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Changes in kinematics and work physiology during progressive lifting in healthy adults

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A R T I C L E I N F O

Keywords:
Functional capacity evaluation
Observation
Motion analyses
Electromyography
Heart rate. WorkWell functional capacity evaluation

A B S T R A C T

Purpose: To analyze progression of changes in kinematics and work physiology during progressive lifting in healthy adults.
Methods: Healthy participants were recruited. A standardized lifting test from the WorkWell Functional Capacity Evaluation (FCE) was administered, with five progressive lifting low series of five repetitions. The criteria of the WorkWell observation protocol were studied: changes in muscle use (EMG), heart rate (heart rate monitor), base of support, posture and movement pattern (motion capture system). Repeated measures ANOVA's were used to analyze changes during progressive workloads.
Results: 18 healthy young adults participated (8 men, 10 women; mean age 22 years). Mean maximum weight lifted was 66 (±3.2) and 44 (±7.4) kg for men and women, respectively. With progressive loads, statistically significant ($p < 0.01$) differences were observed: increase in secondary muscle use at moderate lifting, increase of heart rate, increase of base of support and movement pattern changes were observed; differences in posture were not significant.
Conclusions: Changes in 4 out of 5 kinematic and work physiology parameters were objectively quantified using lab technology during progressive lifting in healthy adults. These changes appear in line with existing observation criteria.

1. Introduction

The determination of work ability in patients with musculoskeletal conditions remains challenging. Based on complex biopsychosocial interactions, as described in the work disability prevention model (Loisel et al., 2005) or the International Classification of Functioning, disabilities and health (ICF) ((WHO., 2001), it can be recommended that unidimensional evaluation methods will be insufficient to cover the complete domain of work ability. Functional Capacity is one of the dimensions of work ability and can be measured with Functional Capacity Evaluations (FCE). FCE can be defined as an evaluation of the capacity to perform activities, that is used to make recommendations for participation in work, while considering the person's body functions and structures, environmental factors, personal factors and health status (Soer et al., 2008a). FCE's consist of several tests addressing lifting and carrying of materials, working in static postures and repetitive movements. FCEs are commonly used within post-offer/pre-employment testing, work hardening programs or workers' compensation claims and attempt to objectively and reliably test the persons functional capacity. Making a balanced and complete evaluation of a persons' functional capacity is a complex task, therefore a basic requirement is that the individual kinematic and physiological responses to progressive loads can be objectively quantified.

Traditionally, visual observations were the basis to establish whether a person has reached capacity from a biomedical perspective. While manually handling increasing workloads, a person will show biomechanical and kinematic changes. Observational criteria for FCE test evaluators were developed for the Work Well Systems (WWS) FCE to operationally define these changes (WorkWell, 2006) (Table 1). The WWS FCE is one of the most studied FCE protocols (Kuijer et al., 2006, 2012a; Bieniek and Bethge, 2014) and is used at the authors centers in Groningen and Enschede in the Netherlands. The inter- and

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intra-observer reliability were established in healthy workers, patients with chronic musculoskeletal pain (Trippolini et al., 2014), individuals with early osteoarthritis of hip and/or knee (van Ittersum et al., 2009) and patients with chronic neck pain (Trippolini et al., 2013). The validity of these observations to identify levels of effort, for example submaximal capacity, has been established (Van der Meer et al., 2013). Validity of identification of maximal performance has not been established, possibly because of the absence of a gold standard (Reneman et al., 2005).

Since the beginning of the 21st century, in research literature a shift from observation driven (maximal effort and reliability studies) to measurement driven evaluation methods can be detected including the use of optical motion capture systems (Lang and Dickerson, 2017; Valevicius et al., 2018) and electromyography (Fabian et al., 2005; Gagnon et al., 2001). The underlying changes in kinematics and physiological measures during lifting of progressive loads may assist in determination of normal or abnormal movement patterns (Lang and Dickerson, 2017; Ogata et al., 2018) and muscle use (Fabian et al., 2005). It is unknown if and to what extent these measures change during progressive workloads and whether they are useful to identify levels of effort. Therefore, it may be relevant to test the underlying assumptions of the observation criteria. While these assumptions are generally plausible and based on well-established work physiology principles (such as heart rate increase, muscle activation patterns, force-velocity curves), the suggested stepwise or even linear progression of these phenomena (i.e. light workload <25%, moderate workload <50%, heavy workload <75%, maximum workload <100%) has not been substantiated. A non-linear progression has also been suggested and is theoretically underpinning category ratio scales such as the CR10 scale (Neely et al., 1992). Based on this, a linear categorical scaling may be trivial. Additionally, this CR10 scale excludes a definition of 'maximum', because it is deemed impossible to define an absolute maximum in human physical performance (Neely et al., 1992). To summarize, there is insufficient knowledge on the validity of observation criteria to detect workload, which may limit the ability of professionals to adequately test functional capacity and to inform on work ability. The objective of this study was to test progression of changes in kinematics and work physiology during progressive lifting in healthy adults. We hypothesized to observe progressive changes in muscle use, heart rate, base of support, posture and movement patterns consistent with the observational criteria (Table 1).

2. Methods

2.1. Participants

A convenience sample of healthy participants was recruited from Saxion University of Applied Sciences in The Netherlands. Included were participants without any musculoskeletal condition and a negative score on the Physical Activity Readiness Questionnaire (Thomas et al., 1992).

2.2. Design

A cross sectional study in an experimental setting was conducted.

2.3. Procedures

The lifting low test of the WorkWell FCE was administered (WorkWell, 2006); (Fig. 1). This test was selected because it is one of the most physically challenging tests and also the most studied test of the FCE, yielding robust results (Bieniek and Bethge, 2014). It is considered a key test, for example because the DOT-system (Dictionary Of Occupational titles) describes the physical demands of a job mainly based on lifting tasks. Additionally, it is the test with predictive validity for concurrent and future work (Kuijer et al., 2012b; Gouttebarge et al., 2009). All participants were informed on the aim of the study and signed informed consent prior to participation.

3D motion, right-side surface electromyography (sEMG), and heart rate were recorded through the lifting trials.

Prior to the measurements, participants were instructed in the test procedures and were able to practice before the measurements took place. Participants were free to end the test at any moment if they wanted to. As a warm-up and confirmation of proper protocol performance, all participants first performed the test with four kilograms in the crate. Subsequently, the individual load levels (light to maximum) were established by the test leaders, using the observation criteria, in four progressive load levels without fixed increments (four sets of five repetitions each: numbered as set I – IV hereafter). Participants were blinded to the details of the study, i.e. they were not instructed on their base of support, musculature use, posture or movement patterns.

This study was part of educational purposes at the department of Health at Saxion University of Applied Sciences. The study plan was submitted to the Saxion Ethical Advice Committee (SEAC) who advised the authors to perform a self-check to decide if permission by a medical ethical committee was needed. Because the study includes healthy participants who perform an activity from daily life (i.e. a lifting task) and the use of FCE in healthy participants and patients with low back pain (LBP) is considered safe (Soer et al., 2008b; Reneman et al., 2006) we concluded this was not the case. Participants were then informed about the aim of the study, they gave informed consent and filled out the Physical Activity Readiness (PAR) questionnaire.

2.4. Measurements

WorkWell Lifting Low test: The objective is to test the capacity of lifting from table to floor and vice versa. Five lifts from table at 74 cm to floor v.v. within 90 s in standing position were performed for four weight increments (set I-IV) until maximum amount of weight lifted was reached. A plastic receptacle (40 × 30 × 26 cm) was used for testing. Test-retest reliability is good with Intraclass Correlation Coefficient (ICC) = 0.81 in patients with LBP (Brouwer et al., 2003) and ICC = 0.95 in healthy individuals (Reneman et al., 2004).

For the following measurements observation criteria 1 to 5 refer to the observation scheme (Table 1) (WorkWell, 2006; Van der Meer et al.,

Table 1
WorkWell observation checklist.

Item	Light	Medium	Heavy/very heavy	Maximal
Use of musculature	Only prime movers. No secondary and tertiary muscle use.	Prime movers plus light secondary and tertiary muscle use.	Prime movers plus medium secondary and tertiary muscle use.	Prime movers plus strong secondary and tertiary muscle use.
Base of support	Natural position.	Stable base.	Solid base.	Very solid base.
Posture	Natural upright posture.	Light counter balancing of the trunk.	Medium counter balancing of the trunk.	Strong counter balancing of the trunk.
Heart rate increase	Light.	Medium.	Strong.	Very strong.
Movement pattern	Easy movement patterns.	Fluent movements.	Use of impulse, difficult but not maximal.	Use of impulse, difficult but still controlled.

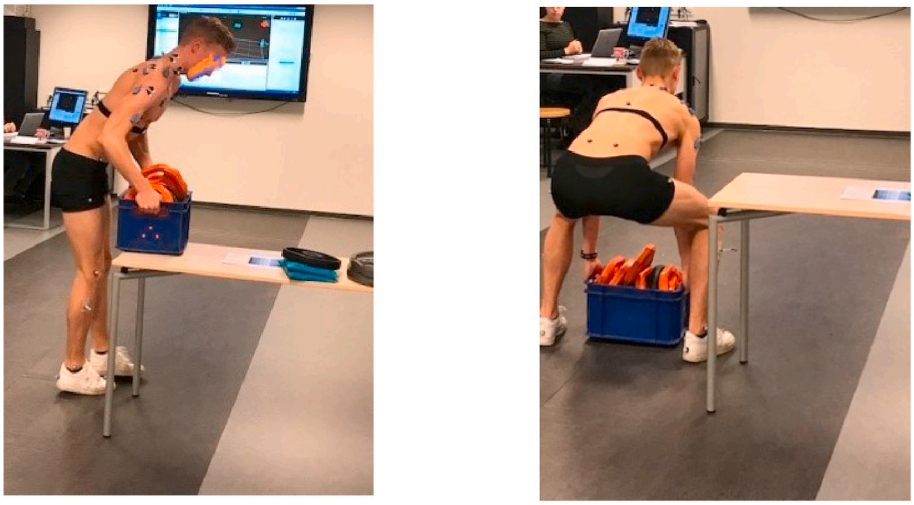

Fig. 1. The FCE-test 'lifting low': the subject lifts the crate from the table to the floor and back, rotating the feet 90°.

2013):

Surface EMG *(observation criterion 1, use of musculature)*: Primary muscles for lifting low were the m. trapezius descendens and the m. biceps. Secondary muscles were the m. deltoid and m. pectoralis major and for tertiary musculature (that could be validly reached by surface EMG without cross talk), the m. sternocleidomastoid and m. levator scapulae were used. The sEMG signals were detected using Mini wave EMG sensors (Cometa Systems, Italy). The skin was cleaned by mildly scrubbing it with Nuprep skin preperation gel. Electrodes were placed on the belly of the muscle with a distance of 2 cm apart in the direction of the muscle fibers, following SENIAM methods (Hermens et al., 2000) (Fig. 2; except M.levator scapulae sensor placement). The sensors were attached to the skin with a double-sided adhesive interface. Raw EMG signals were analyzed using Matlab (Mathworks R2019b), A bandpass butterworth filter with cutoff frequencies of 20 Hz and 500 Hz was applied. The maximum amplitude (in millivolts) of each of the 5 lifts per set (I-IV) was determined and subsequently the average peak of these five repetitions was calculated. Inter- and intra-rater reliability of measurements on the trapezius is high (ICC = 0.91) (Barbero et al., 2011), but unknown for other muscles. Test-retest reliability of peak activity is good (Khoddami et al., 2017).

Movement analyses *(observation criteria 2-3-5, base of* support *– posture – movement pattern):* The Vicon V5 optical motion capture system was used as objective standard. The system uses eight infrared cameras (Vicon Vantage V5, 100 frames per second, Vicon Motion Systems, Ltd., Oxford, UK) and two video cameras (Vicon Bonita 720c, 120 Hz, Vicon Motion Systems, Ltd., Oxford, UK) to register reflective body markers on the lifting crate and on anatomical landmarks. The software (Vicon Nexus version 2.6) tracks the motion of the markers with a precision of 63 μm with a standard deviation of 5 μm (Windolf et al., 2008).

Base of Support was determined as the distance between both lateral malleoli, which were marked by a reflective marker to be determined by Vicon optical motion system.

Posture: as a proxy measure for counterbalancing, the degree of extension of the spine was determined. Four markers were placed on the bony landmarks of the spinous process at C7, the spinous process at Th10 and both posterior inferior iliac spine (PIIS). The angle between the line C7–Th10 and the line PIIS-Th10 was presented in a graph (Fig. 3); maximal extension angles during the sets were recorded to express posture/counterbalancing of the spine.

Movement pattern was defined as the impulse the subject transferred to the crate to start moving it upwards. Impulse is defined in physics as the integral of force over time (Andrews et al., 2008), which mathematically equals mass*velocity. We interpreted 'impulse' in the WWS observation scheme as the force generated to move (accelerate) the crate from the floor during the first 20 cm. The velocity was then analyzed with the Vicon optical motion system as [0.20 m./time needed for this trajectory] and later multiplied by the weight lifted. Reflective markers were fixed on the crate.

Heart rate *(observation criterion 4 – heart frequency):* A Polar heart rate monitor (type FT4) was used to determine heart frequency. The validity and test-retest reliability of the polar is excellent with Intraclass

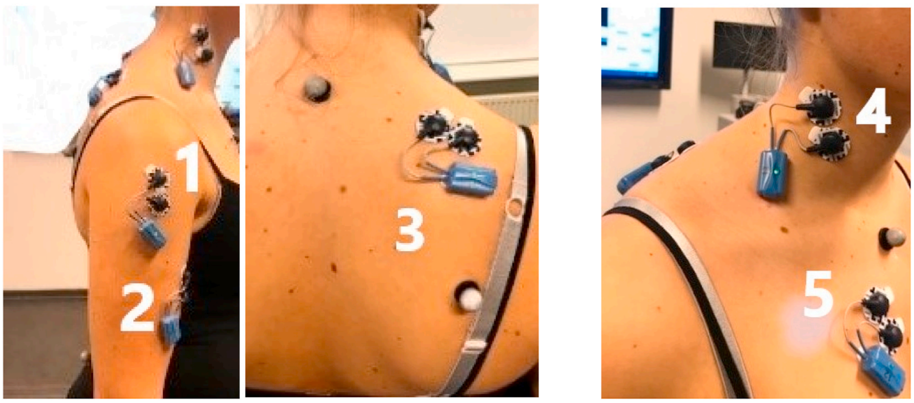

Fig. 2. Placement of the EMG sensors for the selected muscle groups – 1. M.deltoideus, 2. M.biceps, 3. M.trapezius desc., 4. M.sternocleidomastoideus, 5. M.pectoralis major.

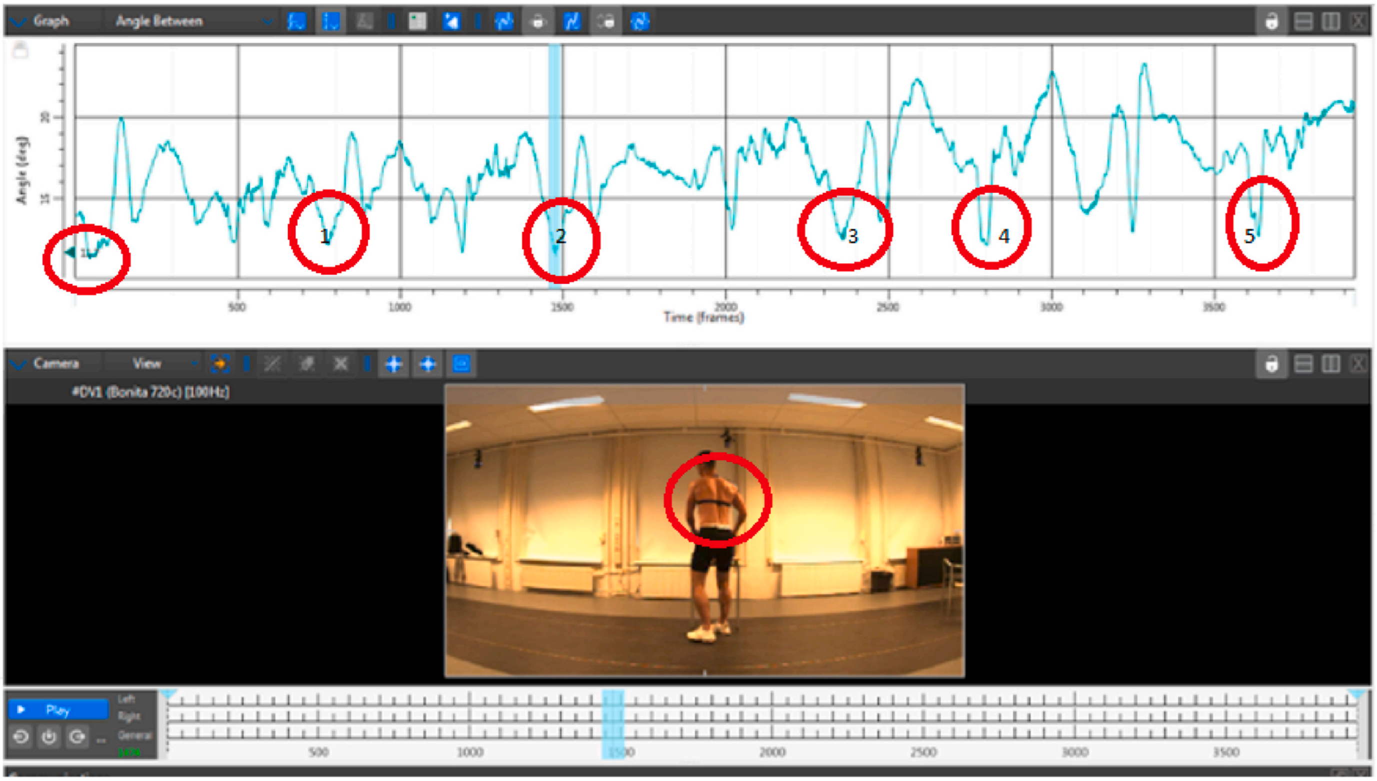

Fig. 3. An example of a video frame with synchronous information of position of the markers in time; the marked maximal extension angles in the graph (red circles) were used as indicators for counter balancing.

correlation coefficients (ICC) between 0.97 and 1.0 (Engström et al., 2012). There are no significant differences between the polar and an electrocardiogram (ICC 0.93–1.0) with a maximal deviation of two heartbeats per minute (Kingsley et al., 2005). Maximal heart rate during a series was noted directly before starting and after finishing the series of 5 repetitions. Increase in heart rate was determined by calculation of difference between post- and pre-test heart rate. Reaching 85% of maximum heart rate (calculated as 220 minus age) was a criterion to end the test; heart rate had to be below 70% of maximum before starting the next load level.

2.5. *Hypotheses on factor objectification*

The aim was to objectively quantify all five factors that can be derived from the observation list:

1. *Use of musculature,* following the observation scheme (Table 1) use of musculature was classified as primary, secondary and tertiary (see 2.4). In the lifting category light it was hypothesized that primary movers would be active, while secondary and tertiary musculature activity would be low. In the medium lifting category, it was hypothesized that secondary muscle activity would increase significantly. In the heaviest lifting conditions, it was expected that also tertiary muscle activity would increase significantly.
2. *Base of Support,* as determined by the distance between both lateral malleoli, was expected to increase with increasing weight.
3. *Posture*: as a proxy measure for counterbalancing, the amount of extension of the spine was determined during lifting. It was expected that there would be a significant increase in low back extension with increasing weights.
4. *Heart frequency:* It was expected that there would be a significant increase in heart rate during lifting with increasing weights.
5. *Movement pattern* was defined as the impulse the subject carried over to the crate during the first 20 cm while lifting it from the floor. Impulse was calculated as velocity (analyzed with the Vicon optical motion system, 0.20 m./time needed for this trajectory) multiplied by the weight lifted and expressed in kg*m/s (=N*s). Reflective markers were fixed on the crate. It was expected that there would be significant increase in impulse during progressive load conditions, because it takes more effort to set a heavier load in motion.

2.6. *Analyses*

The maximum amount that a participant lifted was considered 100%. During analyses, we selected interim lifts of participants that were closest to 25%, 50% and 75% of maximum. We analyzed 4 lifting attempts per participant. Because these attempts were not exactly 25%, 50%, 75% and 100%, we named them: set I, II, III, and IV. Processing of the optical data was performed with Nexus 2.6. Missing marker points were manually filled. All data were checked for normality by normality plots. If normally distributed, each parameter of the observation checklist was tested with repeated measures ANOVA's to correct for dependency of data. Post hoc Bonferroni corrections were applied. All analyses were performed with SPSS-23. P-values < 0.05 were considered statistically significant.

3. Results

In total, 18 participants (8 men, 10 women) participated in this

Table 2
Characteristics of the study population.

Characteristic	Men (n = 8)	Women (n = 10)
Age in years: mean (sd)	23 (2.8)	21 (1.8)
Bodyweight in kg: mean (sd)	73 (6.9)	65 (10.1)
Length in cm: mean (sd)	184 (5.2)	172 (4.0)
Maximum weight lifted in kg: mean (sd)	66 (3.2)	44 (7.4)

study. The mean age was 21.8 (2.4) years. Descriptive statistics are presented in Table 2. All data were considered normally distributed. In Fig. 4, EMG distribution per set is presented.

3.1. *Use of musculature*

In all six muscles that were measured, set I (light) produced the smallest amounts of activity (mV), meaning that muscular activation was smallest in this condition. The results of repeated measures ANOVA's show that in all muscles, there were significant differences between lifting conditions (Table 3). In the muscles considered to be prime movers (m. biceps and m. descending trapezius), activity increased with lifting conditions requirements from light to heavy, but they demonstrated not more activation in set IV (very heavy) compared to set III (Fig. 1a; $p < 0.01$). The pattern of muscle activation in the secondary muscles (m. pectoralis major and m. deltoid) is different from the pattern of that of the prime movers. Here a more sudden increase in activation can be identified between set II and III (Fig. 1b; $p < 0.01$). The tertiary muscles (m. lLevator scapulae and m. sternocleidomastoid) become more active in set III (Fig. 1c; $p < 0.01$).

3.2. *Heart rate*

There were no cases in which the test was terminated because participants' reached their predefined 85% of their maximal heart rate. Heart rate increased between set I and III ($p < 0.01$; see Table 1). In set IV heart rate increased less compared to the previous steps. There was no larger increase in heart rate between set III and set IV, however, the heart rate at initiation of lifting was higher in set IV compared to set III.

3.3. *Base of support*

The base of support progressed to a wider base during progression of loads from 37 cm at set I to 66 cm at set IV ($p < 0.01$; see Table 1).

3.4. *Posture in degrees*

There appeared no significant differences between the sets with regards to extension of the back ($p = 0.09$). A tendency to less extension of the low back with increasing weight could be identified.

3.5. *Use of impulse*

Impulse increased significantly after set I. It should be mentioned that while impulse increased, the velocity of crate being lifted slightly decreased with heavier lifting conditions (6.04–4.82 – 4.19–4.02 m/s respectively). However, with higher weights being lifted in every consecutive set, impulse increased significantly ($p < 0.01$).

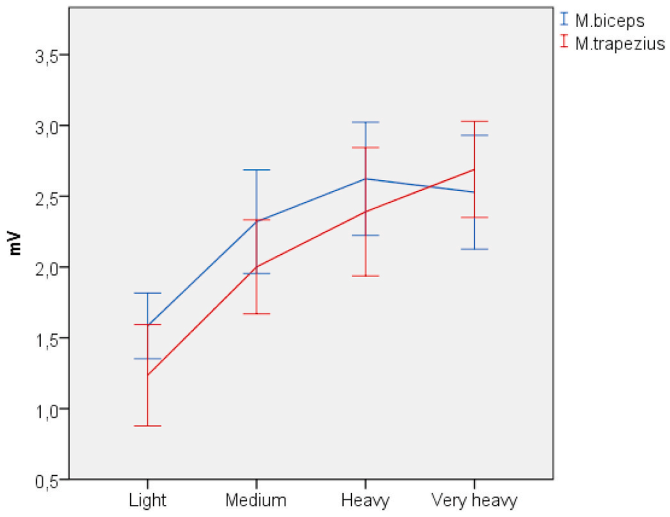

Fig. 4a. EMG signal intensity of primary muscles (error bars indicate ± 2 SE).

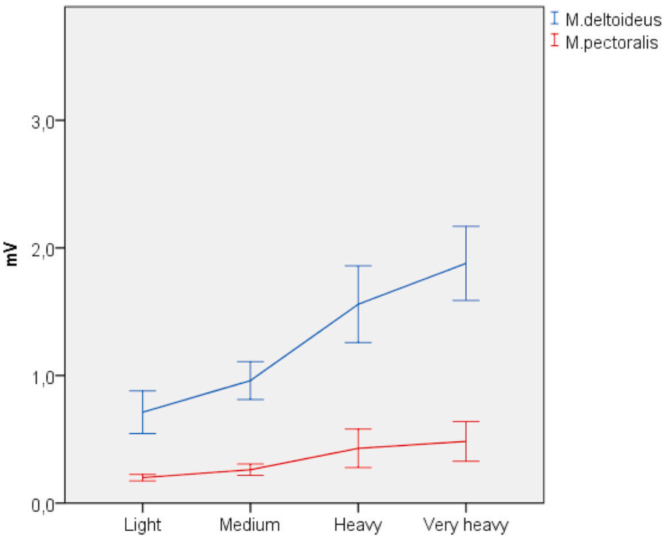

Fig. 4b. EMG signal intensity of secondary muscles.Error bars indicate ± 2 SE.

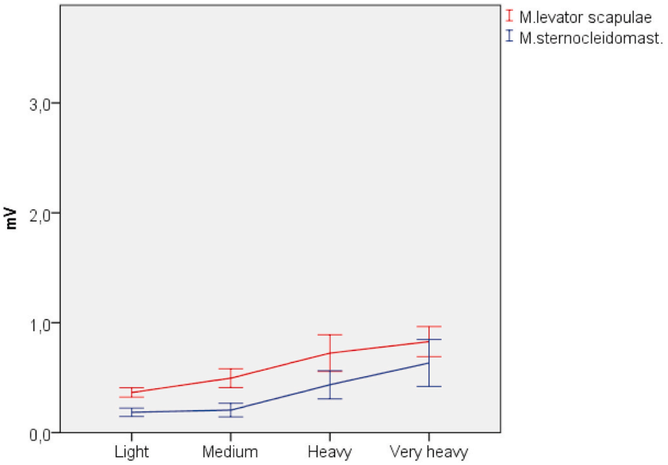

Fig. 4c. EMG signal intensity of tertiary muscles.Error bars indicate ± 2 SE.

4. Discussion

The results of the EMG, heart rate, and movement analysis confirmed most of our hypotheses on muscle use, base of support, cardiovascular response and use of impulse during the FCE lifting low test with healthy young adults. The hypothesis on counterbalancing with increased load was rejected. Thus, objective kinematic and work physiology measures confirmed the general direction of 4 of the 5 observation criteria.

Our results indicate that assessed levels of effort, using observation criteria, correlate with measurement data from technological tools as motion analysis and EMG, during an FCE protocol with stepwise increase in lifting load. The increase of muscle activation and heart rate with increased weights lifted was significant, which means that an observed increase of effort can be objectively quantified. With regard to the use of impulse, we found increases over the progression of sets, however it should be mentioned that this was only due to the fact that load increased and not because of increasing speed or acceleration of the crate. We used the physical definition of impulse being the

Table 3
Differences of observation criteria between series (N = 18).

Variable	set I-light mean (SE)	set II-medium mean (SE)	set III-heavy mean (SE)	set IV-very heavy mean (SE)	F (p)	Post hoc Bonferroni
Lifted Weight (kg)	14.1 (1.9)	27.5 (3.9)	45.0 (12.3)	54.1 (12.7)	n/a	n/a
Biceps brachii (mV)	2.06 (0.65)	2.93 (0.74)	3.07 (0.73)	3.00 (0.68)	26.132 (<0.01)	1 < 2,3,4
Deltoid (mV)	0.95 (0.37)	1.32 (0.46)	2.04 (0.69)	2.38 (0.54)	38.4 (<0.01)	1 < 3,4 2 < 3,4 3 < 4
Trapezius (mV)	1.76 (0.76)	2.51 (0.64)	3.07 (0.64)	3.20 (0.47)	65.1 (<0.01)	1 < 2, 3,4 2 < 3,4
Pectoralis major (mV)	0.24 (0.11)	0.35 (0.27)	0.51 (0.37)	0.62 (0.40)	12.5 (<0.01)	1 < 3,4 2 < 4
Sternocleido-mastoid (mV)	0.20 (0.05)	0.31 (0.20)	0.65 (0.47)	0.82 (0.60)	15.9 (<0.01)	1 < 3,4 2 < 3,4
Levator scapulae (mV)	0.42 (0.09)	0.58 (0.18)	0.87 (0.32)	1.13 (0.36)	35.8 (<0.01)	1 < 2,3,4 2 < 3,4 3 < 4
Heart rate increase from baseline (pre-test; bpm)	33.3 (14.1)	41.4 (14.0)	55.8 (16.6)	54.2 (11.4)	27.5 (<0.01)	1 < 3,4 2 < 4 3 > 1
Base of support (mm)	368 (130)	437 (174)	570 (140)	661 (86)	31.8 (<0.01)	1 < 3,4 2 < 3,4 3 < 4
Posture/counterbalance (degrees)	17.7 (5.8)	17.0 (5.3)	15.8 (5.0)	16.0 (4.4)	2.1 (0.09)	n.s.
Movement pattern (kg*m/s)	85.2 (21.6)	132.6 (42.6)	188.6 (80.1)	217.7 (79.9)	18.3 (<0.01)	1 < 2,3,4 2 < 4

SE = standard error; mV = millivolts; bpm = beats per minute; n/a = not assessed; set I-IV refer to the four load levels.

multiplication of mass and velocity. To move a crate with weights from the floor, a subject has to generate a net impulse by applying a force (mass x acceleration) during a certain time interval. This results in moving a weight with an average speed over a defined trajectory (the first 20 cm in our study). The assumption from the WWS FCE observation scheme that lifting (very) heavy loads demands the use of impulse applies with the laws of physics, but we could not confirm an observable kinematic change corresponding to the intention of this criterion. The interpretation of the term impulse in the WWS manual is somewhat ambiguous and should be further explored.

For the observation of counterbalancing, we found no evidence in extension of the back. This does not necessarily mean, however, that counterbalancing was not present. Positions of other joints such as hips (extension), knees (flexion) and the lumbar spine may have changed to counterbalance the external force and thus to prevent from falling forward. A full body observation and using principle component analyses, were previously found able to detect features of movement over time and may be considered for further validation (Daffertshofer et al., 2004).

While this study has confirmed the general direction of 4 out of 5 observational criteria, this should not be interpreted as confirmation of the validity of the use of these criteria for individual patients. This study has confirmed the average progression of the parameters. The application on individuals has not been studied yet. Also, this study has used healthy young adults as a first stage in validation of the observation scheme. We recognize that conducting FCE's in clinical populations is more complex and may yield different results. Workers with chronic low back pain may demonstrate adapted movement patterns, which we did not see in our study sample. The accuracy of establishing the levels light, medium, heavy and maximal remains uncertain and depends on the terms and operational definitions used to define them. Cut-off points between Light-Medium-Heavy-Maximal lifting have not been established. Especially determining maximal effort remains an issue with conceptual uncertainty, and consequently also operationally. On the other hand, the demonstrated increased activation of secondary and tertiary muscles (with EMG) and the significant increase in heart rate support the use of the observation schedule to establish stepwise increases in load and probably also a heavy load level. In other words, both the muscle activity and the cardiovascular response during the FCE, plausibly confirm an observed effort that can be classified as at least a high effort. Further studies could be aimed at more explicit descriptions of observed indicators during the FCE and trying to assess the relative contribution of each indicator to the decision about level of effort of the individual patient.

With regard to determination of maximal effort and therefore of a purely physiological capacity, it remains uncertain whether this can be determined validly. Based on the definition of capacity within FCE, capacity can be described as the highest probable level of functioning that a person may reach in a domain at a given moment in a standardized environment (Soer et al., 2008a). Physiological capacity tests, such as an aerobic capacity test with breathing gas analyses may lead to a better estimation of capacity, because the evaluator can monitor physiological parameters, in which for example the CO_2/O_2 ratio will exceed. Within more anaerobic and functional measures, this determination is invalid. The observation criteria appear to correlate well with mean objective measures and are able to show differences between levels of effort. Within this context, if an outcome score on FCE is matched to a persons' workload in daily life, it can be seen that FCE performance is frequently higher compared to the observed workload (Soer et al., 2014). Therefore, functional capacity is deemed sufficient when FCE results outperform the workload. A more comprehensive evaluation of context, psychology and ergonomics may find the answer on why certain people are unable at performing their routine jobs when FCE results match demands.

A strength of our study is that to our knowledge it is the first study that explicitly compared protocolled observations to objective motion analyses to study the movement responses during an FCE in a lab situation. In a previous study, EMG has been applied to show the progression of EMG activity during lifting (Fabian et al., 2005). Evidence to support the validity of observational criteria was observed.

A limitation is that healthy young adults participated in this study. Determining levels of effort is particularly relevant when testing persons with ongoing health conditions. Factors that determine level of effort are often related to biological, psychological and social factors (Tuscher et al., 2018). The focus in the present study is on biological factors only, therefore the before mentioned factors were not taken into account. Because the materials and procedures in this study are expensive, time intensive and require specialized levels of analyses, they are at present not feasible to use in routine practice. A future study should be aimed to validate the present observational criteria which are used routinely, with these lab-based measures as gold standard concurrent measures.

Another limitation of this study was the focus on upper body musculature only, while it is obvious that for example the low back extensors and m.quadriceps femoris play an important role in the test lifting low. In future studies force plates could be used to generate a more complete picture of the base of support, by analyzing changes in ground reaction forces that accompany changes in positions of the feet and may give more insight in the determination of impulse. These positions could be further specified into anterior-posterior and medial-lateral components.

5. Conclusion

For the WorkWell FCE test 'lifting low' the observation criteria are useful indicators for level of effort, with the exception of 'counter-balancing' as parameter of postural change. Observation of impulse as indicator of movement pattern could be useful, but needs a better definition to be a valid measurable and observable construct. Further studies should examine the application on individuals, in patients, and in other manual material handling items of the FCE (lifting high and carrying).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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