Chapter 6

Estimation of low-back moments from video analysis
a validation study.

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ABSTRACT

This study aimed to develop, compare and validate two versions of a video analysis method for assessment of low-back moments during occupational lifting tasks since for epidemiological studies and ergonomic practice relatively cheap and easily applicable methods to assess low-back loads are needed. Ten healthy subjects participated in a protocol comprising 12 lifting conditions. Low-back moments were assessed using two variants of a video analysis method and a lab-based reference method. Repeated measures ANOVAs showed no overall differences in peak moments between the two versions of the video analysis method and the reference method. However, two conditions showed a minor overestimation of one of the video analysis method moments. Standard deviations were considerable suggesting that errors in the video analysis were random. Furthermore, there was a small underestimation of dynamic components and overestimation of the static components of the moments. Intra-class correlations coefficients for peak moments showed high correspondence (>0.85) of the video analyses with the reference method. It is concluded that, when a sufficient number of measurements can be taken, the video analysis method for assessment of low-back loads during lifting tasks provides valid estimates of low-back moments in ergonomic practice and epidemiological studies for lifts up to a moderate level of asymmetry.

INTRODUCTION

As low-back pain (LBP) in society is associated with high social suffering and costs (Lambeek et al., 2011), it is important to consider risk factors involved. Associations between physical risk factors and the occurrence of LBP have been reported extensively with lifting, twisting, bending and whole body vibrations being the most commonly reported ones (Lötters et al., 2003; Wai et al., 2010).

Although posture and force measurements and subsequent biomechanical analyses can provide valid and reliable estimates of back load during occupational handling (Kingma et al., 1996), such measurements are time and money consuming and can hardly be used outside the laboratory setting for epidemiological studies. Accordingly, research has focused on less costly (with respect to time and money) low-back load assessment methods, which can be brought into the work place easily. Direct observation combined with simple measurements (i.e. load distances) was shown to provide reasonable estimates of low-back loads during lifting, although systematic underestimation of loads occurred, possibly due to neglecting segment dynamics (van Dieën et al., 2010). Other efforts focused on video analysis methods (Chang et al., 2003; Hsiang et al., 1998; Sutherland et al., 2008; Xu et al., 2011) by assessing body orientations based on observations of selected key video frames. These methods provided acceptable kinematic accuracy (Chang et al., 2010; Neumann et al., 2001b; Xu et al., 2011). Furthermore, quasi-static biomechanical calculation using these kind of models showed small but significant errors in peak (Chang et al., 2003; Hsiang et al., 1998) and cumulative (Sutherland et al., 2008) lumbar compression forces. Although promising, these methods suffer from some shortcomings. Segment orientations were based on crude categorizations (Hsiang et al., 1998; Sutherland et al., 2008), segment dynamics were not taken into account (Sutherland et al., 2008) or only movements in the sagittal plane could be determined (Chang et al., 2003; Chang et al., 2010). Therefore, better posture matching strategies should be investigated. The aim of the present study was thus to develop, compare and validate (against a reference laboratory-based 3D inverse dynamics method) two versions of a video analysis method for estimation of mechanical back load (expressed in peak and mean moments) during occupational lifting tasks. With this method, we aim to overcome the abovementioned shortcomings by quasi-three-dimensional coding and online posture matching.

METHOD

Participants and procedure

After signing an informed consent, 10 healthy subjects (6 female and 4 male, age 23 (4) years, body mass 67 (7) kg and stature 1.76 (0.12) m) participated in a repeated measures experimental design approved by the ethics committee of the VU University, Amsterdam. Using a height adjustable shelf, subjects lifted a 15 kg box (0.57×0.38×0.37 m) in 12 different conditions: 2 horizontal initial positions of the box (at the front and at 0.57m from the front of the shelf), 3 vertical initial positions of the box (ground, hip and shoulder height) and 2 different types of lifting (symmetric and asymmetric lifting). For the symmetric lifting conditions, the subjects were asked to step towards the box, position the feet symmetrically, grab the box by its handles and lift it to chest height. For the asymmetric lifting conditions, subjects were asked to step towards the box, place the right foot in front of the left foot, grab the box by its handles and lift it with a 180° rotation to chest height. Lifting conditions were unconstrained, so no instructions were given with respect to lifting posture or exact foot placement, therefore, lifting conditions are assumed to resemble occupational tasks.

Reference measurement method

As a reference method, a dynamic three-dimensional linked segment model, described and validated by Kingma and colleagues (1996; 2010) was used. Kinematics of the box, lower arms (and hands), upper arms, trunk (and head) and pelvis were measured using cluster markers strapped to the body segments. Three-dimensional positions of the cluster markers were measured at a sample rate of 50 samples/s using the Optotrak motion capture system (Northern Digital Inc., Waterloo ON, Canada).

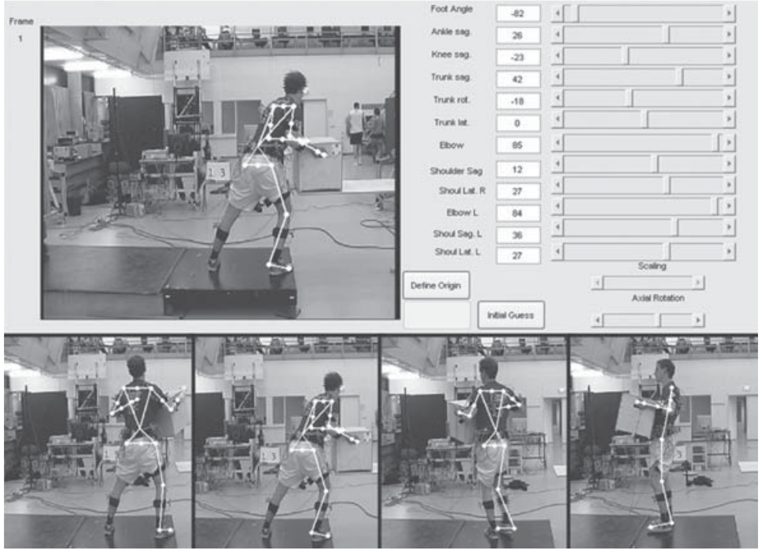
Anatomical landmarks were related to cluster markers using a probe with six markers (Cappozzo et al., 1995). Kinematic data were low-pass filtered using a cut-off frequency of 5 Hz. Segment masses, positions of the center of mass and inertia tensors were estimated using regression equations based on individual segment lengths and circumferences (Zatsiorsky, 2002).

Video measurement method

All lifting conditions were recorded with a Canon XM2 camera, while recordings were digitally captured and compressed into AVI format digital videos at a sample rate of 25 Hz. The camera was placed on a tripod which was situated perpendicular to the sagittal plane of the subject's initial lifting posture in the symmetrical lifting conditions. Videos and motion captured data were synchronized using an impulse light which was visible in all videos.

Video analyses were performed by a single observer (PC) using a video coding system with a graphical user interface (Figure 6.1) adjusted from an earlier method (Chang et al., 2003; Xu et al., 2011) using custom-made Matlab software (version 7.7.0). Initially, begin and end frames of the lifting condition were selected by replaying the video. The begin frame is the video frame of the initial lifting posture when the box gets clear from the shelf surface. The end frame is the frame in which the box was closest to the body. Additionally, two equally spaced frames between begin and end frames were selected, to obtain a total of four key frames (Xu et al., 2010b).

For the assessment of body kinematics during lifting, a quasi-three-dimensional manikin consisting of nine segments (right foot, lower leg and upper leg; pelvis, trunk/head, upper arms, forearms/hands) was fitted to the key frame pictures (Figure 6.1). This manikin allows for the following quasi-three-dimensional joint movements: ankle flexion/extension, knee flexion/extension, hip flexion/extension, trunk flexion/extension, trunk rotation, trunk lateral flexion, shoulder flexion/extension, shoulder abduction and elbow flexion/extension. Note that angles of the foot, ankle, knee and hip are required to correctly estimate upper body accelerations. Furthermore, the manikin can be scaled, translated and axially rotated for an optimal fit. Two variants for the composition of the manikin were assessed in the present study. The manikin could be fitted by adjusting the joint angles (video analysis method 1) or an initial guess of joint angles of all segments was calculated based on joint positions that were obtained by clicking on the video frame after scaling, translation and axial rotation of the manikin (video analysis method 2). In this algorithm, the above mentioned segment angles were calculated so that, based on the constrained segments lengths, a minimal difference in joint position compared to the joint position of the ankle, knee, hip, shoulders and hand that was clicked in the video frame was obtained. Subsequently, the observer could adjust joint angles to improve postural matching.



Foot Angle -82
Ankle sag. 26
Knee sag. -23
Trunk sag. 42
Trunk rot. -18
Trunk lat. 0
Elbow 85
Shoulder Sag 12
Shoul Lat. R 27
Elbow L 84
Shoul Sag. L 36
Shoul Lat. L 27

Figure 6.1 | Video analysis method. The upper part of the figure shows the graphical user interface in which a three-dimensional manikin is plotted online to a video key frame by axial rotation, scaling and translation and adjustment of segment angles. The lower part of the figure shows four key frames of an asymmetric lifting condition. These key frames show a representative sample of a video frame of an asymmetric lift as analyzed by the observer.

A cubic spline interpolation of the segment angles over the four key frames was applied to estimate segment angles over the entire lifting trajectory (Xu et al., 2010a). Segment mass, length, position of the center of mass and inertia tensor were estimated based on regression equations using total body mass and stature (Zatsiorsky, 2002). The relative flexion of the pelvis and trunk were estimated from upper body flexion and knee angle using regression equations (Anderson et al., 1985). Furthermore, the position of L5S1 was estimated at 19% of the length of the upper body segment (de Looze et al., 1992) and shoulder width was based on Dumas et al. (2007). The position and acceleration of all segments were constructed by linking all the segments from the right ankle through the hands/box.

Data analysis

To estimate total moments at L5S1 during all lifting conditions in all methods, a top-down calculation of the net moments at L5S1 was performed using external forces (mass and acceleration of the box), segment kinematics and anthropometrics using a global equation of motion (Hof, 1992). Repeated measures ANOVAs were performed with analysis method (reference vs. the two video analysis methods separately) and type of lifting condition (symmetry, horizontal load distance and vertical load distance) as within subject factors; and peak and mean moments as dependent variables. In addition, repeated measures t-tests were used to compare the two video analysis methods with the reference method for each condition separately for peak and mean moments. For all statistical tests, $p<0.05$ was assumed to be significant. To assess the origin of possible errors, static and dynamic components of the total moment at the instant of peak moment were calculated. Furthermore, segment center of mass moment arms with respect to the L5S1 joint were calculated. For the peak moments intra-class correlations coefficients (ICCs) were calculated across subjects and conditions using ICC(3,1) for an individual estimate (Shrout & Fleiss, 1979). ICCs<0.40 were assumed poor, while ICCs 0.40–0.75 are good and ICCs>0.75 are excellent (Fleiss, 1986). Asymmetric components (i.e. trunk rotation, trunk lateral flexion, arm abduction and axial rotation) at the instant of peak moment were calculated from the reference method in all lifting conditions to assess the amount of asymmetry.

RESULTS

An analysis of the resulting asymmetry of the lifts at the instant of peak total moment showed relatively small trunk rotation and trunk lateral flexion (9.1 (4.6)° and 5.4 (3.4)°, respectively), however, a large whole body axial rotation (63.8 (42.5)°) in the asymmetric conditions (Table 6.1; Figure 6.1). Overall peak and mean moments were not significantly different between the reference method and the two video analysis methods, nor was there a significant interaction of analysis method with type of lifting condition (Table 6.2 and 6.3). Averaged peak moment errors were 4.49 (28.27) and 2.41 (27.84) Nm and averaged mean moments errors were 6.21 (13.88) and 1.81 (14.88) Nm, for video analysis methods 1 and 2, respectively. For both mean and peak moments, errors were not larger in asymmetric conditions compared to symmetric conditions (Table 6.2 and 6.3). T-tests on separate conditions showed no significant differences between the reference method and the two video analysis methods concerning peak moments in any of the conditions. However, for mean moments there was an overestimation of the moment in video analysis method 1 in two of the conditions (Table 6.2 and 6.3; Figure 6.2). Typical examples of total moment estimations obtained from video analysis method 2 and the reference method are shown in Figure 6.3. The static component of the moments shows some overestimation in both versions of the video analysis method by 10.28 (24.29) and 7.74 (24.12) Nm, respectively, while the dynamic components of the moment revealed some underestimation in both versions of the video analysis method by –6.82 (15.84) and –6.14 (16.27) Nm, respectively (Table 6.4). Moment arms of all segment centers of mass (Table 6.5) show relatively small errors in moments arms of the trunk and load (≤4 cm), and somewhat larger for the arms (≤12 cm).

Table 6.1 | Asymmetric components of the lifting tasks: trunk rotation, trunk lateral flexion, arm abduction and axial rotation (all expressed in degrees) obtained from the reference method for both the symmetric and asymmetric lifting conditions.

	Symmetric Conditions		Asymmetric Conditions	
Asymmetric components	Mean and Std. (Degrees)		Mean and Std. (Degrees)	
Trunk rotation	2.69	1.18	9.05	4.55
Trunk lateral flexion	1.07	0.62	5.41	3.43
Arm abduction	25.34	13.74	27.76	11.66
Axial Rotation	2.72	3.23	63.78	42.46

Table 6.2 | Outcomes of repeated measures ANOVAs testing for effects in peak moments for both variants of the video analysis method. p-values of within subject effects of the main and two-way interaction effects of the factor 'analysis method' are presented. Furthermore, differences in peak moments between the reference and video analysis methods 1 and 2, respectively, are presented for all lifting conditions separately. Differences averaged over subjects, standard deviations and levels of significance (repeated measures t-test) are presented. Differences averaged over subjects and conditions, all symmetric conditions and all asymmetric conditions are shown as well.

	ANOVA	
Factor	Video Analysis Method 1	Video Analysis Method 2
Analysis	0.47	0.70
Analysis*Vertical	0.87	0.85
Analysis*Horizontal	0.12	0.11
Analysis*Symmetry	0.27	0.43

T-test

Condition				Video Analysis Method 1			Video Analysis Method 2		
Nr.	Symmetry	Vertical	Horizontal	Mean and Std. (Nm)		Sig.	Mean and Std. (Nm)		Sig.
1	Symmetric	Ground	Close	16.00	28.51	0.11	15.56	28.54	0.12
2			Far	13.73	37.53	0.28	13.55	37.74	0.29
3		Shoulder	Close	1.21	20.94	0.86	-3.23	22.40	0.66
4			Far	9.59	23.46	0.23	4.15	19.80	0.52
5		Hip	Close	-3.78	23.69	0.63	-7.87	24.12	0.33
6			Far	9.51	35.25	0.42	5.85	35.21	0.61
All symmetric conditions				7.71	28.52		4.67	28.75	
7	Asymmetric	Ground	Close	6.72	24.58	0.41	6.90	24.32	0.39
8			Far	5.71	23.28	0.46	4.45	22.32	0.54
9		Shoulder	Close	-8.90	19.63	0.19	-8.68	18.60	0.17
10			Far	-1.94	22.03	0.79	0.88	23.03	0.91
11		Hip	Close	-7.99	35.20	0.49	-12.61	34.12	0.27
12			Far	14.06	37.16	0.26	9.98	34.38	0.38
All asymmetric conditions				0.22	27.88		-0.73	26.94	
All conditions				4.49	28.27		2.41	27.84	

Table 6.3 | Outcomes of repeated measures ANOVAs testing for effects in mean moments for both variants of the video analysis method. p-values of within subject effects of the main and two-way interaction effects of the factor 'analysis method' are presented. Furthermore, differences in mean moments between the reference and video analysis methods 1 and 2, respectively, are presented for all lifting conditions separately. Differences averaged over subjects, standard deviations and levels of significance (repeated measures t-test) are presented. Differences averaged over subjects and conditions, all symmetric conditions and all asymmetric conditions are shown as well. Bold numbers indicate significant values ($p<0.05$).

	ANOVA	
Factor	Video Analysis Method 1	Video Analysis Method 2
Analysis	0.08	0.64
Analysis*Vertical	0.88	0.89
Analysis*Horizontal	0.77	0.53
Analysis*Symmetry	0.09	0.12

T-test

Condition				Video Analysis Method 1			Video Analysis Method 2		
Nr.	Symmetry	Vertical	Horizontal	Mean and Std. (Nm)		Sig.	Mean and Std. (Nm)		Sig.
1	Symmetric	Ground	Close	7.28	12.33	0.09	1.61	15.22	0.75
2			Far	3.67	15.98	0.49	0.63	16.48	0.91
3		Shoulder	Close	6.70	9.74	0.06	4.67	9.49	0.15
4			Far	12.56	17.22	**0.04**	7.92	13.79	0.10
5		Hip	Close	5.85	9.50	0.08	-0.70	10.87	0.84
6			Far	11.73	19.40	0.09	4.04	20.71	0.55
All symmetric conditions				7.97	14.26		3.03	14.54	
7	Asymmetric	Ground	Close	1.02	14.50	0.83	-0.53	17.13	0.92
8			Far	-2.26	14.52	0.63	-3.11	19.65	0.63
9		Shoulder	Close	8.96	13.98	0.07	5.34	11.13	0.16
10			Far	4.84	9.74	0.15	1.38	8.61	0.62
11		Hip	Close	5.92	16.45	0.28	-2.93	19.89	0.65
12			Far	8.20	9.29	**0.02**	3.37	13.61	0.45
All asymmetric conditions				4.41	13.37		0.53	15.24	
All conditions				6.21	13.88		1.81	14.88	

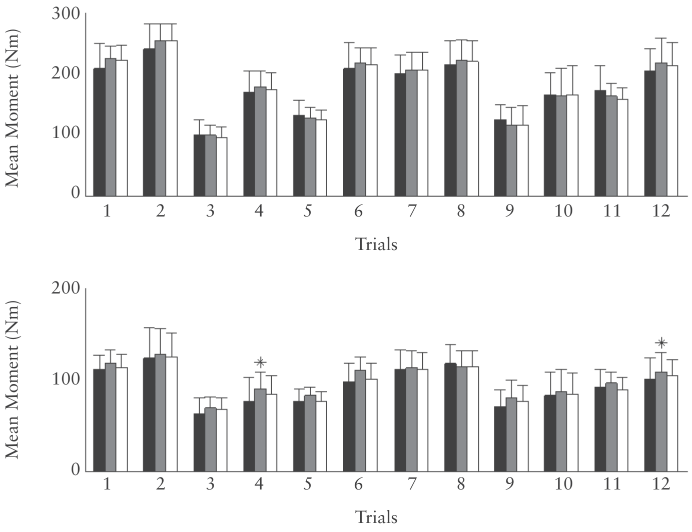


Figure 6.2 | Peak (upper panel) and mean (lower panel) total low-back moments of the 12 lifting conditions. Moments averaged over subjects and standard deviations (error bars) are presented. Moments estimated by the reference method (black bars), video analysis method 1 (gray bars) and analysis method 2 (white bars) are presented. * indicates significant differences (p<0.05) of one of the video analysis methods compared to the reference method. Trial numbers correspond to the numbers indicated in Table 6.2 and Table 6.3.

ICCs of peak moments over all pooled individual conditions (12 conditions x 10 subjects) were 0.86 between the reference method and both video analysis methods (Figure 6.4). The ICCs were higher when data were averaged over conditions (0.98 for both versions) and were lower when data were averaged over subjects (0.72 and 0.73 for video analysis methods 1 and 2, respectively; Figure 6.5).

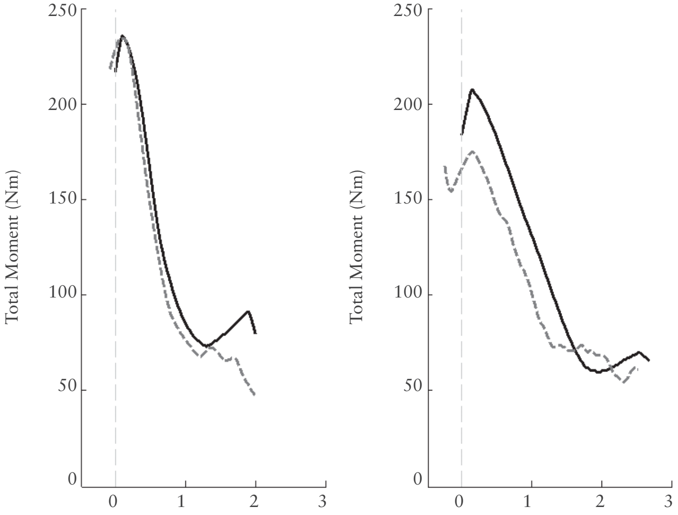


Figure 6.3 | Typical examples of total low-back moments obtained from video analysis method 2 (solid lines) and the reference method (dashed lines) in two lifting conditions. The left panel displays a relatively good fit of the video analysis method to the reference method for a symmetric lifting condition from a floor level initial lifting position. The right panel displays an overestimation of the moment obtained by the video analysis method compared to the reference method in an asymmetric lifting condition from a hip height initial lifting position. The error in the right panel is mainly caused by static errors (i.e. errors in positioning of the manikin). The slightly sharper peak in the video analysis method is a consequence of the spline interpolation based on a limited number of video frames. Examples of video analysis method 1 are comparable.

Table 6.4 | Mean and standard deviations of difference in static and dynamic components of the total moments at instant of peak in both versions of the video analysis method compared to the reference method. The most right columns present the mean and standard deviation of static and dynamic components of the total moment obtained from the reference method.

	Difference in Video Analysis Method 1		Difference in Video Analysis Method 2		Moment from reference method	
	Mean and Std. (Nm)		Mean and Std. (Nm)		Mean and Std. (Nm)	
Static Moments	10.28	24.29	7.74	24.12	162.30	47.06
Dynamic Moments	-6.82	15.84	-6.14	16.27	19.71	14.79

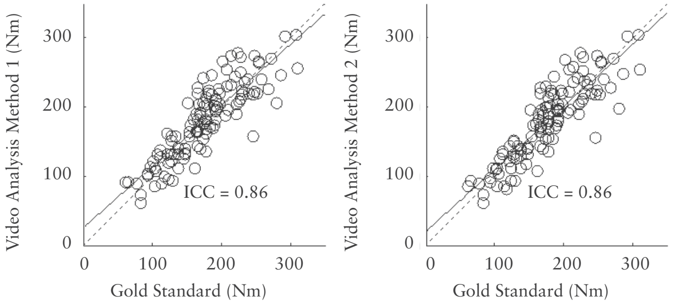


Figure 6.4 | Scatter plots illustrating the relations between peak moment estimated by the reference method and video analysis method 1 (left panel) and video analysis method 2 (right panel). Data of all subjects in all lifting conditions are presented. Furthermore, a linear fit through the data points (solid line) and a x=y reference line (dotted line) are plotted and calculated ICCs are presented.

Table 6.5 | Mean and standard deviations of differences in segment moment arms of the trunk/head, upper arms, lower arms/hand and load segments with respect to the L5S1 joint (expressed in m) for both versions of the video analysis method compared to the reference method. Moment arms are presented for all lifting conditions and for the symmetric and asymmetric lifting conditions separately.

		Video method 1		Video method 2	
Segment		Mean (m)	Std	Mean (m)	Std
Trunk/head	Symmetric conditions	0.02	0.04	0.02	0.04
	Asymmetric conditions	0.01	0.04	0.01	0.04
	All conditions	0.02	0.04	0.02	0.04
Upper Arms	Symmetric conditions	0.09	0.11	0.09	0.11
	Asymmetric conditions	0.04	0.14	0.04	0.14
	All conditions	0.06	0.13	0.06	0.13
Lower Arms	Symmetric conditions	0.10	0.07	0.12	0.08
	Asymmetric conditions	0.05	0.10	0.07	0.10
	All conditions	0.07	0.09	0.09	0.10
Load	Symmetric conditions	-0.04	0.09	-0.02	0.09
	Asymmetric conditions	-0.01	0.10	0.00	0.09
	All conditions	-0.02	0.09	-0.01	0.09

DISCUSSION

In the present study, we aimed to develop, compare and validate two versions of a video analysis method for the assessment of low-back moments during occupational lifting by a comparison with a reference method. ANOVA results revealed no overall differences in peak and mean moments between the reference method and the two video analysis methods. Furthermore, all conditions separately showed no systematic differences for peak moments between the two video analysis methods and the reference method, however, there was an overestimation of the mean moments in two conditions for video analysis method 1. The ICCs revealed a strong correspondence between the video analysis method and the reference method concerning the assessment of peak moments. This correspondence was stronger for data averaged over conditions compared to data averaged over subjects, which can be explained by the higher variance between conditions than between subjects. While we found only 2 small but significant differences between the reference method and one of the video analyses methods, due to the relative small sample size combined with large standard errors, we cannot exclude that with a higher sample size, some more differences might have become significant. However, as can be appreciated from Figure 6.2, the magnitude of the differences was small, so that even if a difference would become significant, it would likely be small. Note however that, while systematic errors in video analysis method 2 were absent, random errors were substantial as shown by the relatively large standard deviations (Tables 6.2 and 6.3). These data indicate that the proposed video analysis method is useful to determine differences in back load between subjects as well as between conditions. However, reliable back load estimation with video analyses does require a substantial number, i.e. about 10, repeated conditions.

The importance of establishing back load during lifting is underlined by in vitro studies showing damage to spinal segments at high peak (Brinckmann et al., 1989; Hansson et al., 1980) and repetitive loads (Brinckmann et al., 1988; Hansson et al., 1987). Furthermore, epidemiological studies have shown that peak (Norman et al., 1998) and cumulative low-back loads (Kumar, 1990; Norman et al., 1998) are biomechanical risk factors for LBP. While back load can be established accurately in the laboratory (Kingma et al., 1996), lifting behavior may differ between laboratory and actual working conditions, which highlights the importance of establishing back load at the workplace (Faber et al., 2011). The results of the present study show that the two versions of the video based method are valid for mean and peak moment determination up to a moderate level of asymmetry, thereby providing a useful tool for epidemiological studies on dose–response relationships and for ergonomic practice.

While errors were not explicitly compared between the two versions of the video analysis method, Tables 6.2 and 6.3 suggest that errors were smaller in video analysis method 2. ICCs were comparable for both video analysis methods. Due to these findings and since video method 2 roughly halves the analysis time compared to video method 1, video analysis method 2 seems to be the best applicable method for future research and ergonomic applications.

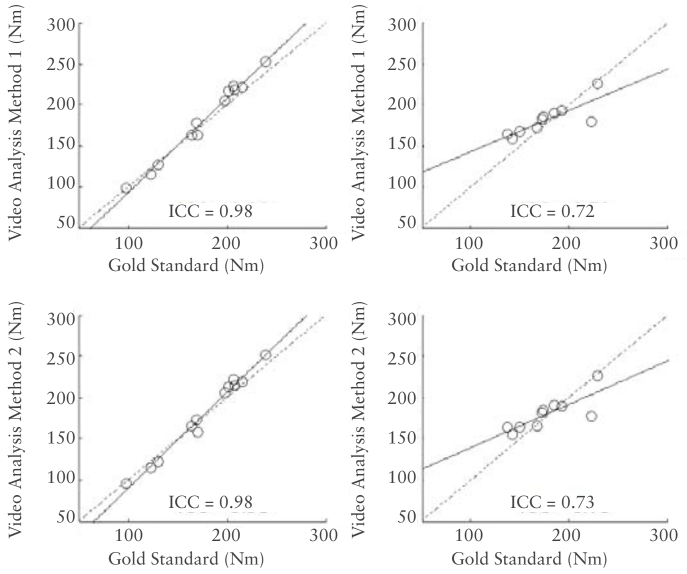


Figure 6.5 | Scatter plot illustrating the relations between peak moment estimated by the reference method and video analysis method 1 (upper row plots) and video analysis method 2 (lower row plots). Data are averaged over conditions (left plots) and over subjects (right plots). Furthermore, linear fits trough the data points (solid line) and x=y reference line (dotted line) are plotted and calculated ICCs are presented.

The video analysis method presented has a number of advantages compared to models presented earlier. Moments were obtained from a dynamical analysis, meaning that not only the gravitational contribution of the moments but also the angular and linear acceleration contributions were taken into account. Since, the dynamic component of the moment accounted for approximately 11 percent of the total moment for the lifting conditions studied and an average error of less than 4 percent of the total moment was made in the dynamic moment component, it can be concluded that by adding dynamic components to the moments, accuracy of the total moment improves. Furthermore, several studies have reported on the problem of assessing movement outside the sagittal plane due to projection biases (Kingma et al., 1998; Paul & Douwes, 1993). With the current model we aimed at decreasing this source of error since we allowed for axial rotation of the manikin and quasi-three-dimensional movements (i.e., trunk rotation, trunk lateral flexion and arm abduction). The validity of this approach was supported by the fact that errors were not larger in asymmetric conditions compared to symmetric conditions. Although errors in symmetric and asymmetric conditions were not explicitly compared, the non-significant interactions of analysis method and symmetry indicate no differences in errors for peak and mean moments between symmetric and asymmetric conditions. Allowing axial rotation of the manikin appeared to be useful as Table 6.1 showed that those rotations were much larger than the out of plane motions of the trunk in the present study, and did not negatively affect the accuracy. A last source of errors that we aimed to overcome with the present method is the error made by crude categorization of segment orientations (de Looze et al., 1994b; van Wyk et al., 2009), since matching of body orientations can be performed on a continuous scale.

Besides the advantages of the presented video analysis method there are some methodological limitations that have to be taken into account. While we could accommodate for body postures deviating from the plane of the video camera, we cannot exclude projection errors. Nevertheless, asymmetric lifting did not result in larger errors than symmetric lifting, suggesting that projection errors did not play an important role. However, in the present study, moderately asymmetric conditions were studied and although these conditions show substantial asymmetric components with respect to the whole body axial rotation, we cannot exclude that larger errors will occur in other lifting conditions, especially in conditions with more asymmetric trunk and arm movements. Furthermore, in the conditions measured in this study, a box with an even distribution of mass was used. It is not known whether this model can also be applied to conditions in which loads with an uneven mass distribution are lifted. In addition, the separate analysis of static and dynamic moment components showed some systematic overestimation of static moments and some underestimation of dynamic components. Most likely, the overestimation of static moments is due to errors in modeling of the trunk. During forward bending, curvature of the trunk occurs, which reduces the distance between hip and shoulder. In the present video methods, the estimated flexion in the hip and L5S1 joints was based on total trunk inclination and the knee angle, as proposed by Andersson et al. (1985). However, this procedure may have caused some errors since modeling the entire trunk in a pelvis and an upper trunk segment might not provide an accurate representation of the trunk curvature (Lariviere & Gagnon, 1999), as shown by the small overestimation of trunk center of mass moment arm. Furthermore, this procedure does not accommodate sideward bending of the pelvis, so that application to asymmetric lifting could introduce errors. However, in the present study, pelvic sideward bending was hardly noticed and asymmetry was adequately covered by allowing for axial rotation of the whole manikin. Furthermore, in asymmetric lifting conditions symmetry in the lower extremities has been assumed, and this might introduce some error in pelvis orientation. The underestimation of the dynamic component of the moment might have been caused by the spline interpolation between the four key data points, which may cause a somewhat smoother movement trajectory compared to what subjects actually do. Improved interpolation or posture prediction algorithms can possibly be used in future studies to improve interpolation accuracy and reduce analysis time (Zhang & Chaffin, 2000). However, benefits from such improvements can be limited as random errors in positioning the manikin will persist (Xu et al., 2010b). Furthermore, all observations have been performed by the same observer. Therefore, no statements can be made about the inter-rater reliability of the present analysis method. However, since the fit of the stick figure is made within the video frame, and can thus be checked visually, the effect of the expertise of the observer can be assumed to be relatively small. Finally, the video analysis method was tested on a group of healthy young subjects. Generalization of these results should be done with caution as it is not obvious that our results will hold for subjects with deviating anthropometry or lifting behavior (e.g. due to LBP; Marras et al., 2004).

CONCLUSION

The present study reports on two variants of a video analysis method, a simple and relatively cheap method for the assessment of low-back loads during occupational lifting. The absence of substantial differences with the reference method supports the validity of the video method of establishing back load in ergonomic practice and epidemiological studies for lifts up to a moderate level of asymmetry. However, the presence of substantial random errors suggests that care should be taken in interpreting results when only few measurements can be taken.