Comparison of Two Techniques for Lifting Low-lying Objects on a Table

Part I: Setup, ECG and Motion Measurement

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Abstract: "There is a strong belief that stoop lifting is 'bad' and squat lifting is 'good'." In this paper we research a combined motion: lifting and putting a beer crate into a car trunk. This real life task was chosen in the biosignal analysis course at the Brandenburg University of Applied Sciences. We started with the hypothesis that 'the squat lifting technique is more ergonomic, healthy and less exhausting'. Our study was scheduled for one semester including the experiments and a first preliminary analysis of the data to prove or disprove three partial hypotheses. Four male and four female untrained subjects were involved in the experimental part of the study. Physiological parameters like the heart and the respiration rate, the activity of various muscles as well as the motion of the whole body were measured. Questionnaires were developed and carried out before, immediately after and one week after the experiment to acquire information about the fitness of the subjects and the effects of the exercises on their state of wellness and health. First conclusions result in no clear preference for one lifting technique.

1 INTRODUCTION

The purpose of this study was to determine differences in effectiveness, health benefits and fatigue when using various lifting techniques.

In the community "there is a strong belief that stoop lifting is 'bad' and squat lifting is 'good'." (Straker, 2002). Dieen et al. (1999) gave a review of biomechanical studies on lifting techniques concluding that both techniques have positive and negative effects. Straker (2002 and 2003) published a research review regarding both techniques for lifting low-lying objects. In the first paper different criteria of evaluation from about 80 references were discussed. The second paper showed that there is no technique with clear validity summarizing psychophysical, physiological, biomechanical, performance and clinical aspects. Recommendations for correct lifting of low-lying objects are given: keep the load close, use a secure grip and a stable base as well as a smooth movement of moderate pace (Straker, 2003). A biomechanical study of the kinematics of the lower extremity joint, the lumbar lordosis based on three-dimensional motion analysis and the measured EMG is described in (Hwang, 2009). No significant differences in the maximum lumbar joint movements between the two techniques were found. Still, the squat lifting technique is generally recommended as the "correct" one.

In this paper we research a combined motion of 'lifting and putting a beer crate into a car trunk'. We started with the hypothesis that 'the squat lifting technique is more ergonomic, healthy and less exhausting'. Our study was scheduled for one semester including the experiments and a first preliminary analysis of the data to prove or disprove the three partial hypotheses concerning ergonomics, health and exhaustion. First conclusions result in no clear preference for one lifting technique.

2 METHODS AND MATERIALS

This chapter describes the experimental setup (task, phases and selection of subjects) as well as the measurements (equipment, parameters, sensors, data acquisition and analysis).

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2.1 Experimental Setup

After preliminary tests, some discussions and a literature review the task to do for each test subject was defined as follows: lifting a crate of bottles, putting it on a table, taking it again and placing it on the ground. Male subjects handled a full filled crate, females a half filled one.

Figure 1: Stoop technique – half of the cycle.

Figure 2: Squat technique – half of the cycle.

Task. Figure 1 and 2 show half a cycle of the task the subjects need to repeat at least five times per minute for a period of ten minutes. Each cycle starts and ends upstanding, then the subject takes the crate of 15 kg for males and 8.4 kg for females respectively, lifts it up to a position in front of the stomach, puts it on the table with a height of 0.72 m and reverse. While using the stoop technique the legs are stretched during the whole procedure. During the squat technique the body is more or less upright. Before and after the lifting cycle the subject stands upright for one minute to calibrate the sensors and to acquire the vital parameters during the rest.

Phases. Before starting the practical part of the course, the experiment was scheduled and standardized to exclude as many random failures as possible during the preparation of the subject. The sequence is split into four phases. During the first phase (25 minutes) the subject is prepared for the experiment. During the second phase (35 minutes) the electrodes are tested and the maximum voluntary contractions of determined muscles are captured. The experiment starts immediately after the configuration of all involved equipment and software. After one minute rest the subject begins to execute the exercise. After ten minutes the subject rests again for one minute, the protocol is continued and the data are saved (21 minutes). During the wrap-up phase (16 minutes) the blood pressure is measured and the test subject is interviewed to capture his/her subjective impression of the task. All phases take about 98 minutes per subject. Therefore one day is needed to process eight subjects in one technique. The questionnaire was to be filled out immediately after the experiment and during the following seven days. The second technique was executed one week later.

Test Subjects. Eight young and healthy volunteers were enlisted as test subjects in this study: four male and four female subjects of normal weight, between 18 and 26 years old and with a height of 160 to 188 cm. The fitness level of the subjects varied between average and very good. The subjects were asked to take part in a questionnaire to capture their fitness.

2.2 Measurements

Vital and Motion Parameters. To answer the three hypotheses, data about the physiological state of the subject, his/her muscle activities and the motion of the body were captured. The ECG, pulse and blood pressure measurements are standard approaches to evaluate the behaviour of the heart: the heart rate, its variability and adaptability to constant or rising loads. Changes in the respiration rate and surface temperature reflect the rising demand of oxygen and the heat build-up during lifting of high load. EMGs are used to estimate the activities of various muscles or groups of muscles. The RGB video and the skeleton stream of the KINECT sensor are captured to estimate the executed lifting process.

Equipment and Data Acquisition. In this investigation various devices and sensor systems are used to observe the execution as well as the vital parameters of the test person. The data acquisition from all devices running on five computers is synchronized manually by starting the software on demand. The data are sampled with five different rates: 30 Hz on the KINECT (RGB video, depth and the skeleton stream), 256 Hz for respiration, temperature and filtered EMG from ProComp Infiniti, 1024 Hz SHIMMER-EMG, 2048 Hz from ProComp Infiniti ECG and EMG and 51200 Hz from the NEUROWERK-EMG. The KINECT, the ProComp Infiniti encoder as well as the NEUROWERK-EMG sensors are connected by wire. The data of SHIMMER sensors are send wireless (Bluetooth). The data acquisition process is observed in real time using the original software (running plots, RGB video stream). All data are transferred sequentially to the host PC and converted into integer formats to save storage on memory and hard discs.

The skeletal tracking of the KINECT immediately delivers the 3D-positions of 20 points on a fictive skeleton. In the experiment only the left half of the test subject is observed. Our software called KinectStreamer is connected to the device and receives the skeleton data stream as well as the RGB and the depth streams.

Sensors and their Placement. All available sensor systems are used to get a maximum of information about the physiological state of the test subject. The EMG electrodes are placed on those muscles mostly involved in the squat and stoop lifting (for details see Thiers et al., 2013). Both ECG sensors are applied ventral. The KINECT sensor is placed 2.5 m right of the test subject, so that the optical axis is perpendicular to the sagittal plane of the test person.

Signal Analysis. The primary analysis of each signal is processed by programs written in the MATLAB® environment. First of all, the quality and completeness was checked by visual inspection of generated plots. Some signals were corrupted because of failures in data transmission, artefacts or software errors. That data was excluded from further investigation. In a second step signals were filtered and smoothed using band pass filters to reduce high frequency noise and to exclude low frequency drifts. In this paper we focus on the change of all signals or their characteristics over the 10 minute long experiment while the test subject processed more than 50 lifting cycles. The execution of the stoop and lifting technique during one cycle is not evaluated here, no kinematic or kinetic analysis was done.

3 RESULTS

In this section selected results are presented to allow a preliminary answer to the question what lifting technique is to be preferred.

In this paper we explain only results we got from observation and single measurements from ECG and motion capture devices. Results in relation to muscle activities and psychological aspects are discussed by Thiers et al. (2013).

3.1 Observation

All information about the subjects and their individual characteristics (gender, age, height, fitness, performance, impression, pain, pulse, blood pressure before and after the experiment), the number of executions per minute counted by one examiner as well as abnormalities during the measurement (loss of electrodes, interruption of software) were collected in a file. In table 1 some of these data are presented. 50% of the subjects are female, only one does not regularly work out. The pulse measured immediately after the squat technique is for most of the subjects higher than after the stoop cycle - a first indication that squat lifting is more exhausting or less familiar.

Table 1: Selected data of the test subjects (gender and regular sport activities) and their pulse (in beats per minute) immediately before and after the experiment (f-female, m-male).

No.	Gender	Sports	Pulse before/after	
			Stoop	Squat
01	f	yes	68/108	76/112
02	f	yes	84/116	80/120
03	m	yes	84/120	72/132
04	f	yes	80/132	76/132
05	m	yes	72/88	64/96
06	m	no	72/120	92/136
07	f	yes	68/107	60/132
08	m	yes	76/116	64/140

3.2 Electrocardiogram (ECG)

The electrocardiogram was captured parallel using the ProComp Infiniti encoder and SHIMMER ECG sensor. Both sensors recorded similar data.

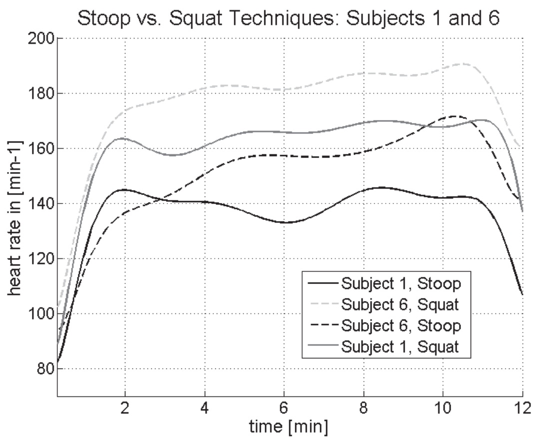

Figure 3: Change of the heart rate of subject 1 (filled) and 6 (dashed) over time using the stoop (black) and squat (gray) technique.

Figure 3 shows the dependency of the heart rate of two test subjects on the repetitions (time). Obviously the heart rate rises rapidly at the beginning of the execution (no warm up). Then the increase becomes moderate and after the lifting was stopped it falls rapidly what is an indicator for the good fitness of the subject. The curves of subject 1 are below the corresponding curves of subject 6 who was the only one not regularly working out.

The slower decrease of the heart rate at the end (last 1.5 minute) supports this fact. More important, the heart rate of the squat lifting is at all times higher than that of the stoop technique.

All effects indicate that the squat lifting technique is more exhausting than the stoop technique.

3.3 Motion

The following results are derived from the vertical motion of the head. During every repetition the subject stoops or squats twice, once to lift the crate and once to drop it. Therefore there are two local minima of the vertical position in each cycle. These minima are detected and used to count the repetitions.

Table 2 lists the number of repetitions counted by an examiner and calculated from skeletal data. Both numbers coincide well, i.e. to use the minimum of the height of the head to split the whole execution into single cycles works satisfactory.

Table 2: Number of repetitions counted and calculated.

No.	Number of repetitions counted		Number of repetitions calculated	
	Stoop	Squat	Stoop	Squat
01	73	59	73	60
02	52	80	56	81
03	78	54	79	55
04	91	104	92	104
05	54	96	54	96
06	66	94	67	94
07	76	70	77	70
08	78	94	78	95

The heights of the head (not shown in this paper) are more or less constant. While the cycle time increases for subject 1 for both techniques, for subject 2 it increases in the stoop technique and decreases in the squat technique. At the same time the repetitions were executed faster. It seems that subject 2 became tired in the course of the experiment.

Analyzing the motion of the head no clear preference for one of the techniques can be concluded.

4 CONCLUSIONS

In this paper the hypothesis that 'the squat lifting technique is more ergonomic, healthy and less exhausting' is investigated in a real life example of a lifting and putting a beer crate onto a table. The conditions of our study are described, a number of experimental results analyzing the ten-minute repetition, not a single cycle, are presented. The observation and the ECG measurements indicate that the squat lifting technique is more exhausting than the stoop technique. That thesis is partly attested by motion analysis. Anyway there is no clear preference for one or the other technique from the prospect of performance.

Further measurements (EMG, interviews), results, discussions and final conclusions are to be found in part II of this paper (Thiers et al., 2013).

The analysis of the data captured during the experiment as well as the study itself will be continued. Single cycles will be evaluated statistically, SHIMMER motion data will be included, kinematics and kinetics will be covered. The experiment with another group of volunteers will be repeated skipping, replacing or adding some sensors.

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