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Recommendations of the GAMMA association for the standardization of clinical movement analysis laboratories

Andreas Kranzl [a], Felix Stief [b], Harald Böhm [c,d,*], Nathalie Alexander [e,f], Katrin Bracht-Schweizer [g,h], Matthias Hartmann [i], Matthias Hösl [j], Ursula Trinler [k], Klaus Widhalm [l], Brian Horsak [m,n,**]

[a] Orthopaedic Hospital Speising, Laboratory of Gait and Motion Analysis, Speisinger Str. 109, Vienna 1130, Austria
[b] Berufsgenossenschaftliche Unfallklinik Frankfurt/Main, Funktion and Motion Lab, Friedberger Landstraße 430, Frankfurt/Main 60389, Germany
[c] Orthopaedic Hospital for Children, Behandlungszentrum Aschau GmbH, Bernauerstr. 18, Aschau i. Chiemgau, 83229, Germany
[d] HAWK University of Applied Sciences and Arts, Faculty of Engineering and Health Göttingen, Annastr 25, Göttingen 37075, Germany
[e] Laboratory for Motion Analysis, Department of Paediatric Orthopaedics, Children's Hospital of Eastern Switzerland, Switzerland
[f] Department of Orthopaedics and Traumatology, Kantonsspital St. Gallen, St. Gallen, Switzerland
[g] Laboratory for Movement Analysis, University Children's Hospital Basel, Spitalstrasse 33, Basel CH-4031, Switzerland
[h] University of Basel, Petersplatz 1, Basel CH-4003, Switzerland
[i] German Center for Pediatric and Adolescent Rheumatology, Garmisch-Partenkirchen, Germany
[j] Gait and Motion Analysis Laboratory, Schön Clinic Vogtareuth, Vogtareuth, Germany
[k] BG Klinik Ludwigshafen, Ludwig-Guttmann-Straße 13, Ludwigshafen 67071, Germany
[l] FH Campus Wien, University of Applied Sciences, Health Sciences, Vienna, Austria
[m] Center for Digital Health and Social Innovation, St. Pölten University of Applied Sciences, Campus-Platz 1, St. Pölten 3100, Austria
[n] Institute of Health Sciences, St. Pölten University of Applied Sciences, Campus-Platz 1, St. Pölten 3100, Austria

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ABSTRACT

Clinical gait analysis involves objective, valid, and reliable techniques for assessing gait function and is crucial for assessing walking patterns and identifying gait abnormalities in various patient populations. By analyzing joint angles, muscle activity, and other biomechanical factors during walking, clinicians can diagnose gait disorders, plan interventions, and improve patient outcomes. The GAMMA association aims to provide recommendations to support the standardization and quality assurance for clinical-instrumented 3D motion analysis services within the German-speaking region in central Europe. The practice recommendations described in this paper cover among others (i) technical requirements for recording data on level ground and on treadmills, (ii) staff management, (iii) recommendations for measurement equipment and quality assurance procedures, (iv) patient referral management, (v) practical recommendations for data acquisition, management, and reporting, and (vi) information to consider when setting up a new gait analysis facility. The GAMMA association aspires for these clinical practice guidelines to enhance motion analysis services, leading to better and more standardized clinical practices, which further contribute to improved patient care, and better conditions for research in central Europe.

1. Introduction

The GAMMA aims to provide support and recommendations for conducting clinical-instrumental 3D gait and motion analysis with this document.

Definition. *Clinical instrumented 3D gait analysis encompasses a defined, systematic, and clearly documented repertoire of objective, valid, and reliable examination techniques and biomechanical measurement methods for functional diagnostics. The support of computer and software tools enables objective evaluation. The systematic approach includes data and information preparation, presentation, structuring, and interpretation.*

* Corresponding author at: Orthopaedic Hospital for Children, Behandlungszentrum Aschau GmbH, Bernauerstr. 18, Aschau i. Chiemgau, 83229, Germany.
** Corresponding author at: Center for Digital Health and Social Innovation, St. Pölten University of Applied Sciences, Campus-Platz 1, St. Pölten 3100, Austria.
E-mail addresses: h.boehm@kiz-chiemgau.de (H. Böhm), brian.horsak@fhsp.ac.at (B. Horsak).

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Clinical gait analyses are typically conducted based on a medical question for a patient (an individual under medical care).

Ideally, this process follows specific rules and within established frameworks. Clinical, instrumented 3D gait analysis is intended for targeted medical application in clinics and practices. The question of the examination defines the use of the respective methods.

Clinical, instrumented 3D gait analysis serves as a diagnostic tool providing insights into the pathobiomechanics or pathophysiology of complex gait disorders, understanding of which is essential for appropriate therapeutic selection. It can be utilized for functional screening following reconstructive or surgical interventions, for quality control, determining the severity of a functional impairment, objectively comparing competing therapeutic approaches, planning surgical procedures, assessing rehabilitation outcomes, and quantitatively evaluating the effects of orthoses, insoles, and footwear. Furthermore, it can also be employed for investigating the causes of overuse injuries. The instrumented 3D gait analysis involves capturing gait function, including precise determination of joint angle patterns, joint moments, and power of e.g., the upper body, hip, knee, and ankle joints. Additionally, dynamic electromyography assesses the activity of superficially located muscles during walking. Pedobarographic measurements indicate load distribution within the contact area. Clinical examination and pain assessment complement the measurements.

Methods of clinical, instrumented 3D gait analysis are thus suitable for detailed diagnostics of gait function, which is not possible with typical imaging techniques such as X-rays, MRI, and CT scans, as these solely depict anatomy, not function or dynamic dysfunction. Two recently published systematic reviews [15,38] as well as a study by McGrath [24] underscore the benefits of instrumented 3D gait analysis in medical decision-making. The use of 3D gait analysis enhances physicians' confidence in treatment planning, leads to better agreement in therapy planning among physicians, reduces the proportion of unnecessary interventions, and can also contribute to improving patient outcomes [15,24,36–38].

This document serves as a quality management tool for laboratories within GAMMA. It also serves as the basis for accreditation as a clinical motion analysis laboratory. Specifically, when establishing a new motion analysis laboratory that should adhere to current standards, this document can serve as a guide.

This document is intended to provide guidance and serve as a guideline for readers in setting up internal quality assurance measures. Additionally, GAMMA, as the largest and most influential representation of clinical gait laboratories in the DACH region, aims to undergo an accreditation process for external quality assurance. This process will involve the evaluation and confirmation of the effectiveness of the proposed internal quality assurance processes by (independent) external experts. The goal of this accreditation process is to ensure transparency and enhance trust in the quality of services provided by clinical, instrumented 3D gait and motion analysis.

Minimum requirements are defined for each area, while optimal conditions are considered recommendations. This document will be adapted over time to reflect the current situation. The present version reflects the initial German version of the GAMMA standards document v1.0-04/2024 is accessible from the GAMMA website.

2. Requirements for facilities

Depending on the analysis protocol and setting (treadmill or walking on level, flat ground), the requirements for the space vary. Additionally, different measurement systems have technical requirements for room size that need to be individually considered. In general, the room should be large enough to meet the specific requirements of the research question. Further details can be found in the respective subsections. Generally, we recommend analyzing the gait on level ground, as adaptation time to a treadmill can be 6 minutes or longer [26].

For the motion analysis laboratory, a close connection with clinical operations (practice) is crucial. This ensures short distances for patients, reducing their time in the clinic/practice. It also facilitates communication with referring physicians. Access to the premises should be adapted to the needs of disabled and secure to protect valuable equipment. Entry during examinations should be designed to prevent any view of the patient. Privacy during measurements must be strictly maintained, employing suitable methods based on individual circumstances.

In general, the design of a desk/computer workstation should also be considered when planning a laboratory. The desk/workstation should be positioned appropriately for observing gait patterns, with a clear view of the patient. Ideally, a lateral positioning offers the best view, followed by a frontal position facing the walking path. However, this depends on the spatial constraints.

Adequate seating for accompanying individuals (such as parents) should be provided. The examination area (e.g., walking path, clinical examination) should be located in a quiet area to prevent disturbances to the patients.

For visual orientation, it's advisable to use a contrasting floor color for the walking path. This creates a visual walking path for the patient. The width of this path should be at least 1 m, which can be crucial for spatial orientation depending on the patient's cognition.

The walking path should be flat, and the flooring should be free of edges. Avoiding different floorings within the walking path, except for specific testing purposes, is recommended. The flooring should also include the force plates, which should be level with the walking path and not visually distinct. If only one force plate is used, expect an increase in the number of trials during gait analysis and a longer measurement duration.

The spatial arrangement of the force plates and their distance from each other largely depend on the type of movement being measured, as well as the size and stride length of the patients. Typical arrangements of force plates may resemble those shown in Fig. 1.

The most used floorings in hospitals across Europe are vinyl (PVC), linoleum, and rubber. Homogeneous PVC floors are best suited, but heterogeneous PVC floors and linoleum are also suitable for certain areas. Hard surfaces such as parquet, solid wood planks, laminate, ceramic tiles, natural stone, or cement screeds are not ideal or too hard for walking without shoes. The floor should not be slippery. Additionally, during cleaning, attention should be paid to preserving the floor, aligning with the hygiene guidelines of the facility.

A non-reflective flooring is important to minimize reflections for the motion analysis system (system-dependent). Regular cleaning of the floor, measurement equipment, and facilities should follow local hospital regulations. The hygiene requirements of the clinical facility should be documented, and the necessary tools for this should be available in the laboratory area (sink, soap, disinfectant, etc.).

Daylight data capture may also play a role depending on the measurement system. For some measurement systems, complete room darkening may be necessary. Window blinds are important for examinations conducted in underwear.

Generally, the room should be large enough to meet the specific requirements of the research question, and there should be changing facilities available for patients undergoing motion analyses in a clinical setting. For clinical examinations, there should be a dedicated room or a separate area where they can be conducted. However, clinical examinations can also take place in the admission room. The examination bed should be adjustable in height and comply with medical guidelines.

2.1. Recordings on level ground

For gait examinations on level ground, a minimum track length of 10 m is recommended. Typically, the force plates are positioned centrally in the walking path, allowing to have the same distance for initiation and termination. It's advisable to avoid phases of excessive acceleration and deceleration during the recording. To accommodate

Fig. 1. Examples of the arrangement of force plates depending on the type of movement being measured, as well as the size and stride length of the patients. LEFT: Three staggered force plates, the first two intended for children (shorter stride length), plates 2 and 3 for adults. CENTER: Parallel arrangement, specifically for jumps or sit-to-stand analyses. RIGHT: Arrangement in a row, for adults, sit-to-stand analyses are also possible.

not only gait analyses but also running analyses (jogging), a room length of approximately 18 m or more is desirable. The goal of the track length is to achieve a homogeneous walking speed within the measurement volume, minimizing phases of acceleration and deceleration. This applies to both pure video recordings and recordings with a motion capture system. The width of the room should be at least 6 m to ensure sufficient distance between the camera and the subject (patient), especially when using pure video systems [4,18]. This also ensures an adequate number of steps for assessment. When using a fisheye lens, the width can be reduced, but attention must be paid to quality to avoid significant distortions.

For the exclusive use of a pressure-sensitive plate (embedded in the floor) without additional video recording, the room width can be narrower. However, even with pressure distribution measurement systems embedded in the floor, the room should have a length of at least 8 m. Studies [8,9,28] have shown that a sufficient approach before and after the plate influences the measurement results within the pressure distribution. Here too, phases of excessive acceleration and deceleration should generally be avoided. At least a 3-step method before and after the plate is ideal (the third step on the pressure-sensitive plate).

Moreover, the issue of "targeting" (i.e., consciously aiming for the force plate) is influenced by the size and length of the measuring plate. A flush installation of the pressure and force plates into the floor is preferred. Alternatively, the walking path can be adjusted to the level of the measuring instrument. For pressure plates, it's important that the color matches the floor covering. With current commercially available systems, achieving a color-coordinated design is not always feasible. Upon consultation with the manufacturer, thin films can be applied to the measuring surface, allowing the plate to match the floor color. For an overview of recommendations for level walking see Fig. 2.

The construction for the installation of force and pressure plates should adhere to the manufacturer's specifications. For force plates, it is essential to ensure that there is no force transmission to the surrounding floor. Installation must take place on solid and level concrete flooring, with a minimum concrete thickness of 15 centimeters. In general, it is important to consider the manufacturer's recommendations in this regard.

Room height: For walking/running on level ground, we recommend a minimum room height of 2.20 m. For a 3D motion analysis, including the use of ramps, stairs, etc., a minimum ceiling height of 3.20 m is required, which may need to be higher depending on the setup, especially for longer stairs/ramps and the installation of ceiling-mounted safety systems. An alternative to ramps is conducting walking/running on uneven terrain on an instrumented treadmill with adjustable incline angles.

Temperature: When considering room temperature, it's important to note that the patient will be moving in sportswear or underwear during the measurement. Therefore, the room temperature should be maintained between 23 and 25°C. Exceptions can be made for summer temperatures up to 25°C (following hospital guidelines). According to a survey, the average temperature in gait labs is approximately 23.5°C (based on Heiko Gasser's thesis, available on the GAMMA- website in the members' area). Hence, it's advisable to have air conditioning/air purifiers/cooling ceilings, particularly due to the heat generated by the measurement system and computers.

Work environment: Depending on the facility's requirements, two office spaces (with at least two workstations) are considered beneficial in close proximity to the motion analysis laboratory.

In addition to the main motion analysis laboratory, two adjacent separate rooms should be available: a changing room for patients and another room/storage space necessary for storing equipment used during motion analysis (e.g., platforms, stairs, ramps, examination bed). This room/storage space should have a minimum size of 30 square meters and include a sink and cabinets for storing materials (e.g.,

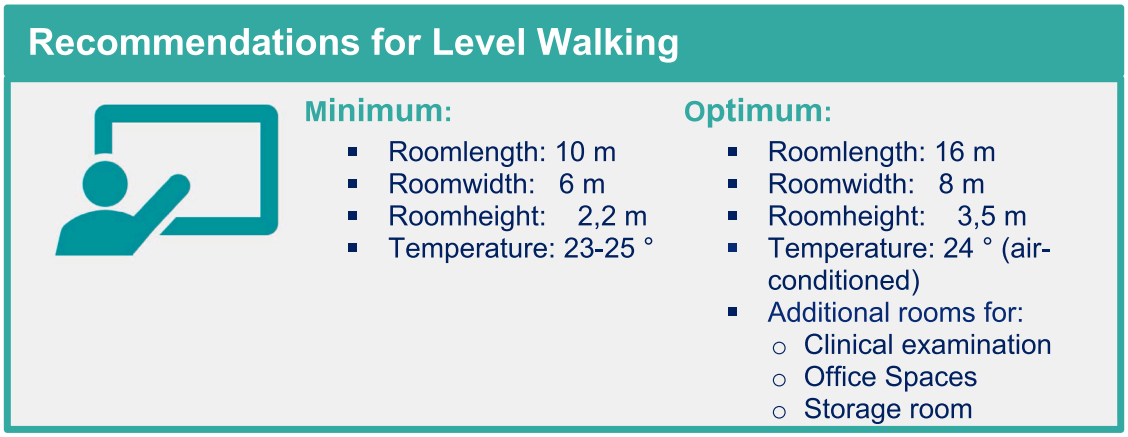

Fig. 2. Overview of recommended facility requirements for level walking.

documents, adhesive tape, disinfectants, razors, etc.).

A bathroom (toilet with shower) for patients/athletes in the immediate vicinity of the motion analysis laboratory would be desirable.

2.2. Recordings on the treadmill

When recording on a treadmill, a certain room size should also be available depending on the treadmill's dimensions. Legal requirements for the fall space and safety devices for patients must be considered (for example, see European Standard EN 957–1 and 957–6). According to these standards, there should be a free fall space of at least 2 m in length and 1 m in width behind the treadmill. Alternatively, a safety system must be in place.

The installation or use of video cameras or an instrumented motion capture system requires a certain distance around the treadmill. A distance of 3 m in all directions is recommended here. The treadmill's motorization should be chosen so that placing the foot while walking or running does not change the treadmill's speed. When using a treadmill with a side rail, ensure that it does not obscure relevant measurement points. Regular cleaning of the treadmill surface and handrails should be performed according to manufacturer guidelines/hygiene regulations.

Regarding types of treadmills, there is a fundamental distinction between mechanical and electric treadmills. Mechanical treadmills do not have a motor and therefore do not rely on a power source, as is the case with typical motorized treadmills. Mechanical treadmills are powered solely by the user's pushing on the belt as they walk/run. This is not preferable for clinical, instrumental gait analysis as controlled examination conditions can be difficult to achieve. An electric treadmill, on the other hand, is motor-driven. It allows for walking or running at a set or controlled speed. Many foldable treadmills have similar characteristics to static electric treadmills. We recommend a fixed location for the treadmill. If a mobile treadmill is used, this must be considered in terms of calibration, etc. Vibrations of the treadmill should also be considered, which is why robust treadmills are preferred. Anti-gravity treadmills or partial weight relief systems are mostly used in therapy settings.

Considerations:

- Instrumented vs. non-instrumented (pressure measurement, force measurement)
- Handrail, yes, or no? (potential obstruction of sagittal view)
- Safety systems: Which are sufficient for my application?
- Is ceiling suspension necessary? How high must the room be then? Or should only patients who can walk without assistance be on the treadmill?
- Does it have to be a belt, or can it also be a slatted treadmill with different surfaces?
- Self-selected walking speed ("self-paced"): yes, or no?

Specialized treadmills require different room sizes than a standard treadmill.

The use of a treadmill has both advantages and disadvantages that should be considered in the planning process regarding the research questions. Specifically, the adaptation time for children/adolescents with disabilities or for elderly individuals needs to be carefully weighed. For an overview of recommendations for recordings on treadmills see Fig. 3.

3. Staff

An interdisciplinary team of staff including both clinical and technical, as well as scientific expertise, should be aimed for. However, in the clinical motion analysis laboratory, there should be at least two staff members: ideally, one with a technical background and one with a clinical background. These staff members should have completed a certified gait analysis course offered by a recognized society (such as ESMAC, GCMAS, GAMMA, SIAMOC, etc.). Staff should engage in regular professional development, which should be documented (see Appendix 12.7 of the German version of the GAMMA Standards [19]). A protocol for the onboarding program for new staff members must be in place. Onboarding should be conducted by the most experienced staff members. Staff should be given the opportunity to visit other motion analysis laboratories. Regular exchange with a partner laboratory or multiple laboratories should be facilitated (every one to two years).

Regular reproducibility checks should be conducted in the laboratory (recommendation: every 2 years) to assess the reliability of measurements taken by individual staff members by repeating measurements on the same individuals. Evaluation of the reproducibility of results by new staff members should also be carried out. These tests should be recorded and documented accordingly. Records of staff members should be maintained. Documentation should include details of regular training, workshops, and professional development on specific systems and in the field. Results of reproducibility tests per person should also be recorded. All staff members should convene once a year to discuss the entire measurement process (especially clinical examination and marker/EMG placement).

4. Equipment

In clinics, it is advisable to involve staff from the medical technology sector as early as possible in the design and equipment selection process.

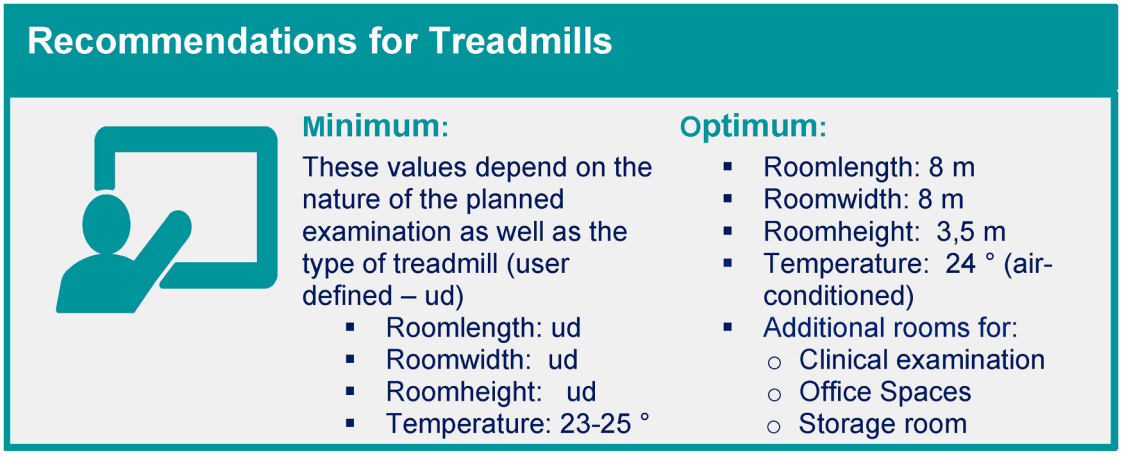

Fig. 3. Overview of recommended facility requirements for recordings on treadmills.

In addition, compliance with regulations should also be ensured. Procurement of measurement devices, if available, should be done in collaboration with medical technology professionals. Compliance with the guidelines of the Medical Devices Act should be verified by medical technicians. Legal inspections of equipment must be conducted by medical technicians or appropriate companies. Staff should regularly check whether the functionality and proper operation of the equipment are still ensured. Written documentation should be available, kept in the laboratory or with the medical technology department.

Staff should conduct regular tests of the measurement devices. a distinction should be made between daily/weekly simple tests and comprehensive testing over a longer period. This is intended for quality assurance, with particular attention to the following points:

- Calibration of the camera system
- Dust accumulation on the lenses
- Visual inspection of force plate signals
- Alignment of video cameras
- Verification of the vertical total force of the force plates using standard weights
- Force application point and direction of the force plates

4.1. Video recording (2D)

Recordings should be conducted in frontal and sagittal planes, with cameras securely fixed in place. When using tripods, there is a risk of displacement. The frontal camera should be aligned parallel to the direction of movement, with its height position determined by the area of interest, typically at hip level to capture the entire body, as upper body and arm movements are often included in gait analysis. The side camera should be strictly positioned laterally at a 90-degree angle to the direction of movement. Documentation of upper body movement can also be valuable here. Camera settings, including recording frequency, exposure time, and aperture, should be documented in both the camera and software settings.

For gait analysis recordings, the recording frequency should be at least 50 Hz. For recordings during jogging or fast walking, we recommend a minimum of 100 Hz. The spatial resolution (HD, UHD, etc.) should be at least 720 × 1280 pixels. Regular checks of camera and software settings, as well as camera alignment, are recommended. For an overview of recommendations for video recordings see Fig. 4.

4.2. Optoelectronic 3D systems

The system should be calibrated regularly according to the manufacturer's instructions. Depending on the camera setup, this may need to be done daily (possibly before each measurement) or weekly. Checking the orientation of the cameras based on their positioning should be done daily. Depending on the research question, an appropriate recording frequency should be selected. A minimum of 120 Hz is recommended in the study by Fallahtafti et al., [14] (other sources: [16]). The system settings should be documented and regularly reviewed. It's important to note that infrared camera systems require some warm-up time, so depending on the manufacturer, it's recommended to let the system warm up before the first measurement. This also applies to calibration, which should not be done when the system is cold. Data processing (reconstruction, filtering, etc.) should be documented in a document (not for each measurement, but how the evaluation is generally done; any deviations should be documented for each measurement, see Appendix 12.4 of the German version of the GAMMA Standards [19].

The markers/sensors used should be regularly checked for quality and cleaned or replaced as needed. The system's measurement accuracy should be known and regularly verified, both for static and dynamic recordings. Several authors describe possible testing methods [12,13,35]. Furthermore, the integration of force plates should be checked regarding their position and orientation in the room. There are various tests for this purpose [2,10,11,17,21,30].

4.3. Force plates

The force plate signals should be regularly checked for interference, for example, through visual inspection of the force plate signals. Software settings should be documented and backed up. The positioning of the force plates in the coordinate system of the motion capture system should be regularly verified using Cal-Tester methods [2,10,11,17,21,30]. Similarly, the positioning of the force application point and the orientation of the force vector should be regularly checked using the Pole-Test method [2]. Vertical force should be checked using weights. The test weight should be standardized and correspond to the weight of the patient group under investigation. The number and arrangement of force plates may vary. We recommend at least two force plates placed consecutively for gait analysis (possibly slightly staggered for children or individuals with limited mobility). If additional tasks such as jumps or sit-to-stand movements are to be performed, two plates should be placed side by side, with the third plate behind them. The spacing of the force plates in the direction of walking also depends on the patient group under investigation (children/adults).

4.4. Pressure plates

The pressure plates should be calibrated regularly according to the manufacturer's instructions. Daily checks should include verifying any faulty sensors that may cause false triggers, which should be monitored during measurements. These checks are typically prescribed in the medical technology protocol.

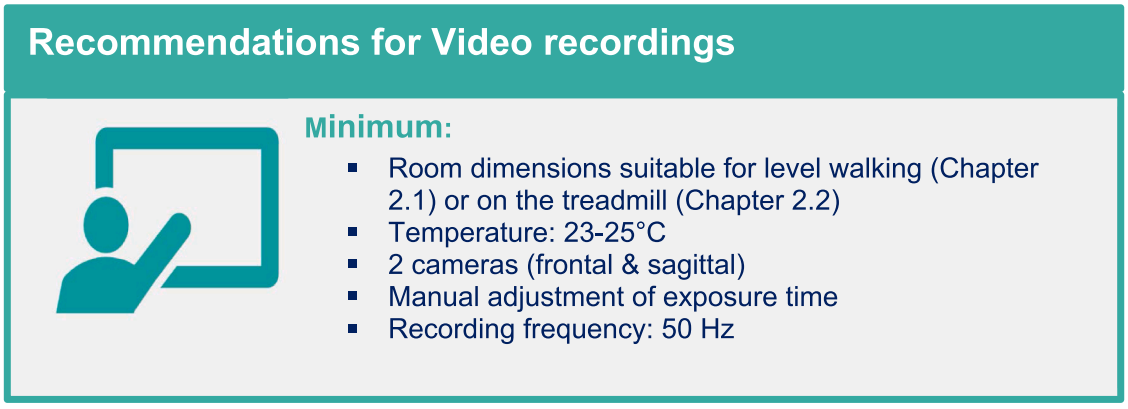

Fig. 4. Overview of minimum requirements for video recordings.

4.5. Electromyography (EMG)

The cable connections, if present, should be regularly checked for failures. For telemetry transmissions, knowledge of latency is crucial for time synchronization with another measurement system. Software and hardware settings (e.g., signal pre-filtering, baseline noise) should be documented and backed up. The main preparation, such as electrode application and signal processing should be standardized for clinical gait assessments. Valuable resources include the ISEK website (https://isek.org/emg-standards/) and the SENIAM project (http://www.seniam.org/). In practice, the sampling rate should be 2.5–3 times higher than the highest frequency component contained in the EMG signal [25].

Example of signal conditioning for slow movements such as walking:

- Signal rectification
- Band-pass filtering with 10/500 Hz (possibly depending on the patient group)
- Root mean square (RMS) with a time window of 80 ms
- Normalization to the mean activity during walking
- Further helpful sources: [6,7,22,25]

4.6. Verification of the synchronicity of coupled systems

The interaction between different measurement systems should be periodically assessed, especially when wireless systems are integrated, it's crucial to regularly verify their synchronicity. Regular checks on the appropriate sampling frequency and synchrony of all measurement systems should be conducted. Supplementary tools like tape measures and goniometers should be checked at regular intervals to ensure that they are in good working order. The functionality of measurement systems should be regularly inspected by the manufacturer, in-house medical technology departments, or external companies.

4.7. Laboratory database

In the database, all analyses should be recorded, and the results of each measurement should be accessible. Integration with the hospital information system or alternative server storage with access to findings should be available within the clinic, practice, or internally within the organization. Ideally, both the findings (text and graphics) and the associated reports (X-rays, outpatient clinic notes, etc.) should be accessible to all relevant caregivers of the patient. Results should be stored in written form—preferably both in written and graphical form—within the hospital information system. Data should be protected from unauthorized access, and stored in a way that allows results to be recalculated from the raw data at a later time. Ideally, continuous backups should be made from the laboratory database to an independent location, at least on a daily basis.

4.8. Clinical examination

To assess the collected data from the motion analysis, it is necessary to conduct a clinical examination focusing on the range of motion (ROM) of the joints, if applicable, spasticity/muscle tone, active strength, and functionality. This analysis ideally should coincide with the timing of the clinical motion analysis but should not be more than 3 weeks before or after the motion analysis assessment date. A recommendation for the clinical examination to support gait analysis can be found for download on the GAMMA- website in the members' area (www.g-a-m-m-a.org). The document is titled " *„Körperliche Untersuchung im Kontext der Ganganalyse – Konsensus, Range of Motion', Version 1.0*".

5. Referral management

Referrals to a clinical motion analysis should be clearly defined, including a specific question for the analysis and the chosen examination measures available in the laboratory. The laboratory's capabilities should be documented in local guidelines, specifying the measures and patient populations for which the laboratory has expertise. Additionally, the guidelines should outline the referral process and how results are communicated to the referring entity.

6. Data acquisition

The recordings should primarily be conducted by two individuals. One person handles patient interaction, while the other manages the technical aspects. This arrangement depends largely on the cognitive limitations and mobility levels of the patients. In favourable circumstances, one person may be able to handle both tasks.

For each type of test, there should be a precise protocol outlining the procedure. This includes equipment setup and patient preparation for the analysis. Additionally, the biomechanical model used (marker models/sets) should be clearly defined. The execution protocol detailing the exact steps of the analysis should be available in the laboratory. The positioning of markers/electrodes/notations on relevant anatomical points should follow a guideline. The storage of collected data should be standardized and structured according to a schema (suitable for database storage). The conducted examinations should be documented regarding the conditions of the recordings (barefoot, shoes, orthoses, etc.). The documentation should indicate who performed each measurement, including anthropometric data measurement, marker placement, and analysis (internal documentation). The protocols should also include information on how events were recorded (via force plates and/or software algorithms, manually, etc.) (see Appendix 12.9, of the German version of the GAMMA Standards [19]).

During or at the beginning of the recording session, the quality of the data (EMG artifacts) should be checked. Patient instructions for all analyses should generally follow the same procedure, but adjustments may be necessary based on age and cognitive status. For transparency in analysis, the protocol should specify the software/software version used and the data processing steps applied. This applies to both simple video recordings and complex 3D motion analyses and pressure distribution measurements. This information can be documented separately as a reference for all analyses and any deviations should be noted in the report itself.

When using a biomechanical model, a laboratory document should detail how markers should be placed and the advantages/limitations of the marker model. Information on the use of additional markers and their purpose should also be listed. The calculation methods used for joint centers (hip joint regression equation - which one, knee joint, ankle joint, or functional calculation methods) should also be listed or noted in a comprehensive document for reporting purposes (for traceability).

7. Data and report management

The collected measurement data must be archived according to the relevant guidelines of the local healthcare system. This entails ensuring traceability of how the data were processed and includes the storage of the measurement data. All data should be electronically captured and stored in a central location (laboratory database or hospital information system). This applies to both the raw data collected, the analyzed data, and the report.

Data preparation involves generating both a graphical report and a written interpretation of these measurement data. Graphical measurement data should be standardized in their presentation. The report should also include anthropometric data of the patient, the diagnosis, and the question from the referral, as well as the name of the referring individual. Any conditions and issues (patient compliance, etc.) during the recording should be noted in the report. The report can either reflect a representative trial [34] or present the mean plus standard deviation over multiple trials. When presenting the mean, individual trials

(consistency) should also be depicted. This should be clearly discernible from the measurement data/graphical report. The arrangement of the graphical representation of kinematics, kinetics, EMG, and pressure distribution should be clearly identifiable through page labeling and color-coding.

For assessing mean curves, at least 7 gait cycles should be evaluated for joint kinematics/kinetics [20]. For electromyographic recordings, 10 or more cycles should be evaluated due to expected variability. For pressure distribution measurements, a minimum of 3 steps per side should be recorded (preferably 5 recordings per side). When using a representative cycle, the report should indicate how it was selected (based on subjective choice or, for example, through mathematical methods) [8,32]. An example of a graphical report can be found in the Appendix 12.10 of the German version of the GAMMA Standards [19].

Essential information in the graphical report:

- Patient-specific information: Diagnosis, gender, age, etc.
- Recording-specific information such as date, used aids, aid settings, etc.
- References to healthy normative data
- Number of gait cycles used
- Normalization of EMG data (amplitude)
- Referral to an internal document with evaluation information such as filtering, etc., would be beneficial

Joint moments can be indicated as either internal or external moments. In the report/data, it must be clearly indicated which moments are being depicted. We recommend a matrix arrangement for reports as shown in Fig. 5. In the first column, information about the sagittal plane (e.g., knee flexion/extension) should be displayed, in the second column, information about the frontal plane (e.g., knee varus/valgus), and in the third column, information about the transverse plane (e.g., internal/external rotations). We recommend a top-down presentation row-wise (from pelvis downwards). Using the example of the lower extremities, the order would be “Pelvis, Hip, Knee, and Ankle."

The color scheme of the curves should be consistent across the DACH region. GAMMA recommends using red for the left side and blue for the right side of the body. When comparing conditions or different measurement days, the color scheme should remain the same, but with a slightly reduced color intensity and/or altered line style. For pure video documentation, a standardized documentation form such as the Edinburgh Gait Scale, by J. Perry, etc.[27,31] should be used.

7.1. *Normative data*

In graphical reports, results should be accompanied by normative data, typically generated within the laboratory itself. These data should be presented as mean curves ± a simple standard deviation. The number of normative subjects should ideally be at least 30 [3,23], and the data can be stratified by age (in decades) and walking speed. The laboratory’s own normative data should have been compared with the literature, and it should be noted how the normative data were obtained (subject selection, inclusion, and exclusion criteria) in an internal document. It is important that all normative data were collected using the same marker model.

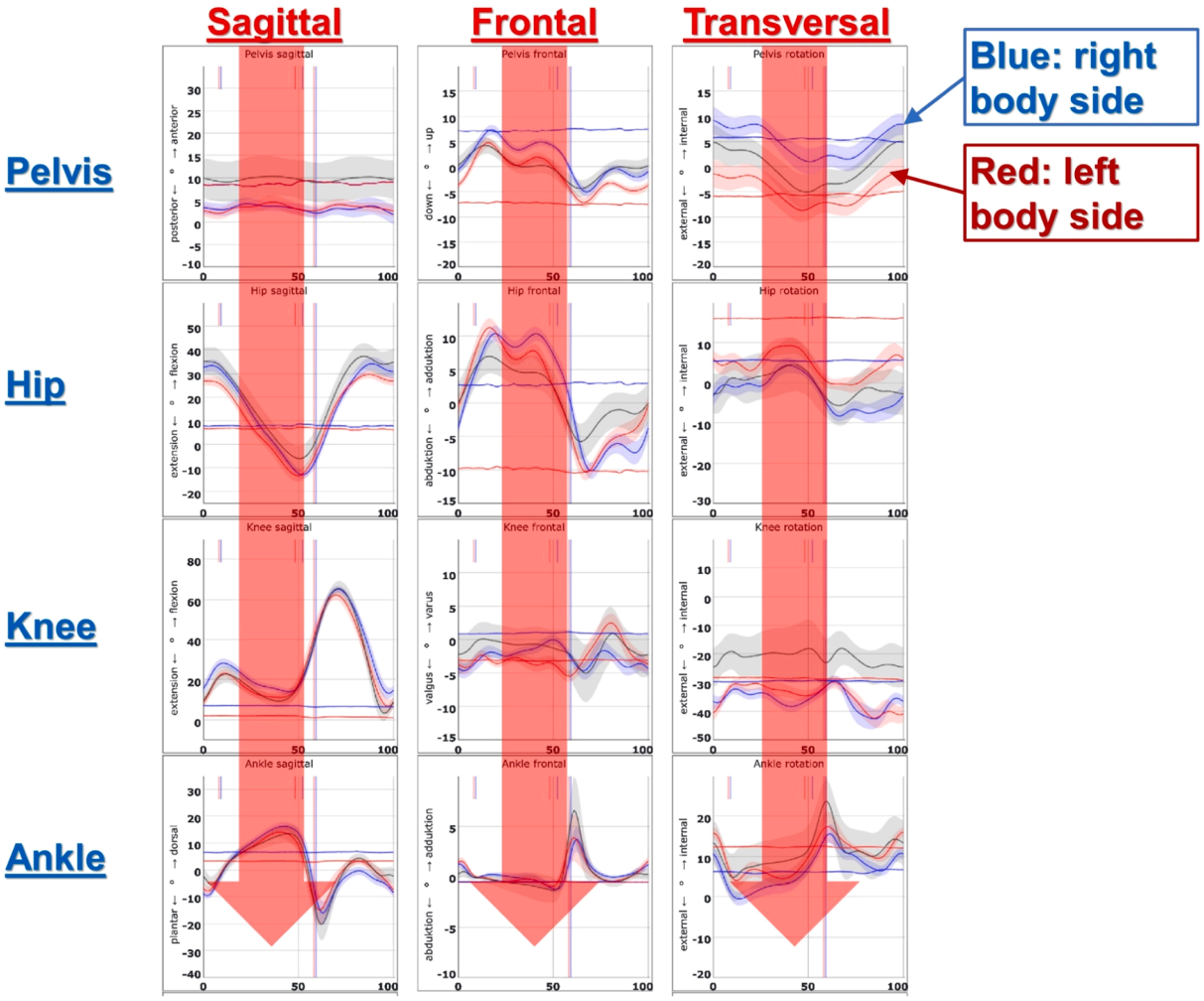

Fig. 5. *An example illustrating the arrangement of planes and joints of the lower extremity in a report.*

During normative data acquisition, prior orthopedic surgeries, injuries, and complaints should be excluded using an orthopedic survey form. Additionally, clinical examination should confirm the absence of lower extremity movement restrictions. Axial deviations (intermalleolar or intercondylar distances), leg length discrepancies, or foot deformities (e.g., pes planus) with orthotic correction should also be excluded. Since patients often walk slower or faster than normative subjects, it is recommended to include both self-selected and slower/faster walking speeds during normative data collection.

Considerations:

- Walking speed: self-selected/prescribed or different speeds, as walking speed influences kinematics, kinetics, EMG, and spatiotemporal parameters [33].
- Barefoot/with shoes
- Additional recordings that may be required for specific patient groups for comparison purposes (e.g., sit-to-stand)
- Own normative data should be compared with literature e.g. Schwartz et al., [33]. Symmetrical alignment of body sides should also be verified. Subsequently, the data can be incorporated into the normative database.
- An equal proportion of female and male subjects is aimed for.

8. Information for establishing a motion analysis laboratory

This chapter outlines additional considerations to keep in mind when setting up a motion analysis laboratory.

Electrical connections and cable channels should be adequately accounted for, including provisions for future system upgrades or additional equipment. Depending on the measurement system, a flooring material should be chosen that does not reflect light and provides sufficient contrast to the feet of the test subject.

Raised flooring: Utilizing raised flooring facilitates the later installation of power and measurement lines but reduces ceiling height. Additionally, incorporating a force plate or pressure measurement plate is easier with raised flooring. Consideration should be given to the load-bearing capacity of the raised floor, especially when using a treadmill. Regarding equipment, it is essential to ensure that purchased devices comply with current standards and medical device regulations.

The timeline for commissioning the clinical recording laboratory depends on the prior knowledge of the staff and the resulting shorter or longer introductory phase. Setting up a clinical motion analysis laboratory can take up to 12 months before valid, reliable data can be collected from patients. This includes establishing a database, training staff, and gathering healthy normative data.

It is advisable to establish contact with another laboratory before making purchases to gather information on setup and laboratory procedures.

Data backup procedures should be tailored to local conditions and IT infrastructure. The volume of data generated by the measurement system should be estimated, and appropriate data backup and recovery measures should be established in accordance with prevailing legal regulations.

When budgeting for the laboratory, in addition to equipment and personnel costs, expenses for room renovations and IT infrastructure (e.g., storage space, connections, and cable installation) should be considered.

9. Data protection

According to local regulations, data protection policies must be adhered to. These policies pertain to both the collection and documentation of patient information and the conduct of the actual measurements, including potential video recordings. Additionally, data transmission and storage of reports must comply with data protection regulations. Storing data on a web server must align with the relevant regional requirements.

10. Performance description for clinical gait analysis

The definitions of performance descriptions are currently under development and will soon be available on the GAMMA-Website in the members' area for download.

For further information on standardizing clinical gait analysis: various countries already have existing guidelines, protocols, and recommendations on this topic. In the United Kingdom and Ireland, for example, there is the CMAS association (https://cmasuki.org/). The ESMAC society (www.esmac.org, [1]) is currently working on issuing recommendations. Published standards are available from the Italian society SIAMOC (https://www.siamoc.it/, [5]) and from the ANZ-CMAG society [29] in Australia/New Zealand. Additionally, documents on standards and recommendations in clinical gait analysis can be found in Special Issue von Gait & Posture.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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