# Supplementary Materials: Comparison of IMU-Based Knee Kinematics with and without Harness Fixation against an Optical Marker-Based System

Jana G. Weber [1,†], Ariana Ortigas-Vásquez [1,2,†], Adrian Sauer [1,*], Ingrid Dupraz [1], Michael Utz [1], Allan Maas [1,2] and Thomas M. Grupp [1,2]

[1] Research and Development, Aesculap AG, 78532 Tuttlingen, Germany;

[2] Department of Orthopaedic and Trauma Surgery, Musculoskeletal University Center Munich (MUM), Campus Grosshadern, Ludwig Maximilians University Munich, 81377 Munich, Germany

[*] Corresponding Author: adrian.sauer@aesculap.de

† These authors contributed equally to this work.

# 1 Averaged over all knees and cycles

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 | 0.0 | 11.1 | 12.7 |
| Ry | 8.0 | 15.6 | 8.2 | 16.4 |
| Rz | 19.8 | 25.1 | 25.8 | 31.0 |

**Table S1:** Absolute maximum (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all knees and cycles.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 | 0.0 | 0.0 | 18.4 | 21.1 | 20.6 |
| Ry | 16.0 | 14.7 | 32.7 | 13.0 | 14.2 | 31.9 |
| Rz | 22.7 | 15.3 | 26.8 | 23.1 | 16.8 | 24.4 |

**Table S2:** Absolute maximum (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all knees and cycles.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 11.3 | 12.7 | 3.1 | 3.9 | 3.5 | 6.5 |
| abduction/adduction | 11.7 | 10.5 | 1.6 | 3.3 | 1.9 | 3.9 |
| external/internal rotation | 11.6 | 13.9 | 2.1 | 7.4 | 2.1 | 7.3 |

**Table S3:** Maximum (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all knees and cycles.

# 2 Averaged plots for individual knees

## 2.1 Averaged plots for individual knee 1

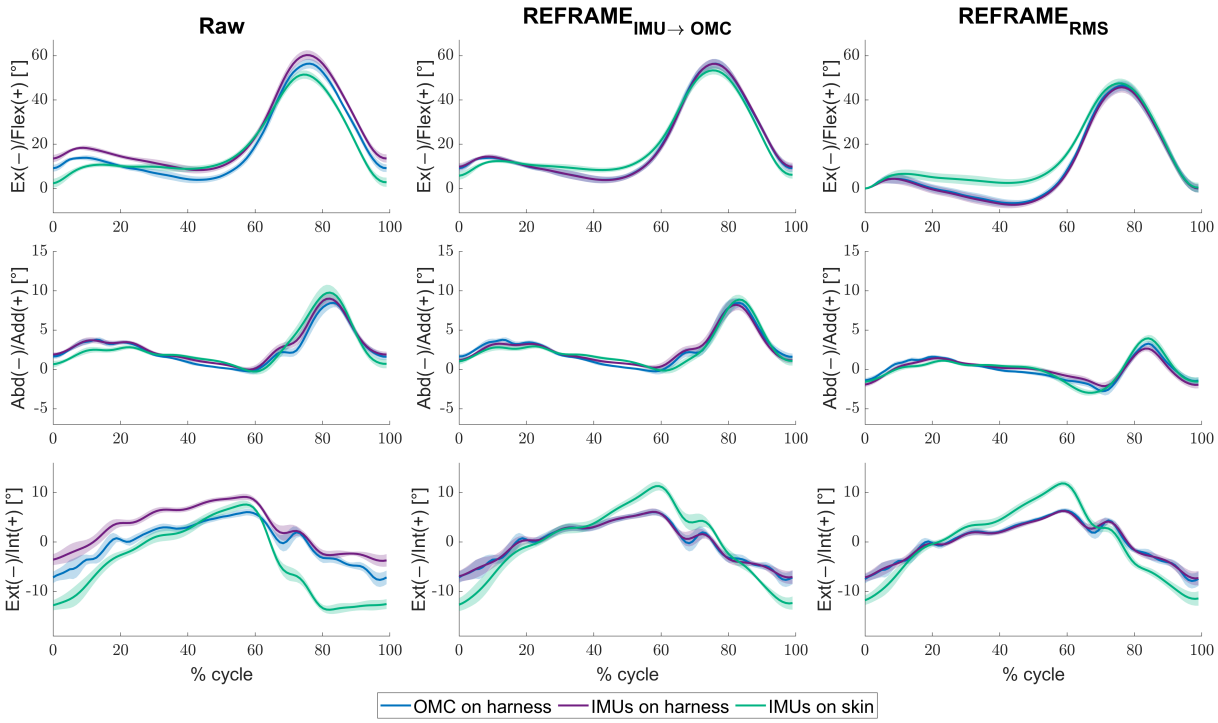



**Figure S1:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 1. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.0 ± 0.1 | -0.5 ± 0.2 |
| Ry | -3.4 ± 0.2 | -13.4 ± 1.1 | -4.2 ± 0.2 | -13.9 ± 1.2 |
| Rz | 1.7 ± 0.1 | 4.1 ± 0.8 | -2.1 ± 0.1 | 3.2 ± 0.3 |

**Table S4:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 1.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 10.1 ± 1.5 | 14.4 ± 1.6 | 5.6 ± 2.0 |
| Ry | -5.5 ± 0.9 | -9.3 ± 0.9 | -12.6 ± 1.6 | -7.3 ± 1.0 | -12.2 ± 1.0 | -14.0 ± 1.6 |
| Rz | -2.9 ± 0.8 | -1.1 ± 0.7 | -1.4 ± 1.1 | -3.0 ± 1.0 | -4.2 ± 0.9 | 0.0 ± 0.9 |

**Table S5:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 1.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 4.2 ± 0.1 | 4.8 ± 0.2 | 0.6 ± 0.1 | 3.0 ± 0.3 | 0.8 ± 0.1 | 5.6 ± 0.5 |
| abduction/adduction | 0.5 ± 0.0 | 1.0 ± 0.2 | 0.4 ± 0.0 | 0.6 ± 0.1 | 0.4 ± 0.0 | 0.6 ± 0.1 |
| external/internal rotation | 3.0 ± 0.1 | 5.4 ± 0.4 | 0.4 ± 0.0 | 3.2 ± 0.3 | 0.4 ± 0.0 | 3.2 ± 0.2 |

**Table S6:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 1.

## 2.2 Averaged plots for individual knee 2

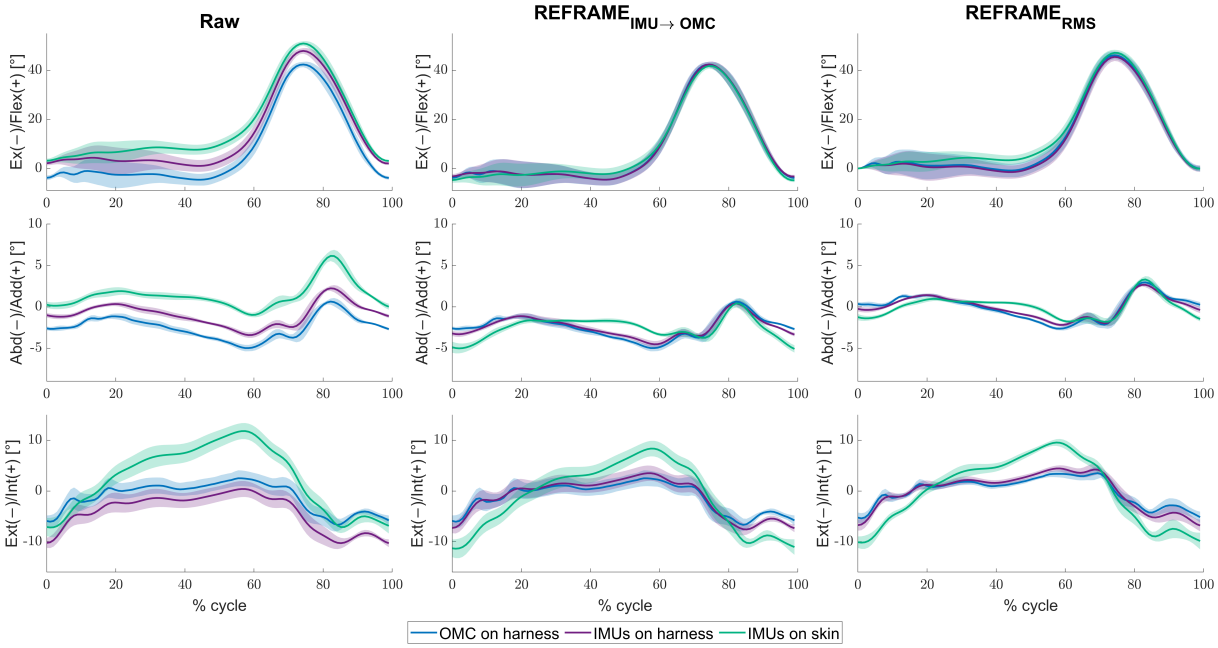



**Figure S2:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 2. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 5.7 ± 0.1 | 8.9 ± 0.6 |
| Ry | 0.1 ± 0.3 | -3.7 ± 1.0 | -1.1 ± 0.3 | -7.8 ± 1.1 |
| Rz | 0.5 ± 0.2 | -0.3 ± 1.0 | 3.4 ± 0.2 | -4.2 ± 1.1 |

**Table S7:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 2.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | -3.8 ± 1.0 | 2.6 ± 0.9 | 3.7 ± 0.8 |
| Ry | -3.2 ± 1.6 | -3.5 ± 1.8 | -3.4 ± 1.4 | -0.6 ± 1.6 | -2.4 ± 1.7 | -4.5 ± 1.3 |
| Rz | -0.1 ± 0.4 | 0.5 ± 0.4 | -1.3 ± 0.8 | 0.7 ± 1.1 | 4.0 ± 1.3 | -4.3 ± 2.0 |

**Table S8:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 2.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 5.6 ± 0.1 | 9.6 ± 0.5 | 0.5 ± 0.0 | 1.4 ± 0.2 | 0.8 ± 0.1 | 2.5 ± 0.7 |
| abduction/adduction | 1.6 ± 0.1 | 3.9 ± 0.3 | 0.4 ± 0.0 | 1.4 ± 0.1 | 0.4 ± 0.0 | 1.0 ± 0.1 |
| external/internal rotation | 3.0 ± 0.2 | 5.3 ± 0.3 | 0.9 ± 0.1 | 4.0 ± 0.2 | 0.9 ± 0.1 | 4.0 ± 0.2 |

**Table S9:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 2.

## 2.3 Averaged plots for individual knee 3

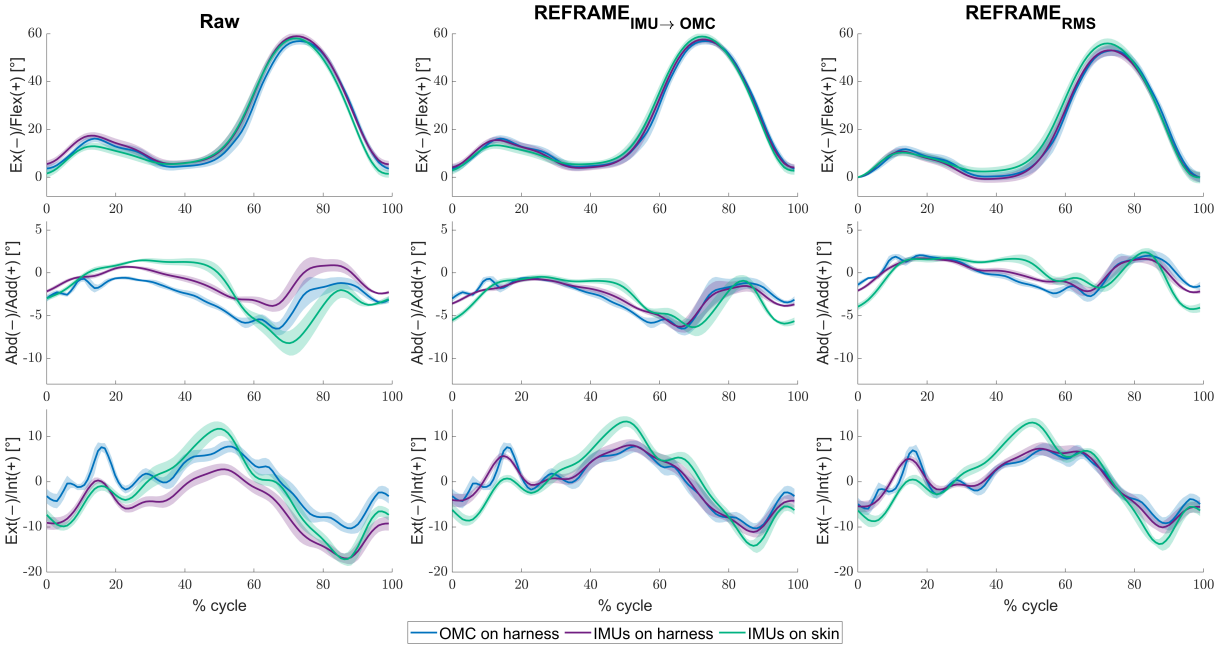



**Figure S3:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 3. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.9 ± 0.1 | -0.0 ± 0.2 |
| Ry | -2.2 ± 0.2 | -2.1 ± 0.9 | -3.3 ± 0.2 | -4.9 ± 0.9 |
| Rz | -0.5 ± 0.3 | 6.7 ± 0.9 | 4.3 ± 0.2 | 7.8 ± 0.5 |

**Table S10:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 3.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.9 ± 1.6 | 6.6 ± 1.5 | 2.7 ± 1.8 |
| Ry | -5.6 ± 1.8 | -6.8 ± 1.8 | -2.7 ± 2.3 | -3.8 ± 1.8 | -5.7 ± 1.8 | -3.3 ± 2.5 |
| Rz | 5.1 ± 1.1 | 4.4 ± 1.2 | 10.2 ± 1.8 | 3.2 ± 1.0 | 7.9 ± 1.0 | 11.1 ± 1.2 |

**Table S11:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 3.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 2.2 ± 0.1 | 2.8 ± 0.3 | 1.3 ± 0.2 | 2.4 ± 0.4 | 1.4 ± 0.2 | 3.0 ± 0.5 |
| abduction/adduction | 1.8 ± 0.1 | 2.4 ± 0.3 | 0.6 ± 0.1 | 1.6 ± 0.2 | 0.7 ± 0.1 | 1.6 ± 0.2 |
| external/internal rotation | 5.7 ± 0.2 | 4.5 ± 0.4 | 1.3 ± 0.1 | 3.9 ± 0.4 | 1.3 ± 0.1 | 3.9 ± 0.4 |

**Table S12:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 3.

## 2.4 Averaged plots for individual knee 4

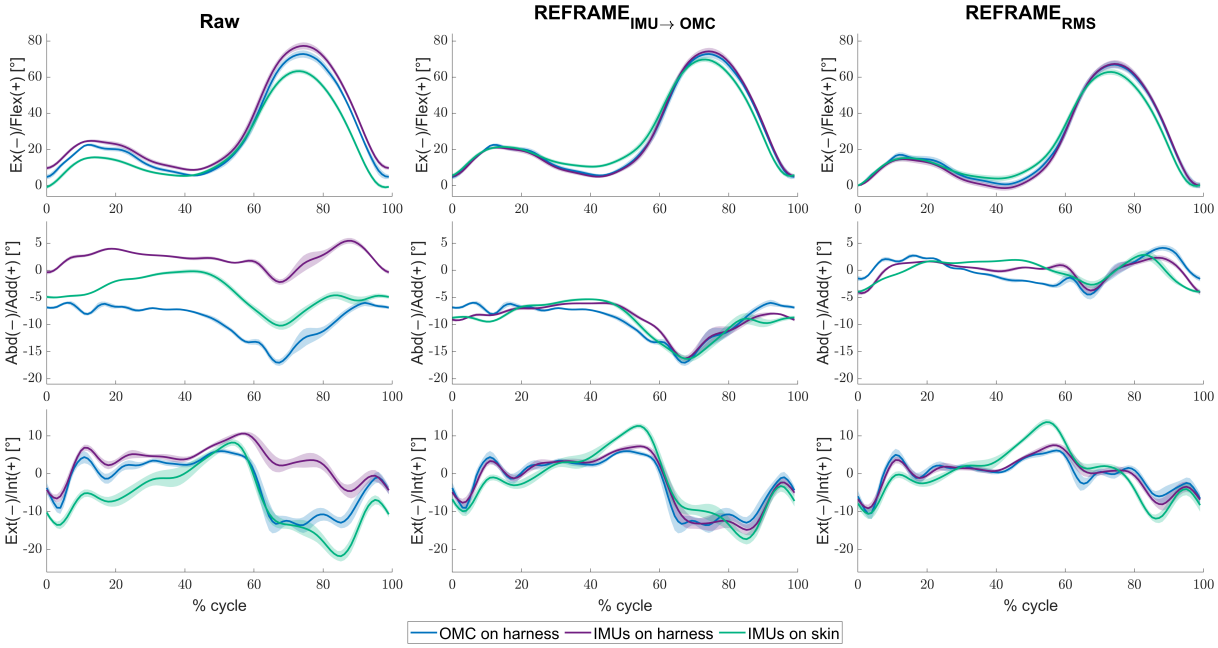



**Figure S4:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 4. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 2.6 ± 0.1 | -5.4 ± 0.2 |
| Ry | 7.7 ± 0.2 | -2.4 ± 0.8 | 0.4 ± 0.2 | -7.1 ± 1.0 |
| Rz | -12.6 ± 0.2 | -1.6 ± 1.0 | -12.4 ± 0.2 | 2.2 ± 0.6 |

**Table S13:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 4.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 5.2 ± 1.2 | 9.9 ± 1.1 | 1.1 ± 1.1 |
| Ry | -7.4 ± 1.7 | 0.4 ± 1.5 | -7.6 ± 1.9 | -1.7 ± 1.7 | -2.6 ± 1.6 | -6.5 ± 1.9 |
| Rz | 13.5 ± 0.8 | 1.0 ± 0.9 | 12.0 ± 1.2 | 10.8 ± 0.8 | -1.6 ± 0.9 | 14.6 ± 0.8 |

**Table S14:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 4.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.9 ± 0.1 | 6.9 ± 0.1 | 1.3 ± 0.0 | 3.6 ± 0.2 | 1.7 ± 0.2 | 3.5 ± 0.2 |
| abduction/adduction | 11.5 ± 0.1 | 5.4 ± 0.2 | 1.6 ± 0.1 | 1.8 ± 0.1 | 1.7 ± 0.1 | 2.5 ± 0.1 |
| external/internal rotation | 7.7 ± 0.2 | 5.6 ± 0.3 | 1.4 ± 0.2 | 3.7 ± 0.4 | 1.3 ± 0.1 | 4.0 ± 0.4 |

**Table S15:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 4.

## 2.5 Averaged plots for individual knee 5

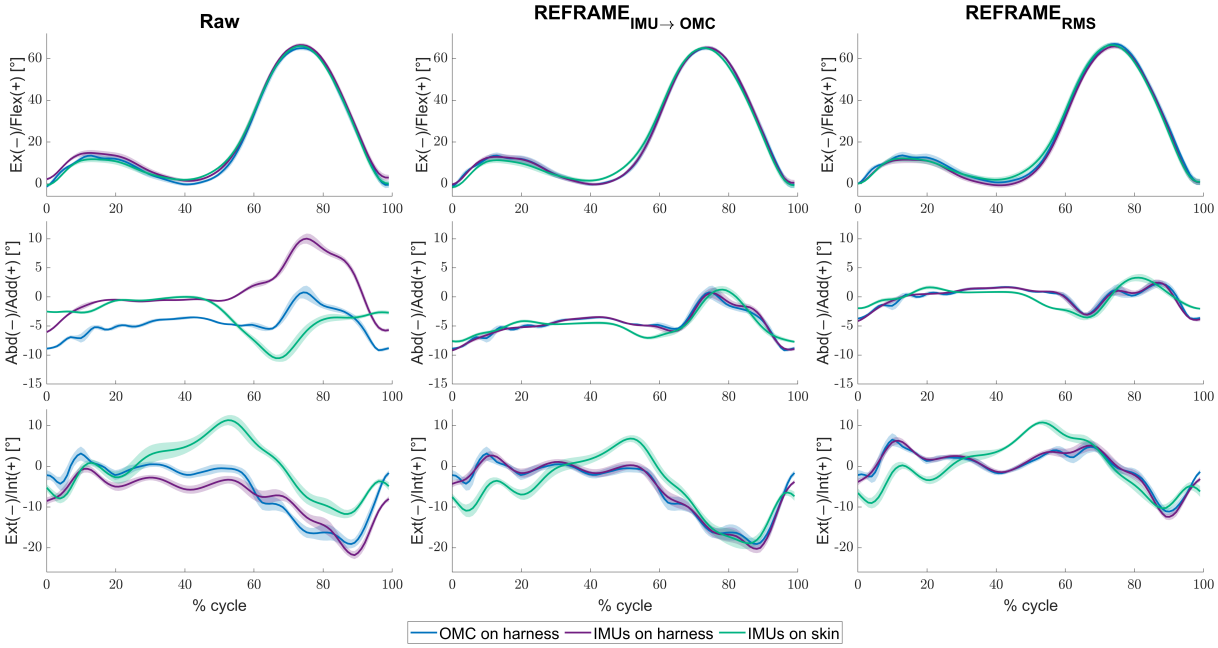



**Figure S5:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 5. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.2 ± 0.1 | 1.3 ± 0.3 |
| Ry | 2.7 ± 0.3 | 9.9 ± 1.2 | -0.3 ± 0.3 | 5.2 ± 1.2 |
| Rz | -8.5 ± 0.2 | 6.7 ± 0.9 | -4.4 ± 0.1 | 3.9 ± 0.4 |

**Table S16:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 5.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | -0.7 ± 0.5 | 3.2 ± 0.6 | -0.3 ± 0.8 |
| Ry | -14.3 ± 0.9 | -11.8 ± 0.9 | -2.2 ± 1.5 | -9.2 ± 0.9 | -9.5 ± 1.0 | -1.7 ± 1.4 |
| Rz | 3.8 ± 0.5 | -4.3 ± 0.6 | 8.9 ± 1.0 | 4.1 ± 0.6 | 0.2 ± 0.5 | 7.6 ± 0.7 |

**Table S17:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 5.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.9 ± 0.1 | 1.7 ± 0.2 | 0.9 ± 0.2 | 2.1 ± 0.3 | 1.7 ± 0.2 | 1.9 ± 0.4 |
| abduction/adduction | 6.0 ± 0.1 | 4.3 ± 0.2 | 0.4 ± 0.1 | 1.2 ± 0.1 | 0.4 ± 0.1 | 1.4 ± 0.1 |
| external/internal rotation | 3.4 ± 0.2 | 7.4 ± 0.3 | 0.9 ± 0.2 | 4.6 ± 0.2 | 0.8 ± 0.1 | 4.8 ± 0.2 |

**Table S18:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 5.

## 2.6 Averaged plots for individual knee 6

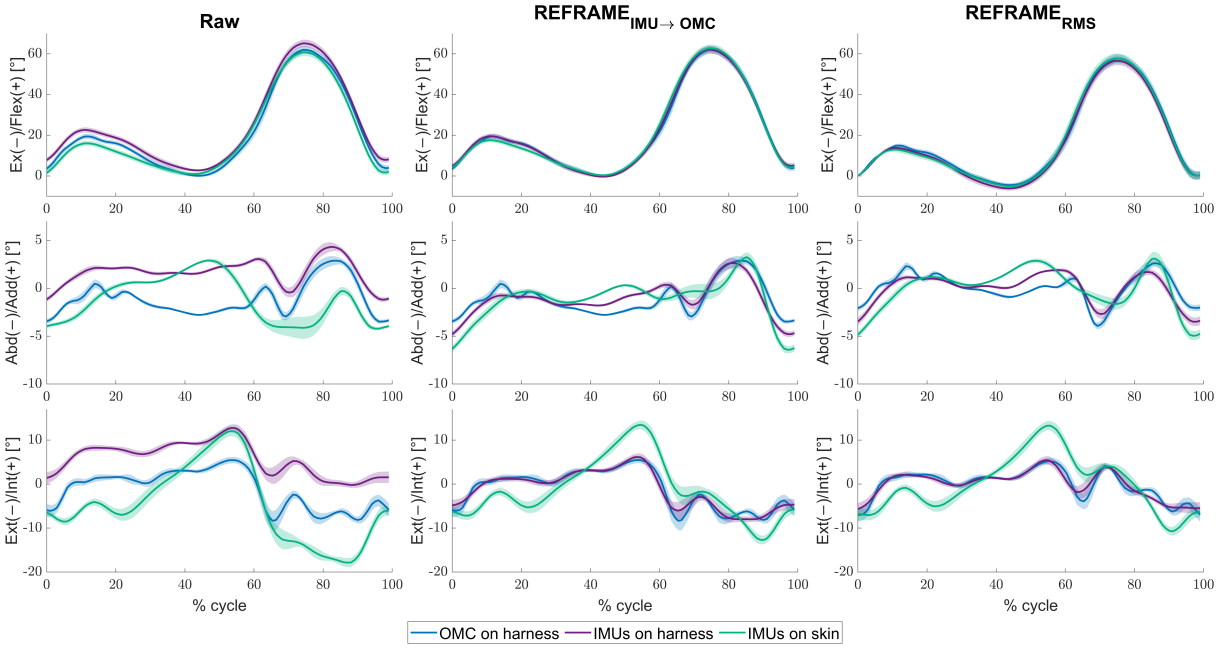



**Figure S6:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 6. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.0 ± 0.1 | -0.3 ± 0.3 |
| Ry | 3.1 ± 0.2 | -6.5 ± 1.0 | -0.7 ± 0.2 | -9.6 ± 1.1 |
| Rz | 1.0 ± 0.1 | 11.4 ± 0.4 | -5.0 ± 0.1 | 11.5 ± 0.3 |

**Table S19:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 6.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.3 ± 1.1 | 7.7 ± 1.0 | 4.2 ± 1.2 |
| Ry | -8.7 ± 0.6 | -5.8 ± 0.7 | -14.1 ± 1.8 | -7.0 ± 0.6 | -8.3 ± 0.7 | -14.6 ± 1.8 |
| Rz | 1.1 ± 0.5 | 2.4 ± 0.4 | 12.1 ± 0.8 | -0.2 ± 0.5 | -4.8 ± 0.4 | 12.1 ± 0.5 |

**Table S20:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 6.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.3 ± 0.1 | 2.7 ± 0.4 | 1.1 ± 0.2 | 1.7 ± 0.3 | 1.7 ± 0.5 | 1.6 ± 0.3 |
| abduction/adduction | 3.0 ± 0.1 | 3.1 ± 0.1 | 1.0 ± 0.0 | 1.7 ± 0.1 | 1.0 ± 0.0 | 1.8 ± 0.1 |
| external/internal rotation | 7.1 ± 0.1 | 6.4 ± 0.3 | 0.9 ± 0.1 | 4.5 ± 0.3 | 1.0 ± 0.1 | 4.5 ± 0.3 |

**Table S21:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 6.

## 2.7 Averaged plots for individual knee 7

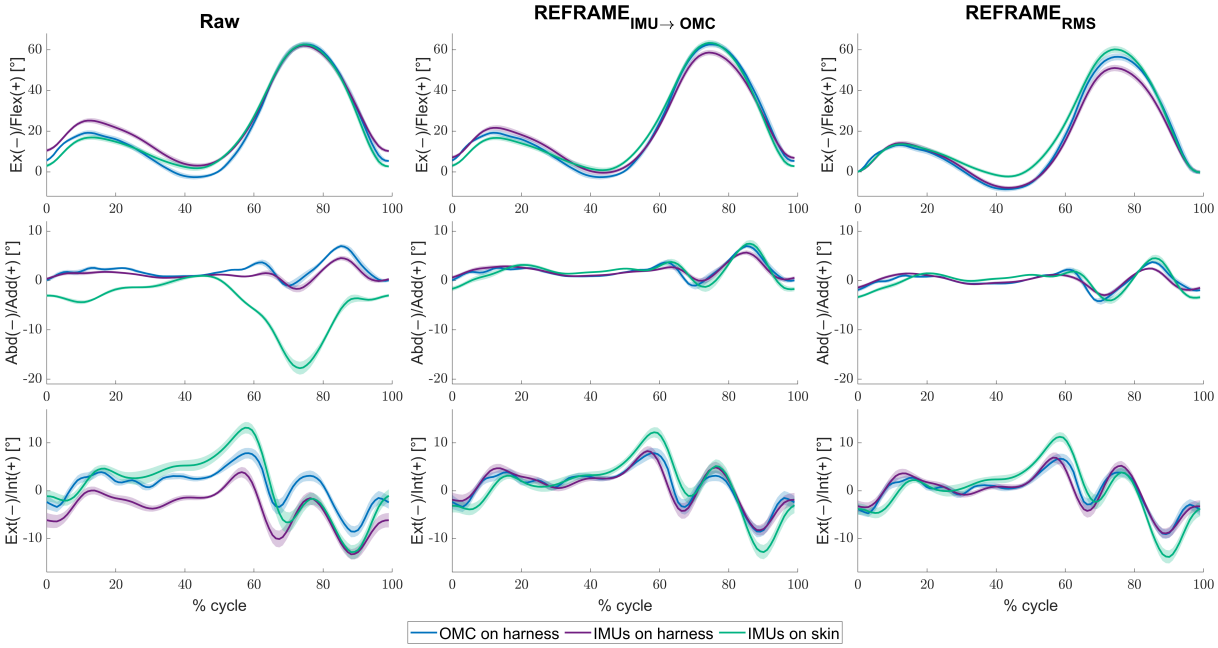



**Figure S7:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 7. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.5 ± 0.2 | 0.5 ± 0.1 |
| Ry | -1.3 ± 0.5 | 0.7 ± 1.0 | -1.0 ± 0.5 | 1.3 ± 1.0 |
| Rz | 2.6 ± 0.2 | 17.6 ± 0.5 | 6.7 ± 0.3 | 15.6 ± 0.4 |

**Table S22:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 7.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 5.8 ± 0.7 | 11.0 ± 0.9 | 3.9 ± 0.9 |
| Ry | -3.0 ± 0.7 | -3.9 ± 0.9 | 0.5 ± 1.5 | -4.7 ± 0.7 | -4.5 ± 0.9 | 0.3 ± 1.4 |
| Rz | -0.2 ± 0.4 | 2.2 ± 0.4 | 16.1 ± 0.8 | -1.7 ± 0.5 | 5.1 ± 0.5 | 13.2 ± 0.7 |

**Table S23:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 7.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 4.5 ± 0.1 | 3.0 ± 0.1 | 2.8 ± 0.1 | 2.9 ± 0.2 | 3.2 ± 0.2 | 4.1 ± 0.3 |
| abduction/adduction | 1.2 ± 0.1 | 8.6 ± 0.3 | 0.7 ± 0.1 | 1.0 ± 0.1 | 0.7 ± 0.1 | 1.1 ± 0.1 |
| external/internal rotation | 5.0 ± 0.2 | 3.5 ± 0.2 | 1.1 ± 0.2 | 2.6 ± 0.2 | 1.1 ± 0.2 | 2.7 ± 0.2 |

**Table S24:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 7.

## 2.8 Averaged plots for individual knee 8

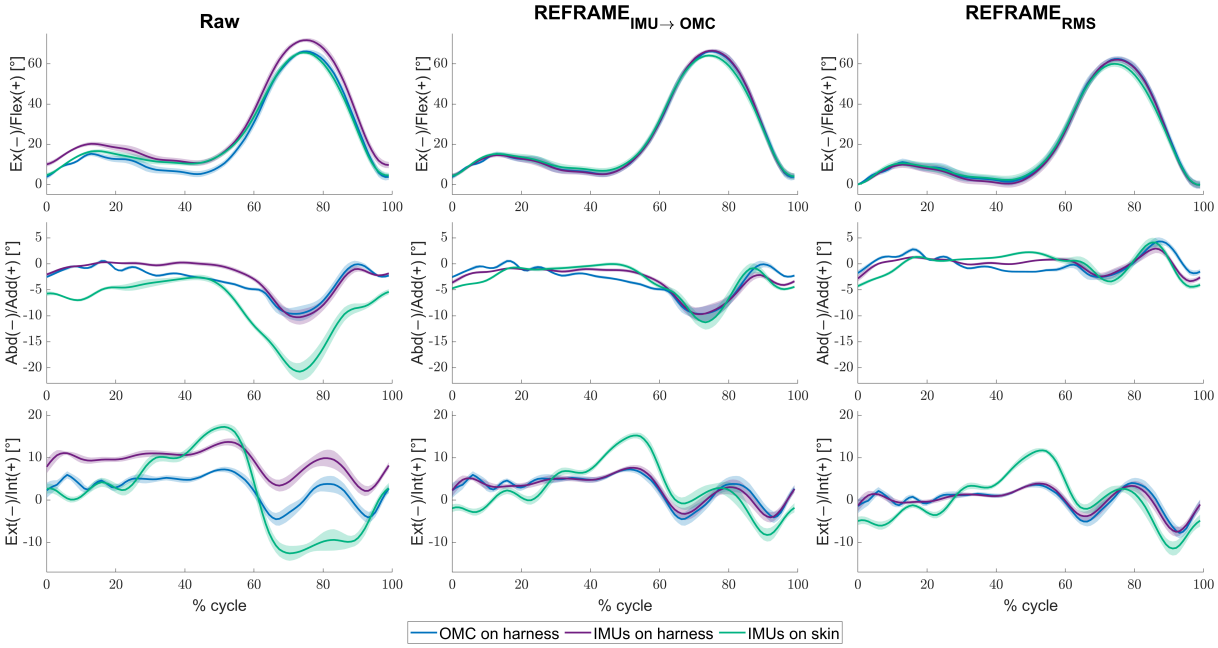



**Figure S8:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 8. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 5.8 ± 0.1 | 1.3 ± 0.2 |
| Ry | 2.8 ± 0.2 | -10.6 ± 0.9 | 0.4 ± 0.2 | -10.7 ± 1.0 |
| Rz | 0.9 ± 0.3 | 17.5 ± 0.6 | -4.7 ± 0.2 | 12.1 ± 0.5 |

**Table S25:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 8.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.0 ± 1.2 | 10.6 ± 1.1 | 6.0 ± 1.0 |
| Ry | -0.0 ± 1.0 | 2.9 ± 1.1 | -9.2 ± 2.1 | 0.6 ± 0.9 | 0.7 ± 1.0 | -7.6 ± 1.8 |
| Rz | 7.8 ± 0.9 | 8.7 ± 0.9 | 24.9 ± 1.3 | 3.9 ± 1.0 | -0.7 ± 1.1 | 17.0 ± 1.3 |

**Table S26:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 8.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 5.6 ± 0.1 | 3.0 ± 0.2 | 0.9 ± 0.1 | 1.6 ± 0.2 | 1.2 ± 0.2 | 1.7 ± 0.3 |
| abduction/adduction | 1.5 ± 0.1 | 6.1 ± 0.2 | 1.2 ± 0.1 | 1.8 ± 0.1 | 1.3 ± 0.1 | 2.2 ± 0.1 |
| external/internal rotation | 6.3 ± 0.3 | 7.2 ± 0.3 | 0.8 ± 0.1 | 4.6 ± 0.2 | 0.8 ± 0.1 | 4.5 ± 0.2 |

**Table S27:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 8.

## 2.9 Averaged plots for individual knee 9

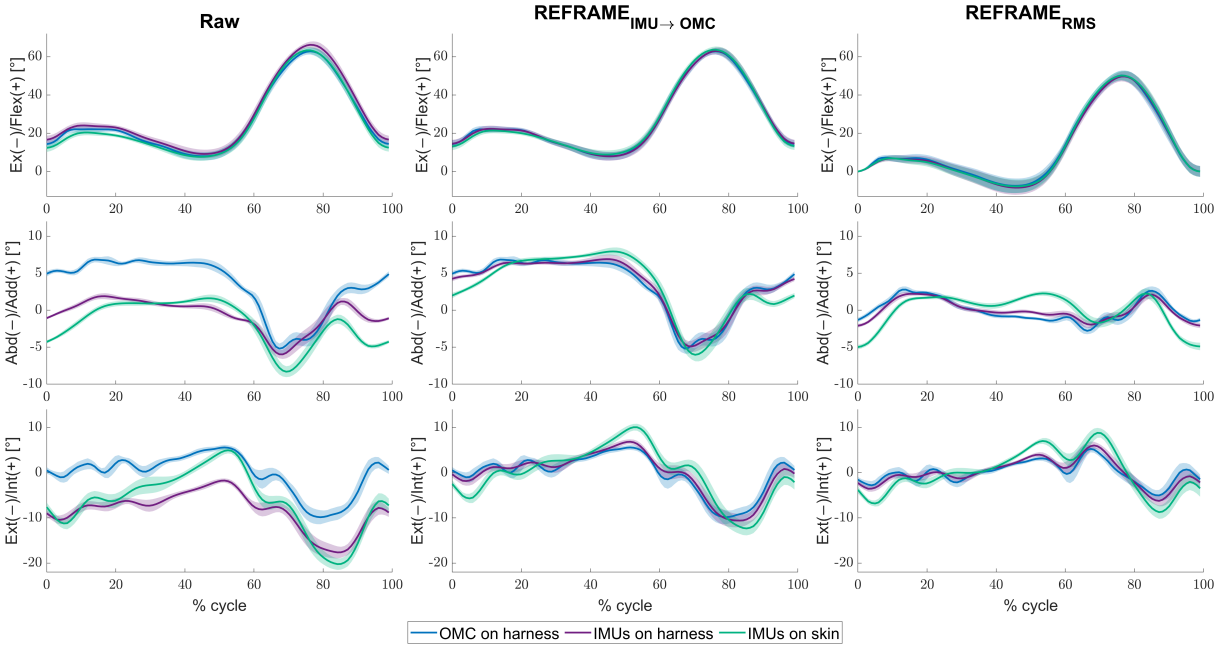



**Figure S9:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 9. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.8 ± 0.1 | -0.8 ± 0.2 |
| Ry | -1.7 ± 0.2 | -6.3 ± 0.7 | 5.7 ± 0.2 | 0.5 ± 0.7 |
| Rz | -6.6 ± 0.2 | -1.9 ± 0.6 | 1.7 ± 0.2 | 1.9 ± 0.6 |

**Table S28:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 9.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 14.8 ± 2.1 | 17.8 ± 2.0 | 14.7 ± 2.1 |
| Ry | -4.2 ± 1.7 | -6.3 ± 1.6 | -10.3 ± 1.6 | -10.3 ± 1.7 | -4.6 ± 1.5 | -9.1 ± 1.5 |
| Rz | 16.1 ± 0.8 | 9.6 ± 0.8 | 14.3 ± 1.1 | 15.3 ± 0.7 | 15.6 ± 0.7 | 17.2 ± 0.9 |

**Table S29:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 9.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 2.3 ± 0.1 | 1.6 ± 0.2 | 0.7 ± 0.1 | 1.3 ± 0.1 | 1.1 ± 0.1 | 1.1 ± 0.2 |
| abduction/adduction | 4.5 ± 0.1 | 5.6 ± 0.1 | 0.5 ± 0.0 | 1.6 ± 0.1 | 0.6 ± 0.0 | 2.2 ± 0.1 |
| external/internal rotation | 8.3 ± 0.1 | 7.0 ± 0.3 | 1.1 ± 0.1 | 3.2 ± 0.1 | 1.0 ± 0.2 | 2.9 ± 0.1 |

**Table S30:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 9.

## 2.10 Averaged plots for individual knee 10

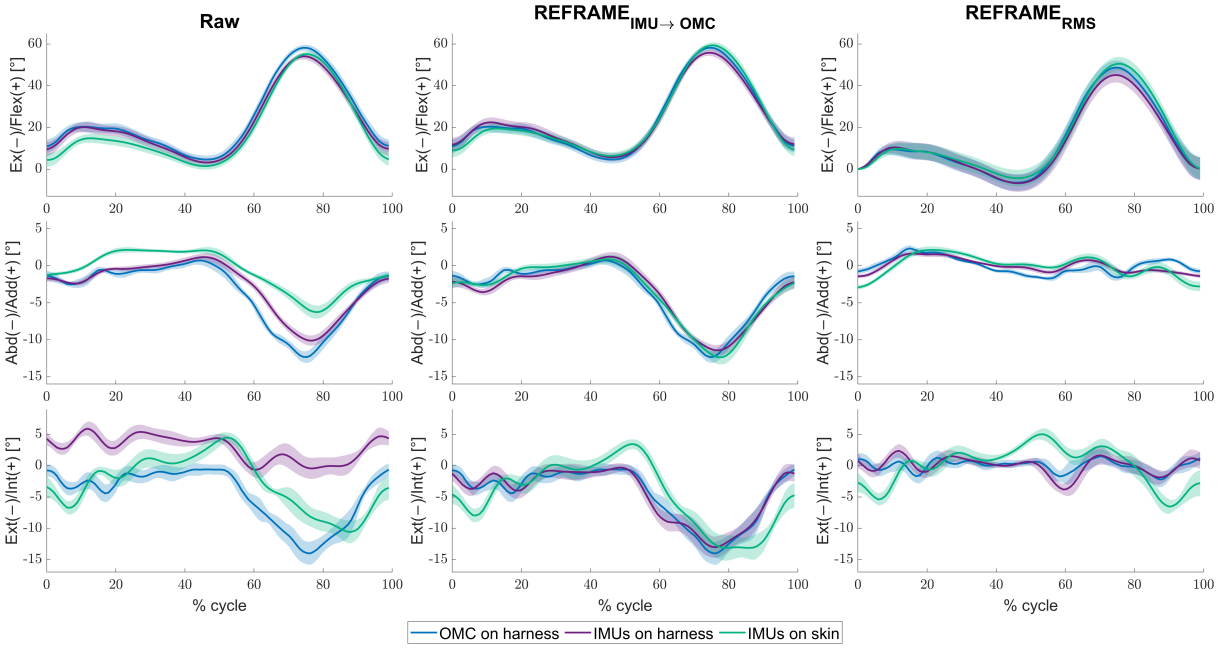



**Figure S10:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 10. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -1.9 ± 0.1 | -4.8 ± 0.2 |
| Ry | 6.8 ± 0.4 | -0.7 ± 1.2 | 7.6 ± 0.3 | -0.9 ± 1.2 |
| Rz | -6.1 ± 0.4 | -7.4 ± 0.7 | -10.1 ± 0.3 | -8.5 ± 0.3 |

**Table S31:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 10.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 11.1 ± 3.2 | 9.9 ± 3.4 | 5.4 ± 3.4 |
| Ry | -5.5 ± 1.5 | 1.2 ± 1.6 | -5.7 ± 1.7 | -4.7 ± 1.6 | 0.7 ± 1.5 | -6.9 ± 1.7 |
| Rz | 19.0 ± 1.0 | 13.4 ± 1.1 | 11.5 ± 1.2 | 20.5 ± 1.0 | 9.6 ± 0.9 | 12.2 ± 1.2 |

**Table S32:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 10.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 2.5 ± 0.1 | 4.9 ± 0.2 | 1.6 ± 0.1 | 1.7 ± 0.2 | 2.0 ± 0.2 | 1.9 ± 0.3 |
| abduction/adduction | 1.4 ± 0.1 | 3.5 ± 0.2 | 1.0 ± 0.1 | 0.9 ± 0.1 | 0.8 ± 0.0 | 1.3 ± 0.2 |
| external/internal rotation | 8.0 ± 0.3 | 3.9 ± 0.3 | 1.0 ± 0.1 | 3.2 ± 0.3 | 1.1 ± 0.1 | 3.1 ± 0.3 |

**Table S33:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 10.

## 2.11 Averaged plots for individual knee 11

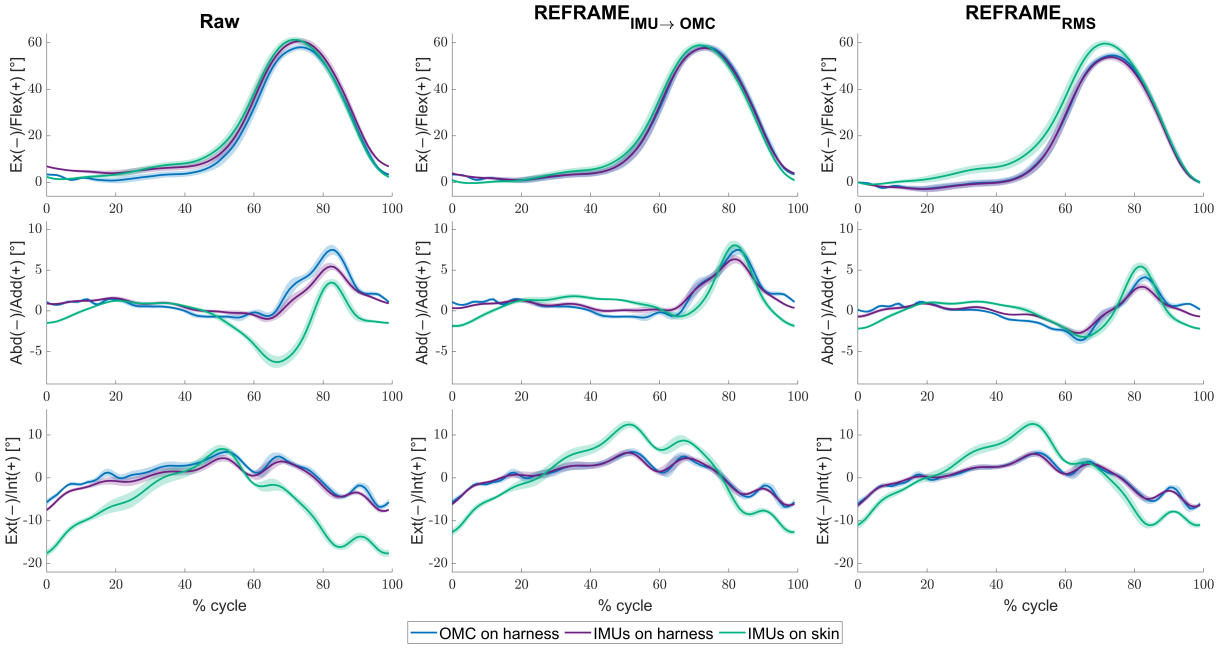



**Figure S11:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 11. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 2.9 ± 0.1 | 2.5 ± 0.1 |
| Ry | 1.5 ± 0.2 | -2.4 ± 0.5 | 1.2 ± 0.2 | -2.2 ± 0.5 |
| Rz | 1.2 ± 0.1 | 8.1 ± 0.6 | 2.7 ± 0.1 | 12.9 ± 0.2 |

**Table S34:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 11.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.5 ± 0.5 | 6.9 ± 0.4 | 1.6 ± 0.8 |
| Ry | -0.6 ± 0.8 | 1.1 ± 0.7 | 3.0 ± 1.1 | -1.2 ± 0.9 | 0.4 ± 0.8 | 3.0 ± 1.1 |
| Rz | -3.6 ± 0.3 | -2.4 ± 0.5 | 2.4 ± 0.9 | -4.0 ± 0.3 | -1.2 ± 0.3 | 8.9 ± 0.3 |

**Table S35:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 11.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.0 ± 0.1 | 3.6 ± 0.1 | 0.7 ± 0.1 | 2.3 ± 0.1 | 0.9 ± 0.1 | 5.1 ± 0.4 |
| abduction/adduction | 0.9 ± 0.1 | 3.4 ± 0.2 | 0.6 ± 0.0 | 1.6 ± 0.1 | 0.6 ± 0.0 | 1.3 ± 0.1 |
| external/internal rotation | 1.3 ± 0.1 | 7.8 ± 0.3 | 0.5 ± 0.1 | 4.4 ± 0.2 | 0.6 ± 0.1 | 4.1 ± 0.2 |

**Table S36:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 11.

## 2.12 Averaged plots for individual knee 12

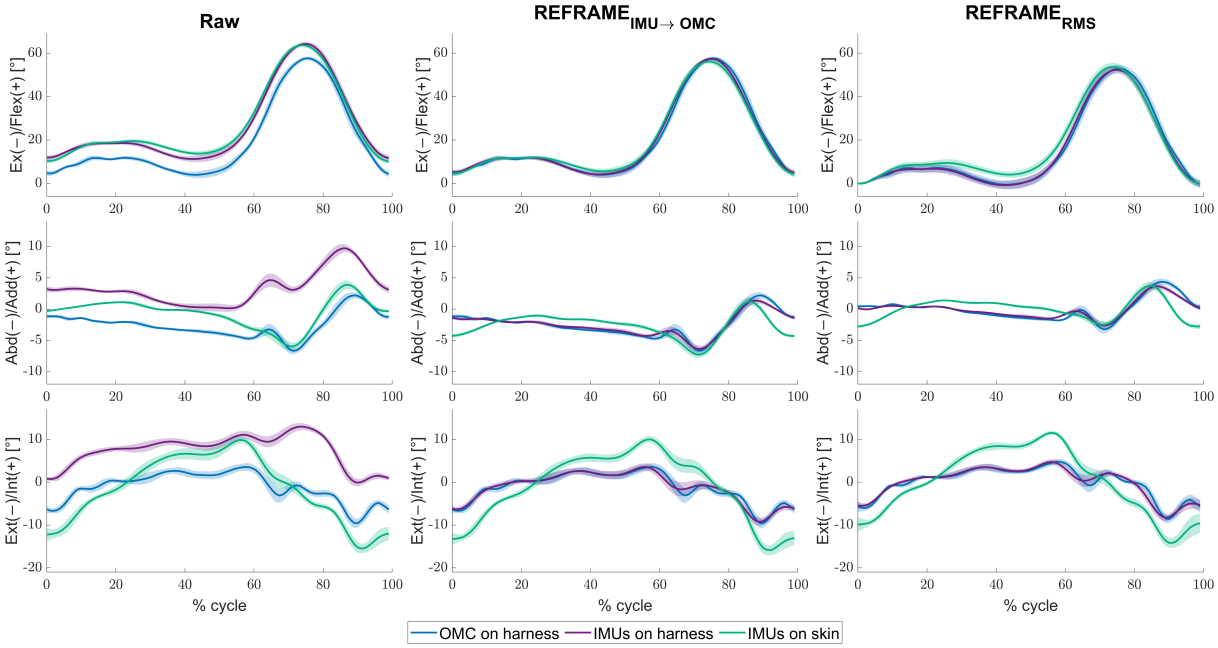



**Figure S12:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 12. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 6.5 ± 0.1 | 7.5 ± 0.2 |
| Ry | 2.6 ± 0.2 | -3.8 ± 1.1 | -1.1 ± 0.2 | -6.7 ± 1.4 |
| Rz | -10.0 ± 0.1 | 3.9 ± 1.0 | -16.5 ± 0.1 | 2.6 ± 0.4 |

**Table S37:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 12.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.6 ± 1.3 | 11.9 ± 1.1 | 10.0 ± 1.2 |
| Ry | -1.3 ± 1.3 | 1.9 ± 1.3 | 3.3 ± 1.9 | 0.9 ± 1.2 | -1.3 ± 1.3 | 3.0 ± 2.1 |
| Rz | 2.3 ± 0.5 | -7.6 ± 0.6 | 3.2 ± 1.3 | 2.9 ± 0.6 | -13.1 ± 0.6 | 5.3 ± 0.5 |

**Table S38:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 12.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 7.1 ± 0.1 | 8.0 ± 0.2 | 1.3 ± 0.2 | 2.1 ± 0.2 | 1.4 ± 0.2 | 3.8 ± 0.4 |
| abduction/adduction | 6.2 ± 0.1 | 2.3 ± 0.1 | 0.4 ± 0.0 | 1.7 ± 0.0 | 0.4 ± 0.0 | 1.9 ± 0.1 |
| external/internal rotation | 9.0 ± 0.1 | 4.5 ± 0.2 | 0.7 ± 0.1 | 4.9 ± 0.3 | 0.7 ± 0.1 | 4.6 ± 0.2 |

**Table S39:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 12.

## 2.13 Averaged plots for individual knee 13

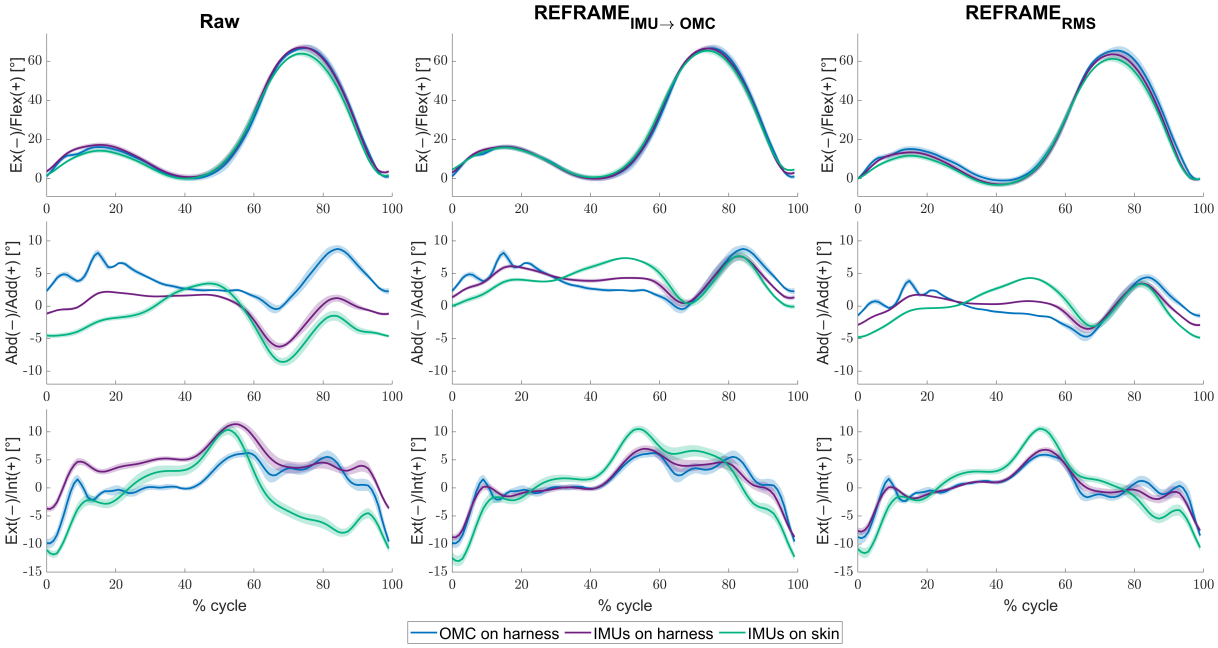



**Figure S13:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 13. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.4 ± 0.1 | -2.0 ± 0.2 |
| Ry | -2.1 ± 0.2 | -7.8 ± 1.0 | 0.1 ± 0.2 | -4.6 ± 0.7 |
| Rz | 6.4 ± 0.1 | 11.0 ± 0.5 | 1.1 ± 0.2 | 9.1 ± 0.4 |

**Table S40:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 13.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.0 ± 0.8 | 3.8 ± 0.8 | 2.8 ± 0.5 |
| Ry | 4.5 ± 0.9 | 2.7 ± 0.8 | -1.8 ± 1.1 | 0.9 ± 0.9 | 1.2 ± 0.8 | -1.5 ± 1.1 |
| Rz | -3.2 ± 0.5 | 3.3 ± 0.5 | 7.4 ± 0.7 | -2.1 ± 0.4 | -0.7 ± 0.4 | 7.4 ± 0.6 |

**Table S41:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 13.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.5 ± 0.1 | 2.5 ± 0.1 | 1.3 ± 0.2 | 1.8 ± 0.1 | 2.2 ± 0.6 | 3.5 ± 0.6 |
| abduction/adduction | 4.7 ± 0.1 | 7.3 ± 0.3 | 1.3 ± 0.1 | 2.8 ± 0.1 | 1.4 ± 0.1 | 3.2 ± 0.1 |
| external/internal rotation | 4.2 ± 0.1 | 5.6 ± 0.2 | 1.0 ± 0.1 | 3.3 ± 0.2 | 1.0 ± 0.1 | 3.1 ± 0.2 |

**Table S42:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 13.

## 2.14 Averaged plots for individual knee 14

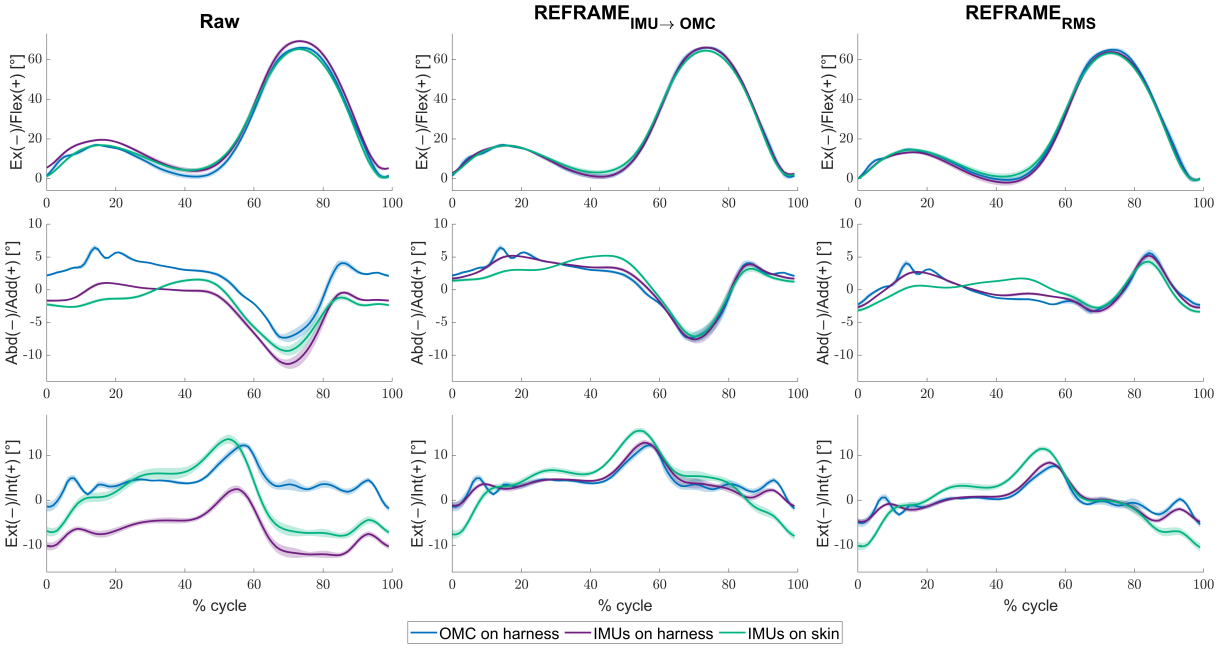



**Figure S14:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 14. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 2.8 ± 0.1 | -0.3 ± 0.1 |
| Ry | -4.5 ± 0.2 | -11.3 ± 0.5 | -0.8 ± 0.2 | -8.0 ± 0.5 |
| Rz | 3.5 ± 0.4 | 5.7 ± 0.7 | 12.2 ± 0.1 | 4.6 ± 0.2 |

**Table S43:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 14.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.8 ± 0.6 | 6.0 ± 0.5 | 2.4 ± 0.5 |
| Ry | 4.6 ± 0.6 | 0.2 ± 0.7 | -4.4 ± 0.9 | 0.3 ± 0.6 | 0.3 ± 0.6 | -5.0 ± 0.9 |
| Rz | 6.8 ± 0.5 | 10.2 ± 0.6 | 11.1 ± 0.7 | 3.3 ± 0.7 | 15.5 ± 0.7 | 7.9 ± 0.6 |

**Table S44:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 14.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.1 ± 0.1 | 2.3 ± 0.1 | 0.9 ± 0.1 | 1.7 ± 0.1 | 1.6 ± 0.4 | 1.8 ± 0.1 |
| abduction/adduction | 4.0 ± 0.1 | 4.3 ± 0.1 | 0.5 ± 0.1 | 1.6 ± 0.1 | 0.6 ± 0.1 | 1.8 ± 0.1 |
| external/internal rotation | 11.2 ± 0.3 | 6.4 ± 0.1 | 1.0 ± 0.0 | 3.7 ± 0.2 | 1.0 ± 0.0 | 3.6 ± 0.2 |

**Table S45:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 14.

## 2.15 Averaged plots for individual knee 15

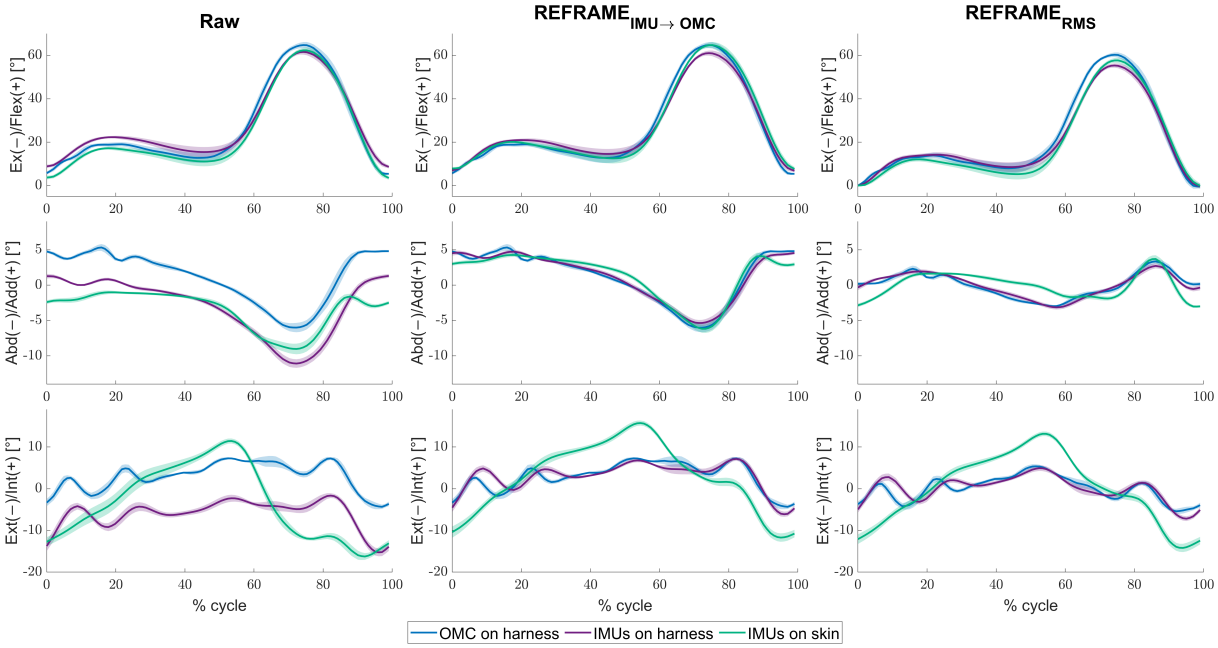



**Figure S15:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 15. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.4 ± 0.1 | -2.9 ± 0.2 |
| Ry | 1.9 ± 0.3 | -11.3 ± 1.2 | 5.1 ± 0.3 | -7.3 ± 1.5 |
| Rz | 1.8 ± 0.6 | 5.1 ± 1.2 | 11.3 ± 0.3 | 6.1 ± 0.5 |

**Table S46:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 15.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 5.3 ± 0.8 | 6.0 ± 0.9 | 5.3 ± 0.9 |
| Ry | 10.2 ± 0.8 | 12.4 ± 0.9 | -4.8 ± 1.2 | 6.0 ± 0.7 | 12.6 ± 0.8 | -4.1 ± 1.3 |
| Rz | 4.6 ± 0.4 | 6.9 ± 0.6 | 11.4 ± 1.2 | 4.8 ± 0.4 | 16.0 ± 0.4 | 12.0 ± 0.7 |

**Table S47:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 15.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.2 ± 0.2 | 3.0 ± 0.2 | 2.7 ± 0.2 | 2.5 ± 0.4 | 3.1 ± 0.2 | 3.4 ± 0.5 |
| abduction/adduction | 4.3 ± 0.1 | 4.9 ± 0.1 | 0.5 ± 0.1 | 1.0 ± 0.2 | 0.5 ± 0.1 | 1.7 ± 0.1 |
| external/internal rotation | 9.1 ± 0.4 | 10.0 ± 0.5 | 1.7 ± 0.2 | 5.9 ± 0.2 | 1.6 ± 0.2 | 5.8 ± 0.2 |

**Table S48:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 15.

## 2.16 Averaged plots for individual knee 16

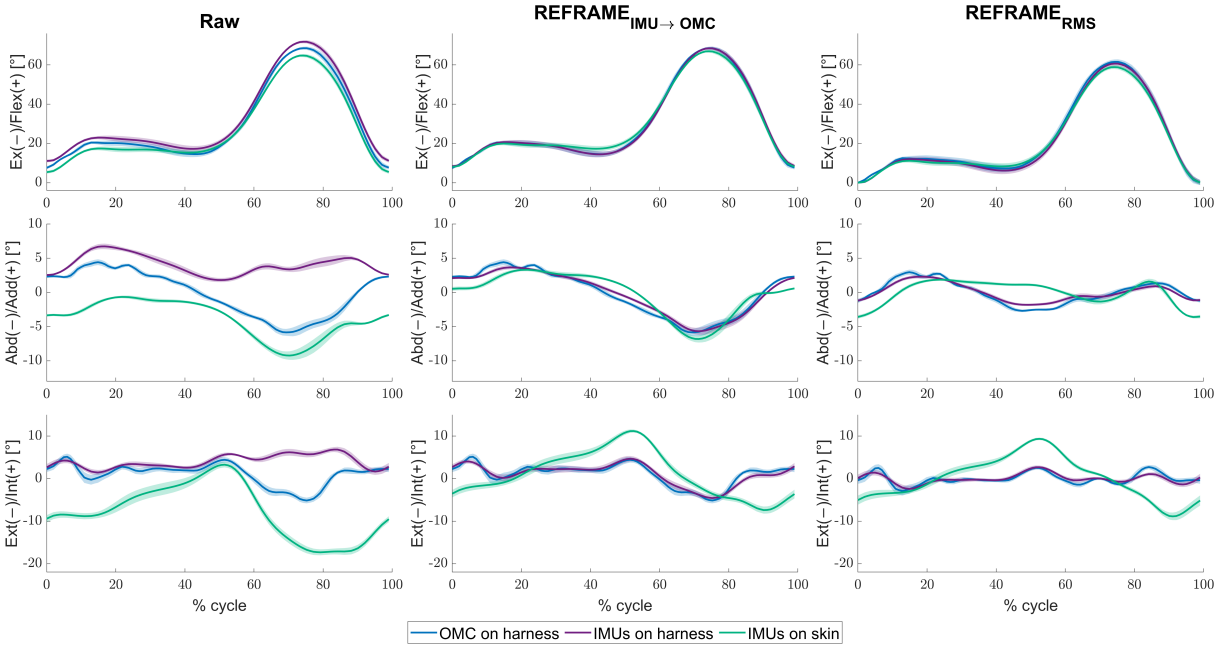



**Figure S16:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 16. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.5 ± 0.1 | -2.1 ± 0.2 |
| Ry | 2.6 ± 0.2 | -7.2 ± 1.0 | 3.8 ± 0.2 | -4.1 ± 1.1 |
| Rz | -13.3 ± 0.2 | 3.1 ± 0.7 | -12.6 ± 0.2 | 8.2 ± 0.4 |

**Table S49:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 16.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 7.7 ± 0.7 | 10.9 ± 0.7 | 6.9 ± 0.6 |
| Ry | 0.2 ± 0.9 | 2.7 ± 1.0 | -5.1 ± 1.4 | -3.6 ± 0.9 | -1.5 ± 0.9 | -4.2 ± 1.5 |
| Rz | 10.8 ± 0.5 | -2.6 ± 0.5 | 13.0 ± 1.1 | 8.5 ± 0.6 | -4.5 ± 0.5 | 17.1 ± 0.7 |

**Table S50:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 16.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.0 ± 0.1 | 2.9 ± 0.1 | 1.0 ± 0.2 | 1.7 ± 0.2 | 1.3 ± 0.2 | 1.8 ± 0.2 |
| abduction/adduction | 5.1 ± 0.1 | 4.0 ± 0.1 | 0.6 ± 0.1 | 1.4 ± 0.1 | 0.5 ± 0.1 | 2.1 ± 0.1 |
| external/internal rotation | 4.6 ± 0.2 | 10.3 ± 0.3 | 0.8 ± 0.1 | 5.2 ± 0.2 | 0.7 ± 0.1 | 5.0 ± 0.2 |

**Table S51:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 16.

## 2.17 Averaged plots for individual knee 18

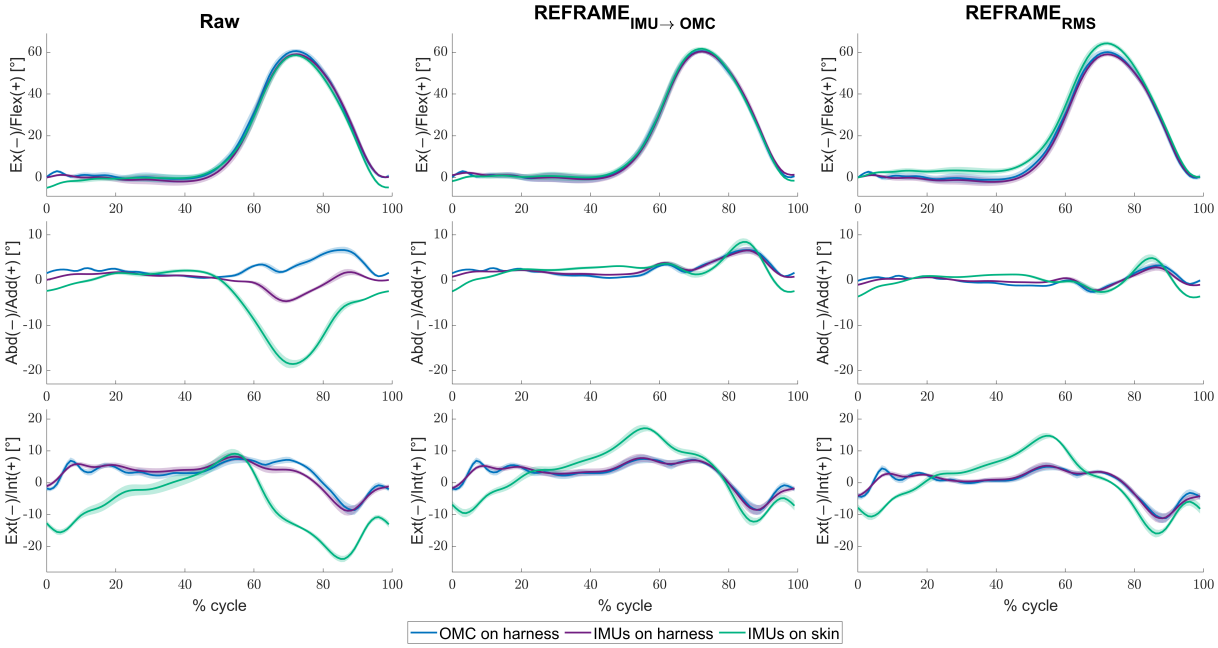



**Figure S17:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 18. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -1.2 ± 0.1 | -1.5 ± 0.2 |
| Ry | 0.0 ± 0.1 | -4.2 ± 0.8 | 0.5 ± 0.1 | -3.8 ± 0.8 |
| Rz | 7.5 ± 0.1 | 24.1 ± 0.6 | 6.9 ± 0.1 | 30.3 ± 0.4 |

**Table S52:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 18.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.3 ± 0.6 | 0.1 ± 0.4 | -3.5 ± 0.4 |
| Ry | -0.2 ± 1.0 | -0.4 ± 0.9 | 0.1 ± 0.6 | -1.9 ± 1.0 | -1.5 ± 0.9 | -1.8 ± 0.6 |
| Rz | -3.2 ± 0.4 | 4.3 ± 0.4 | 18.9 ± 0.7 | -5.6 ± 0.3 | 1.3 ± 0.3 | 23.9 ± 0.3 |

**Table S53:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 18.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.5 ± 0.1 | 2.5 ± 0.2 | 1.0 ± 0.1 | 1.2 ± 0.2 | 1.3 ± 0.1 | 3.3 ± 0.6 |
| abduction/adduction | 3.5 ± 0.1 | 10.1 ± 0.2 | 0.5 ± 0.0 | 1.8 ± 0.1 | 0.5 ± 0.0 | 1.6 ± 0.1 |
| external/internal rotation | 1.5 ± 0.1 | 12.1 ± 0.4 | 0.7 ± 0.1 | 5.9 ± 0.2 | 0.7 ± 0.1 | 5.8 ± 0.2 |

**Table S54:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 18.

## 2.18 Averaged plots for individual knee 19

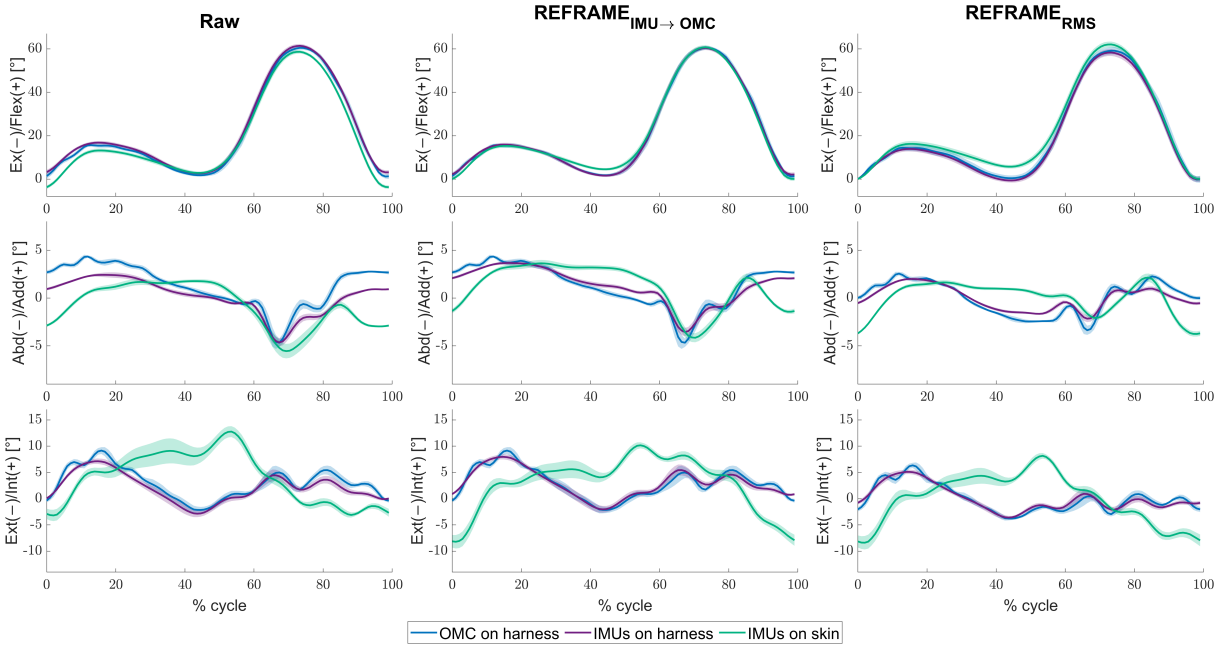



**Figure S18:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 19. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.0 ± 0.1 | -3.2 ± 0.2 |
| Ry | -0.2 ± 0.1 | -9.5 ± 1.3 | 1.0 ± 0.1 | -8.2 ± 1.4 |
| Rz | -0.1 ± 0.1 | 5.6 ± 0.7 | 0.7 ± 0.1 | 0.6 ± 0.5 |

**Table S55:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 19.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.4 ± 1.2 | 3.2 ± 1.0 | -3.3 ± 0.8 |
| Ry | 5.0 ± 0.6 | 4.9 ± 0.6 | -1.1 ± 1.0 | 2.3 ± 0.6 | 3.5 ± 0.6 | -2.1 ± 0.9 |
| Rz | 2.4 ± 0.4 | 2.2 ± 0.3 | 5.9 ± 0.7 | 0.8 ± 0.3 | 1.4 ± 0.3 | 0.8 ± 0.9 |

**Table S56:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 19.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.3 ± 0.1 | 3.1 ± 0.2 | 0.9 ± 0.2 | 1.7 ± 0.1 | 1.3 ± 0.4 | 3.2 ± 0.5 |
| abduction/adduction | 1.3 ± 0.0 | 3.0 ± 0.1 | 0.7 ± 0.0 | 2.1 ± 0.0 | 0.7 ± 0.0 | 2.1 ± 0.1 |
| external/internal rotation | 1.2 ± 0.1 | 6.5 ± 0.5 | 0.8 ± 0.1 | 6.0 ± 0.4 | 0.7 ± 0.1 | 5.8 ± 0.4 |

**Table S57:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 19.

## 2.19 Averaged plots for individual knee 20

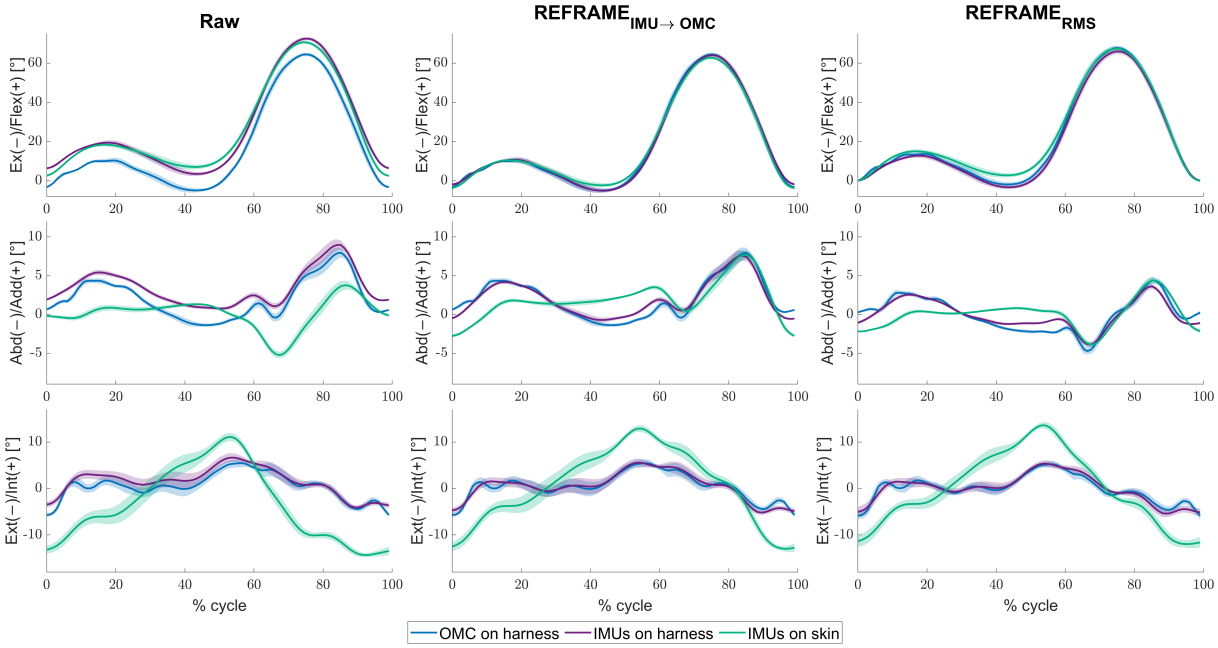



**Figure S19:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 20. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 8.5 ± 0.1 | 8.4 ± 0.1 |
| Ry | -1.2 ± 0.2 | -5.9 ± 0.7 | -3.0 ± 0.2 | -6.0 ± 0.7 |
| Rz | 1.5 ± 0.1 | 10.7 ± 0.3 | 0.5 ± 0.1 | 11.8 ± 0.3 |

**Table S58:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 20.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | -3.2 ± 0.4 | 6.6 ± 0.6 | 3.8 ± 0.5 |
| Ry | -0.5 ± 0.8 | -2.0 ± 0.9 | -2.8 ± 1.3 | -1.2 ± 0.8 | -4.6 ± 0.9 | -4.0 ± 1.2 |
| Rz | -3.9 ± 0.5 | -2.5 ± 0.5 | 4.8 ± 0.5 | -4.1 ± 0.6 | -3.9 ± 0.7 | 6.7 ± 0.9 |

**Table S59:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 20.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 8.7 ± 0.1 | 8.7 ± 0.2 | 1.1 ± 0.2 | 1.6 ± 0.1 | 1.7 ± 0.2 | 2.5 ± 0.2 |
| abduction/adduction | 1.5 ± 0.1 | 3.3 ± 0.1 | 0.7 ± 0.1 | 2.3 ± 0.1 | 0.8 ± 0.1 | 1.9 ± 0.1 |
| external/internal rotation | 1.3 ± 0.1 | 7.4 ± 0.2 | 0.7 ± 0.1 | 5.6 ± 0.2 | 0.8 ± 0.1 | 5.6 ± 0.2 |

**Table S60:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 20.

## 2.20 Averaged plots for individual knee 21

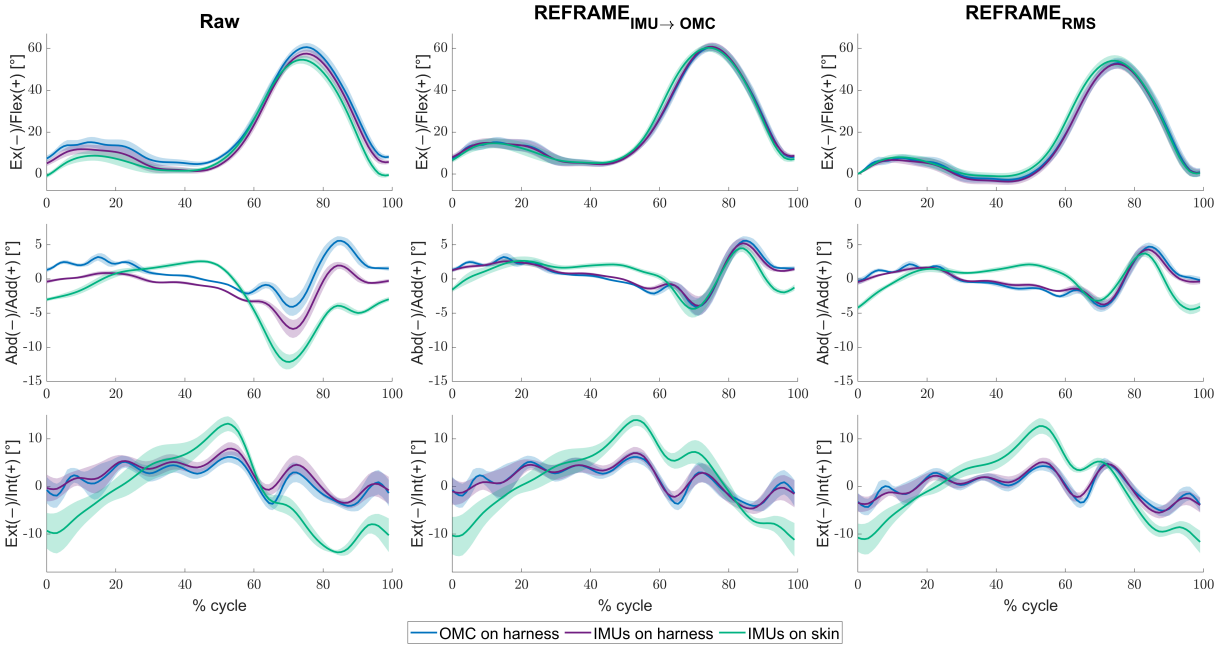



**Figure S20:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 21. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -3.0 ± 0.1 | -5.4 ± 0.3 |
| Ry | 1.8 ± 0.2 | -8.8 ± 1.1 | 3.3 ± 0.2 | -10.0 ± 1.3 |
| Rz | 1.6 ± 0.2 | 14.9 ± 0.9 | 1.1 ± 0.2 | 13.3 ± 0.7 |

**Table S61:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 21.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 7.3 ± 1.4 | 5.0 ± 1.3 | 1.3 ± 1.1 |
| Ry | -3.2 ± 3.0 | -1.2 ± 2.9 | -6.2 ± 4.5 | -4.8 ± 3.1 | -1.2 ± 3.1 | -7.1 ± 4.6 |
| Rz | 3.1 ± 1.9 | 4.7 ± 1.7 | 15.8 ± 2.4 | 0.8 ± 0.8 | 1.6 ± 0.7 | 14.5 ± 0.9 |

**Table S62:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 21.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.2 ± 0.1 | 5.9 ± 0.3 | 0.7 ± 0.1 | 2.0 ± 0.2 | 1.1 ± 0.3 | 2.7 ± 0.7 |
| abduction/adduction | 2.3 ± 0.1 | 5.4 ± 0.2 | 0.4 ± 0.0 | 1.8 ± 0.2 | 0.4 ± 0.0 | 2.5 ± 0.2 |
| external/internal rotation | 1.3 ± 0.1 | 6.8 ± 0.5 | 0.8 ± 0.1 | 5.9 ± 0.5 | 0.7 ± 0.1 | 5.5 ± 0.4 |

**Table S63:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 21.

## 2.21 Averaged plots for individual knee 22

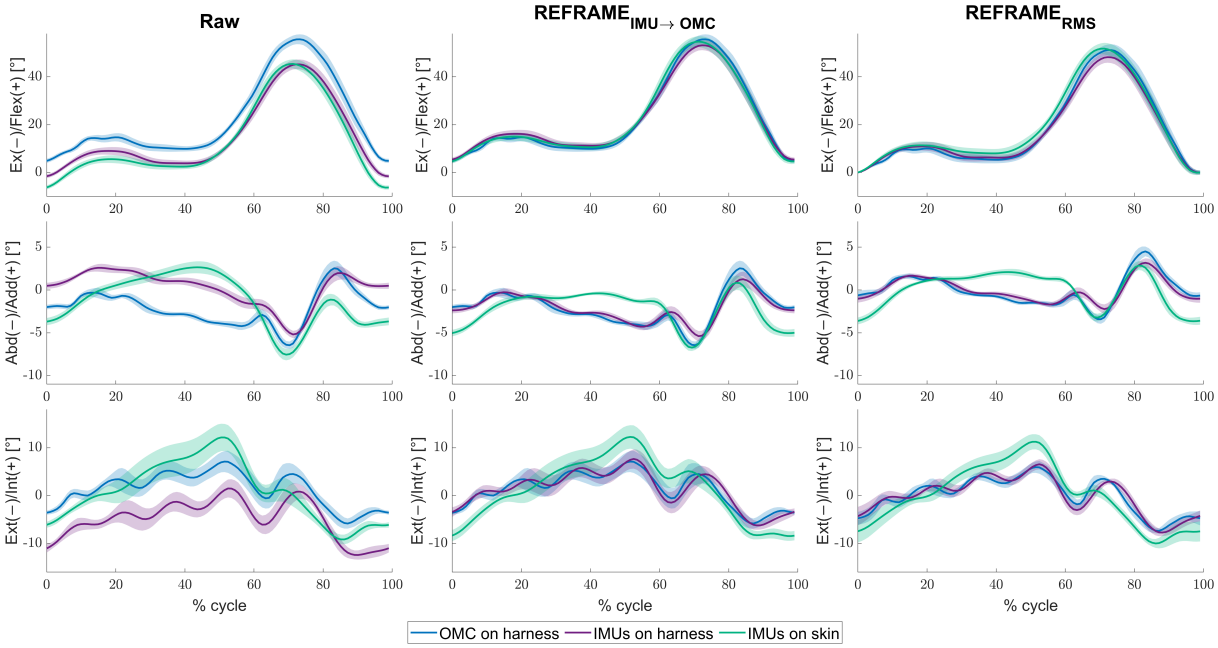



**Figure S21:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 22. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -7.3 ± 0.1 | -9.4 ± 0.4 |
| Ry | 5.9 ± 0.7 | -5.1 ± 2.0 | 1.5 ± 0.6 | -8.1 ± 2.0 |
| Rz | 2.5 ± 0.4 | 7.4 ± 0.8 | 10.5 ± 0.3 | 5.4 ± 0.6 |

**Table S64:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 22.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.7 ± 0.8 | -2.6 ± 0.7 | -5.9 ± 0.8 |
| Ry | 0.7 ± 2.3 | 7.6 ± 2.7 | 0.8 ± 3.3 | 2.4 ± 2.5 | 5.6 ± 3.0 | 0.2 ± 3.5 |
| Rz | 1.0 ± 1.1 | 3.3 ± 1.2 | 6.0 ± 1.6 | -0.3 ± 1.2 | 10.1 ± 1.2 | 5.0 ± 1.6 |

**Table S65:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 22.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 7.5 ± 0.1 | 9.5 ± 0.2 | 1.7 ± 0.1 | 1.6 ± 0.2 | 1.8 ± 0.1 | 2.5 ± 0.4 |
| abduction/adduction | 2.8 ± 0.1 | 3.4 ± 0.2 | 0.7 ± 0.1 | 2.1 ± 0.2 | 0.7 ± 0.1 | 2.2 ± 0.1 |
| external/internal rotation | 6.4 ± 0.3 | 3.5 ± 0.5 | 1.1 ± 0.1 | 3.4 ± 0.5 | 1.1 ± 0.1 | 3.3 ± 0.5 |

**Table S66:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 22.

## 2.22 Averaged plots for individual knee 23

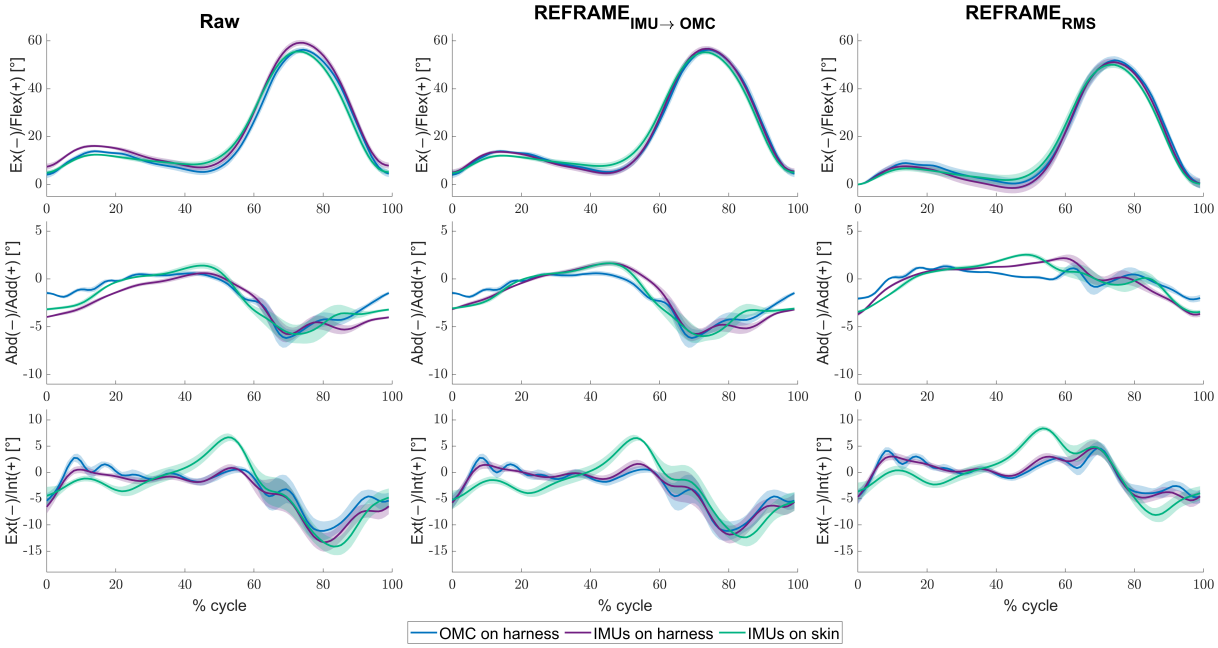



**Figure S22:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 23. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 2.4 ± 0.1 | 0.5 ± 0.1 |
| Ry | -1.2 ± 0.3 | -3.8 ± 1.3 | -0.0 ± 0.3 | -3.8 ± 1.3 |
| Rz | -0.5 ± 0.2 | 1.8 ± 0.3 | 0.0 ± 0.2 | 0.7 ± 0.6 |

**Table S67:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 23.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.9 ± 1.6 | 8.5 ± 1.4 | 6.0 ± 1.3 |
| Ry | -4.6 ± 2.3 | -5.6 ± 2.2 | -6.4 ± 2.4 | -4.7 ± 2.3 | -4.3 ± 2.2 | -6.2 ± 2.3 |
| Rz | 9.8 ± 0.9 | 9.3 ± 0.9 | 10.4 ± 1.0 | 10.5 ± 0.8 | 10.7 ± 1.0 | 11.0 ± 0.9 |

**Table S68:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 23.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 2.7 ± 0.1 | 2.7 ± 0.2 | 1.0 ± 0.2 | 2.3 ± 0.2 | 1.5 ± 0.2 | 2.3 ± 0.2 |
| abduction/adduction | 1.2 ± 0.0 | 0.9 ± 0.1 | 0.9 ± 0.0 | 0.8 ± 0.0 | 1.0 ± 0.0 | 1.1 ± 0.1 |
| external/internal rotation | 1.4 ± 0.1 | 3.1 ± 0.1 | 0.9 ± 0.1 | 3.1 ± 0.1 | 0.8 ± 0.1 | 3.2 ± 0.1 |

**Table S69:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 23.

## 2.23 Averaged plots for individual knee 24

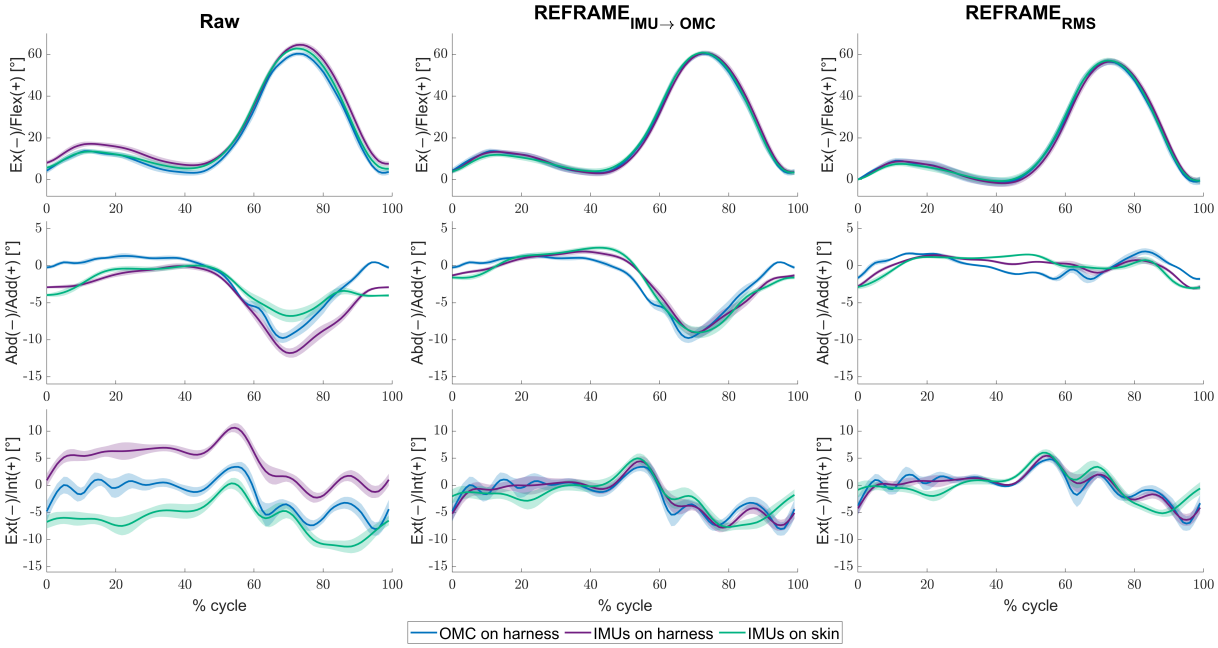



**Figure S23:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 24. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.1 ± 0.1 | 1.4 ± 0.2 |
| Ry | 0.5 ± 0.3 | -0.6 ± 0.4 | 2.0 ± 0.3 | 2.3 ± 0.5 |
| Rz | 1.1 ± 0.1 | -5.4 ± 0.4 | -5.2 ± 0.2 | -0.8 ± 0.3 |

**Table S70:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 24.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.5 ± 1.3 | 8.7 ± 1.0 | 5.7 ± 1.1 |
| Ry | 1.2 ± 1.1 | 1.0 ± 1.0 | 0.6 ± 1.2 | 0.1 ± 1.2 | 1.0 ± 1.1 | 2.4 ± 1.3 |
| Rz | 11.2 ± 0.7 | 12.4 ± 0.7 | 5.8 ± 0.7 | 12.2 ± 0.5 | 6.8 ± 0.5 | 11.3 ± 0.6 |

**Table S71:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 24.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 4.2 ± 0.1 | 2.1 ± 0.2 | 1.4 ± 0.2 | 1.2 ± 0.1 | 1.6 ± 0.2 | 1.3 ± 0.2 |
| abduction/adduction | 2.4 ± 0.0 | 2.3 ± 0.1 | 1.2 ± 0.1 | 1.4 ± 0.1 | 1.1 ± 0.1 | 1.5 ± 0.1 |
| external/internal rotation | 6.2 ± 0.1 | 4.9 ± 0.3 | 1.0 ± 0.1 | 2.2 ± 0.2 | 0.9 ± 0.1 | 2.2 ± 0.2 |

**Table S72:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 24.

## 2.24 Averaged plots for individual knee 25

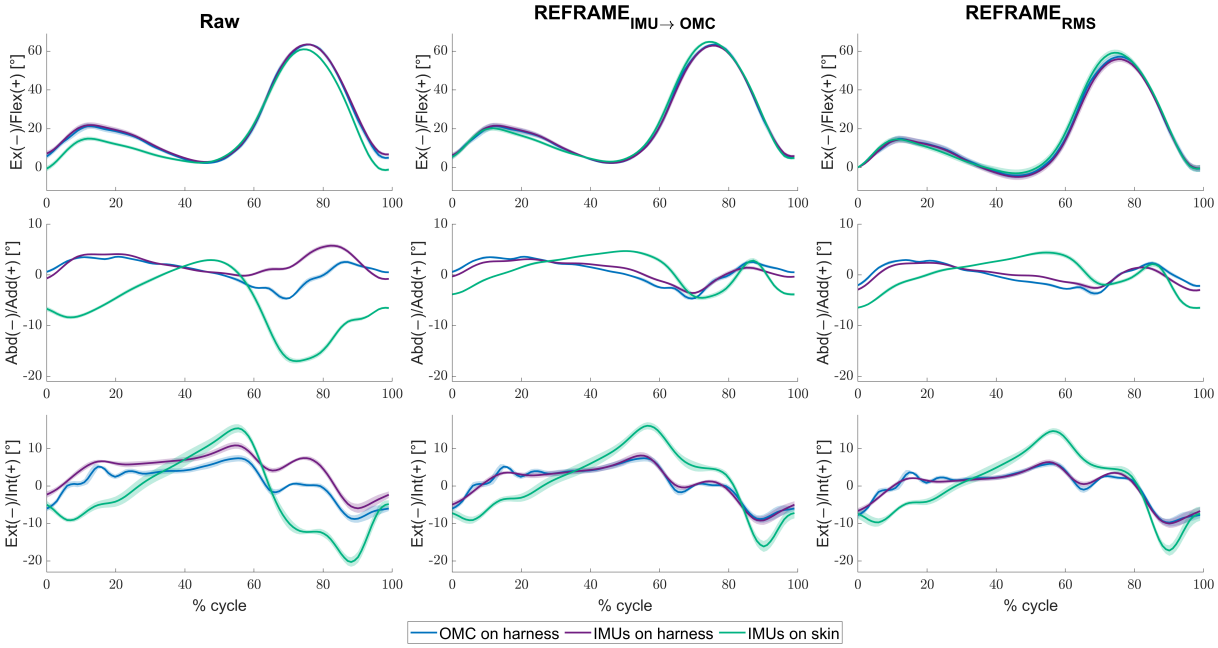



**Figure S24:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 25. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.9 ± 0.1 | -3.7 ± 0.3 |
| Ry | -0.5 ± 0.2 | -11.2 ± 0.9 | 0.7 ± 0.1 | -10.2 ± 0.9 |
| Rz | -7.2 ± 0.2 | 18.8 ± 0.4 | -9.9 ± 0.2 | 16.3 ± 0.6 |

**Table S73:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 25.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 6.2 ± 1.3 | 7.2 ± 1.3 | 2.5 ± 1.3 |
| Ry | -1.6 ± 0.8 | -2.5 ± 0.9 | -9.2 ± 2.3 | -3.6 ± 0.8 | -4.4 ± 1.0 | -8.3 ± 2.2 |
| Rz | 4.7 ± 0.4 | -2.4 ± 0.4 | 22.3 ± 0.9 | 3.1 ± 0.4 | -6.8 ± 0.4 | 20.2 ± 0.4 |

**Table S74:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 25.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.1 ± 0.1 | 4.6 ± 0.2 | 0.9 ± 0.1 | 1.7 ± 0.2 | 1.2 ± 0.2 | 1.9 ± 0.4 |
| abduction/adduction | 2.6 ± 0.1 | 8.8 ± 0.1 | 0.8 ± 0.0 | 3.2 ± 0.1 | 0.9 ± 0.1 | 3.8 ± 0.1 |
| external/internal rotation | 3.7 ± 0.1 | 7.6 ± 0.3 | 0.8 ± 0.0 | 5.8 ± 0.2 | 0.8 ± 0.0 | 5.3 ± 0.2 |

**Table S75:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 25.

## 2.25 Averaged plots for individual knee 26

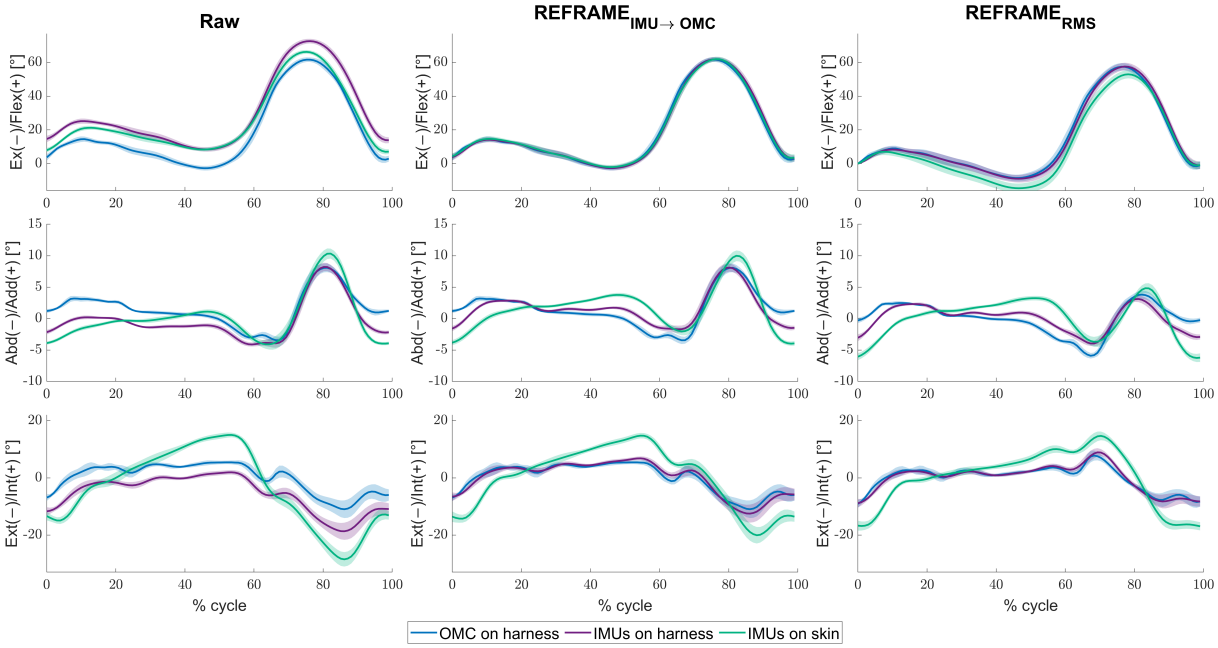



**Figure S25:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 26. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 11.0 ± 0.1 | 7.1 ± 0.5 |
| Ry | -2.6 ± 0.4 | -13.6 ± 0.6 | -0.0 ± 0.4 | -12.8 ± 0.7 |
| Rz | 2.0 ± 0.2 | 8.0 ± 0.7 | 6.3 ± 0.2 | 6.8 ± 0.6 |

**Table S76:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 26.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 5.0 ± 2.0 | 17.2 ± 1.9 | 16.9 ± 2.3 |
| Ry | -9.4 ± 1.5 | -13.3 ± 1.2 | -30.3 ± 2.0 | -10.3 ± 1.5 | -11.0 ± 1.2 | -29.3 ± 1.9 |
| Rz | 1.2 ± 0.7 | 3.5 ± 0.9 | 11.7 ± 1.0 | -0.8 ± 0.8 | 5.7 ± 1.1 | 10.3 ± 1.4 |

**Table S77:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 26.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 11.2 ± 0.1 | 7.4 ± 0.3 | 1.6 ± 0.2 | 1.3 ± 0.2 | 1.8 ± 0.2 | 5.3 ± 0.8 |
| abduction/adduction | 2.1 ± 0.0 | 2.7 ± 0.1 | 1.3 ± 0.1 | 2.8 ± 0.1 | 1.4 ± 0.1 | 3.2 ± 0.2 |
| external/internal rotation | 5.7 ± 0.2 | 9.6 ± 0.3 | 1.2 ± 0.1 | 6.7 ± 0.3 | 1.0 ± 0.1 | 6.3 ± 0.3 |

**Table S78:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 26.

## 2.26 Averaged plots for individual knee 27

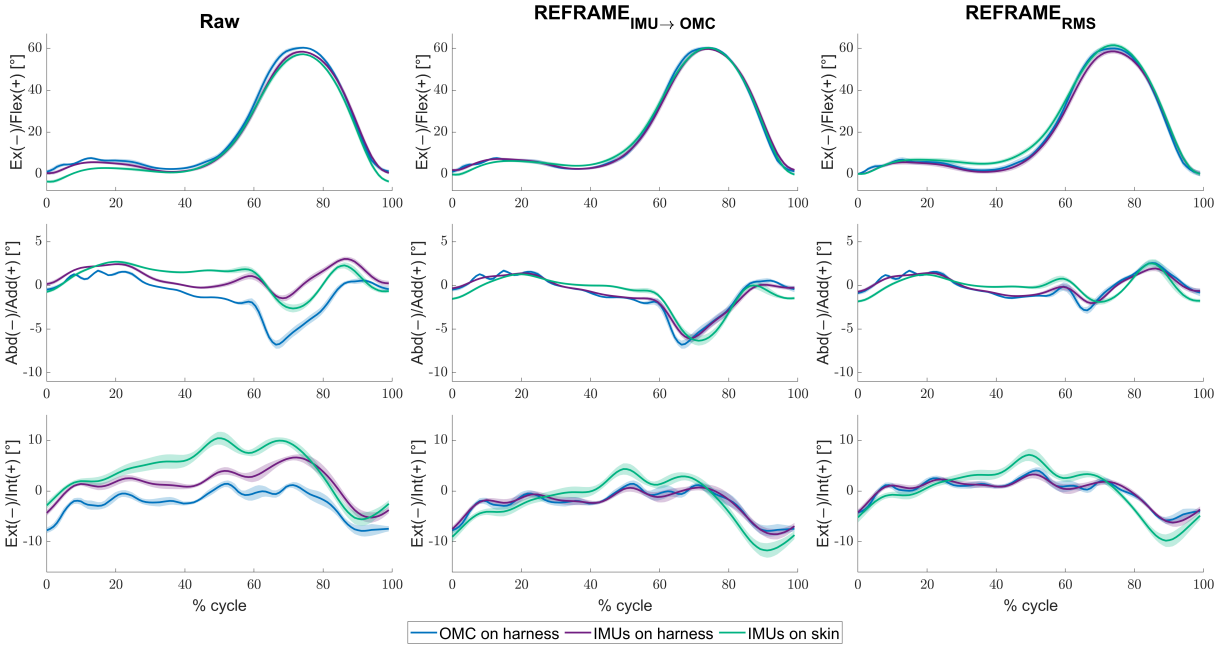



**Figure S26:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 27. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -1.4 ± 0.1 | -3.4 ± 0.2 |
| Ry | 0.3 ± 0.2 | -0.2 ± 0.6 | -0.1 ± 0.2 | -1.2 ± 0.6 |
| Rz | -5.0 ± 0.1 | -2.4 ± 0.3 | -8.2 ± 0.1 | -8.6 ± 0.4 |

**Table S79:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 27.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.5 ± 0.8 | 0.1 ± 0.7 | -3.8 ± 0.7 |
| Ry | 4.8 ± 0.7 | 4.7 ± 0.8 | 5.2 ± 0.8 | 4.5 ± 0.7 | 3.8 ± 0.8 | 3.9 ± 0.8 |
| Rz | 2.9 ± 0.4 | -2.0 ± 0.4 | 0.1 ± 0.5 | 6.4 ± 0.4 | -1.9 ± 0.4 | -2.2 ± 0.4 |

**Table S80:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 27.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.9 ± 0.1 | 3.5 ± 0.1 | 1.3 ± 0.1 | 1.5 ± 0.1 | 1.6 ± 0.1 | 2.1 ± 0.2 |
| abduction/adduction | 2.6 ± 0.1 | 2.5 ± 0.1 | 0.4 ± 0.0 | 1.0 ± 0.1 | 0.4 ± 0.0 | 1.0 ± 0.1 |
| external/internal rotation | 4.0 ± 0.1 | 6.8 ± 0.3 | 0.5 ± 0.0 | 2.4 ± 0.4 | 0.5 ± 0.0 | 2.4 ± 0.4 |

**Table S81:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 27.

## 2.27 Averaged plots for individual knee 28

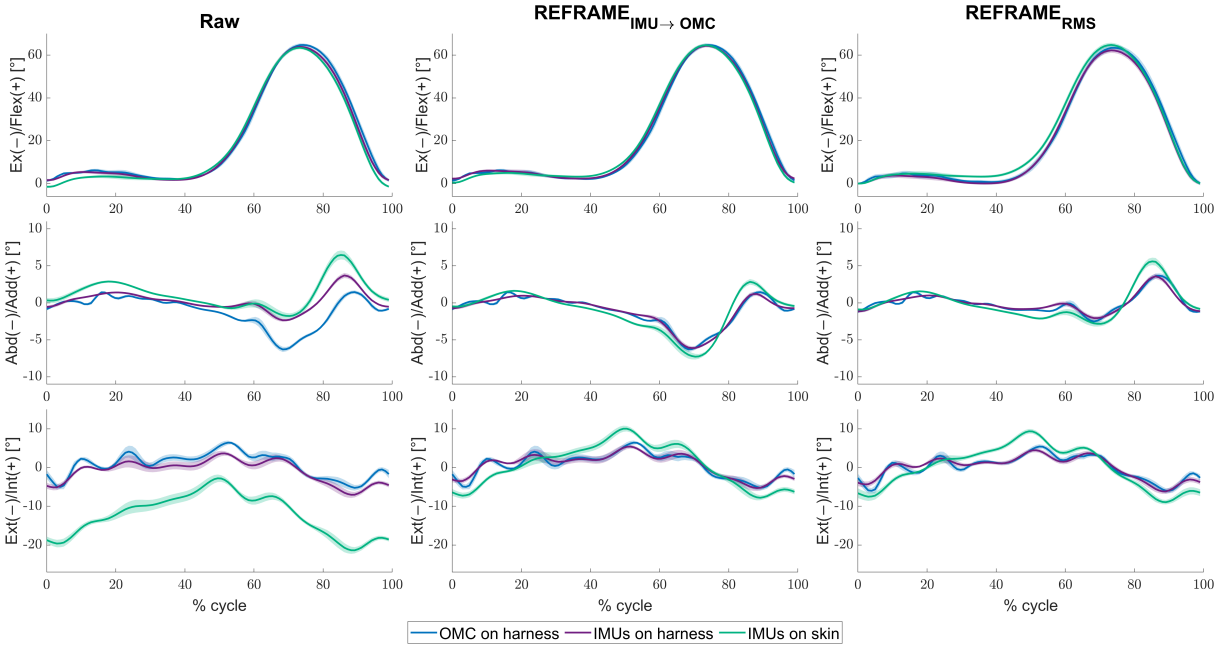



**Figure S27:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 28. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -0.6 ± 0.1 | -0.6 ± 0.1 |
| Ry | -1.3 ± 0.2 | -3.0 ± 0.6 | -1.4 ± 0.2 | -4.3 ± 0.5 |
| Rz | -3.4 ± 0.2 | -3.1 ± 0.6 | -1.8 ± 0.1 | 9.2 ± 0.3 |

**Table S82:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 28.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.5 ± 0.8 | 1.6 ± 0.6 | -0.9 ± 0.5 |
| Ry | 0.8 ± 0.5 | -0.1 ± 0.4 | -0.2 ± 0.6 | 0.4 ± 0.5 | -0.6 ± 0.5 | -1.9 ± 0.6 |
| Rz | 4.3 ± 0.3 | 0.9 ± 0.4 | 0.6 ± 0.6 | 3.3 ± 0.4 | 1.7 ± 0.4 | 12.7 ± 0.5 |

**Table S83:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 28.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.5 ± 0.2 | 2.9 ± 0.2 | 1.3 ± 0.2 | 2.1 ± 0.2 | 1.5 ± 0.4 | 2.7 ± 0.2 |
| abduction/adduction | 1.9 ± 0.1 | 2.9 ± 0.2 | 0.3 ± 0.1 | 1.0 ± 0.1 | 0.4 ± 0.1 | 0.9 ± 0.1 |
| external/internal rotation | 1.8 ± 0.1 | 13.2 ± 0.4 | 0.9 ± 0.1 | 2.9 ± 0.2 | 0.9 ± 0.1 | 2.9 ± 0.2 |

**Table S84:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 28.

## 2.28 Averaged plots for individual knee 29

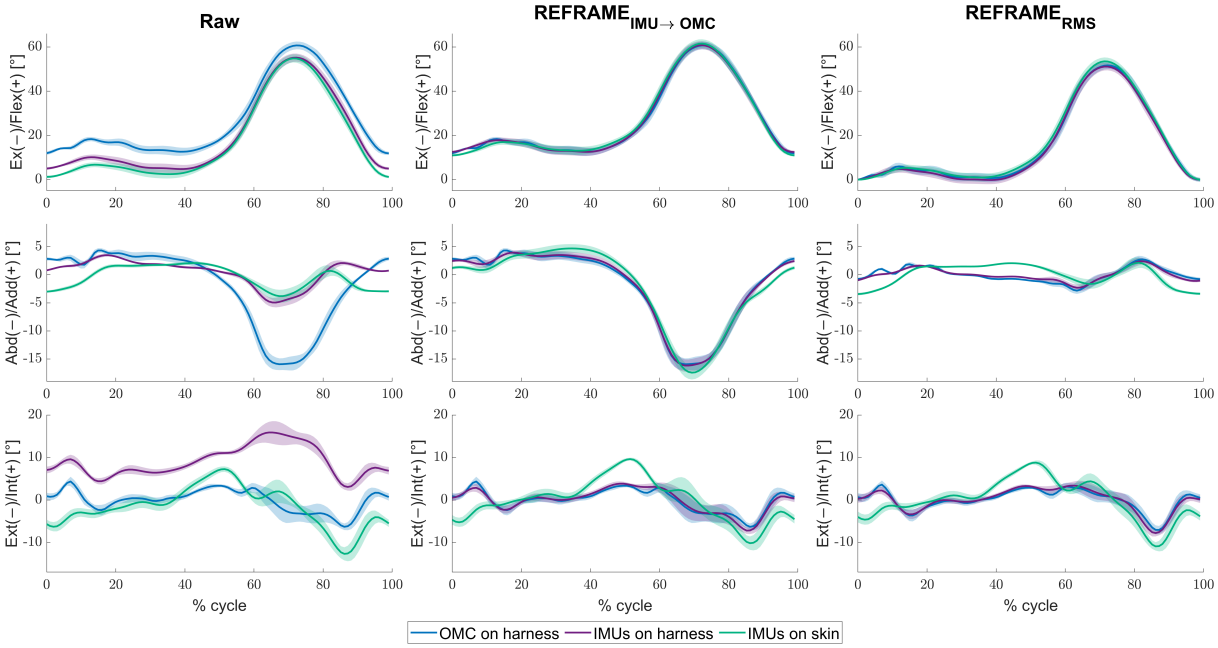



**Figure S28:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 29. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -5.1 ± 0.0 | -8.6 ± 0.2 |
| Ry | 1.1 ± 0.3 | -10.1 ± 1.7 | 7.4 ± 0.3 | -3.5 ± 1.8 |
| Rz | -19.5 ± 0.2 | -17.0 ± 0.7 | -25.6 ± 0.1 | -17.1 ± 0.7 |

**Table S85:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 29.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 12.2 ± 0.8 | 6.0 ± 0.6 | 1.4 ± 0.7 |
| Ry | 9.5 ± 1.7 | 10.1 ± 1.5 | 0.4 ± 1.7 | 5.8 ± 1.7 | 7.7 ± 1.5 | 0.2 ± 1.6 |
| Rz | 20.8 ± 1.0 | 1.5 ± 0.9 | 3.0 ± 1.0 | 21.1 ± 1.1 | -5.3 ± 1.0 | 4.5 ± 1.1 |

**Table S86:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 29.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 7.1 ± 0.1 | 9.4 ± 0.2 | 0.8 ± 0.1 | 1.3 ± 0.2 | 1.0 ± 0.2 | 1.4 ± 0.3 |
| abduction/adduction | 5.5 ± 0.2 | 6.3 ± 0.3 | 0.4 ± 0.0 | 1.4 ± 0.1 | 0.4 ± 0.0 | 2.0 ± 0.1 |
| external/internal rotation | 10.0 ± 0.2 | 4.1 ± 0.3 | 0.7 ± 0.0 | 3.7 ± 0.2 | 0.7 ± 0.1 | 3.4 ± 0.2 |

**Table S87:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 29.

## 2.29 Averaged plots for individual knee 30

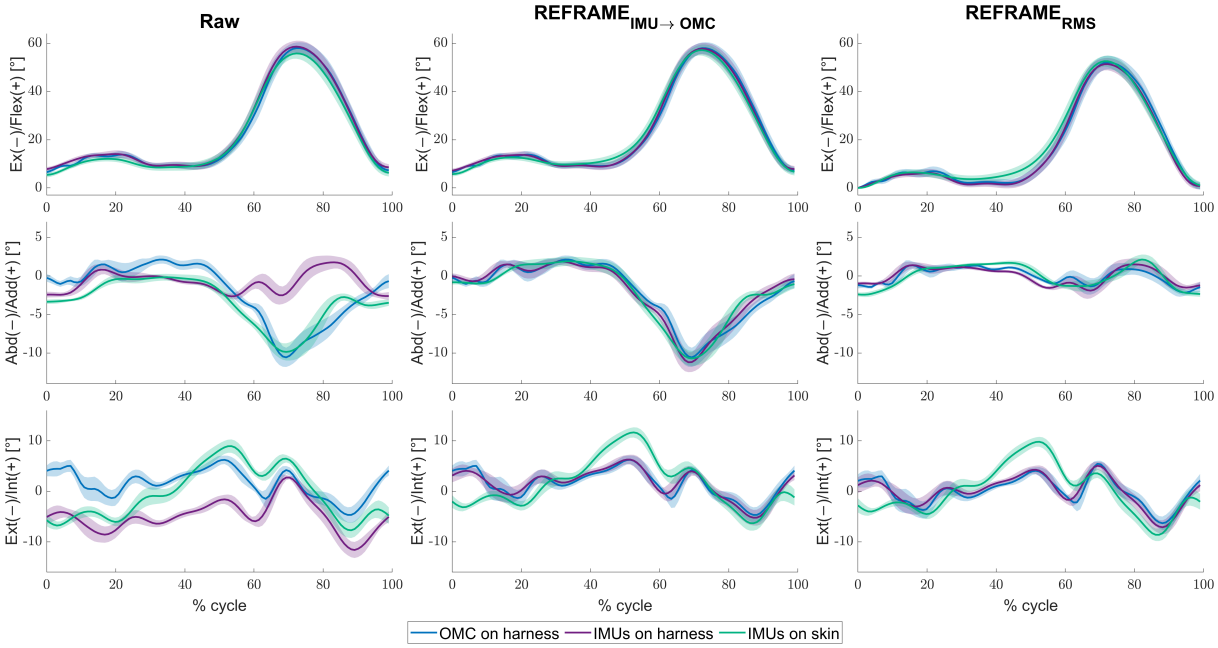



**Figure S29:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 30. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.5 ± 0.1 | -1.1 ± 0.2 |
| Ry | -0.1 ± 0.2 | 3.6 ± 0.8 | 4.3 ± 0.2 | 6.6 ± 0.9 |
| Rz | -15.9 ± 0.1 | -6.4 ± 0.4 | -7.6 ± 0.1 | -2.3 ± 0.4 |

**Table S88:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 30.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 6.9 ± 1.0 | 7.3 ± 0.8 | 4.5 ± 1.1 |
| Ry | 3.0 ± 1.0 | 3.3 ± 1.1 | 10.0 ± 1.0 | 1.6 ± 1.1 | 5.4 ± 1.0 | 11.4 ± 1.0 |
| Rz | 12.2 ± 0.6 | -3.8 ± 0.6 | 4.2 ± 0.7 | 10.2 ± 0.6 | 2.2 ± 0.7 | 6.8 ± 0.9 |

**Table S89:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 30.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.3 ± 0.2 | 2.0 ± 0.2 | 1.0 ± 0.2 | 2.0 ± 0.3 | 1.3 ± 0.3 | 2.7 ± 0.3 |
| abduction/adduction | 4.3 ± 0.1 | 2.0 ± 0.1 | 0.7 ± 0.1 | 1.1 ± 0.2 | 0.5 ± 0.0 | 0.8 ± 0.1 |
| external/internal rotation | 7.0 ± 0.2 | 4.9 ± 0.3 | 0.8 ± 0.1 | 3.7 ± 0.4 | 0.8 ± 0.1 | 3.6 ± 0.3 |

**Table S90:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 30.

## 2.30 Averaged plots for individual knee 31

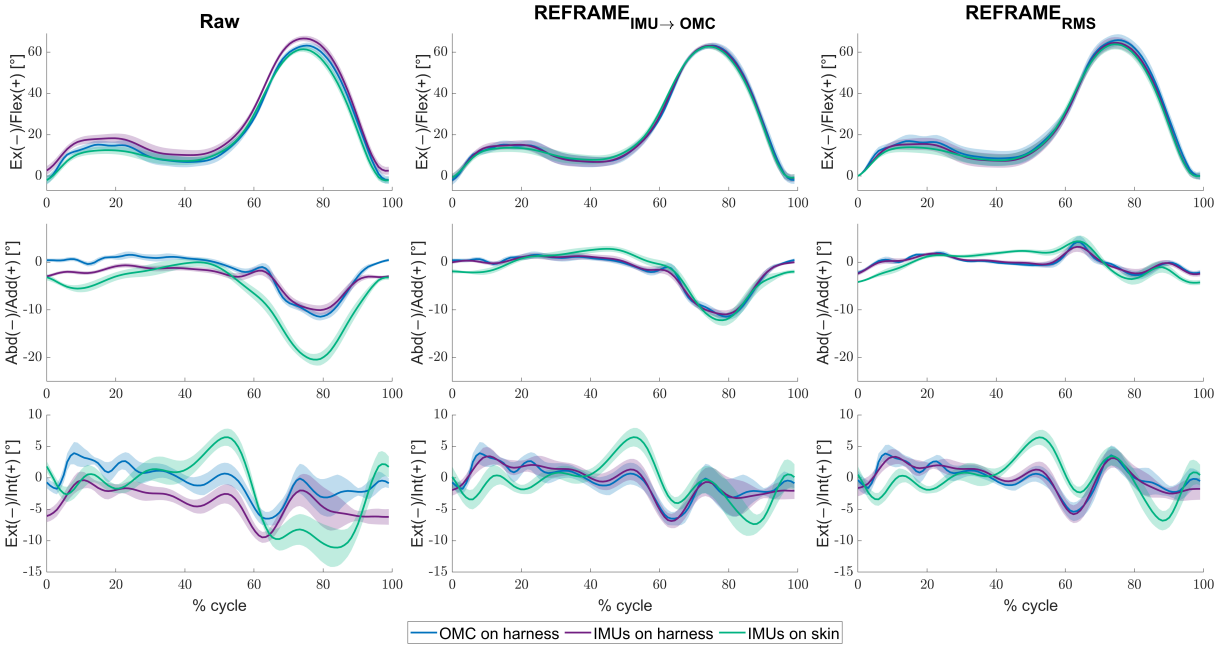



**Figure S30:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 31. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.1 ± 0.1 | -1.0 ± 0.3 |
| Ry | 0.6 ± 0.4 | -4.9 ± 1.1 | 3.8 ± 0.4 | -3.5 ± 1.1 |
| Rz | -4.8 ± 0.4 | 10.5 ± 1.1 | -0.9 ± 0.2 | 9.0 ± 0.9 |

**Table S91:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 31.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | -1.6 ± 2.1 | 2.5 ± 2.0 | -0.6 ± 1.8 |
| Ry | 2.9 ± 2.0 | 3.4 ± 2.2 | -2.0 ± 2.2 | 0.3 ± 2.3 | 4.3 ± 2.5 | -2.7 ± 2.5 |
| Rz | 11.0 ± 1.1 | 6.1 ± 1.2 | 21.2 ± 1.2 | 11.3 ± 1.0 | 10.5 ± 0.9 | 20.1 ± 1.2 |

**Table S92:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 31.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.6 ± 0.1 | 2.4 ± 0.2 | 1.0 ± 0.1 | 1.7 ± 0.2 | 1.6 ± 0.3 | 2.3 ± 0.5 |
| abduction/adduction | 2.0 ± 0.1 | 5.3 ± 0.4 | 0.4 ± 0.1 | 1.6 ± 0.2 | 0.4 ± 0.0 | 1.8 ± 0.1 |
| external/internal rotation | 3.5 ± 0.4 | 4.9 ± 0.4 | 0.7 ± 0.1 | 3.5 ± 0.4 | 0.7 ± 0.1 | 3.5 ± 0.3 |

**Table S93:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 31.

## 2.31 Averaged plots for individual knee 32

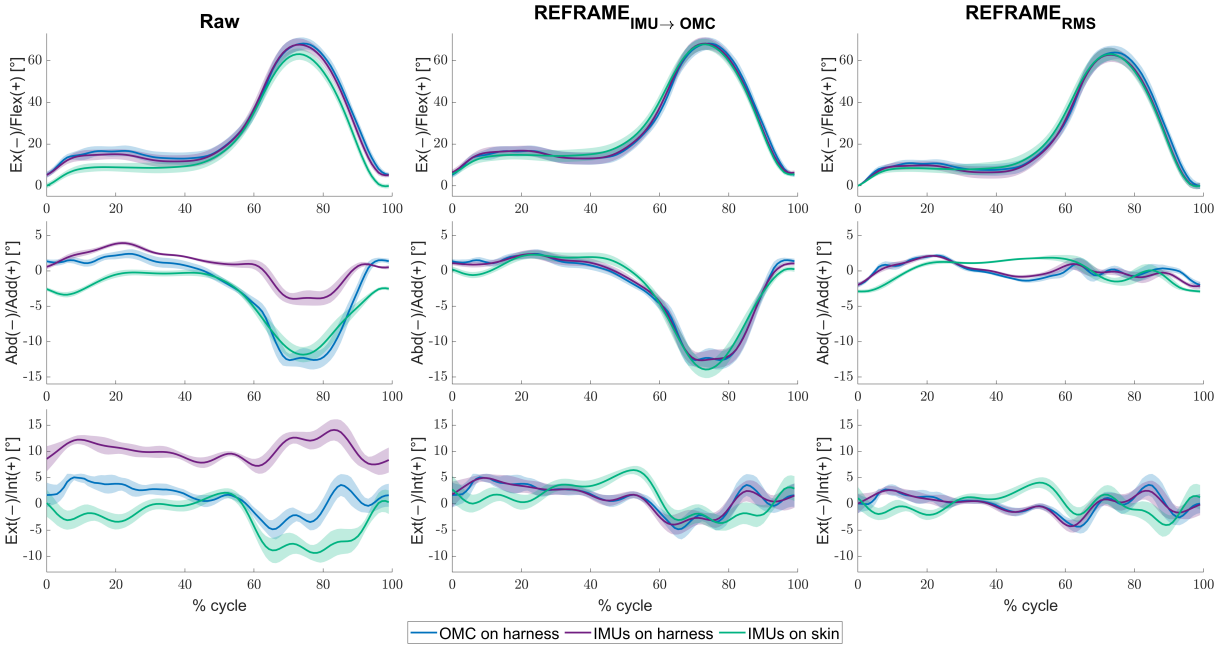



**Figure S31:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 32. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -0.4 ± 0.1 | -5.7 ± 0.3 |
| Ry | 1.2 ± 0.2 | -6.4 ± 1.2 | 3.1 ± 0.2 | -3.3 ± 1.4 |
| Rz | -12.1 ± 0.3 | -2.2 ± 1.1 | -18.7 ± 0.2 | 0.1 ± 0.6 |

**Table S94:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 32.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 5.8 ± 1.4 | 5.7 ± 1.4 | 0.6 ± 1.1 |
| Ry | 5.1 ± 1.5 | 6.0 ± 1.4 | -1.6 ± 2.1 | 1.6 ± 1.5 | 2.5 ± 1.4 | -1.9 ± 2.2 |
| Rz | 14.9 ± 0.6 | 3.1 ± 0.7 | 13.0 ± 1.2 | 13.4 ± 0.6 | -5.4 ± 0.6 | 14.0 ± 0.7 |

**Table S95:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 32.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.8 ± 0.3 | 6.1 ± 0.3 | 1.4 ± 0.3 | 2.7 ± 0.2 | 1.8 ± 0.4 | 2.6 ± 0.4 |
| abduction/adduction | 4.4 ± 0.2 | 2.5 ± 0.2 | 0.4 ± 0.1 | 1.2 ± 0.1 | 0.5 ± 0.1 | 1.7 ± 0.1 |
| external/internal rotation | 9.5 ± 0.2 | 5.3 ± 0.4 | 0.7 ± 0.1 | 3.0 ± 0.3 | 0.7 ± 0.1 | 3.0 ± 0.3 |

**Table S96:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 32.

## 2.32 Averaged plots for individual knee 33

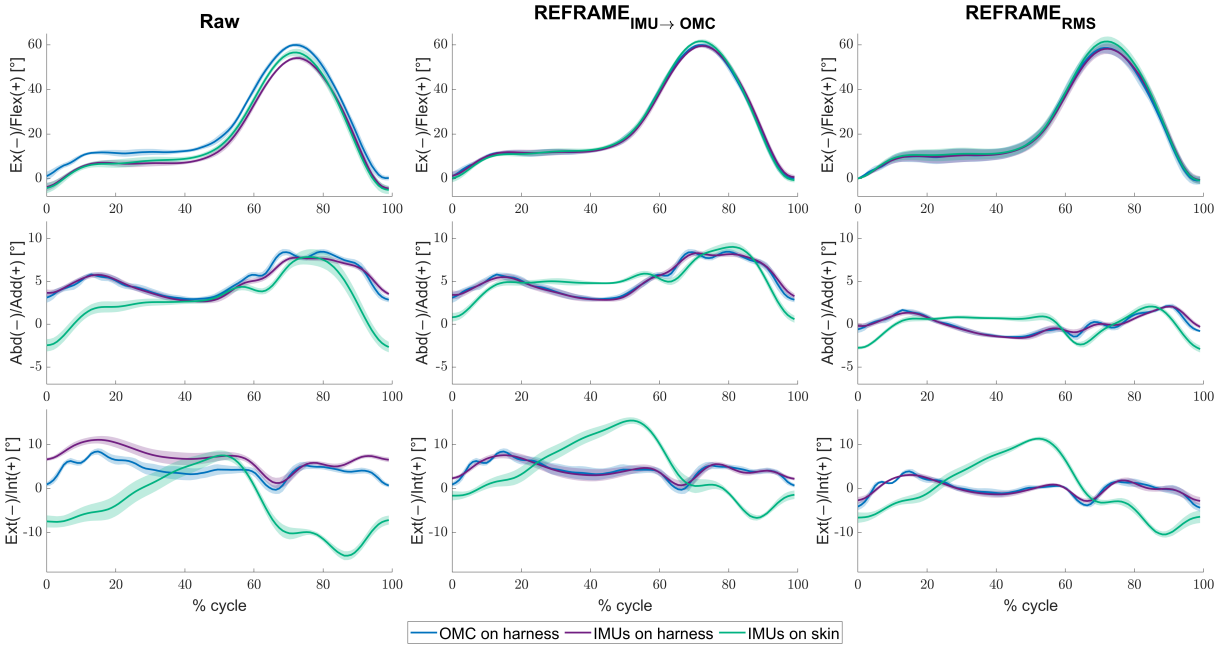



**Figure S32:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 33. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -5.5 ± 0.1 | -4.1 ± 1.3 |
| Ry | -3.1 ± 0.2 | -5.0 ± 1.0 | -2.8 ± 0.3 | -2.2 ± 0.9 |
| Rz | 2.4 ± 0.2 | -0.3 ± 0.6 | -2.3 ± 0.1 | 5.7 ± 0.8 |

**Table S97:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 33.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.9 ± 2.0 | -5.0 ± 2.0 | -3.2 ± 2.5 |
| Ry | -3.6 ± 0.8 | -6.7 ± 1.0 | -8.4 ± 1.4 | -7.3 ± 0.7 | -10.1 ± 0.8 | -9.2 ± 1.2 |
| Rz | -3.3 ± 0.4 | -1.1 ± 0.5 | -3.9 ± 0.5 | -8.3 ± 0.6 | -10.7 ± 0.7 | -2.8 ± 1.3 |

**Table S98:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 33.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 5.2 ± 0.1 | 4.5 ± 1.3 | 1.1 ± 0.1 | 1.1 ± 0.3 | 1.2 ± 0.2 | 1.6 ± 0.3 |
| abduction/adduction | 0.5 ± 0.1 | 3.0 ± 0.3 | 0.3 ± 0.0 | 1.4 ± 0.1 | 0.3 ± 0.0 | 1.5 ± 0.2 |
| external/internal rotation | 3.1 ± 0.2 | 10.7 ± 0.6 | 0.6 ± 0.1 | 6.9 ± 0.3 | 0.6 ± 0.1 | 6.8 ± 0.2 |

**Table S99:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 33.

## 2.33 Averaged plots for individual knee 34

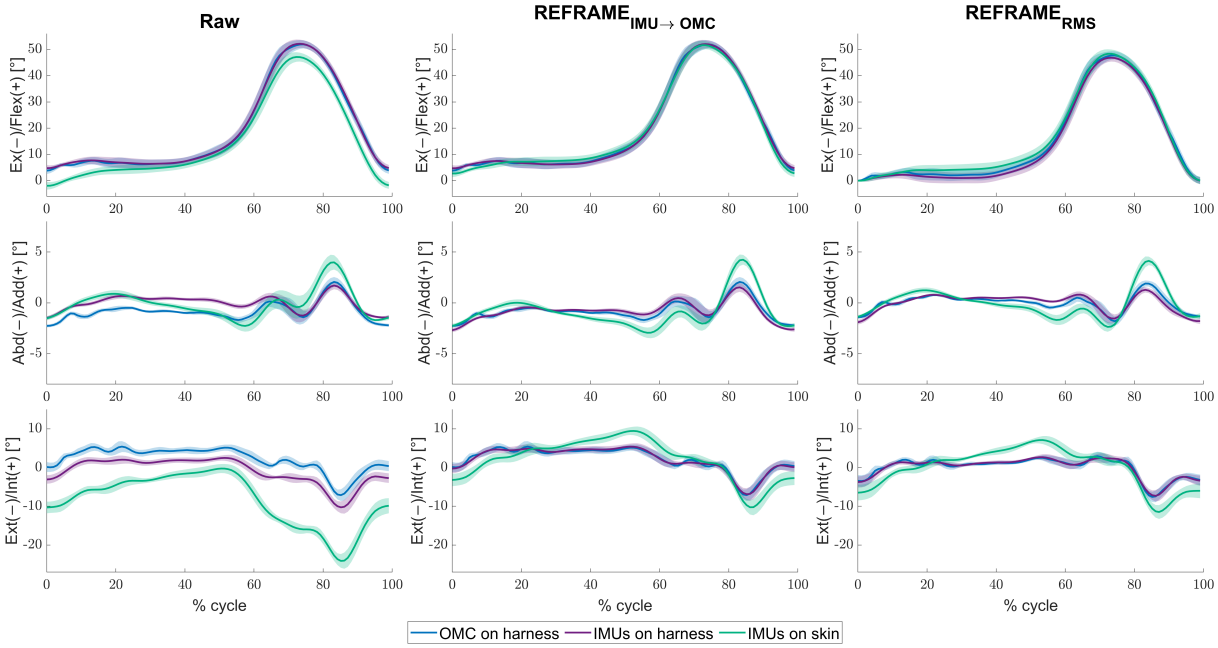



**Figure S33:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 34. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.2 ± 0.1 | -2.2 ± 0.3 |
| Ry | -0.4 ± 0.3 | -11.4 ± 1.4 | -1.7 ± 0.3 | -13.0 ± 1.3 |
| Rz | 2.0 ± 0.3 | 4.1 ± 0.6 | 4.7 ± 0.1 | 11.0 ± 0.8 |

**Table S100:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 34.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.8 ± 1.3 | 5.2 ± 1.2 | 1.1 ± 1.6 |
| Ry | -6.1 ± 0.9 | -6.7 ± 1.0 | -16.2 ± 2.0 | -5.2 ± 0.9 | -6.9 ± 1.0 | -16.1 ± 2.0 |
| Rz | 1.0 ± 0.5 | 3.1 ± 0.5 | 4.3 ± 0.9 | -2.7 ± 0.5 | 2.3 ± 0.5 | 8.6 ± 1.0 |

**Table S101:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 34.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 0.6 ± 0.0 | 4.4 ± 0.1 | 0.6 ± 0.0 | 1.2 ± 0.1 | 1.1 ± 0.1 | 1.4 ± 0.2 |
| abduction/adduction | 1.0 ± 0.1 | 1.1 ± 0.2 | 0.3 ± 0.0 | 1.0 ± 0.1 | 0.4 ± 0.0 | 0.9 ± 0.1 |
| external/internal rotation | 3.1 ± 0.2 | 11.4 ± 0.3 | 0.5 ± 0.1 | 3.0 ± 0.3 | 0.5 ± 0.1 | 3.1 ± 0.3 |

**Table S102:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 34.

## 2.34 Averaged plots for individual knee 35

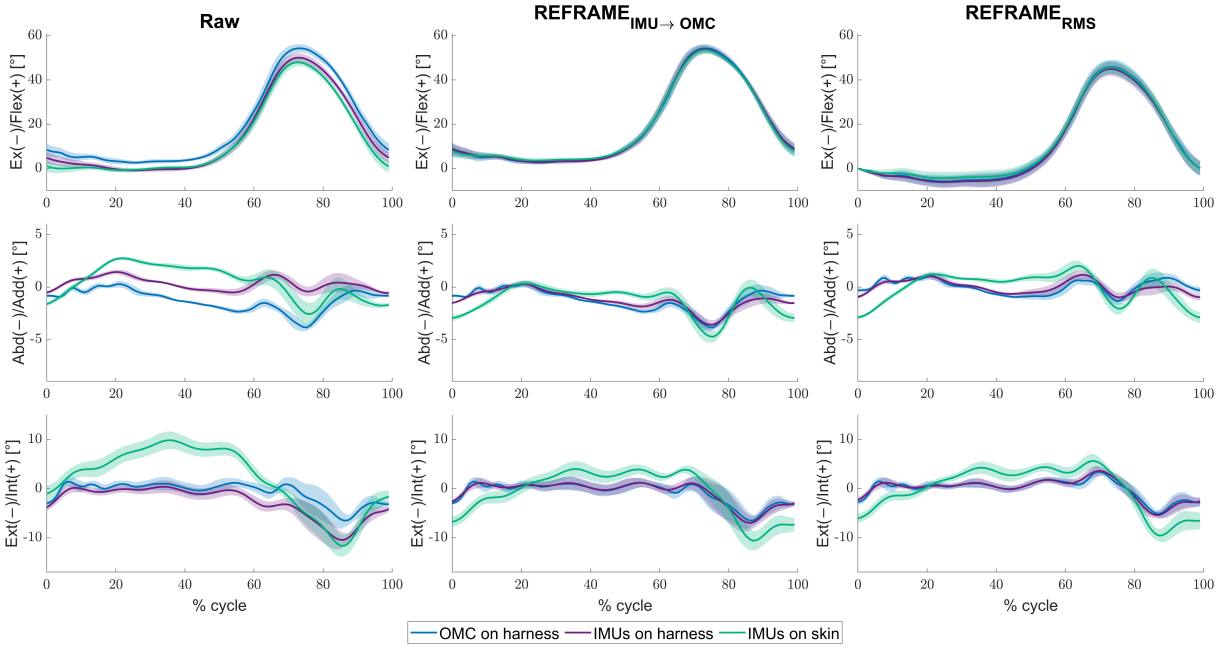



**Figure S34:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 35. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -3.7 ± 0.1 | -6.4 ± 0.3 |
| Ry | -5.1 ± 0.2 | -12.5 ± 0.8 | -6.2 ± 0.1 | -14.6 ± 0.9 |
| Rz | -0.5 ± 0.2 | 5.4 ± 0.8 | -0.0 ± 0.2 | -1.8 ± 0.8 |

**Table S103:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 35.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 8.5 ± 2.9 | 5.3 ± 2.7 | 1.7 ± 2.9 |
| Ry | -1.6 ± 2.2 | -6.8 ± 2.1 | -13.3 ± 2.4 | -0.7 ± 2.2 | -6.8 ± 2.1 | -14.5 ± 2.4 |
| Rz | 3.2 ± 1.3 | 2.8 ± 1.4 | 8.2 ± 1.9 | 3.3 ± 1.4 | 4.3 ± 1.5 | 3.3 ± 2.1 |

**Table S104:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 35.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 3.9 ± 0.1 | 5.7 ± 0.2 | 0.6 ± 0.1 | 0.9 ± 0.2 | 0.8 ± 0.2 | 1.1 ± 0.4 |
| abduction/adduction | 1.8 ± 0.2 | 2.3 ± 0.2 | 0.4 ± 0.0 | 1.1 ± 0.1 | 0.4 ± 0.0 | 1.4 ± 0.1 |
| external/internal rotation | 2.4 ± 0.1 | 5.5 ± 0.4 | 0.5 ± 0.1 | 3.1 ± 0.4 | 0.5 ± 0.1 | 3.0 ± 0.4 |

**Table S105:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 35.

## 2.35 Averaged plots for individual knee 36

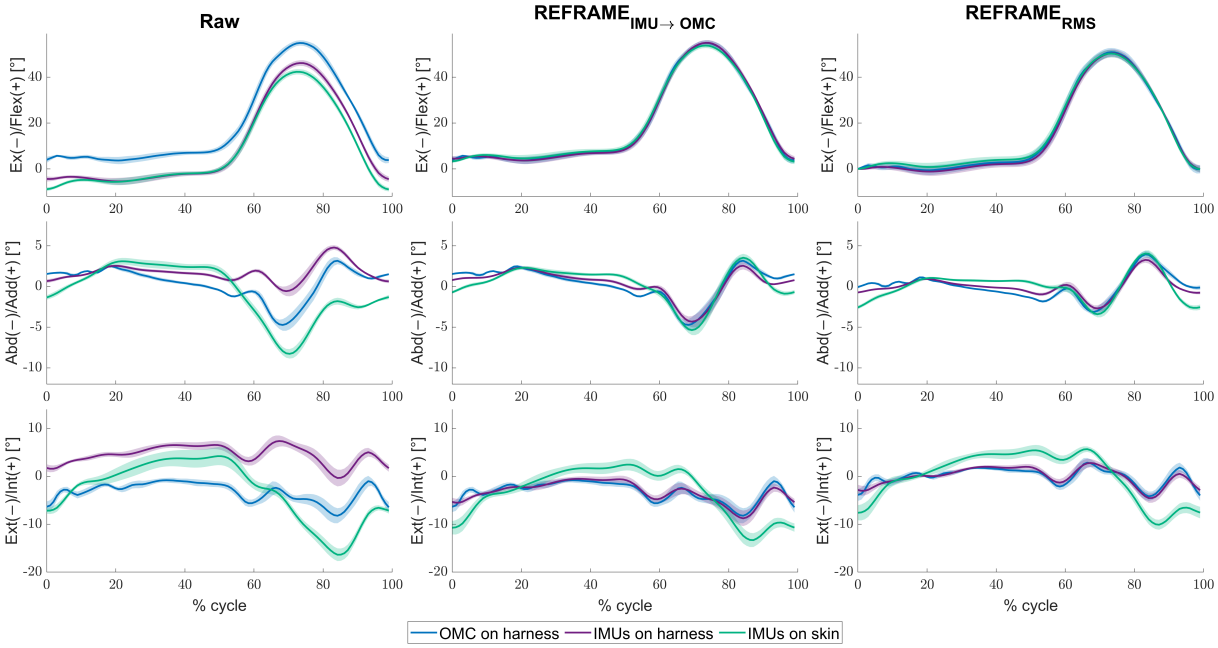



**Figure S35:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 36. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -8.7 ± 0.1 | -10.8 ± 0.2 |
| Ry | 1.4 ± 0.2 | -9.5 ± 1.5 | 2.2 ± 0.2 | -10.8 ± 1.5 |
| Rz | -5.0 ± 0.1 | 8.4 ± 0.5 | -12.1 ± 0.1 | 4.5 ± 0.6 |

**Table S106:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 36.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 4.3 ± 1.3 | -4.4 ± 1.1 | -6.9 ± 0.7 |
| Ry | -1.5 ± 1.4 | -0.3 ± 1.5 | -9.2 ± 2.0 | -2.6 ± 1.5 | -1.5 ± 1.5 | -11.3 ± 2.1 |
| Rz | 4.7 ± 0.5 | -0.3 ± 0.5 | 12.4 ± 0.8 | 7.3 ± 0.6 | -5.0 ± 0.6 | 12.3 ± 0.8 |

**Table S107:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 36.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 9.0 ± 0.1 | 11.0 ± 0.1 | 0.7 ± 0.1 | 1.1 ± 0.1 | 0.9 ± 0.2 | 1.4 ± 0.4 |
| abduction/adduction | 1.9 ± 0.1 | 2.7 ± 0.2 | 0.5 ± 0.0 | 1.1 ± 0.1 | 0.6 ± 0.0 | 1.3 ± 0.1 |
| external/internal rotation | 7.9 ± 0.1 | 4.9 ± 0.5 | 0.7 ± 0.1 | 4.1 ± 0.4 | 0.7 ± 0.1 | 4.1 ± 0.4 |

**Table S108:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 36.

## 2.36 Averaged plots for individual knee 37

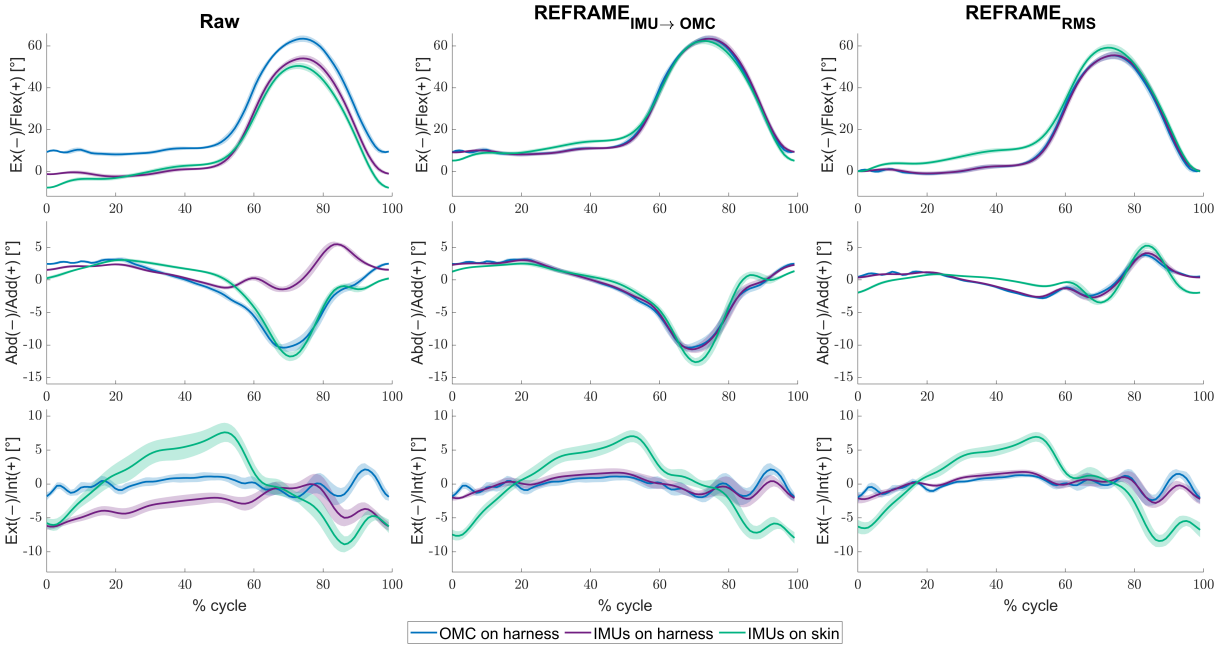



**Figure S36:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 37. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -9.8 ± 0.1 | -12.5 ± 0.2 |
| Ry | -1.9 ± 0.2 | -5.9 ± 0.9 | -0.4 ± 0.1 | -6.3 ± 0.9 |
| Rz | -11.3 ± 0.2 | 2.4 ± 0.8 | -7.7 ± 0.2 | 0.0 ± 0.7 |

**Table S109:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 37.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 9.0 ± 0.4 | -1.6 ± 0.4 | -7.3 ± 0.4 |
| Ry | 5.2 ± 0.9 | 3.0 ± 1.0 | 1.5 ± 0.9 | 3.5 ± 0.9 | 1.7 ± 1.0 | -1.4 ± 0.9 |
| Rz | 10.1 ± 0.4 | -1.4 ± 0.4 | 12.0 ± 0.8 | 10.3 ± 0.6 | 2.7 ± 0.5 | 11.4 ± 0.8 |

**Table S110:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 37.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 10.1 ± 0.1 | 12.4 ± 0.2 | 1.0 ± 0.1 | 2.3 ± 0.1 | 1.0 ± 0.1 | 5.0 ± 0.2 |
| abduction/adduction | 4.7 ± 0.1 | 1.5 ± 0.1 | 0.3 ± 0.0 | 1.1 ± 0.1 | 0.3 ± 0.0 | 1.4 ± 0.1 |
| external/internal rotation | 3.6 ± 0.2 | 4.5 ± 0.3 | 0.7 ± 0.1 | 4.3 ± 0.3 | 0.7 ± 0.1 | 4.1 ± 0.3 |

**Table S111:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 37.

## 2.37 Averaged plots for individual knee 38

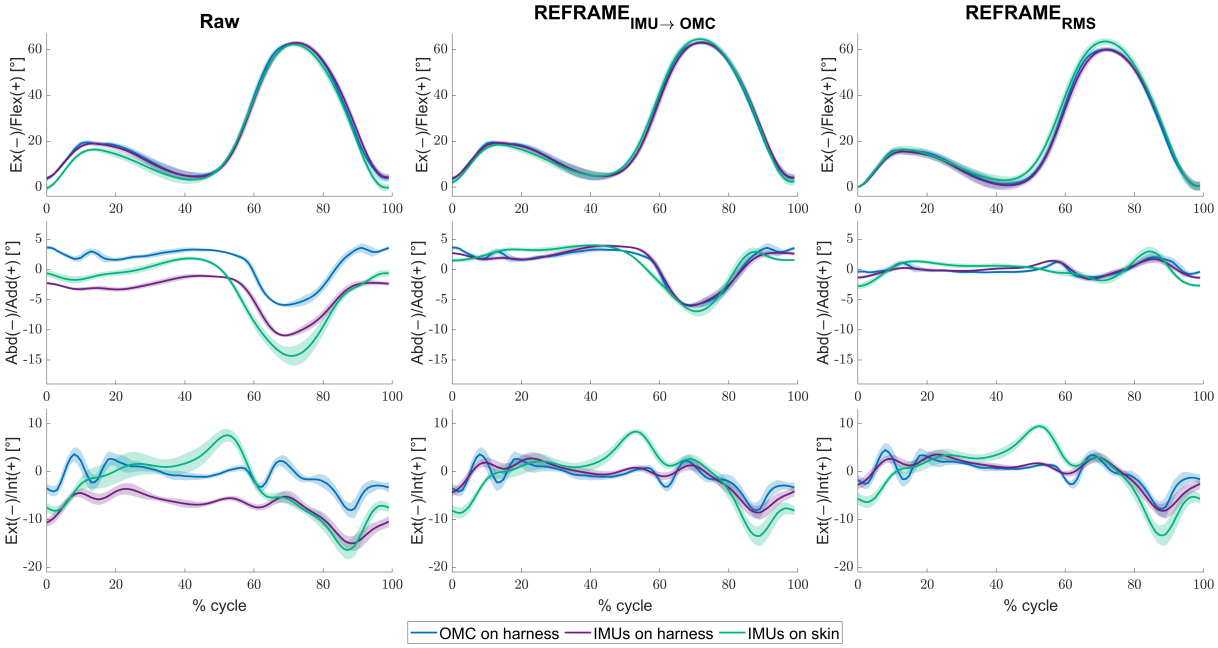



**Figure S37:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 38. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -0.7 ± 0.1 | -2.4 ± 0.3 |
| Ry | -0.3 ± 0.3 | -4.9 ± 1.0 | 4.6 ± 0.3 | -3.5 ± 0.9 |
| Rz | 0.1 ± 0.2 | 9.4 ± 1.2 | 6.4 ± 0.2 | 8.6 ± 0.8 |

**Table S112:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 38.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.4 ± 0.9 | 3.1 ± 0.8 | 0.2 ± 1.2 |
| Ry | 5.1 ± 0.7 | 4.3 ± 0.6 | 1.7 ± 0.6 | 1.3 ± 0.7 | 5.9 ± 0.6 | -0.4 ± 0.7 |
| Rz | 6.9 ± 0.6 | 7.2 ± 0.4 | 15.4 ± 1.5 | 8.8 ± 0.5 | 15.0 ± 0.4 | 17.2 ± 0.7 |

**Table S113:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 38.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.2 ± 0.1 | 2.7 ± 0.3 | 1.0 ± 0.1 | 1.5 ± 0.1 | 1.2 ± 0.3 | 2.3 ± 0.4 |
| abduction/adduction | 5.0 ± 0.1 | 5.1 ± 0.5 | 0.5 ± 0.1 | 1.2 ± 0.2 | 0.5 ± 0.1 | 1.2 ± 0.2 |
| external/internal rotation | 6.6 ± 0.2 | 5.6 ± 0.3 | 1.4 ± 0.1 | 4.3 ± 0.3 | 1.4 ± 0.1 | 4.2 ± 0.3 |

**Table S114:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 38.

## 2.38 Averaged plots for individual knee 39

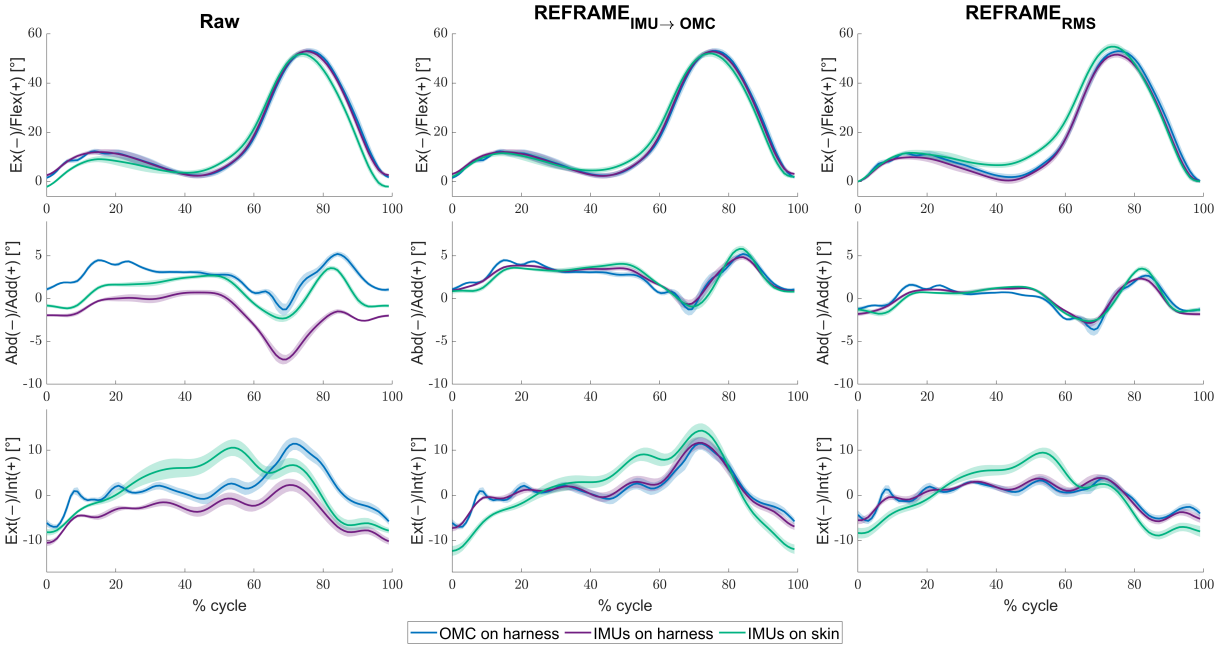



**Figure S38:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 39. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -0.2 ± 0.1 | -2.6 ± 0.2 |
| Ry | -4.7 ± 0.3 | -12.2 ± 1.2 | -2.3 ± 0.2 | -11.2 ± 1.2 |
| Rz | 7.7 ± 0.1 | 6.3 ± 0.6 | 10.7 ± 0.1 | 1.9 ± 0.6 |

**Table S115:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 39.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.6 ± 0.6 | 1.5 ± 0.5 | -2.7 ± 0.5 |
| Ry | 10.4 ± 1.5 | 6.1 ± 1.5 | 4.5 ± 1.5 | 8.2 ± 1.5 | 6.7 ± 1.5 | 3.7 ± 1.5 |
| Rz | -4.5 ± 0.4 | 3.1 ± 0.4 | -0.9 ± 0.6 | -2.6 ± 0.5 | 8.1 ± 0.6 | -1.0 ± 1.0 |

**Table S116:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 39.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 1.0 ± 0.2 | 3.8 ± 0.2 | 1.0 ± 0.2 | 2.5 ± 0.3 | 1.6 ± 0.2 | 3.9 ± 0.2 |
| abduction/adduction | 4.5 ± 0.1 | 2.0 ± 0.1 | 0.4 ± 0.1 | 0.8 ± 0.1 | 0.6 ± 0.1 | 0.7 ± 0.1 |
| external/internal rotation | 5.5 ± 0.1 | 5.0 ± 0.3 | 0.9 ± 0.1 | 4.3 ± 0.3 | 0.8 ± 0.1 | 3.7 ± 0.3 |

**Table S117:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 39.

## 2.39 Averaged plots for individual knee 40

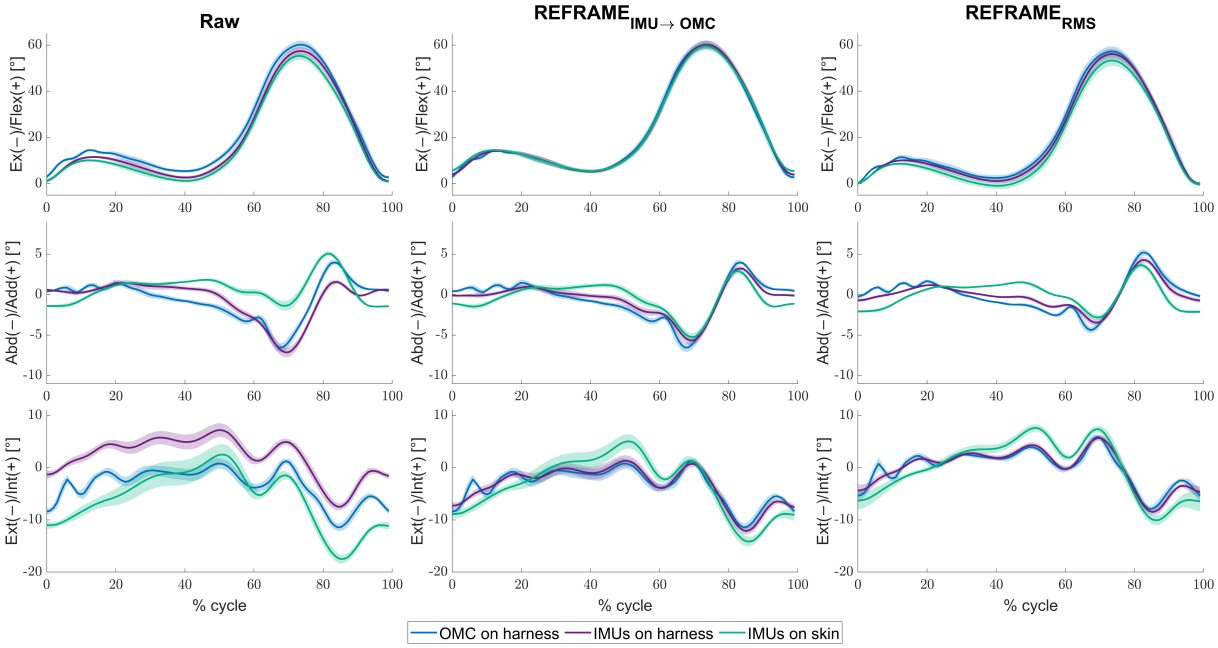



**Figure S39:** Mean tibio-femoral joint angles (solid lines) ± standard deviation (shaded areas), in degrees, as estimated by inertial measurement units (IMUs) on harness (purple), IMUs on skin (green), and optical motion capture (OMC) on harness (blue), averaged over all cycles for knee 40. Angles are shown as a percentage of the gait cycle under three conditions: 1) raw, i.e. in the absence of post-processing methods to correct reference frame orientation differences (left), 2) after implementation of REFRAME$_{IMU->OMC}$ (middle), and 3) after implementation of REFRAME$_{RMS}$ (right).

| | Femur | | Tibia | |
|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | -2.7 ± 0.1 | -4.1 ± 0.1 |
| Ry | -0.7 ± 0.3 | -2.8 ± 0.7 | -1.7 ± 0.3 | -3.0 ± 0.8 |
| Rz | 3.6 ± 0.3 | -3.0 ± 0.6 | -2.5 ± 0.1 | -1.0 ± 0.3 |

**Table S118:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{IMU->OMC}$, calculated across all cycles of knee 40.

| | Femur | | | Tibia | | |
|---|---|---|---|---|---|---|
| | OMC on harness | IMUs on harness | IMUs on skin | OMC on harness | IMUs on harness | IMUs on skin |
| Rx | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.0 ± 0.8 | 1.3 ± 0.7 | 2.1 ± 0.9 |
| Ry | -0.1 ± 1.1 | -1.2 ± 1.3 | -4.9 ± 2.2 | -0.3 ± 1.0 | -2.5 ± 1.3 | -5.3 ± 2.3 |
| Rz | 3.0 ± 0.5 | 6.6 ± 0.7 | 1.0 ± 1.4 | 6.0 ± 0.6 | 3.6 ± 0.6 | 5.7 ± 0.7 |

**Table S119:** Mean ± standard deviation (in degrees) of the rotational transformations (Rx: Rotation around X, Ry: Rotation around Y, Rz: Rotation around Z) applied to the femoral and tibial segment frames as part of REFRAME$_{RMS}$, calculated across all cycles of knee 40.

| | **Raw** | | **REFRAME**$_{IMU->OMC}$ | | **REFRAME**$_{RMS}$ | |
|---|---|---|---|---|---|---|
| | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin | IMUs on harness | IMUs on skin |
| flexion/extension | 2.8 ± 0.1 | 4.4 ± 0.1 | 1.0 ± 0.1 | 1.2 ± 0.1 | 1.5 ± 0.3 | 3.3 ± 0.4 |
| abduction/adduction | 1.2 ± 0.0 | 2.6 ± 0.1 | 0.7 ± 0.1 | 1.6 ± 0.0 | 0.7 ± 0.1 | 1.9 ± 0.1 |
| external/internal rotation | 5.5 ± 0.3 | 3.9 ± 0.2 | 0.8 ± 0.1 | 2.7 ± 0.4 | 0.8 ± 0.1 | 2.6 ± 0.3 |

**Table S120:** Mean ± standard deviation (in degrees) root-mean-square errors between tibio-femoral joint rotations estimated by the IMU-based systems and the optical reference on harness, calculated across all trials of knee 40.

# 3 Statistical Analysis

| | **Raw vs. REFRAME**$_{IMU->OMC}$ | **Raw vs. REFRAME**$_{RMS}$ |
|---|---|---|
| flexion/extension | $1.3 * 10^{-7}$ | $2.9 * 10^{-6}$ |
| abduction/adduction | $9.0 * 10^{-9}$ | $1.0 * 10^{-9}$ |
| external/internal rotation | $1.5 * 10^{-12}$ | $1.4 * 10^{-12}$ |

**Table S121:** p-values associated with a two-tailed paired t-test performed on the mean RMSEs between tibiofemoral joint rotations estimated by the IMUs on harness and the OMC on harness.

| | **Raw vs. REFRAME**$_{IMU->OMC}$ | **Raw vs. REFRAME**$_{RMS}$ |
|---|---|---|
| flexion/extension | $1.2 * 10^{-7}$ | $4.4 * 10^{-5}$ |
| abduction/adduction | $1.7 * 10^{-9}$ | $7.6 * 10^{-9}$ |
| external/internal rotation | $6.7 * 10^{-8}$ | $2.0 * 10^{-8}$ |

**Table S122:** p-values associated with a two-tailed paired t-test performed on the mean RMSEs between tibiofemoral joint rotations estimated by the IMUs on skin and the OMC on harness.