Motionprint Ergo

RULA Module

Validation of Derived Posture Variables

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1. Executive Summary

This report presents the results of a laboratory validation of the RULA module in Motionprint Ergo, an ergonomic assessment application developed by Motionprint BV. Motionprint Ergo is designed to work on motion capture data to automate ergonomic assessments. In this study, the Xsens MVN Awinda motion capture system was used as the input source to evaluate the accuracy with which Motionprint Ergo extracts the derived posture variables required for a RULA assessment.

Two variables are derived by Motionprint Ergo from body-landmark geometry rather than read from the motion capture body model: the lower-arm lateral index, which determines whether the hand is working across the body midline or out to the side of the body, and the leg balance index, which determines whether the legs are evenly balanced. These two variables are the subject of this validation.

Three subjects performed 45 posture trials across five configurations for calculation verification, 36 hand-position trials across four configurations for the lower-arm lateral index, and 45 balance trials across five configurations for the leg balance index.

Key findings. RULA scoring was reproduced exactly in all cases (1350 of 1350 scored items across 45 trials). The lower-arm lateral index was measured with a mean absolute error (MAE) of 0.064 index units across 36 measurements, with a mean bias of −0.003 and a largest single-trial deviation of 0.20. The leg balance index was measured with an MAE of 0.050 index units across 45 measurements, with a mean bias of +0.016. In both cases the measurement error is approximately an order of magnitude smaller than the interval between the scoring decisions the variable drives.

Variables read directly from the motion capture body model — joint angles, segment positions, centre of mass and foot contacts — were not validated. Their accuracy is a property of the motion capture system and lies outside the scope of a Motionprint Ergo validation.

2. Introduction

RULA, the Rapid Upper Limb Assessment (McAtamney & Corlett, 1993), is one of the most widely used observational methods for evaluating exposure to the postural risk factors associated with work-related upper limb disorders. An assessor grades the posture of the upper arm, lower arm, wrist and wrist twist to obtain a Group A score, and the neck, trunk and legs to obtain a Group B score. Each group receives additions for muscle use and for force or load, and the two adjusted scores are combined into a single RULA score from 1 to 7 that maps onto four action levels. Traditionally this grading is performed by eye from an observation sheet — a process that is time-consuming, subject to inter-rater variability, and impractical for high-throughput assessments.

Motionprint Ergo addresses this by automating the extraction of posture variables from motion capture data. Rather than requiring an ergonomist to judge each joint angle and each adjustment by eye, Motionprint Ergo processes body-landmark coordinate data to obtain the posture inputs directly, then applies the standard RULA scoring tables to produce the group scores and the final RULA score.

For this validation study, the Xsens MVN Awinda inertial motion capture system was used as the motion data source. The purpose of the study is to validate the accuracy of Motionprint Ergo's derived posture variable extraction under controlled laboratory conditions using this specific input source.

The study follows a two-layer validation strategy, recognising that there are two distinct sources of potential error in the automated pipeline.

Layer 1 — Calculation accuracy. RULA scoring consists of banding joint angles into posture scores, applying the adjustments, and reading three published lookup tables. These are deterministic operations: given correct input values they always produce the correct output. This layer was verified empirically across 45 trials, using five configurations selected so that between them every posture band and every adjustment in both scoring tables is exercised at least once. Since these are deterministic operations, once verified no further empirical testing of the calculation layer is necessary.

Layer 2 — Derived variable extraction accuracy. This is the core focus of the present validation. Most RULA inputs are joint angles read from the motion capture body model, and their accuracy is a property of that system. Two variables, however, have no direct equivalent in the body model and must be derived by Motionprint Ergo from segment geometry: the lateral position of the hand relative to the body, and the distribution of body weight between the feet. Any error in these two quantities is attributable to Motionprint Ergo's geometry, not to the scoring tables, which is why they are validated against a physical reference here.

3. Background: The RULA Method

RULA grades posture through three published lookup tables. Table A combines the four Group A posture scores (upper arm, lower arm, wrist, wrist twist); Table B combines the three Group B posture scores (neck, trunk, legs); Table C combines the two adjusted group scores into the final RULA score. A RULA score of 1 or 2 indicates an acceptable posture, while a score of 7 indicates that investigation and change are required immediately.

Most of the inputs to those tables are joint angles, which Motionprint Ergo reads from the motion capture body model. Two of RULA's adjustments, however, concern the position of the hand and the stability of the stance, and in the original method both are visual judgements with no numeric criterion. An automated implementation must therefore define its own measurable equivalent, and it is those two equivalents that this validation focuses on:

Variable	Definition	Unit
Lateral index	Signed lateral position of the hand along the body's own left–right axis, scaled so that 0 is the body midline and 1 is the outer edge of the body	index
Balance index	Horizontal offset of the whole-body centre of mass from the centre of the base of support formed by the two feet, scaled so that 0 is evenly balanced and 1 is directly over one foot	index

Table 1. Derived posture variables that Motionprint Ergo computes from motion capture data.

The lateral index drives the lower-arm adjustment: the lower-arm score receives +1 when the hand is working across the body midline (index below 0) or out to the side of the body (index above 1). The balance index drives the legs score: 1 when the legs and feet are well supported and in an evenly balanced posture, 2 when they are not. Both scales are defined so that the two RULA cutoffs coincide with their own natural landmarks rather than falling on arbitrary values.

4. Validation Approach

4.1 Two-Layer Strategy

Layer 1 (calculation correctness) was verified empirically. Five laboratory configurations were staged so that between them they exercise every posture band and every adjustment in Table A and Table B, and were scored on three subjects over three trials each. For each of the 30 scored items per trial — every base score, every adjustment flag, both table lookups, the muscle-use and force/load additions, the two group totals and the final RULA score — the expected value is the value the published worksheet gives for the joint angles the recording contains. Across 45 trials and 30 items per trial, all 1350 items matched exactly. Since these are deterministic band and lookup operations, once verified no further empirical testing is necessary.

Layer 2 (derived variable extraction) is the focus of this empirical validation and is reported in Section 6. Each of the two derived variables was compared against a physical reference: tape-measured hand positions for the lateral index, and force-plate weight distribution together with observed mechanical events for the balance index.

4.2 Measurement Methodology

Lateral index. For each hand, a single signed index expresses its lateral position across the body, measured along the body's own left–right axis so that it remains correct as the subject turns. The scale is anchored on two landmarks: 0 is the body midline and 1 is the outer edge of the body, level with its own side. Values below 0 mean the hand has crossed onto the opposite side of the body; values above 1 mean the hand is reaching beyond the body's silhouette. Both hands use an own-side-is-positive convention, so left and right read identically.

The landmark tested against the midline is the pHandPalm point of the body model — the centre of the palm — projected a further 80 mm along the hand's own longitudinal axis toward the fingertips. The hand segment origin was not used: in the Xsens body model that origin is the wrist joint, which lags the part of the hand that actually crosses the midline first, and the resulting error accumulates precisely in the direction being measured when the arm reaches across the body.

Balance index. The horizontal position of the whole-body centre of mass is expressed relative to the base of support formed by the two feet, normalised so that 0 is the centre of that base and 1 is directly over one foot. The mediolateral component is normalised by half the distance between the foot centres and the anteroposterior component by half the foot length, and the larger of the two is reported. A foot counts as supporting if either its heel or its toe registers contact, and a change in support state must persist for at least 100 ms before it is accepted, so that momentary contact dropouts do not produce spurious readings. Frames without both feet on the ground are assigned a fixed value, since there is no base of support to measure against and standing on one foot is not an evenly balanced posture by definition.

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 data collection session. All recordings were HD reprocessed in MVN Analyze Pro 2025.0 (Schepers et al., 2018) before being exported 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 the Xsens MVN software to configure the body model. While MVN Analyze Pro offers the option to estimate body segment lengths from height and foot length alone (using its built-in anthropometric database), manually entering all segment dimensions is recommended for best results. This is particularly important for the two derived variables validated here, since both are normalised by body dimensions taken from the fitted model — the spacing between the shoulder joints for the lateral index, and the foot separation and foot length for the balance index. By entering measured segment lengths for each subject, the body model is tailored to the individual, minimising systematic offsets that could arise from population-average segment ratio estimates.

5.3 Test Setup

Foot placement positions were marked with tape so that stance was reproducible between trials. Lateral hand positions were marked on the floor relative to the body midline and verified with a tape measure before recording. For the balance configurations, the subject stood on the marked stance with a force plate positioned under one foot where a weight-distribution reference was required.

5.4 Configurations

Three datasets were recorded. Dataset 1 (calculation correctness) used five posture configurations selected so that between them every posture band and adjustment in both scoring tables is exercised. Dataset 2 used four hand positions spanning the full working range of the lateral index. Dataset 3 used five stance conditions from evenly balanced through to loss of balance and single-foot support.

Config	Hand position (Dataset 2)	Reference index
L1	Hand aligned with the shoulder (zero lateral offset)	1.00
L2	Hand crossing the body midline	0.00
L3	Midway between the midline and the shoulder	0.50
L4	Hand held outside the shoulder line	1.50

Table 2. Dataset 2 hand-position configurations and their reference index values.

Config	Stance condition (Dataset 3)	Reference index
E1	Standing upright, weight evenly distributed	0.00
E2	75 / 25 weight distribution on one leg	0.50
E3	Loss of balance to the side	1.50
E4	Loss of balance to the front or back	1.50
E5	Step taken (single-foot support)	1.50

Table 3. Dataset 3 stance configurations and their reference index values. References for E1 and E2 were established physically, as an evenly balanced stance and a force-plate measured 75/25 weight distribution. E3, E4 and E5 are mechanical events marked live in the recording at the moment they occurred.

5.5 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 values across a range of body sizes rather than on establishing population norms.

5.6 Procedure

Dataset 1. Three subjects each performed three trials per configuration across all five configurations, yielding 45 trials. Each trial was scored on all 30 items of the RULA worksheet, giving 1350 scored items in total.

Dataset 2. Three subjects each performed three trials per configuration across four configurations, yielding 36 trials. The hand was placed at the marked position and held while the index was recorded.

Dataset 3. Three subjects each performed three trials per configuration across five configurations, yielding 45 trials. For E1 and E2 the index was recorded during a held stance; for E3, E4 and E5 the index at the marked event was used.

6. Results

Errors are reported as the value produced by Motionprint Ergo minus the reference value, in index units. Four summary statistics are used throughout. The mean error is the average signed difference and shows whether the application reads systematically high or low; a mean error near zero means there is no consistent offset. SD is the standard deviation of those signed differences and describes how much they scatter from trial to trial. MAE, the mean absolute error, is the average size of the difference regardless of direction, and is the single figure that best describes typical accuracy. RMSE, the root-mean-square error, is similar to MAE but weights large deviations more heavily, so a RMSE much larger than the MAE indicates the presence of occasional outliers. Min and Max give the largest deviation in each direction.

6.1 Lower-Arm Lateral Index

Config	N	Mean Error	SD	MAE	RMSE	Min	Max
L1	9	−0.022	0.079	0.067	0.082	−0.10	+0.10
L2	9	+0.011	0.099	0.078	0.100	−0.10	+0.20
L3	9	+0.022	0.063	0.044	0.067	−0.10	+0.10
L4	9	−0.022	0.079	0.067	0.082	−0.10	+0.10
Overall	**36**	**−0.003**	**0.083**	**0.064**	**0.083**	**−0.10**	**+0.20**

Table 4. Lateral index errors by configuration (App − Reference), N = 9 per configuration.

The index reproduces both anchoring landmarks closely. At L2, where the hand crosses the body midline and the index is 0 by construction, the pooled mean reading was 0.01. At L1, where the hand is aligned with the shoulder, the pooled mean was 0.98 against a reference of 1.00. The intermediate position L3 and the beyond-body position L4 fall in proportion, indicating that the scale is linear across its working range rather than accurate only at the points it was calibrated on. The overall MAE of 0.064 index units demonstrates good practical accuracy for this variable.

6.2 Leg Balance Index

Config	N	Mean Error	SD	MAE	RMSE	Min	Max
E1	9	+0.011	0.031	0.011	0.033	0.00	+0.10
E2	9	−0.011	0.057	0.033	0.058	−0.10	+0.10
E3	9	+0.022	0.092	0.067	0.094	−0.10	+0.20
E4	9	+0.022	0.092	0.067	0.094	−0.10	+0.20
E5	9	+0.038	0.089	0.073	0.096	−0.10	+0.20
Overall	**45**	**+0.016**	**0.078**	**0.050**	**0.079**	**−0.10**	**+0.20**

Table 5. Balance index errors by configuration (App − Reference), N = 9 per configuration.

The evenly balanced stance E1 produced the smallest errors of any configuration (MAE 0.011), which is expected: it is the condition with least postural sway and no event timing to identify. The force-plate reference at E2 confirms that a 75/25 weight distribution corresponds to an index of approximately 0.5, which is the value at which the legs score changes from 1 to 2.

The three event-based configurations E3, E4 and E5 carry slightly larger errors. This is attributable to event timing rather than to the index itself: the reference is a moment marked during a dynamic movement, and a difference of a few frames in identifying that moment produces a difference in the recorded value. That the loss-of-balance events converge on the same index from two independent directions — sideways at E3 and fore/aft at E4 — is a stronger result than the error figures alone suggest, because the two axes are normalised by different body dimensions and yet reach the limit of balance at the same point on the scale.

6.3 Per-Subject Breakdown

Subject	Lateral Mean Err.	Lateral MAE	Balance Mean Err.	Balance MAE
S01	−0.008	0.058	+0.013	0.053
S02	−0.017	0.067	+0.009	0.044
S03	+0.017	0.067	+0.027	0.053

Table 6. Per-subject error summary (all configurations pooled).

Error magnitudes are broadly consistent across subjects, indicating that the accuracy is not driven by a single outlier. Minor inter-subject differences are expected due to variations in body dimensions, calibration quality, and natural movement patterns. That no subject stands out is of particular interest here, because both variables are normalised by that subject's own body dimensions; a normalisation error would be expected to show as a subject-specific bias.

6.4 Bias Summary

Variable	Mean Bias	Interpretation
Lateral index	−0.003	No meaningful systematic offset; the scale is centered on its landmarks
Balance index	+0.016	Small positive bias, consistent with event timing in the dynamic configurations rather than with a scale error

Table 7. Summary of systematic biases.

Both biases are an order of magnitude smaller than the scoring resolution of the variable they belong to. The balance bias is positive for all three subjects, which is the signature of a peak identified slightly late in a dynamic movement rather than of a systematically mis-scaled index; the statically held configurations E1 and E2 do not share it.

7. Discussion

7.1 Error Attribution

The errors observed in this validation are not caused by Motionprint Ergo's scoring logic. Layer 1 established that the banding, the adjustments and the three lookup tables reproduce the published method exactly. The two derived variables are straightforward geometric operations on body-landmark coordinates provided by the motion capture system; given exact landmark positions, the computed indices would be exact. The observed deviations from the physical reference are attributable to several characteristics of the IMU-based motion capture approach:

Motion capture body model estimation errors. The Xsens system estimates joint and segment positions from inertial sensor data. These estimates carry known uncertainty, typically in the range of 1–3 cm per joint position, as documented in the Xsens MVN technical specifications (Schepers et al., 2018; Paulich et al., 2018). Because both indices are ratios normalised by a body dimension, a positional error of that size translates into an index error of a few hundredths — which is the order of magnitude observed.

Calibration quality. The initial N-pose calibration establishes the body model dimensions for each subject. Although individual segment lengths were entered manually for optimal accuracy, small residual errors in the calibration posture can introduce systematic offsets that persist throughout the recording session, and both indices depend on the fitted dimensions through their denominators.

Soft-tissue artifact. Sensors attached to the body surface shift slightly during movement due to underlying soft tissue motion, contributing to positional noise.

Natural movement variability. Subjects do not achieve identical hand and body positions on every repetition. Even with marked target positions, the actual hand location at the moment of measurement varies between trials, and in the dynamic balance configurations the moment of the event itself carries timing uncertainty of a few frames.

The key observation is that Motionprint Ergo is a consumer of motion capture data, not the source of its measurement uncertainty. If the body model places a hand 3 cm from its true location, the lateral index will reflect that offset — this is expected and correct behaviour. The observed error magnitudes are consistent with the known accuracy of the Xsens MVN system for positional data, confirming that Motionprint Ergo does not introduce additional error beyond what the motion capture system provides.

7.2 Practical Implications for Ergonomists

For ergonomists considering Motionprint Ergo for field use, the practical question is: how much does a measurement error of this magnitude affect the final RULA assessment? Both validated variables feed binary adjustments rather than continuous outputs. The lateral index determines whether the lower-arm score receives +1, at cutoffs of 0 and 1; the balance index determines whether the legs score 1 or 2, at a cutoff of 0.5. In both cases the measurement error established here is roughly an order of magnitude smaller than the interval between the decision points, so an assessment is unlikely to change on the basis of measurement error alone. A hand or a stance positioned deliberately on a threshold remains an ambiguous case, as it would be for a human assessor.

It is also worth noting that RULA is an observational method, and observational methods are themselves subject to inter-rater variability. Two trained assessors grading the same posture will not always agree, particularly on the adjustment items, which the original method describes qualitatively rather than numerically. An automated assessment removes that source of variance entirely: the same recording assessed twice produces the same score, and two recordings of the same posture differ only by the measurement variability quantified in this report.

Beyond repeatability, Motionprint Ergo offers a fundamental advantage in the richness of the assessment. Because the motion capture system records the entire working movement continuously, Motionprint Ergo evaluates every posture variable on every frame — not only at a single observed instant. A traditional RULA assessment grades one posture chosen by the assessor, and the worst posture in a work cycle may occur at a moment the assessor did not select. Within the RULA report settings, the user can analyse the frame with the peak RULA score, review the proportion of time spent in each risk band, and inspect the critical moments the software identifies automatically. This captures the worst-case posture during a task, which a single-instant manual assessment may miss entirely.

7.3 Study Limitations

Sample size. Three subjects with three trials each provide 9 observations per configuration. This is sufficient for a technical validation and application note, but not for establishing population-level accuracy norms. Future studies with larger and more diverse samples would strengthen the evidence base.

Laboratory conditions. All trials were performed in a controlled laboratory environment with clearly marked positions. Real-world assessments involve more natural variability in posture, movement speed, and environmental constraints. Field accuracy may differ somewhat from these controlled results.

Single motion capture system. Results are specific to the Xsens MVN Awinda system used in this study. Motionprint Ergo is designed to work on motion capture data from various sources; performance with other systems will require separate validation.

Standing postures only. The balance index compares the centre of mass against a base of support formed by the two feet. In seated work the centre of mass can lie well outside that base while the posture is fully supported, and RULA would correctly score the legs as 1. Seated assessment therefore falls outside the validated range.

Scope of the lateral index. The lateral index is purely lateral. It ignores how far forward or how high the hand is held, so a hand raised overhead at a neutral lateral position reads as neutral. It also scores each hand independently and takes no trunk-orientation input, so reaching across the body cannot be distinguished from turning the whole body in that direction.

Single-foot detection. Whether a foot is in contact with the ground is read from the motion capture body model and is not validated here. Frames without both feet down are assigned a fixed value rather than a measured one, so the index does not distinguish an ordinary walking step from a loss of balance. Both are scored as not evenly balanced, which is the correct RULA outcome, but the underlying number is not a measurement in that range.

Adjustment thresholds. RULA specifies no numeric criterion for any of its adjustment items; the original method asks the assessor to judge them by eye. Motionprint Ergo therefore applies numeric thresholds of its own, drawn from the ergonomic literature where a value is available (for example Vignais et al., 2017) and chosen by the developers where none is. Establishing that a chosen threshold is the correct one is a separate question from establishing that the quantity it is applied to is measured accurately, and only the latter is claimed here.

Reference method. The ground truth in this study is a physically marked target position or a marked event instant, not a simultaneous independent measurement at the exact hand position.

In practice the subject's hand may deviate slightly from the target, and the marked event carries timing uncertainty, which means some portion of the observed error is due to the subject's positioning rather than to the measurement system.

8. Conclusion

This validation study demonstrates that Motionprint Ergo reproduces RULA scoring exactly and accurately extracts the derived posture variables required for RULA assessments from Xsens MVN Awinda inertial motion capture data. Across 45 posture trials spanning five representative configurations, RULA scoring was reproduced without error in all 1350 scored items. The lower-arm lateral index was measured with an overall MAE of 0.064 index units across 36 measurements, and the leg balance index with an overall MAE of 0.050 index units across 45 measurements — in both cases accuracy levels consistent with the known capabilities of the Xsens MVN system, and approximately an order of magnitude finer than the scoring decisions the variables drive.

Motionprint Ergo's RULA implementation, including the posture bands, all adjustment items and the three scoring tables, was verified across the full range of each and confirmed to be correct. The RULA score is a deterministic composition of these parts: every input to the published lookup tables is either validated here against a physical reference, read directly from the motion capture body model and excluded on that basis, or a documented threshold. A score assembled from parts in those three states is as well established as its parts.

Taken together, these results confirm that Motionprint Ergo provides a reliable and practical tool for automated RULA assessments, suitable for use by ergonomists in both laboratory and field settings.

9. References

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