). During one rowing cycle, the legs undergo a flexion (slide) followed by an extension pattern (drive), which has been defined as a flexion-extension cycle (FEC) (Held et al., 2020b; 2020c). On the muscle level, a combination of active stretching (i.e., eccentric muscle action) and subsequently active shortening (i.e., concentric muscle action) is defined as a stretch-shortening cycle (SSC), which enables up to 50% higher muscle force, work, and power output compared with isolated muscle shortening (Bosco et al., 1987; Cavagna et al., 1968; Flanagan and Comyns, 2008). Since FEC rowing revealed a notable performance enhancement of around 10% (compared to purely concentric rowing) (Held et al., 2020b), it was speculated that this is due to the mechanisms underlying the SSC (Held et al., 2020b, 2020c). Accordingly, the differentiation between an isolated concentric (drive phase only) and a FEC-type rowing is essential (Held et al., 2020b).

Rowing ergometers play a crucial role in rowers' training and testing procedure (Boyas et al., 2006; Hopkins et al., 2001; Smith and Hopkins, 2012). Thereby, the wind-braked Concept 2 rowing ergometer (Concept 2/Type D, Morrisville, NC, United States) are regarded as the most commonly used devices (Boyas et al., 2006). This Concept 2 rowing ergometer is considered as the gold standard, which enables a valid and reliable (standard error of measurement of about 0.5%) testing device for longer test duration like the most common 2000m time trials (Hopkins et al., 2001; Smith and Hopkins, 2012). Since, peak power (highest power output during one rowing stroke) is highly correlated (r = 0.92; $p \leq 0.001$) to the 2000m time trial performance (Bourdin et al., 2004), the concept 2 rowing ergometer is frequently used for shorter test durations of 30s (Mikulić et al., 2009), 20s (Cataldo et al., 2015), 15s (Boyas et al., 2006) or 5 to 7 stroke peak power tests (Ingham et al., 2002; Metikos et al., 2015; Nugent et al., 2019; Sprague et al., 2007). Unfortunately, power measurement of the first (about 5) strokes are particularly inaccurate on the Concept 2 ergometer (Boyas et al., 2006; Holt et al., 2021). Therefore, the Concept 2 ergometer is usually modified with additional (force) sensors (Boyas et al., 2006; Held et al., 2020b; Metikos et al., 2015; Sprague et al., 2007), which enables sufficient (between day) reliability indicators (ICC = 0.87; CV < 6.5%; SEM < 17%) (Metikos et al., 2015; Sprague et al., 2007). However, these additional sensors result in higher financial and organizational resources, which hampers the accessibility of such testing procedures for coaches and athletes. To what extent the (within and between day) reliability of the non-modified Concept 2 rowing ergometer (for short test durations) can be improved by averaging several strokes is currently unknown. Thereby, within day reliability is crucial for monitoring acute strain during training sessions, between-day reliability plays an important role in detecting chronic performance developments (Atkinson and Nevill, 1998).

Against this background, the objective of our study was to quantify within and between day reliability of the non-modified Concept 2 rowing ergometer for assessing rowing power during both isolated concentric and FEC-type rowing. Essentially, the novelty of this research is based on the currently unknown reliability indices of the non-modified rowing ergometer for peak power testing. Furthermore, if the reliability of the non-modified rowing ergometer is high, this would strongly improve the accessibility and feasibility of peak power testing during rowing. Athletes and coaches could perform reliable peak power testing without additional effort and cost. Thereby, training induced performance changes or acute changes due to fatigue can be reliably detected. In addition, we aimed to examine whether the improved performance of FEC-type rowing compared to isolated concentric rowing (Held et al., 2020b) could also be replicated with an non-modified

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Concept 2 rowing ergometer. We hypothesis that the non-modified rowing ergometer is reliable, which additionally could detect the performance enhancement effects of FEC-type rowing compared to isolated concentric rowing. The resulting data would have an impact on the conceptualization of rowing-specific testing and training by providing easier access to reliable test settings.

Methods

Participants

Fifty-two trained male rowers (21.0 ± 2.9 years; 1.89 ± 0.05 m; 83.2 ± 8.2 kg; self-reported 2,000-m ergometer Time Trial mean power: 369 ± 57 W) were enrolled in this randomized controlled crossover reliability study. All participants had a minimum of 4 years of rowing competition experience, at least 6 or more weekly training sessions, were at least 18 years of age, did not present any health impairments and had not reported any history of neuromuscular or skeletal impairments in the past six months. Prior to the testing procedure, all participants were accustomed to the required equipment, procedure and the exercises. After providing all relevant study information, informed written consent was provided by all athletes prior to the start of the study. The study protocol complied with the Declaration of Helsinki and fulfilling the international ethical standards (Harriss and Atkinson, 2015). The German Sports University Research Ethics Committee has approved the study (No. 001/2019).

Data collection

After a standardized 10-min warm-up program (10-min rowing at a low intensity/heart rate, which corresponds to a blood lactate concentration <2 mmol/L), the participants performed four isolated concentric rowing strokes (DRIVE), and four single FEC-type rowing strokes (SLIDE-DRIVE) in a randomized order. After a 20-min rest, all measurements (DRIVE and SLIDE-DRIVE) were repeated (within day reliability assessment). 25 participants repeated all measurements again 7 days afterwards (between day reliability assessment). The previously randomized test order of each participant was not changed for all measurements. In order to control for potential circadian effects on performance, all measurements were conducted at similar times of the day for each participant. The DRIVE measurements started at the catch position and consisted only of the drive phase until the finish position. The SLIDE-DRIVE measurements comprised a full rowing cycle (slide and drive phase), starting at the finish position. The participants received the instructions to generate maximum power for each measurement trial. The mean rowing power of the three rowing strokes with the highest power outputs (of the four attempts) for each rowing condition were included into further analyses. Between all rowing strokes, a 2-min rest was guaranteed. The flywheel of the rowing ergometer was standing still at the start of the measurements during all rowing conditions. The rowing ergometer was calibrated with a drag factor of 145 (Ns^2/m^2) according to the specifications of the national rowing federation. A complete familiarization session (consisting of 10 DRIVE, and SLIDE-DRIVE rowing strokes) was completed 1 week before the measurement, and the athletes were asked to refrain from any strenuous activity 24 h prior to each assessment condition. All tests were performed on a wind-braked rowing ergometer (Concept 2/Type D, Morrisville, NC, United States), equipped with an PM5 Monitor (Concept 2, Morrisville, NC, United States). Details on power calculation of the Concept 2 rowing ergometer are given by Boyas and colleagues (2006). Briefly, the combination of acceleration (during the drive phase) and deceleration (during the slide phase) of the flywheel is used to calculate corresponding rowing power outputs (Boyas et al., 2006).

Statistics

All data are presented as group means ± standard deviation or with 95% confidence intervals. Normal distribution of DRIVE and SLIDE-DRIVE data was verified via Shapiro-Wilk tests ($p \geq 0.11$). In addition, variance homogeneity was visually verified via plotting residuals. Several one factorial (within day time: set 1 vs set 2; or between day time: lab visits 3 vs 4; or condition: DRIVE vs. SLIDE-DRIVE) repeated measures analysis of variance (rANOVA) were computed separately for the rowing power as primary outcome measure. rANOVA effect sizes were given as ηp^2 with values ≥0.01, ≥0.06, ≥0.14 indicating small, moderate, or large effects, respectively (Cohen, 1988). Standardized mean differences as a measure of pairwise effect size estimation were calculated (SMD; trivial: SMD < |0.2 |; small: |0.2 | ≤ SMD < |0.5 |; moderate: |0.5 | ≤ SMD < |0.8 |; large SMD ≥ |0.8 |) (Cohen, 1988). The agreement of within and between day reliability were analyzed by calculating the systematic bias (mean difference between measurements) and the limits of agreement (LoA: 1.96*standard deviation of the difference between both devices), considering a 95% random error component (Atkinson and Nevill, 1998) and plotting Bland-Altman plots (Bland and Altman, 1986). Standard error of measurement (SEM), coefficient of variation (CV), and intraclass correlation coefficients (ICC) were calculated (Atkinson and Nevill, 1998). ICC were calculated as random effect variance divided by the total variance; i.e. the sum of the random effect variance and the residual variance. In addition, ICC were rated as excellent (0.9 to 1), good (0.74 to 0.9), moderate (0.4 to 0.73) and poor (0 to 0.39) (Fleiss, 1988). In addition, the minimal detectable change (MDC) was calculated as typical error (TE) * 1.96 * $2^{0.5}$ (Beaton, 2000). The smallest worthwhile changes (SWC) were calculated as 30% of baseline standard deviation (Hopkins, 2004). The statistical analyses were conducted using R (version 4.0.5) and RStudio (version 1.4.1106) software.

Results

Within and between day reliability

The rANOVA revealed no significant effects ($p \geq 0.385$; $\eta_p^2 \leq 0.025$; SMD ≤ 0.04) for within and between day reliability of DRIVE and SLIDE-DRIVE measurements. SEM and CV were low for both DRIVE and SLIDE-DRIVE within and between day reliability testing (see Table 1). In addition, ICCs can be classified as excellent for both DRIVE and SLIDE-DRIVE within and between day

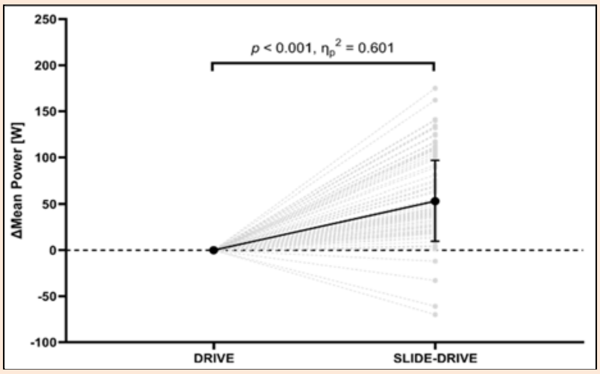

Figure 2. Rowing power comparison between DRIVE and SLIDE-DRIVE measurements (mean difference between DRIVE and SLIDE-DRIVE; with standard derivation). In addition, rANOVA significance (*p*) and effect size (η_p^2) are given.

reliability testing (see Table 1). LoA ranged from 19 to 30 W (see Figure 1). The MDC of both DRIVE (19 to 23 W) and SLIDE-DRIVE (29 to 30 W) were smaller than the respective SWC (47 W).

DRIVE Vs SLIDE-DRIVE

The rANOVA revealed a significant effect ($p \leq 0.001$; $\eta_p^2 = 0.601$) between DRIVE and SLIDE-DRIVE. Therefore, SLIDE-DRIVE (423 ± 157 W) revealed higher rowing power outputs (+53 ± 44 W; SMD = 0.34) compared to DRIVE (370 ± 154 W) (see Figure 2).

Discussion

This is the first study that assessed within and between day reliability data of a commercially available non-modified Concept 2 rowing ergometer for assessing maximal rowing

Table 1. Within and between day reliability indicators for DIRVE and SLIDE-DRIVE.

	power [W]	MD [W]	SEM [%]	CV [%]	ICC (95%CI)	LoA [W]
DRIVE: within day	test 1: 371 ± 156 test 1: 370 ± 154	-1 ± 12	0.6	3.1	1.00 (0.99-1.00)	23
DRIVE: between day	day 1: 275 ± 59 day 2: 277 ± 57	2 ± 10	1.1	3.5	0.99 (0.97-0.99)	19
SLIDE-DRIVE: within day	test 1: 423 ± 158 test 2: 423 ± 157	0 ± 15	1.0	3.5	1.00 (0.99-1.00)	29
SLIDE-DRIVE: between day	day 1: 312 ± 63 day 2: 315 ± 61	2 ± 15	2.7	4.9	0.97 (0.94-0.99)	30

MD = Mean Difference, SEM = Standard Error of the Mean, CV = Coefficient of Variation, ICC = Interclass Correlation Coefficient, CI = Confidence Interval, LoA = Limits of Agreement.

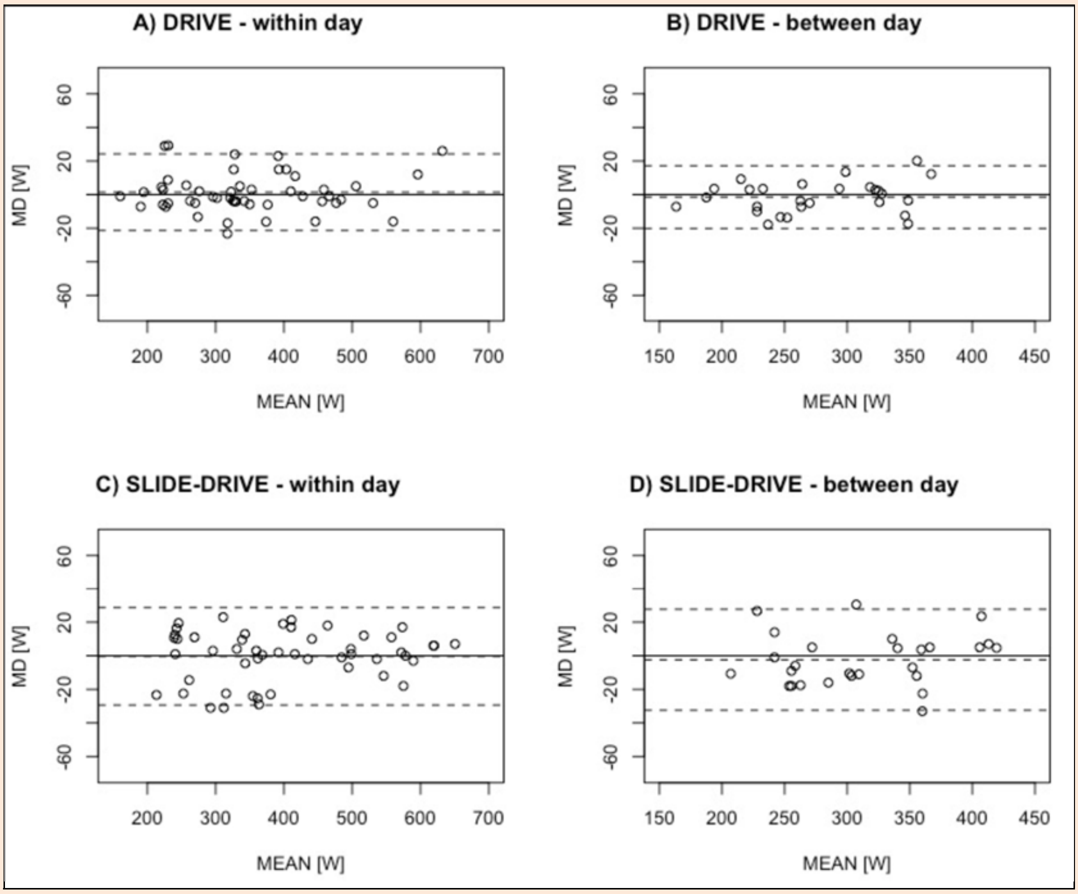

Figure 1. Bland–Altman plots (MD: mean difference between both devices; MEAN: average of both devices) for the within and between day reliability of DIRVE (A and B) and SLIDE-DRIVE (C and D).

power during isolated concentric and FEC-type rowing. Based on excellent intraclass correlation, low standard error of measurement (SEM), and low coefficient of variation (CV), we observed good to excellent (within and between day) reliability for both isolated concentric and FEC-type rowing measurements. The level of agreements ranged from 19 to 30 W for both isolated concentric and FEC-type rowing. In addition, the minimal detectable change of both conditions were below the corresponding smallest worthwhile change. Furthermore, FEC-type rowing revealed remarkably higher rowing power compared to purely concentric rowing.

Previous research showed good to excellent intraclass correlation (0.81 - 0.99), low to moderate standard error of measurement (9 to 28W), and low coefficient of variation (<6.5%) for within day reliability of a 6 and 7 stroke peak power test on modified Concept 2 rowing ergometer, respectively (Metikos et al., 2015; Nugent et al., 2019; Sprague et al., 2007). Using slightly longer test durations (20 to 30 s), non-modified ergometers also provided acceptable reliability indicators (20s: ICC = 0.98 to 1.00; CV = 2.5%; 30s: ICC = 0.99 to 1.00; CV < 3.4%) (Cataldo et al., 2015; Mikulić et al., 2009). Compared to previous data (Cataldo et al., 2015; Metikos et al., 2015; Mikulić et al., 2009; Sprague et al., 2007), our findings revealed comparable or even superior (within and between day) reliability indicators (ICC $\geq$ 0.94 to 1.00, SEM $\leq$ 2.7%, CV $\leq$ 4.9%) for the non-modified Concept 2 rowing ergometer. During rowing (ergometer) training and testing, the intensity is usually controlled via the 500m split time rather than power (in watts). Thereby, the calculated 500m split time of each stroke (round to full seconds) is displayed by the PM5 Monitor (Concept 2, Morrisville, NC, United States) (Boyas et al., 2006; van Holst, 2008). The calculated limits of agreements (19 to 30 W) would imply a 500m split time difference of 1.4 to 2.1 s. Furthermore, these calculated limits of agreements and the minimal detectable change (for both within and between day reliability of both conditions) were below the smallest worthwhile change (calculated as 30% of pretest standard derivation = 47 W) (Hopkins, 2004). Therefore, the used measurement setup can be classified as reliable for within and between day testing.

In line with previous research (Held et al., 2020b) (using a modified rowing ergometer), our findings (using a non-modified rowing ergometer) clearly showed that FEC rowing led to notably higher rowing power output compared to isolated concentric rowing movements. Therefore, the performance enhancement effects of FEC-type rowing were equally observable with a modified (Held et al., 2020b) and non-modified (current findings) rowing ergometer. The performance enhancement effects are in line with the general force, work, and power enhancement during SSC (Bosco et al., 1987; Cavagna et al., 1968; Flanagan and Comyns, 2008). Increased performance of (SSC based) countermovement jumps (CMJ) compared to (purely concentric) squat jumps has traditionally been seen as a measure of the efficiency of the SSC (Bobbert and Casius, 2005; Kozinc et al., 2021; Van Hooren and Zolotarjova, 2017). These assumptions are in contrast to recent findings (Kozinc et al., 2021), which contributes increased jump heights of CMJ to greater uptake of muscle slack (Van Hooren and Zolotarjova, 2017) and the active state developed during the preparatory countermovement (Bobbert and Casius, 2005). However, previous rowing-related research revealed higher rowing power, leg power, and work per stroke during FEC rowing compared to pure concentric rowing strokes with isometric preactivation (Held et al., 2020b). Compared to pure muscle shortening from rest, isometric preactivation results in increased muscle activity at the beginning of leg extension (Svantesson et al., 1994). Therefore, the contribution of the muscle slack (Van Hooren and Zolotarjova, 2017) and increased contraction time (Flanagan and Comyns, 2008; Turner and Jeffreys, 2010) cannot fully explain the enhanced performance during FEC rowing compared with pure leg extension rowing strokes with an isometric preactivation. Furthermore, FEC rowing did not reveal preactivation before the active stretch phase and no reflex activity within sEMG measurements of the leg extensor muscles (Held et al., 2020c), which likely excludes the contribution of neural mechanisms to the performance improvements during FEC rowing. Therefore, the storage and release of elastic energy (Bojsen-Møller et al., 2005; Kubo et al., 1999) and the stretch-induced force enhancement that persists during the shortening phase of SSCs (Rode et al., 2009; Seiberl et al., 2015; Tomalka et al., 2020) might be the most likely contributors to the observed performance enhancements in FEC rowing (Held et al., 2020b). Nevertheless, a SSC on fascicle level has yet not been observed during rowing (Held et al., 2020a, 2020b, 2020c). Therefore, future research should precisely determine whether the muscle fascicle complete an SSC during rowing and investigate the verification of the SSC in rowing.

A limitation of this study is that the results are necessarily linked to the chosen settings. Therefore, a high degree of standardization is therefore necessary for practical application: (i) Sufficient familiarization to the testing procedure; (ii) refraining from any strenuous activity 24 h prior to each testing day; (iii) fixed testing at similar times of the day for each participant, to control for potential circadian effects on performance; (iv) standardized warm-up protocol; (v) standardized calibration with a drag factor of 145 (Ns^2/m^2); (vi) taking care, that the flywheel of the rowing ergometer is still standing at the start of each measurement; (vii) performing four rowing strokes, with 2-min rest in-between; and (viii) using the mean rowing power of the three rowing strokes with the highest power outputs (of the four attempts) for further analyses. Nevertheless, the confirmed reliability of this non-modified rowing ergometer approach improves accessibility and feasibility of peak power testing during rowing, which enables reliable peak power testing without additional effort and cost. Since only male participants were measured, the non-generlizability for female athletes should be mention.

Conclusion

In summary, (i) the commercially available non-modified Concept 2 rowing ergometer revealed excellent intraclass correlation, low standard error of measurement, and low coefficient of variation for (within and between day) reliability of isolated concentric and FEC-type rowing, (ii) the level of agreements and minimal detectable changes were sufficient low for detecting chronic performance developments, and (iii) FEC-type rowing revealed remarkably higher rowing power compared to purely concentric rowing. In conclusion, the commercially available non-modified Concept 2 rowing ergometer can be considered to be a reliable measurement device for measuring rowing power during both isolated concentric and FEC-type rowing. In addition, the performance enhancement effects of FEC-type rowing compared to isolated concentric rowing (Held et al., 2020b) were also observable with a non-modified Concept 2 rowing ergometer.

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Key points

- The non-modified rowing ergometer (Concept 2/Type D, Morrisville, NC, United States) enable a feasible, low cost, and reliable peak power measurement during isolated concentric and combined eccentric and concentric (FEC) rowing strokes.
- The resulting muscular performance is considered notably higher during a stretch shortening cycle (SSC) compared to an isolated concentric contraction.
- These performance enhancement effects could be confirmed during FEC (compared to an isolated concentric contraction), which may refer to an underlying SSC.

AUTHOR BIOGRAPHY

Steffen HELD
Employment
Department of Intervention Research in Exercise Training, Institute of Exercise Training and Sport Informatics, German Sport University, Cologne, Germany
Degree
PhD
Research interests
Muscle activity profiles in lab and in-field rowing; the link between rowing power output and rowing cycle configuration and the strength and endurance development for rowing.
E-mail: s.held@dshs-koeln.de

Ludwig RAPPELT
Employment
Department of Intervention Research in Exercise Training, Institute of Exercise Training and Sport Informatics, German Sport University, Cologne, Germany
Degree
MSc
Research interests
The effects of alternative and complementary muscle training methods on neuromuscular and cardiorespiratory performance indices.
E-mail: l.rappelt@dshs-koeln.de

Lars DONATH
Employment
Prof., Department of Intervention Research in Exercise Training, Institute of Exercise Training and Sport Informatics German Sport University, Cologne, Germany
Degree
PhD
Research interests
Exercise-based health promotion across lifespan. His research focuses on acute & longitudinal responses & adaptations upon different modalities of neuromuscular & cardiocirculatory exercise in various populations and settings.
E-mail: l.donath@dshs-koeln.de

✉ **Steffen Held**
Department of Intervention Research in Exercise Training, Institute of Exercise Training and Sport Informatics, German Sport University, 50933 Cologne, Germany.