ISSN: 2798-7345 (online)
ISSN: 2830-2648 (print)
JOURNAL OF EDUCATION AND SPORT SCIENCE (JESS)
http://publikasiilmiah.unwahas.ac.id/index.php/JESS
Vol (7) No (2)

Biomechanical Indicators and Their Effectiveness in Dynamic Balance During the Performance of Compound Feints in Handball Players

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Abstract

This study aimed to identify the biomechanical indicators most strongly associated with the effectiveness of dynamic balance during the performance of compound feints and to develop a verifiable predictive model. The proposed protocol initially targets the recruitment of **67 players** to retain approximately **60 complete cases**; however, this number is not considered a definitive sample-size calculation. Prior to data collection, the minimum required sample size should be determined based on the number of model parameters, a conservative anticipated R^2, the targeted shrinkage, and the desired precision for estimating the mean and residual variance, with recalculation performed if adjustment variables or interaction terms are added.

Each player performs **five standardized trials** using two synchronized force platforms combined with three-dimensional motion analysis. The median of valid trials is used as the primary unit of analysis. Center-of-pressure velocity, sway area, time to stabilization (TTS), and trunk–pelvis separation are measured, while two blinded assessors independently assign an effectiveness score without access to the instrument-derived measurements or the attacking outcome.

To illustrate the analytical procedures and evaluate the model structure prior to field implementation, a reproducible illustrative dataset comprising **60 cases** was used. The outputs demonstrated inverse associations between center-of-pressure velocity and TTS and effectiveness, whereas trunk–pelvis separation showed a positive association with effectiveness. The model explained **77.8% of the apparent variance**, while the optimism-corrected bootstrap-adjusted R^2 was **0.760**, and the optimism-corrected RMSE was **4.41 degrees**. These findings are presented as preliminary analytical outputs intended to test the model procedures prior to their application to field-collected data.

Keywords: biomechanical indicators; dynamic balance; compound feints; center of pressure; time to stabilization; handball; predictive modeling.

1. Research Overview

1.1 Introduction and Significance of the Study

A compound feint requires a rapid transition from a deceptive movement cue to an actual offensive action while simultaneously controlling weight transfer and changing direction. Its successful execution depends on the organization of the kinetic chain and neuromuscular coordination rather than on speed alone (Bastawisi, 1996; Abdullah & Badawi, 2006). Studies in

handball have emphasized the importance of sport-specific motor abilities, transition speed, and coordination for high-quality technical performance, particularly in situations involving changes of direction combined with shooting or defensive movement (Issa, 2012; Ghazi & Hassoun, 2019). Moreover, a recent kinematic study of feinting in handball demonstrated the potential to quantitatively differentiate deceptive movement characteristics across different performance levels (Burger et al., 2023).

Dynamic balance refers to the player's ability to control the center of mass within a continuously changing base of support and to regain a position that allows the performance to continue without excessive corrective steps. Force platforms provide quantitative measures such as center-of-pressure (COP) path length, COP velocity, and sway area; however, the interpretation of these measures is influenced by the motor task, measurement window, and filtering procedures (Caballero et al., 2015). This is consistent with Arabic-language literature linking the efficiency of dynamic balance to lower-limb capacities, movement speed, and agility in sporting activities (Maseer Yaseen, 2012).

Postural control efficiency in handball is influenced by the player's level of experience and ability to regulate the transition from loading to directional change and subsequent offensive action. A compound feint also requires a systematically controlled discrepancy between the apparent movement cue and the actual action. Accordingly, trunk and pelvic motion and weight transfer represent important sources of information that may determine the success of a feint. Applied studies in handball support the importance of motor abilities and coordination for performance under changing game demands (Ghazi & Hassoun, 2019; Khan Afdal & Hami, 2023), while recent kinematic analyses further support the feasibility of objectively characterizing deceptive movements (Burger et al., 2023).

The integration of objective biomechanical measurement with independent technical assessment is therefore important, together with establishing measurement validity and reliability and standardizing testing conditions before interpreting differences between players (Hassanein, 2004; Allawi & Rateb, 1999). The principal variables and analytical plan should also be specified a priori, with confidence intervals, effect sizes, and model-assumption diagnostics reported to minimize overinterpretation of findings and maintain consistency in the statistical procedures.

1.2 Research Problem

Some compound-feint attempts fail because of an additional corrective step or delayed recovery to an executable position. Visual observation alone cannot quantify COP displacement, time to stabilization (TTS), or trunk–pelvis separation. Furthermore, incorporating device-derived measures or the success of the offensive action into the technical rating may inflate the observed association. Accordingly, the present protocol separates objective biomechanical measurements from visual judgment and uses the player as the unit of analysis.

Main research question:
What is the contribution of COP velocity, TTS, and trunk–pelvis separation to estimating dynamic-balance effectiveness after accounting for measurement reliability and internal validation?

1.3 Objectives of the Study

The study aims to:

- Develop a standardized quantitative characterization of biomechanical indicators across the temporal phases of the compound feint.
- Estimate the associations between these indicators and dynamic-balance effectiveness, with confidence intervals and adjustment for multiple comparisons.
- Develop a prespecified linear regression model incorporating three primary predictors and evaluate its assumptions, apparent performance, and internal validation.
- Provide an exploratory endpoint comparison using standardized effect sizes without allowing it to replace the primary continuous analysis.

1.4 Research Hypotheses

The study hypothesizes that:

- COP velocity, sway area, and time to stabilization are inversely associated with dynamic-balance effectiveness.
- Trunk–pelvis kinematic sepa

- **1.5 Scope of the Study**
- **Human scope:** Players from Iraqi Premier League handball clubs during the **2025–2026 sports season**.
- **Geographical scope:** The Indoor Sports Hall of Al-Kut Sports Club.
- **Temporal scope:** From **April 10, 2026, to June 20, 2026**.

- **1.6 Operational Definitions**

Table 1. Operational Definitions

Term	Refined Operational Definition
Dynamic balance	The control of the center of mass and ground-reaction forces during the transition from the deceptive movement to the actual action without excessive corrective movement.
Compound feint	A deceptive movement cue followed by weight transfer and a change of direction, followed by an actual offensive action in the opposite direction.
Center of pressure (COP)	The point of application of the resultant ground-reaction force; total COP is calculated as a force-weighted value across the two force platforms.
95% sway area	The 95% confidence ellipse encompassing COP points within a fixed 1.5-s measurement window following the peak of the directional change.
Functional time to stabilization (TTS)	The interval from the peak of the directional change to the first continuous 250-ms period within the predefined reference range for horizontal force and COP velocity. If the criterion is not achieved within 1.5 s, the trial is recorded as **"not stabilized."**
Dynamic-balance effectiveness	A score ranging from 0 to 100 assigned by two blinded assessors based on balance-related behaviors independently of the instrument-derived measures and the outcome of the offensive action.

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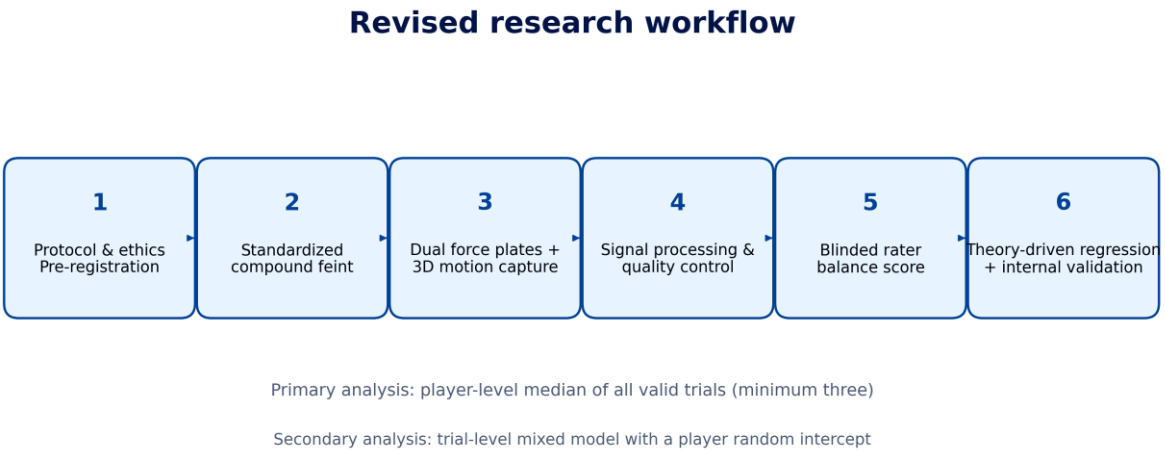


Figure 1. Flowchart of the Research Procedures Following the Systematic Review

2. Research Methodology and Field Procedures

2.1 Research Design

A **descriptive correlational design** was employed to develop a model for a continuous outcome. COP velocity, TTS, and trunk–pelvis separation were prespecified as the primary predictors, whereas the remaining indicators were treated as exploratory variables. For each player, the **median of all valid trials** was used as the primary analytical value, with a minimum of three valid trials required. The statistical analysis plan was finalized before access to the outcome data, in accordance with principles of methodological rigor and reduction of selective reporting bias (Allawi & Rateb, 1999).

2.2 Study Population and Sample

The study population comprised **advanced handball players** with at least four years of playing experience and no current injury likely to affect performance. An initial operational recruitment target of **67 players**, with the aim of retaining approximately **60 valid cases**, was established. The final sample size was to be recalculated before field implementation based on the number of variables entered into the model, the anticipated variance, the desired estimation precision, and the expected attrition rate, while avoiding the inclusion of an excessive number of predictors relative to the available sample size (Allawi & Rateb, 1999).

A trial was excluded in cases of pain, synchronization failure, contact of the foot outside the force-platform surface, or loss of markers that prevented valid analysis. At least **three valid trials** were required for each player. Missing values and their causes and patterns were documented. When missingness was limited, a complete-case analysis was performed together with a sensitivity analysis. If missingness was substantial, multiple imputation at the player level was considered according to a prespecified analytical plan. Trials classified as **"not stabilized"** were not imputed, and missing TTS values were not artificially generated. The sex of participants and playing positions were prespecified to avoid combining small, heterogeneous subgroups.

2.3 Equipment and Measurement Instruments

Table 2. Equipment and Measurement Instruments

Equipment/Instrument	Minimum Specification	Purpose and Quality Control
Two flush-mounted force platforms –	Sampling frequency ≥1,000 Hz with common synchronization	Measurement of ground-reaction forces and COP for each foot and calculation of total COP.
Three-dimensional motion-analysis system	≥8 cameras; sampling frequency ≥200 Hz; volumetric calibration	Extraction of trunk, pelvic, and knee angles and estimation of the center-of-mass trajectory.
Reference video camera	≥100 frames/s	Presentation of trials to assessors and identification of key events without displaying force-platform data.
Processing and analysis software	Low-pass Butterworth filter; cutoff frequency determined through residual analysis	Standardization of data processing, with preservation of the analysis script, variable dictionary, software versions, and decision log.
Refined assessment form	Five observable domains; total score of 100; review by 5–7 experts with calculation of I-CVI and S-CVI	Independent balance-related domains; calculation of ICC(2,k), SEM, and MDC before adopting the mean score.

2.4 Pilot Study

A pilot study was conducted on **8–10 players** who were not included in the main sample to evaluate the workflow, synchronization procedures, and operational definition of TTS. Between **five and seven experts** assessed the suitability of the items included in the technical assessment form. Content validity, inter-rater agreement, and reliability indices were then calculated, together with the **standard error of measurement (SEM)** and the **minimum detectable change (MDC)**. The mean assessor score was not adopted until an acceptable level of inter-rater agreement had been established (Hassanein, 2004; Allawi & Rateb, 1999).

2.5 Main Experiment, Procedures, and Measurements

The main experimental procedures were conducted as follows:

- Ethical approval and informed consent were obtained. Recent injuries, playing position, and years of playing experience were documented.
- A standardized warm-up was performed, followed by placement of the anatomical markers and static and dynamic calibration of the measurement system. Each player then completed a **5-s quiet-standing reference trial** to establish an individualized reference stability range.
- Each player performed **five trials** in front of a trained defender according to two randomized scenarios. Data were recorded from **1 s before the onset of the feint to 2 s after the offensive action**, with sufficient rest provided to minimize fatigue.
- The median of all valid trials for each player was adopted, with a minimum of three valid trials required. As a secondary analysis, the trials were analyzed using a **mixed-effects model with a random intercept for player**, while adjusting for performance scenario.
- The video recordings were presented to **two or more assessors** in randomized order. The assessors were blinded to player identity, force-platform measurements, and the ratings assigned by the other assessor.

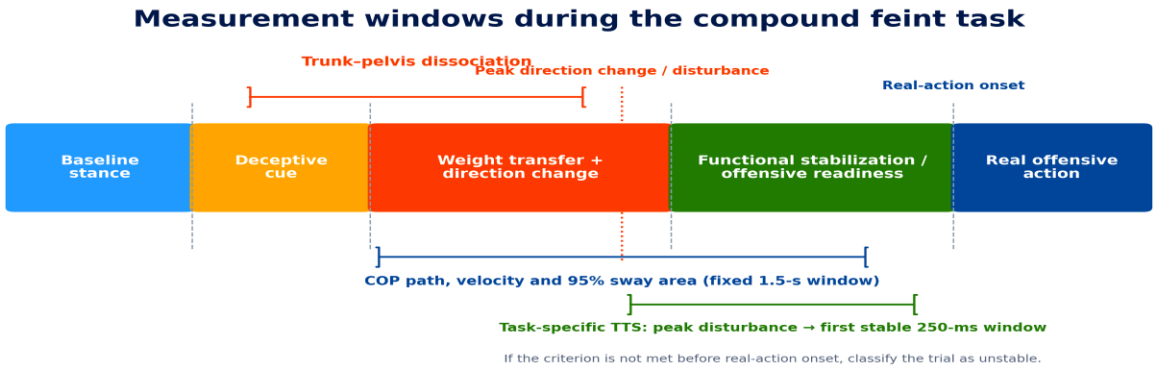


Figure 2. Temporal Phases and Measurement Windows During the Compound Feint

2.6 Signal Processing and Variable Extraction

Motion and force signals were filtered using a **zero-phase Butterworth filter**, with the cutoff frequency determined through residual analysis. The vertical force threshold (**Fz**) used for COP calculation was determined based on the force-platform specifications and the pilot study. Sensitivity testing was initiated at **20 N** and repeated across a range of **10–30 N**; a fixed threshold was not adopted without documentation. Total COP was calculated from the two force platforms using vertical-force weighting. Sampling frequencies, measurement windows, and filtering procedures were documented because these factors may influence stability-related measures, particularly **time to stabilization (TTS)** (Fransz et al., 2015).

COP path length was calculated from the successive point-to-point distances, while COP velocity was calculated by dividing the path length by the duration of the measurement window. Sway area was quantified as the **95% confidence ellipse** within a fixed **1.5-s window**. Caballero et al. (2015) emphasized that the selection and extraction method of COP measures can influence the interpretation of postural control; therefore, the measurement window was standardized across all players.

The stability reference range was derived from the quiet-standing reference trial. TTS commenced at the peak of the directional change and ended at the first continuous **250-ms period** falling within the predefined reference range before the final action. If the criterion was not achieved within **1.5 s**, the trial was classified as **"not stabilized"**, and no numerical TTS value was assigned. This operational definition was evaluated during the pilot study based on the methodological considerations discussed by Fransz et al. (2015).

Table 3. Measured Variables and Their Analytical Roles

Variable	Unit	Measurement Window / Definition	Analytical Role
COP path length	cm	From the onset of weight transfer to the onset of stabilization	Exploratory
COP velocity	cm/s	Path length ÷ duration of the directional-change window	Primary predictor
95% sway area	cm^2	Fixed 1.5-s window following the peak of the directional change	Exploratory
Functional time to stabilization (TTS)	s	From the peak of the directional change to the first stable 250-ms period; maximum 1.5 s; otherwise classified as "not stabilized"	Primary predictor

Knee flexion angle	degrees	At the moment of peak loading on the supporting foot	Exploratory
Trunk inclination	degrees	At the peak of the deceptive signal and during the actual action	Exploratory
Trunk–pelvis separation	degrees	Difference in axial rotation at the peak of the deceptive movement	Primary predictor
Balance effectiveness	score /100	Mean of assessor ratings; independent of instrument-derived measures and offensive outcome	Dependent variable

2.7 Statistical Methods

- Means, standard deviations, ranges, and confidence intervals were reported. Distributional plots and potential outliers were examined before conducting inferential analyses.
- **Pearson's correlation coefficient** was calculated when the assumption of linearity was satisfied, whereas **Spearman's rank correlation coefficient** was used when linearity was not supported. **95% confidence intervals** were reported. Multiplicity was controlled for exploratory correlation analyses, and the magnitude of the association was interpreted alongside statistical significance.
- A **prespecified multiple linear regression model** incorporating the three primary predictors was fitted. Stepwise regression and automated variable elimination based on *p*-values were not used.
- Linearity, residual behavior, homoscedasticity, **variance inflation factors (VIFs)**, and **Cook's distance** were examined. Adjusted R^2, RMSE, and calibration were reported. Optimism in model performance was corrected using **bootstrap resampling**, with a minimum of **1,000 resamples**; **2,000 resamples** were used for the illustrative model. A small hold-out test sample was not created.
- Potential **ceiling and floor effects** in the 0–100 effectiveness score were examined. If substantial boundedness was evident, a sensitivity analysis using a model appropriate for a bounded outcome was performed.

3. Presentation, Analysis, and Discussion of the Results

3.1 Quantitative Description of the Biomechanical Indicators

For the purposes of testing the analytical procedures and assessing reproducibility, an **illustrative dataset comprising 60 cases** was generated using a fixed random seed (**20260813**). The tables, figures, and equation presented below were derived from this dataset. The dataset is used solely to evaluate the analytical framework pending completion of the field data collection.

Table 4. Descriptive Statistics for the Analytical Model Dataset (n = 60)

Variable	Unit	Mean	Standard Deviation	Minimum	Maximum
COP path length	cm	42.60	5.10	28.31	54.34
COP velocity	cm/s	9.80	1.40	6.42	12.92
95% sway area	cm^2	6.40	1.10	4.11	9.25

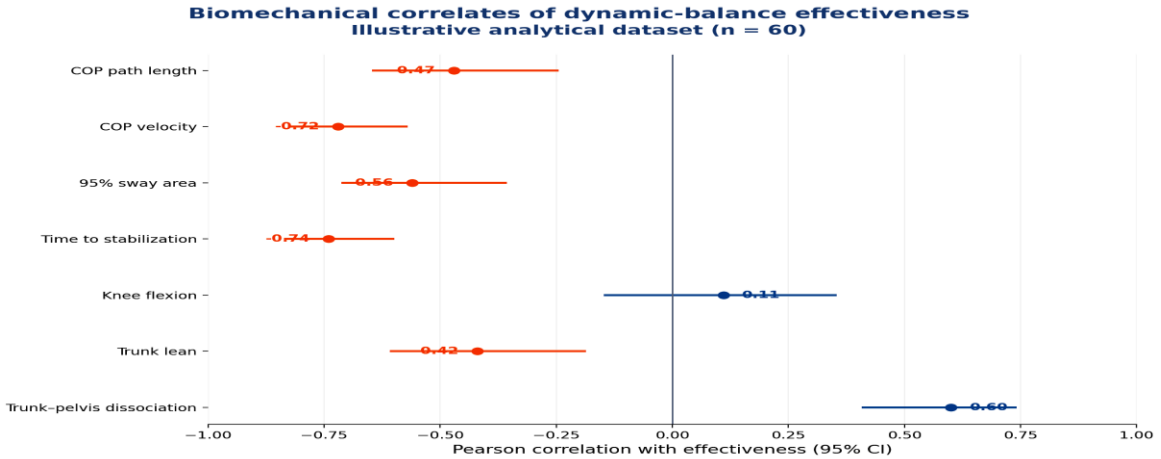
Time to stabilization (TTS)	s	0.85	0.12	0.57	1.10
Knee flexion angle	degrees	38.20	4.60	24.53	47.99
Trunk inclination angle	degrees	11.50	2.30	4.37	16.42
Trunk–pelvis separation	degrees	22.80	4.80	10.72	34.38
Balance effectiveness	score /100	76.40	8.90	60.25	95.21

3.2 Correlations with Effectiveness

In the analytical model dataset, COP velocity, COP path length, sway area, and TTS were inversely associated with effectiveness, whereas trunk–pelvis separation showed a positive association. No clear association was observed for knee flexion angle. The reported associations remained statistically significant after **false discovery rate (FDR) correction**, supporting the suitability of the proposed analytical procedures for hypothesis testing in the field study.

Table 5. Bivariate Correlations with Effectiveness in the Analytical Model Dataset

Variable	r	95% Confidence Interval	p	FDR-adjusted q	Interpretation
COP path length	−0.470	[−0.647, −0.245]	< 0.001	< 0.001	Moderate inverse association
COP velocity	−0.720	[−0.823, −0.570]	< 0.001	< 0.001	Strong inverse association
Sway area	−0.560	[−0.713, −0.357]	< 0.001	< 0.001	Moderate-to-strong inverse association
Time to stabilization (TTS)	−0.740	[−0.837, −0.599]	< 0.001	< 0.001	Strong inverse association
Knee flexion angle	0.110	[−0.148, 0.354]	0.403	0.403	Unclear association
Trunk inclination angle	−0.420	[−0.609, −0.186]	< 0.001	< 0.001	Moderate inverse association
Trunk–pelvis separation	0.600	[0.408, 0.741]	< 0.001	< 0.001	Strong positive association



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JOURNAL OF EDUCATION AND SPORT SCIENCE (JESS)
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Vol (7) No (2)

Figure 3. Correlation Coefficients and 95% Confidence Intervals in the Analytical Model

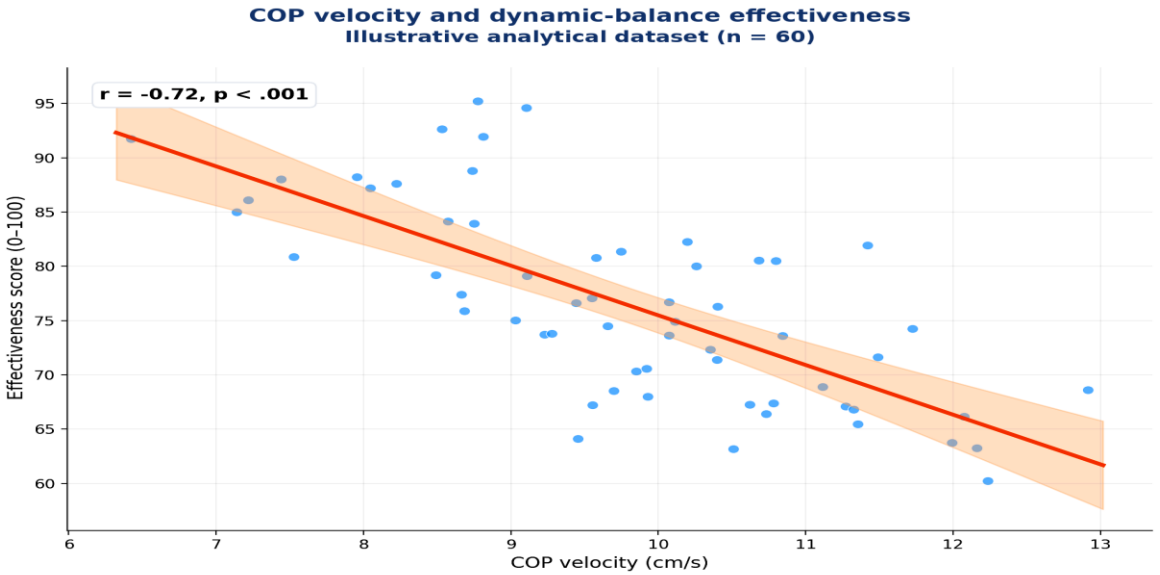

Figure 4. Relationship Between COP Velocity and Dynamic-Balance Effectiveness

3.3 Prespecified Predictive Model

The three predictors were entered simultaneously into a single model. The model yielded **R = 0.882, R^2 = 0.778, and adjusted R^2 = 0.766**, with **F(3,56) = 65.27, p < 0.001**. The apparent RMSE was **4.16**. After correcting for optimism in model fit using **2,000 bootstrap resamples**, the optimism-corrected **R^2 was 0.760**, and the optimism-corrected **RMSE was 4.41**.

Variance inflation factors (VIFs) ranged from **1.14 to 2.11**, indicating no substantial multicollinearity among the predictors. The Shapiro–Wilk test for the model residuals yielded **p = 0.200**. The maximum Cook's distance was **0.069 for case 60**, which was close to the approximate screening threshold of **0.067 (4/60)**. Excluding this case in a sensitivity analysis resulted in **R^2 = 0.787**, while the direction and statistical significance of the regression coefficients remained unchanged. Accordingly, this case should be examined rather than automatically excluded when analyzing the field data.

Table 6. Coefficients of the Illustrative Regression Model

Predictor	B	SE	β	t	95% CI for B	p
Intercept	104.77	6.04	—	17.33	[92.66, 116.88]	< 0.001
COP velocity	−2.73	0.56	−0.43	−4.91	[−3.85, −1.62]	< 0.001
TTS	−22.25	6.78	−0.30	−3.28	[−35.84, −8.66]	0.002
Trunk–pelvis separation	0.76	0.12	0.41	6.09	[0.51, 1.01]	< 0.001

The following equation represents the form of the model derived from the illustrative analytical dataset. Its practical application requires **re-estimation of the model coefficients and validation of model performance using field-collected data**:

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Effectiveness = 104.77 − 2.73(COP velocity) − 22.25(TTS) + 0.76(Trunk–pelvis separation)

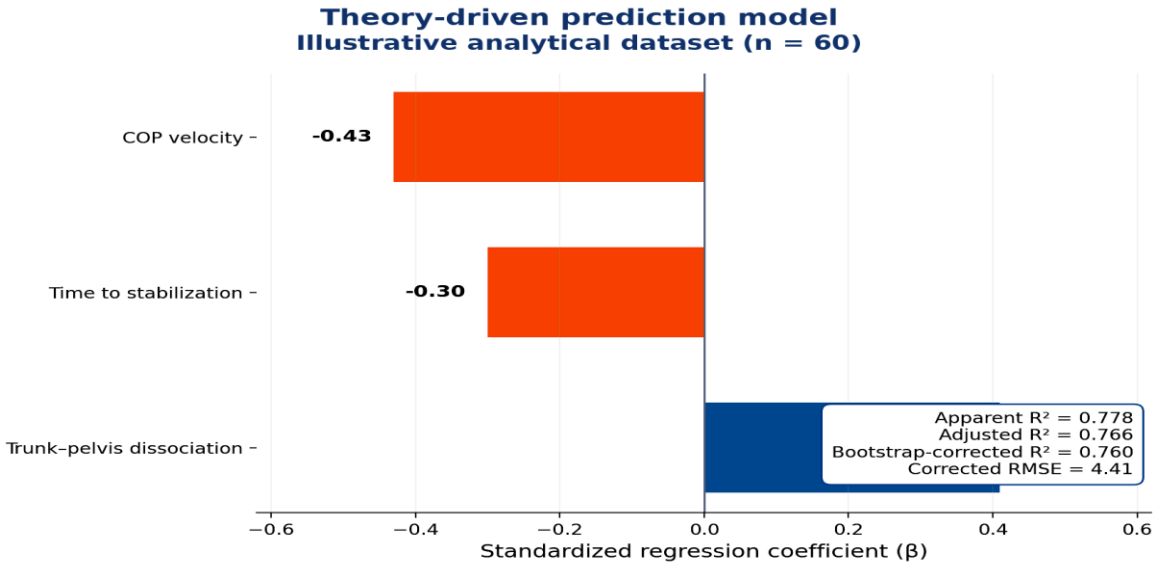

Figure 5. Standardized Beta Coefficients and Apparent and Bootstrap-Corrected Model Performance

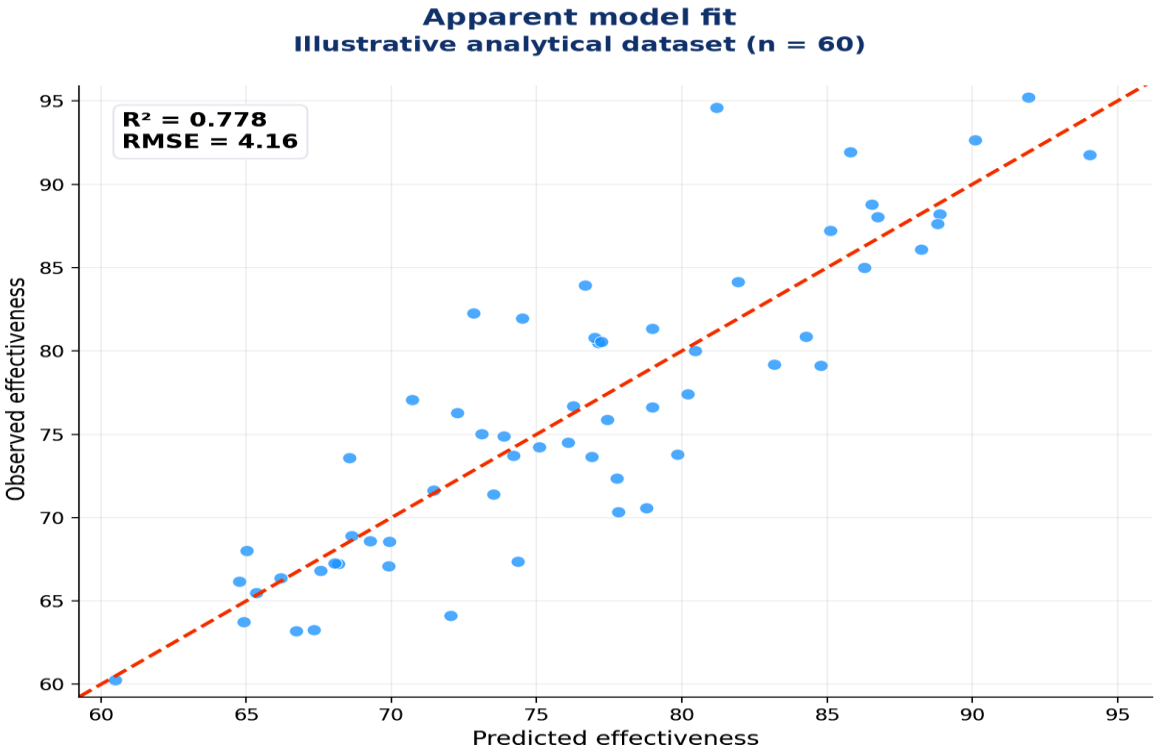

Figure 6. Observed and Predicted Values in the Analytical Model

3.4 Exploratory Extreme-Group Comparison

For descriptive comparison purposes, the analytical model dataset was dichotomized at the median into two equal groups (**n = 30 per group**). Because dichotomization reduces the information contained in the continuous variables, it was not used to construct the predictive

model. Instead, it was restricted to illustrating the direction and magnitude of between-group differences using **Welch's t-test**, **Hedges' g effect size**, and **95% confidence intervals**.

Table 7. Exploratory Extreme-Group Comparison in the Analytical Model

Variable	**High Group M ± SD**	**Low Group M ± SD**	***t***	***p***	**Effect Size, Hedges' *g* [95% CI]**
COP velocity (cm/s)	8.94 ± 1.19	10.66 ± 1.03	−5.96	< 0.001	−1.52 [−2.10, −0.94]
Time to stabilization (s)	0.782 ± 0.105	0.918 ± 0.093	−5.36	< 0.001	−1.37 [−1.93, −0.80]
Sway area (cm²)	5.81 ± 0.90	6.99 ± 0.96	−4.95	< 0.001	−1.26 [−1.82, −0.70]
Trunk–pelvis separation (degrees)	25.02 ± 4.17	20.58 ± 4.40	4.01	< 0.001	1.02 [0.48, 1.56]

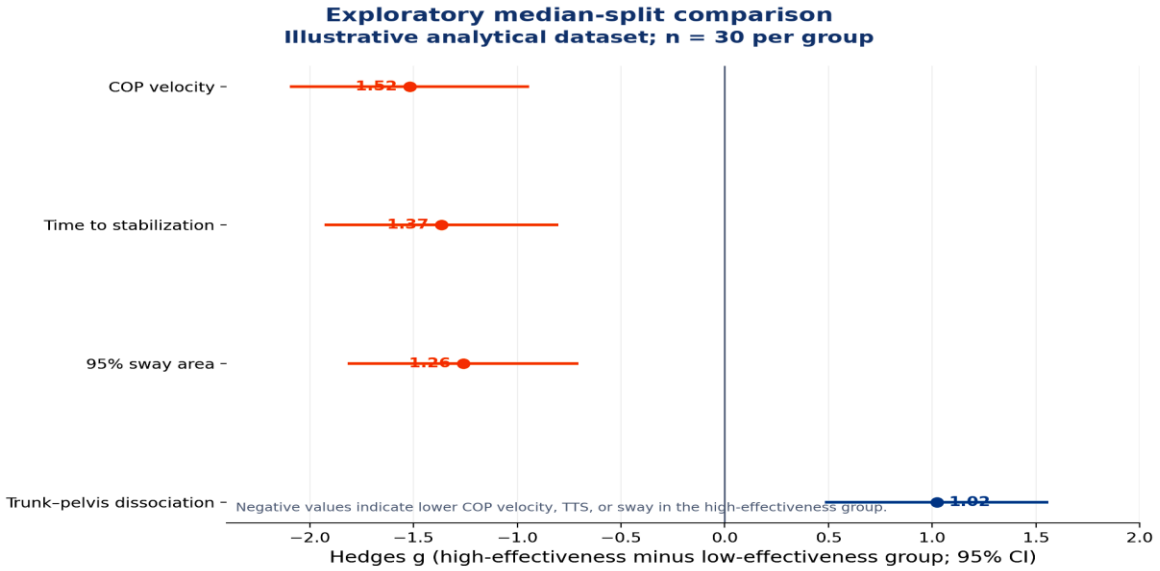

Figure 7. Standardized Effect Sizes for the Exploratory Extreme-Group Comparison

3.5 Disciplined Applied Interpretation

Higher COP velocity or TTS may indicate greater difficulty in controlling weight transfer, whereas greater trunk–pelvis separation may reflect a more effective deceptive movement while maintaining a stable base of support. However, an association does not establish a causal relationship; therefore, external validation is required.

3.6 Discussion of the Findings Within the Analytical Model

The observed patterns suggest that higher COP velocity and longer time to stabilization may be associated with a greater need for postural corrections following a change of direction. In other words, the player may require more time or greater movement to re-establish a stable base that permits continuation of the performance. This interpretation is consistent with the

understanding that COP measures are sensitive to task characteristics and the methods used to calculate them; therefore, increases or decreases in these measures should not be interpreted independently of the movement context (Caballero et al., 2015). Similarly, the definition of TTS is influenced by the measurement window, filtering procedures, and stability criterion, making standardized measurement procedures essential for comparisons between players (Fransz et al., 2015). This interpretation is also consistent with Maseer Yaseen (2012), who reported associations between dynamic balance and lower-limb capacities, speed, and agility.

These indicators may be particularly important in handball because a compound feint does not end with the change of direction itself; rather, the player must finish the movement in a position that permits an immediate shot, pass, or penetration. Bastawisi (1996) and Abdullah and Badawi (2006) emphasized that effective skill performance depends on the integration of the components of the kinetic chain and the coordinated transfer of force between body segments. Issa (2012) demonstrated the importance of specific physical abilities in supporting performance associated with the jump shot in handball, whereas Ghazi and Hassoun (2019) reported that physical exertion influences motor abilities and defensive movements in handball players. These findings support the need to examine balance under conditions that resemble actual game demands.

Trunk–pelvis kinematic separation can be interpreted as an indicator of the player's ability to generate a deceptive trunk movement while retaining the capacity to change direction and rapidly reorganize body position. Burger et al. (2023) reported kinematic differences in single-feint movements across different levels of handball players, supporting the use of three-dimensional motion analysis to identify differences that may not be readily apparent through visual observation alone. Accordingly, the value of trunk–pelvis separation should not be interpreted as representing a fixed "optimal angle," but rather in relation to movement timing, transition velocity, and stability of the base of support.

The exploratory comparison between players with higher and lower effectiveness provides an applied perspective that may assist coaches in understanding the movement profile. However, continuous analysis of the variables preserves more information than dividing players into two groups. This principle is consistent with the importance of correlational and predictive analyses in sports-performance research, while avoiding the conversion of statistical associations into causal conclusions (Allawi & Rateb, 1999). Khan Afdal and Hami (2023) similarly demonstrated the potential use of correlational and regression models to explain aspects of handball skill performance, provided that interpretation remains linked to the characteristics of the sample and the variables actually measured.

From a measurement perspective, the accuracy of the findings depends not only on the strength of the statistical model but also on the validity and reliability of the measurements. Accordingly, standardizing marker placement, calibrating the force platforms, controlling synchronization between the platforms and the motion-analysis system, and training assessors according to uniform criteria are essential procedures before adopting the balance-effectiveness score or comparing players. Hassanein (2004) emphasized the need to establish validity, reliability, and objectivity in sports measurement, while Allawi and Rateb (1999) highlighted the relationship between the quality of inference and the quality of data-collection procedures and control of potential sources of error.

The predictive model findings indicate that combining COP velocity, TTS, and trunk–pelvis separation may be more informative than relying on a single indicator because dynamic balance during a compound feint is a multidimensional process involving weight transfer, speed of

postural correction, trunk and pelvic organization, and immediate readiness for the subsequent offensive action. Nevertheless, a high coefficient of determination does not mean that the three predictors represent direct causes of effectiveness, nor does it imply that improving any single predictor in isolation will necessarily improve performance. The equation should therefore be interpreted as a descriptive and predictive tool within the specified measurement conditions rather than as a causal training prescription.

From an applied perspective, this framework may be used to develop a player-specific diagnostic profile incorporating COP velocity, TTS, and trunk–pelvis separation alongside technical observation. Changes in these indicators could then be monitored following training programs targeting weight-transfer control, directional changes, and stabilization. However, training decisions should not be based on a single value or trial; rather, they should rely on repeated and reliable measurements linked to skill performance in handball-specific situations. This approach is consistent with Arabic-language literature emphasizing the integration of physical, motor, and technical abilities in handball (Issa, 2012; Ghazi & Hassoun, 2019), as well as with recent kinematic evidence provided by Burger et al. (2023) on feinting movements.

Taken together, the indicators suggest that dynamic-balance control during a compound feint cannot be reduced to COP velocity alone. COP path length and sway area describe the magnitude and spatial extent of postural movement, whereas TTS adds a temporal dimension by indicating how long the player requires to return to a functional state that permits the subsequent offensive action. Thus, a player may exhibit high COP velocity as a result of an intentional and rapid transfer without this necessarily indicating poor balance, unless the higher velocity is accompanied by a longer COP path, greater sway area, or delayed stabilization. This interpretation is consistent with Caballero et al. (2015), who noted that the meaning of COP measures depends on task characteristics and the movement context, and with Hassanein (2004), who emphasized the need to interpret measurement outcomes in relation to the characteristics of the test rather than as isolated numerical values.

TTS emerges as an indicator with particular applied relevance in handball because successful feinting is not limited to displacing the defender or changing body direction; it also requires the player to regain a position that permits shooting, passing, or penetration without an additional corrective step. Therefore, a shorter TTS—if confirmed in field data—may reflect greater efficiency in reorganizing forces after the peak of the directional change, whereas a prolonged TTS may indicate that the player executed the feint at the expense of subsequent stability. Fransz et al. (2015) demonstrated that TTS is substantially influenced by the calculation method, sampling frequency, filtering settings, and trial duration. This supports the protocol's emphasis on standardizing the measurement window and stability criteria before interpreting differences between players.

From a kinetic-chain perspective, trunk–pelvis separation does not function as an isolated angle but forms part of a temporal organization linking lower-limb movement with weight transfer, trunk direction, and preparation for the actual offensive action. Bastawisi (1996) and Abdullah and Badawi (2006) indicated that the quality of movement performance is related to the sequencing and integration of body segments and the transfer of force between them. This allows trunk–pelvis separation to be understood as part of the feinting strategy rather than as an independent training target. Burger et al. (2023) also identified kinematic differences in feinting performance among handball players, indicating that the quality of a feint may be expressed through movement details, trajectories, and timing rather than solely through the final outcome of the trial.

This interpretation is consistent with the importance of lower-limb physical and motor capacities in stabilizing the base of support following a rapid change of direction. Maseer Yaseen (2012) reported associations between certain lower-limb capacities and dynamic balance, while Issa (2012) demonstrated the role of developing specific physical abilities in supporting technical performance in handball. From an applied perspective, this suggests that improving balance during feinting should not be limited to standing or static-stability exercises. Instead, it may progressively incorporate exercises involving weight transfer, stopping, reacceleration, and immediate transition into an offensive skill. However, this remains a training hypothesis that requires experimental testing before its effectiveness can be established.

The influence of physical exertion should also be considered when interpreting these indicators. A player may demonstrate a favorable postural profile during isolated trials but be unable to maintain it under fatigue or the time pressure of match play. Ghazi and Hassoun (2019) reported effects of physical exertion on certain motor abilities and defensive movements in handball players. Accordingly, future studies could compare COP velocity, TTS, and sway area at the beginning and end of a testing session or under standardized loading conditions to determine whether post-feint stabilization remains stable or deteriorates with accumulated exertion. This represents a proposed extension of the present study rather than a conclusion derived from the data presented here.

The exploratory extreme-group comparison provides a visually accessible means of understanding the direction of the differences; however, correlation and regression coefficients remain more appropriate for model development because they preserve the continuous nature of the variables and avoid the information loss resulting from median-based dichotomization. Allawi and Rateb (1999) emphasized the importance of selecting statistical methods according to the nature of the variables and the research objective, while Khan Afdal and Hami (2023) demonstrated the potential application of correlation and regression analyses to predict aspects of skill performance in handball. Accordingly, the extreme-group comparison is used here to facilitate applied interpretation rather than as an alternative to the continuous model or as the sole basis for player classification.

From a training and assessment perspective, the proposed indicators may contribute to the development of a multidimensional biomechanical profile for each player. Rather than relying on a single effectiveness score, coaches may consider COP velocity, TTS, sway area, and trunk–pelvis separation together and interpret them alongside technical performance. For example, a player who successfully performs the feint but exhibits prolonged TTS may require greater emphasis on post-direction-change control, whereas another player may demonstrate stable movement but insufficient trunk–pelvis separation to produce an effective deceptive signal. Such interpretations should be based on repeated and reliable measurements, consistent with Hassanein's (2004) emphasis on validity, reliability, and objectivity in sports measurement.

Thus, the principal value of the model does not lie in identifying a single fixed “optimal” value for each variable, but rather in identifying the pattern formed by transition velocity, magnitude of postural correction, time to stabilization, and trunk–pelvis organization. This means that future field application should focus on the overall response profile and its change following training rather than on mechanically reducing COP velocity or TTS. Any interpretation of improvement should also remain linked to the skill context because balance in handball is functional balance that serves movement and decision-making rather than a state of stillness. Accordingly, integrating biomechanical analysis with independent technical assessment provides a more comprehensive approach to understanding compound-feint quality and guiding training on measurable and verifiable grounds.

4. Conclusions and Recommendations

4.1 Conclusions

- The revised protocol provides a reproducible framework for assessing dynamic balance during compound feinting, with a clear separation between objective biomechanical measurement and technical assessment.
- COP velocity, TTS, and trunk–pelvis separation represent theoretically plausible primary predictors; however, their actual predictive strength cannot be determined before the field data are collected.
- Model performance following internal and external validation should serve as the basis for judging the practical utility of the model rather than relying solely on its apparent R^2.

4.2 Recommendations

- Complete data collection using the calculated sample size and replace all data presented in Section 3 with the actual outputs from the analytical dataset.
- Finalize the statistical analysis plan before examining the results and retain the variable dictionary, data-processing and analysis scripts, software versions, and analytical decision log, together with an anonymized copy of the field dataset.
- Assess the content validity of the technical assessment form using the I-CVI and S-CVI indices, followed by assessor training and evaluation of ICC, SEM, and MDC before adopting the dependent-variable score.
- Restrict the use of the current equation to methodological verification and re-estimate the model coefficients and validate its performance before any diagnostic or training application.
- Once the associations have been confirmed, evaluate relevant training interventions and subsequently extend validation across different player populations and playing positions.

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