Motionprint Ergo

KIM-LHC Module

Validation of Posture Classification and Module Scoring

Motionprint BV
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motion-print.com

1. Executive Summary

This report presents the results of a laboratory validation study for the KIM-LHC module of **Motionprint Ergo**, an ergonomic assessment application developed by Motionprint BV. Motionprint Ergo is designed to process motion capture data and automate ergonomic assessments. In this study, the **Xsens MVN Awinda** inertial motion capture system was used as the input source to evaluate the accuracy with which Motionprint Ergo classifies body posture and extracts the kinematic variables required by the Key Indicator Method for Lifting, Holding, and Carrying (KIM-LHC) (Klussmann et al., 2018).

Three subjects performed a total of 45 handling trials across five task configurations for posture classification and kinematic variable validation (Dataset 1), and 36 load distance trials across four configurations (Dataset 2). Motionprint Ergo output was compared against expert observation for posture classification and against physically measured reference values for kinematic variables.

Key finding: Body posture was classified correctly in 100% of trials (90/90 posture evaluations across all three subjects and five configurations). Trunk twisting was measured with an overall mean absolute error (MAE) of 3.19° across 90 measurements. Vertical hand asymmetry was measured with an overall MAE of 9.13 mm and lateral hand asymmetry with an overall MAE of 9.41 mm across 90 measurements each. Load distance was measured with an overall MAE of 5.5 mm across 36 trials. Side-bending angle, hand height relative to elbow/shoulder, hand/arm position, and difficulties due to holding/carrying are derived directly from the Xsens MVN body model and were not subject to separate empirical validation; their accuracy is governed by the Xsens system specification. These results confirm that Motionprint Ergo provides reliable posture classification and variable extraction suitable for practical KIM-LHC assessments.

2. Introduction

The Key Indicator Method for Lifting, Holding, and Carrying (KIM-LHC) is a standardized procedure for assessing the physical workload associated with manual handling tasks (Klussmann et al., 2018). It computes an End Score from a weighted combination of body posture, load weight, trunk twisting, and other task parameters. The method is widely used in occupational health practice for risk screening and ergonomic intervention planning.

Motionprint Ergo automates the KIM-LHC assessment by processing body-landmark coordinates and joint angles produced by motion capture systems. Rather than requiring an ergonomist to observe and manually record posture categories and angles for each handling cycle, the application derives these values directly from recorded kinematic data and applies the KIM-LHC scoring formulas to compute the End Score and risk level.

For this validation study, the **Xsens MVN Awinda** inertial motion capture system was used as the motion data source (Paulich et al., 2018; Schepers et al., 2018). The purpose of the study is to validate the accuracy of Motionprint Ergo's posture classification and kinematic variable extraction under controlled laboratory conditions.

The study follows a **two-layer validation strategy**. Layer 1 addresses calculation correctness: the KIM-LHC scoring formulas implemented in Motionprint Ergo were verified analytically by hand-calculation against the published method, confirming exact agreement. Layer 2 addresses the empirical accuracy of posture classification and kinematic variable extraction from motion capture data, which is the focus of this report.

3. Background: The KIM-LHC Method

The KIM-LHC computes a risk assessment through a structured scoring procedure. An End Score is calculated from the sum of a Body Posture Score and a set of Additional Points, multiplied by a Time-Weight multiplier and the number of objects handled per shift. The End Score maps to one of four risk levels (1–4), guiding intervention priority.

Motionprint Ergo captures all KIM-LHC input variables through a combination of user entries, motion capture computation, and Xsens MVN body-model outputs. Module 2 (load weight) and the shift-duration component of Module 1 are entered by the user directly. The lift frequency in Module 1 is derived automatically: cycle duration is calculated from the number of frames in the trimmed recording section divided by the recording frame rate, then divided by the number of lifting tasks marked by the user; the ratio of total shift duration to cycle duration yields the frequency figure used in the KIM-LHC time-weight lookup. Modules 3 through 11 are derived from motion capture data, while Modules 12 through 16 (working conditions sub-items) are user-entered. The motion-capture-derived modules are the focus of this validation:

#	Description	Data source	Validated here?
1a	Shift duration	User input	No
1b	Lifting frequency (lifts/shift)	Calculated: trimmed-clip duration ÷ number of marked lifting tasks, scaled to shift duration	No — deterministic arithmetic, verified in Layer 1
2	Load weight	User input	No
3	Body posture (start + finish, mapped to posture groups)	Calculated from Xsens MVN body-model joint angles and landmark coordinates (trunk flexion, shoulder elevation, elbow flexion, knee flexion, knee height, hand height)	Yes — classification accuracy
4	Trunk twisting	Calculated from heading of T8 segment relative to foot sagittal plane	Yes — angle error
5	Trunk side-bending	Directly from the Xsens MVN body model (Vertical_T8 ergo joint, lateral component)	No — accuracy governed by Xsens MVN body model
6	Vertical hand asymmetry	Calculated from left/right hand landmark vertical positions (body-landmark Z-coordinates)	Yes — distance error
7	Lateral hand asymmetry	Calculated from the difference between left/right hand horizontal-plane distances to the pelvis	Yes — distance error

#	Description	Data source	Validated here?
8	Load distance from body	Calculated using trunk-local forward axis and minimum palm-to-trunk projection, with 190 mm anatomical offset	Yes — distance error
9	Hand height relative to elbow / shoulder	Directly from Xsens MVN body-model landmark Z-coordinates	No — accuracy governed by Xsens MVN body model
10	Hand/arm position (wrist flexion/extension, radial/ulnar deviation, forearm pronation/supination)	Directly from Xsens MVN body-model joint angles	No — accuracy governed by Xsens MVN body model
11	Difficulties due to holding / carrying	Calculated: holding duration from selected frame range; carrying distance from cumulative pelvis XY displacement	No — not in study scope; geometrically deterministic
12	Force transfer / force application	User input	No
13	Adverse ambient conditions	User input	No
14	Spatial conditions / restricted workspace	User input	No
15	Extra workload from impairing clothing / PPE	User input	No
16	Work organization	User input (×2 weighting in End Score)	No

Table 1. KIM-LHC input variables and data sources in Motionprint Ergo. Modules marked "directly from the Xsens MVN body model" are not validated separately; their accuracy is governed by the Xsens system.

Body posture is classified into one of ten categories, which map to four posture groups used in the Body Posture Score lookup table (Appendix A). The classifier uses six features: four joint angles (trunk flexion, shoulder elevation, elbow flexion, knee flexion) and two landmark Z-coordinates (knee height and hand height). Seven of the ten categories were covered in Dataset 1; the three low-position categories (squat low, on knees up, and sitting on knees) were validated in a separate independent test with 100% accuracy.

Trunk twisting is computed from the heading angle of the T8 thoracic segment relative to the sagittal plane defined by foot orientation — not read directly from the Xsens MVN body model — and is therefore validated empirically. Trunk side-bending is derived from the Xsens MVN body-model ergo joint angles (Vertical_T8 lateral component) and is not validated separately. Both vertical and lateral hand asymmetry are computed from body-landmark coordinates provided by the Xsens MVN body model and are validated empirically. The Body Posture Score is determined by a two-dimensional lookup table combining start and finish posture groups (Appendix A).

4. Validation Approach

4.1 Two-Layer Strategy

Layer 1 (calculation correctness) was verified analytically: KIM-LHC Body Posture Scores, Additional Points, and End Scores were hand-calculated from raw module inputs using the published scoring tables and compared against Motionprint Ergo output. In all cases values matched exactly. Since these are deterministic lookup operations, once verified no further empirical testing is necessary.

Layer 2 (posture classification and variable extraction) is the focus of this empirical validation. Laboratory stations were configured to elicit specific target postures and movement patterns. Three subjects performed standardized handling cycles while wearing the Xsens MVN Awinda system. Motionprint Ergo classification outputs were compared against expert observation; kinematic variable values were compared against physically measured reference values.

4.2 Classification and Measurement Methodology

Motionprint Ergo derives KIM-LHC input variables from the body-landmark coordinates and joint angles provided by the Xsens MVN body model. Body posture is classified by analyzing six features at the start and finish of each handling cycle: trunk flexion, shoulder elevation, elbow flexion, and knee flexion (joint angles), together with knee height and hand height (landmark Z-coordinates, which are the dominant discriminating features for kneeling and low-squat postures). Trunk twisting is computed from the heading of the T8 thoracic segment relative to the foot sagittal plane. Vertical hand asymmetry is computed as the absolute vertical difference between the left- and right-hand landmark Z-coordinates. Lateral hand asymmetry is computed as the absolute difference between the horizontal-plane distances of the left and right hands to the pelvis. Load distance is derived using the trunk-local forward axis (defined by the cross product of the trunk axis and shoulder vector) and the minimum forward projection of the left and right palms, with a 190 mm anatomical offset subtracted. These computations are geometrically unambiguous: given exact body-landmark positions the results are exact. Any deviation from reference values is attributable to the accuracy of the Xsens MVN body model.

5. Method

5.1 Equipment

Motion capture data were recorded using the **Xsens MVN Awinda** wireless inertial measurement unit (IMU) system (Paulich et al., 2018). Subjects wore a full-body sensor configuration. Calibration was performed using the N-pose with walking procedure prior to each session. All recordings were HD reprocessed in MVN Analyze Pro 2025.0 (Schepers et al., 2018) before export to .mvnx files for import into Motionprint Ergo.

5.2 Body Model Configuration

For each subject, all individual body segment lengths were manually measured and entered into Xsens MVN Analyze Pro. This is particularly important for joint-angle-based posture classification, where the accuracy of segment orientations directly affects the computed posture category.

5.3 Test Setup

The validation used two height-adjustable stations — one as the handling origin, one as the destination. Station heights were configured to match each target configuration. Foot placement positions were marked with tape for consistent positioning. For configuration D1C4, the destination station was rotated 45° relative to the subject's standing direction. The test load (10 kg) was verified using a calibrated scale (±0.1 kg). Load distance (hand-to-body) was physically measured with a steel tape (±1 mm) per subject prior to collection. For configuration D1C5, the load box was held with one hand at the bottom edge and one hand at the top edge, creating a vertical hand separation. The vertical distance between the two hand contact points was measured at 120 mm (±1 mm, steel tape) and used as the reference value for vertical asymmetry validation.

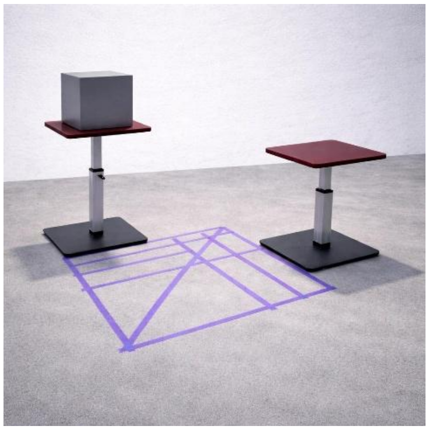

Figure 1. Validation test setup showing the origin station (left), destination station (right), and floor tape marks for foot placement. Stations were adjusted to the required height for each configuration.

5.4 Task Configurations — Dataset 1

Five configurations (D1C1–D1C5) were used for posture classification and kinematic variable validation.

Config	Description	Target Posture (Start)	Target Posture (Finish)	Special Condition
D1C1	Table to Table (baseline)	Slightly bent back (2)	Medium bent back (3)	—
D1C2	Floor to Table	Squat straight back (7)	Bended back (4)	Low origin (floor level)
D1C3	Table to High shelf	Max bended back (5)	Lifting arms (6)	Overhead destination
D1C4	Low shelf to Table (twist)	Bended back (4)	Medium bent back (3)	45° trunk rotation

Config	Description	Target Posture (Start)	Target Posture (Finish)	Special Condition
D1C5	Table to Table (asymm. grip)	Standing straight (1)	Bended back (4)	Vertical hand separation (one hand on bottom, one hand on top of load)

Table 2. Dataset 1 task configurations. All configurations used a 10 kg load.

5.5 Task Configurations — Dataset 2

Four separate configurations (D2C1–D2C4) were used for load distance validation (Dataset 2). These are entirely distinct physical setups from the Dataset 1 configurations above.

Config	Description	Reference load distance
D2C1	Hold load close to body while standing straight	0 mm (+ 190 mm anatomical offset)
D2C2	Stretch arms forward while standing straight	Individually measured hand-palm-to-chest distance
D2C3	Bend back 45° and stretch arms perpendicular to trunk	Individually measured hand-palm-to-chest distance
D2C4	Bend back 45° and keep load close to body	0 mm (+ 190 mm anatomical offset)

Table 2b. Dataset 2 task configurations for load distance validation.

5.6 Participants

Three healthy adult subjects (S01, S02, S03) participated in the study. All were free of musculoskeletal complaints at the time of data collection. Detailed demographic data were not recorded for this technical validation; the focus was on comparing measured versus reference positions across a range of body sizes rather than on establishing population norms. Each subject completed both Dataset 1 (posture classification and kinematic variable trials, all five configurations) and Dataset 2 (load distance trials, four configurations).

5.7 Procedure

Dataset 1 (posture and kinematics). Three subjects each performed three trials per configuration across all five configurations (D1C1–D1C5), yielding 45 trials (5 × 3 × 3). Each trial consisted of five consecutive handling cycles; one representative cycle per trial was selected for analysis, giving one start–finish pair per trial (N=18 per configuration = 3 subjects × 3 trials × 2 phases). Motionprint Ergo identified the start and finish frames and extracted posture classifications and kinematic variables. Posture classifications were compared against expert observation. Kinematic errors were computed as absolute deviations from physically established reference values (0° for trunk twisting in non-twist configurations; 45° for D1C4 finish; 0 mm for vertical and lateral asymmetry in D1C1–D1C4 and for lateral asymmetry in D1C5; 120 mm for D1C5 vertical asymmetry, reflecting the measured box-height separation between hand contact points).

Dataset 2 (load distance). Three subjects each performed three trials per configuration across the four Dataset 2 configurations D2C1–D2C4 (see Section 5.5), yielding 36 trials (4 × 3 × 3). For D2C1 and D2C4 (close-body hold configurations), the load was positioned at body contact (expected 0 mm with 190 mm anatomical offset). For D2C2 and D2C3 (extended-reach configurations), the expected distance equaled the individually measured hand-palm-to-chest distance (S01: 490 mm; S02: 410 mm; S03: 425 mm).

6. Results

6.1 Posture Classification Accuracy

Posture classification was correct in every trial across all three subjects and all five configurations (90/90 evaluations, 100%). No misclassification occurred at either the start or finish phase of any handling cycle. These configurations covered seven of the ten KIM-LHC posture categories. The three-remaining low-position categories (squat low, on knees up, and sitting on knees) were not reproduced in the Dataset 1 configurations but were validated in a separate independent test, in which classification accuracy was also 100%.

Config	N trials	Start agree	Finish agree	Combined	Agreement %
D1C1	9	9/9	9/9	18/18	100%
D1C2	9	9/9	9/9	18/18	100%
D1C3	9	9/9	9/9	18/18	100%
D1C4	9	9/9	9/9	18/18	100%
D1C5	9	9/9	9/9	18/18	100%
Overall	**45**	**45/45**	**45/45**	**90/90**	**100%**

Table 3. Posture classification agreement by configuration, all subjects pooled (Dataset 1).

6.2 Trunk Twisting Measurement

Trunk twisting absolute errors are summarized in Table 5. The reference value was 0° at the start position for all configurations and at the finish for D1C1, D1C2, D1C3, and D1C5. For D1C4 the target finish angle was 45° (a 45° rotation was physically enforced by station placement). The overall MAE across all five configurations and three subjects was 3.19°.

Config	N	MAE (°)	SD (°)	Min (°)	Max (°)
D1C1	18	3.01	1.18	1.00	5.10
D1C2	18	2.82	1.56	0.20	6.00
D1C3	18	3.72	1.91	0.40	6.70
D1C4	18	3.06	1.58	0.50	5.30
D1C5	18	3.37	1.65	0.40	7.20
Overall	**90**	**3.19**	**1.58**	**0.20**	**7.20**

Table 4. Trunk twisting absolute errors by configuration, all subjects pooled

6.3 Vertical Hand Asymmetry

Vertical asymmetry absolute errors are summarized in Table 6. For configurations D1C1–D1C4, the reference asymmetry was 0 mm (symmetric grip). For D1C5, the reference was 120 mm, reflecting the measured box-height separation between the upper- and lower-edge hand contact points. All errors for D1C5 were below 20 mm from this reference, confirming that the asymmetry flag was correctly triggered in all nine D1C5 trials.

Config	N	Reference (mm)	MAE (mm)	SD (mm)	Min (mm)	Max (mm)
D1C1	18	0	10.09	4.91	1.70	17.40
D1C2	18	0	9.04	6.33	0.90	19.60
D1C3	18	0	11.38	5.92	0.90	19.50
D1C4	18	0	10.84	4.71	3.10	21.20
D1C5	18	120	4.28	2.35	0.90	8.20
Overall	**90**	**—**	**9.13**	**5.43**	**0.90**	**21.20**

Table 5. Vertical hand asymmetry absolute errors by configuration, all subjects pooled (Dataset 1, N=18 per config). For D1C5, errors are deviations from the 120 mm reference. Overall row pools all 90 measurements.

6.4 Lateral Hand Asymmetry

Lateral (horizontal) asymmetry absolute errors are summarized in Table 7. The reference lateral asymmetry was 0 mm for all five configurations (including D1C5, where the intentional grip asymmetry was vertical only). The overall MAE across all five configurations and three subjects was 9.4 mm.

Config	N	Reference (mm)	MAE (mm)	SD (mm)	Min (mm)	Max (mm)
D1C1	18	0	7.96	4.52	1.60	18.40
D1C2	18	0	6.81	3.76	1.10	14.30
D1C3	18	0	13.03	3.30	5.90	18.30
D1C4	18	0	8.73	2.98	4.80	15.10
D1C5	18	0	10.54	4.79	4.70	19.90
Overall	**90**	**0**	**9.41**	**4.44**	**1.10**	**19.90**

Table 6. Lateral hand asymmetry absolute errors by configuration, all subjects pooled (Dataset 1, N=18 per config). Reference is 0 mm for all configurations.

6.5 Load Distance

Load distance errors across all three subjects and four Dataset 2 configurations are summarized in Table 8. D2C1 and D2C4 tested close-body handling (0 mm reference); D2C2 and D2C3 tested extended-reach positions using individually measured hand-chest distances. The overall MAE was 5.5 mm.

Config	N	Mean err (mm)	SD (mm)	MAE (mm)	RMSE (mm)	Min (mm)	Max (mm)
D2C1	9	1.33	1.00	1.33	1.63	0.00	3.00
D2C2	9	12.78	3.67	12.78	13.24	5.00	17.00
D2C3	9	6.89	3.82	6.89	7.77	3.00	15.00
D2C4	9	1.11	0.93	1.11	1.41	0.00	3.00
Overall	**36**	**5.53**	**5.51**	**5.53**	**7.75**	**0.00**	**17.00**

Table 7. Load distance absolute errors by Dataset 2 configuration, all subjects pooled (configurations described in Section 5.5).

6.6 Per-Subject Breakdown (Load Distance)

Subject	N	Mean err (mm)	MAE (mm)	RMSE (mm)	Min (mm)	Max (mm)
S01	12	5.33	5.33	7.48	0.00	15.00
S02	12	6.25	6.25	8.21	1.00	16.00
S03	12	5.00	5.00	7.54	0.00	17.00

Table 8. Per-subject load distance error summary, all configurations pooled (Dataset 2).

Error magnitudes are broadly consistent across subjects. Higher errors in D2C2 and D2C3 (extended-reach) compared with D2C1 and D2C4 (close-body) are consistent with known increases in positional estimation uncertainty at greater limb extensions.

7. Discussion

7.1 Error Attribution

The errors observed in this validation are not caused by Motionprint Ergo's computational logic. The application performs geometrically unambiguous operations on body-landmark coordinates and joint angles provided by the Xsens MVN body model. Given exact inputs the results are exact. The observed deviations are attributable to the following:

Motion capture body model estimation errors. The Xsens MVN system estimates joint and segment orientations from inertial sensor data. These estimates carry typical uncertainty of 1–3° for angles and 1–3 cm for positions (Schepers et al., 2018; Paulich et al., 2018; Robert-Lachaine et al., 2017).

Calibration quality. Small residual errors in the N-pose calibration can introduce systematic offsets that persist throughout a session.

Soft-tissue artifact. Sensors attached to the body surface shift slightly during movement, contributing to positional and orientational noise.

Expert subjectivity near posture boundaries. When a posture is close to a category boundary, small IMU estimation errors may produce a different classification. No such boundary effects occurred in this study (100% agreement across all subjects and configurations).

Motionprint Ergo is a consumer of motion capture data, not the source of its measurement uncertainty. Observed error magnitudes (approximately 3–5° for angles, 5–15 mm for distances) are consistent with the known accuracy of the Xsens MVN system.

7.2 Practical Implications for Ergonomists

For the KIM-LHC, posture classification is the most consequential variable since the Body Posture Score ranges from 1 to 20 (Appendix A). The 100% classification accuracy observed across all three subjects and all five configurations confirms reliable performance across the range of postures validated. Trunk twisting errors of approximately 3–4° are relevant only near classification thresholds (10° and 30°); for postures well within a category these errors have no effect on the KIM-LHC score. Both vertical and lateral hand asymmetry errors (MAE below 10 mm) are well below the 100 mm flag threshold, confirming that asymmetry flags are triggered and suppressed correctly. The Additional Points cap of 6 limits the maximum impact of any single misclassification on the End Score.

Traditional manual KIM-LHC assessments are subject to inter-rater variability in posture observation. The automated classification demonstrated here is at minimum equivalent to careful manual observation, with the advantages of objectivity and reproducibility.

7.3 Study Limitations

Laboratory conditions. All trials were performed in a controlled environment. Real-world assessments may involve greater postural variability, movement speed variation, and environmental constraints not represented here.

Single motion capture system. Results are specific to the Xsens MVN Awinda system. Other inertial measurement systems require separate validation.

Reference method. Posture accuracy was assessed against expert observation, which is itself subject to some subjectivity near category boundaries.

Load weight. All trials used a single 10 kg load. Error characteristics may differ with substantially heavier or lighter loads.

Unvalidated modules. Trunk side-bending (Module 5), hand height relative to elbow/shoulder (Module 9), hand/arm position (Module 10), and difficulties due to holding/carrying (Module 11) were not separately validated. Modules 5, 9, and 10 are derived directly from the Xsens MVN body model and their accuracy is governed by that system. Module 11 (holding duration and carrying distance) is geometrically deterministic but its accuracy depends on the Xsens pelvis-position estimate; it was outside the scope of this study.

Posture category coverage. Three of the ten KIM-LHC posture categories (squat low, on knees up, and sitting on knees) were not included in the Dataset 1 configurations. These three categories were validated in a separate independent test with 100% classification accuracy, so all ten posture categories have been verified, but readers should note that the kneeling/low-squat postures were not part of the 90-evaluation dataset reported here.

8. Conclusion

This validation study demonstrates that Motionprint Ergo accurately classifies body posture and extracts the kinematic variables required for KIM-LHC assessments from Xsens MVN Awinda inertial motion capture data. Posture classification was correct in 100% of evaluated trials (90/90 evaluations across three subjects and five configurations). Trunk twisting was measured with an overall MAE of 3.19°. Vertical hand asymmetry was measured with an overall MAE of 9.13 mm; lateral hand asymmetry was measured with an overall MAE of 9.41 mm. Load distance was measured with an overall MAE of 5.5 mm. The KIM-LHC scoring formulas were independently verified by hand-calculation and confirmed exact. These results confirm that Motionprint Ergo provides a reliable and practical tool for automated KIM-LHC assessments suitable for use in laboratory and occupational field settings.

9. References

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Appendix A: Body Posture Combination Matrix

The KIM-LHC Body Posture Score is determined by a two-dimensional lookup table combining the posture group at the start of the lift (rows) with the posture group at the finish (columns).

	Finish: Group 1	Finish: Group 2	Finish: Group 3	Finish: Group 4
Start: Group 1	1	2	4	7
Start: Group 2	2	4	6	11
Start: Group 3	4	6	8	14
Start: Group 4	7	11	14	20

Table A1. Body Posture Score lookup matrix (start group × finish group).

Group	Posture Categories Included
1	Standing straight (1), Slightly bent back (2)
2	Medium bent back (3), Bended back (4), Squat straight back (7)
3	Max bended back (5), Squat low (8)
4	Lifting arms (6), On knees up (9), Sitting on knees (10)

Table A2. Posture category to group mapping.