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# Implementing inertial sensors to quantify whole-body orientation in the roll plane

Stanislas Giroux

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L'INCLINAISON CORPORELLE DANS LE PLAN FRONTAL

THÈSE  
PRÉSENTÉE POUR L'OBTENTION DU TITRE DE DOCTEUR EN MÉDECINE  
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# **Implementing inertial sensors to quantify whole-body orientation in the roll plane**

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**Short title:** Measuring lateropulsion using motion sensors

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## **Abstract**

**Objective:** The present study describes the validity, feasibility and reliability of a new system of wearable inertial motion sensors to measure body segments orientation in the roll plane, especially useful to evaluate lateropulsion for stroke patients.

**Implementation:** We consistently explained the process of sensor selection and tested their validity. After selecting the body-segments and the relative placement of sensors, we established a calibration procedure and tested reliability of first measurements in a laboratory environment. As the results were excellent, we focused on the feasibility of the procedure to determine the ideal protocol for patients routine testing. We finally selected clinically useful data and established a smart data processing workflow.

**Application:** During implementation, we observed several interesting gait and posture behaviors, especially discussed for stroke patients suffering from a bias in their verticality perception. We computed a first reliability analysis on 6 patients with promising results on average inclination and maximum reached angle of body segments for static and dynamic tasks (ICCs 0.77–0.95). Measuring instability of each task using standard deviation of measures showed a poor reliability except for sit-to-stand task (ICC = 0.71 (0.37;0.88)).

**Prospects:** This protocol will be carried out in two upcoming national research protocols about lateropulsion (SCALA) and virtual reality in rehabilitation (VIRGIL).

**Conclusion:** Our new method demonstrates a feasible, cheap, portable, easy to use, clinically useful and reliable tool in measuring body segments orientations in the roll plane especially for stroke patients.

**Key-words:** Stroke, Gait, Lateropulsion, Hemiplegia, Motion Analysis, Accelerometer

## **Résumé**

**Objectif** : Cette étude décrit la faisabilité, la fiabilité et la validité d'un nouveau système de capteurs de mouvements destiné à mesurer l'orientation du corps dans le plan frontal, plus particulièrement pour l'évaluation de la latéropulsion.

**Implémentation** : Nous avons discuté du processus de sélection des capteurs de mouvement et avons testé leur validité. Nous avons établi une procédure de calibration et testé la fiabilité des premières mesures in-vitro. Avec de premiers résultats excellents, nous avons poursuivi notre démarche pour déterminer le protocole idéal pour le testing de patients en routine. Nous avons finalement établi un script intelligent de traitement de données après avoir sélectionné les données cliniquement pertinentes.

**Application** : Nous avons observé d'intéressants comportements de posture chez les patients hémiplegiques avec un biais de perception de la verticale. Nous avons réalisé une analyse de fiabilité sur 6 patients avec des résultats prometteurs sur l'inclinaison moyenne et maximale des segments corporels pendant les tâches statiques et dynamiques (ICCs 0,77–0,95). Les mesures d'instabilité se sont révélées peu fiables sauf pour le passage assis-debout (ICC = 0,71 (0,37;0,88)).

**Perspectives** : Ce nouveau protocole va être intégré à deux travaux nationaux de recherche concernant la latéropulsion (SCALA) et de réalité virtuelle (VIRGIL).

**Conclusion** : Notre nouvel outil offre une méthode de très bonne faisabilité, bon-marché, fiable, portable, facile, et de grande utilité clinique pour la mesure de l'orientation du corps dans le plan frontal, en particulier chez les patients hémiplegiques.

**Mots-clés**: Accident vasculaire cérébral, Marche, Latéropulsion, Hémiplegie, Analyse de mouvement, Accéléromètre

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## 1. Introduction

After a stroke, the ability to control balance in static positions or dynamic tasks is a fundamental skill of motor behavior for achieving autonomy in everyday activities. The postural performance of patients soon after a stroke has been found to be closely correlated with long-term functional improvement (1, 2, 3). Lateropulsion is a clinical sign of a wrong perception of the vertical. It's a major cause of gait and postural disorders after a right hemispheric stroke explaining almost 80% of balance disabilities (4). There is a need to focus on the assessment of lateropulsion in routine clinical practice to characterize spatial cognition disorders for stroke patients (5). Because it may help in establishing the severity and prognosis of a stroke, the early assessment of balance in stroke patients is an important part of the clinical examination (4). Those patients should benefit from a specific rehabilitation program of lateropulsion and postural disorders, aiming to recalibrate their internal model of verticality.

Reliable measurements of body verticality are difficult and expensive: Gold-standard kinematic data is only attainable in motion capture laboratories equipped with multiple cameras that track a subject's motion via reflective markers. This technique requires a heavy laboratory environment, and it can't be used in clinical routine yet. A disadvantage of these camera-based gait analysis systems is that they are relatively expensive, time-consuming and labor-intensive since a specialized and technically educated staff is required. Furthermore, there are no standardized body marks overlaying the body segments needed to be recorded, to get an accurate and reproducible clinical data. In daily rehabilitation practice, there is a need for a new clinical tool to quantify body bending in the roll plane for stroke patients, but also for

other neurological conditions such as Parkinson's disease (especially for Pisa syndrome patients (26)), vestibular or cerebellar diseases.

Inertial measurement units (IMU) are electronic devices that measure a body's specific angular rate using a combination of accelerometers, gyroscopes and magnetometers. Wearable IMU technology has recently emerged allowing an unrestricted, three dimensional analysis of performance, in both laboratory and field environments (6). These systems overcome limitations within traditional biomechanical analysis techniques. In this way data from human motion can be collected outside a laboratory setting under real-life conditions. IMUs are therefore relevant for application in clinical settings such as hospitals to monitor the effect of disease progression, and rehabilitation on gait function.

Accessing to this technology in our unit led us to the idea of implementing a new instrumental method to quantify whole-body bending. We processed step-by-step to deliver the smartest method ready to use in daily practice, but also to enrich ongoing research projects in neuro-rehabilitation, especially with virtual reality. Implementing this new evaluation method would also help to contribute in the making of SCALA, a new and promising tool, designed to detect and evaluate contraversive and ipsiversive post-stroke lateropulsion (27).

The present study describes a new simple, inexpensive and accurate method to assess body tilting during static postures and dynamic tasks. We tested the clinical feasibility, reproducibility and relevance of this new method with multiple motion sensors quantifying the lateral bending of head, trunk and pelvis. In addition, reliability statistics were computed for the described method on a sample of patients.

## 2. Implementation

### 2.1. Motion sensors

Accelerometry has a long history in the field of human motion analysis, and its clinical use is more and more important since accuracy over time improved with the integration of magnetometers to provide an absolute reference of magnetic north to reduce drift. Development of wireless and wearable devices is also an absolute need outside the laboratory field, since patient's behavior tend to be much different inside and outside the laboratory.

That's why we used Xsens Awinda motion sensors in our protocol (Xsens, Enschede Netherlands). Multiple sensors were used, each including a tri-axial accelerometer, a gyroscope and magnetometer allowing to obtain linear acceleration, angular velocity and magnetometer data during the analysis. The IMU sensors we used were sampling at 100 Hz and were small and lightweight (47x30x13 mm, 16 g). Xsens developed a sensor fusion algorithm, a Kalman filter called XKF-3, such that orientation and position of the IMU sensors can be accurately estimated (7).

This proposed IMU system promises accuracy, portability, affordability, real-time measurement of dynamic data, non-invasive application, minimal device footprint, and a high clinical usefulness.

The only drawback is that sensors themselves are very sensitive to electromagnetic interferences. Indeed, their built-in magnetometer used to measure the local earth magnetic field vector can be disturbed by ferromagnetic metals and equipment generating magnetic field. Orientation measurements given by the Kalman filter can rely more on the built-in gyroscope and accelerometer so that magnetometer weights are reduced. This technology provides less interference problems (13).



We encountered no disturbance with the use of electronic equipment nearby such as computers or smartphones, but operators should be careful about this issue.

## 2.2. Validity

### 2.2.1. Introduction

After choosing the ideal sensors, we used an electronic inclinometer (Pro 360 Digital Protractor) to assess the validity of our motion sensors in the measurement of tilt in the roll plane.

### 2.2.2. Methods

Motion sensors data was compared to a professional inclinometer which is the gold standard for tilt measurement. Two raters performed sensors and inclinometer installation by fixing them on a circular wheel and each measured angle values 48 times on a range varying from  $-30^{\circ}$  to  $+30^{\circ}$ . Calibration procedure of motion sensors was repeated before each measurement for each rater, at the equilibrium point of the circular wheel. The two raters were experienced in the use of the system.

We showed agreement between measured data using Pearson's rank correlation coefficients ( $r$ ).

For this part of the analysis and above, descriptive statistics were used to characterize outcomes measures and significance was set at  $p < 0.05$ . Statistical analysis was completed using SPSS v23.0 (IBM Corp., Armonk, NY, USA).

### 2.2.3. Results

Absolute agreement between Xsens motion sensor and inclinometer was excellent (ICC = 1.0 (CI),  $p \leq 0.001$ ). Table II and figure 1 demonstrates agreement for measurements between motion sensors and and inclinometer.

#### 2.2.4. Discussion

Our validity approach confirms that data from IMUs using a Kalman filter are robust and accurate for ambulatory motion recording (14, 15, 16, 17). The range of angular values we tested is way larger than the actual ranges that we expected to record on patients, making us confident about the next part of implementation.

#### 2.3. Body segmentation

We tried to define the main body segments that would be easily accessible for repeated measurements with eminent clinical significance in clinical practice.

Human beings stand upright with the chain of balance beginning at the feet, progressing to the lower limbs, each of the spinal segments, and then ending at the cranium to achieve horizontal gaze and balance using minimum muscle activity. Balance of body segments mostly depends on the alignment to the gravity line.

We chose to use only three sensors to get the best benefit between portability and anatomical accuracy. We placed them in order to capture the orientation of the cranial, upper body, and hip region.

On the one hand, orientation measures recorded from the sacral and the occipital sensors were intended to provide an accurate tilt measurement of the head and pelvis segments of the body. On the other hand, we chose to place a third sensor over C7 to provide the most clinically accurate measure of the trunk tilt. This body-mark is interesting according to the fact that this vertebra crosses the vertical line of the center of mass when a subject is asked to keep a horizontal gaze in upright position (11). Another advantage of placing those sensors on the back of the patient is the ability to easily perform calibration procedure on all sensors at once with an external vertical reference line. This setup exclude the analysis of arms, legs and

shoulders which are too far from the center of mass, and would add a challenging calibration procedure, a lot of artifacts (9), and a very exigent data acquisition workflow. This would be less suitable for a system that tends to be worn outside of the laboratory environment.

#### 2.4. Calibration (Video 2)

Calibration is the most critical part of the procedure. Each sensor has a calibration capability to align the world axes of the sensor to the object on which the sensor is attached, thereafter measuring orientation of the object in the world frame. Calibration procedure for patients with lateropulsion has never been investigated. In most studies dealing with motion analysis, investigators tend to choose a spontaneous upright standing position to represent the most stable body orientation and calibrate the device.

Our calibration method needed to find anatomical body marks that could fit in a reference grid using the collinearity principle.

Three Velcro® straps were placed and tightly adjusted on the waist, the lower part of the neck and the head. The placement of the sensors intended to be over the bones and not the muscles to reduce soft tissues artifact (9). They needed to lay over S1, C7 vertebrae and the occiput. The three sensors were then placed on these points of interest, as close as possible of the median body line. After powering-on the sensors and the computer, the calibration procedure started to set the reference grid: a self-leveling cross line laser was used as a true vertical reference line, and was placed behind the subject on a tripod. We first used a plumb line for its simplicity, but we figured out that it was far less convenient to adjust it according to the patient's or operator's involuntary disturbances (Video 1). The device we used was a Quigo Plus (Robert Bosch Power Tools GmbH, Stuttgart, Germany), equipped with a class II



Video 2



Video 1

laser (635 nm, <1 mW) and had a levelling accuracy of 0.8mm/m. Studies showed this laser will not be as great a concern if one is pointed at someone's eye because of the lower power rating (8).

The three sensors needed to be aligned on this reference axis by manually bending the patient so that the markers of the sensors were aligned on the reference laser line. The alignment reset button was triggered on the computer to begin with tasks recording just after switching off the laser. Once calibrated, the orientation of the coordinate systems of the body segments and the attached sensors were equivalent, according to the anatomic collinearity principle.

The method we developed requires two operators to stabilize the patient with the reference line, but it's a necessity to obtain reliable orientation values. Whereas it is the most efficient in routine conditions due to its simplicity, our calibration procedure gets tricky for very disabled or obese patients. For them, another suggestion would be to calibrate each of the three sensors separately on other reference lines (i.e. bi-pupillary line as a true horizontal reference line for head sensor or intertubercular line for pelvis sensor).

## 2.5. Inter-rater reliability on dummy (known inclinations)

### 2.5.1. Introduction

Once we established the setup of our protocol, we wanted to assess the reliability between raters in a laboratory environment on known inclinations, in order to assess the consistency of our first steps: In the laboratory environment, a dummy was ballasted with different weights on the side to compute the first reliability analysis.

### 2.5.2. Methods

A human sized dummy was ballasted with weighted sandbags of 2, 5, and 7kg on a hook heavily fixed on its upper left side. Two raters each performed sensors installation, calibration and measures of the body tilt for each weight condition. One rater was experienced in the use of the system whereas Rater 2 had no experience with the motion sensors. Rater 2 had 15 minutes acclimatization with the instruments after its layout and technique for use were explained by Rater 1. All measurements were performed on the 3 sensors right after the calibration, when the dummy reached a still inclination, in the roll plane. The entire procedure was repeated ten times for each rater, and the inclinations values of the 3 sensors were recorded.

We assessed reliability between raters using intra-class correlation (ICC) (23) on measured data. The parameters were considered “highly reproducible” when inter-evaluator ICC were over 0.80 (21). Additionally, standard errors of measurement were computed as  $SEM = standard\ deviation \times \sqrt{1 - ICC}$  (22). It was expressed in degrees. Minimal detectable change at the 95% confidence interval ( $MDC_{95} = 1.96 \times SEM \times \sqrt{2}$ ) was also used to estimate the smallest change threshold that indicates a real change in an individual patient beyond that attributable to measurement error (24, 25).

We also showed agreement between measured data using Pearson’s rank correlation coefficients ( $r$ ). Descriptive statistics were used to characterize outcomes measures. During each task recording and for all analysis, significance was set at  $p < 0.05$ .

### 2.5.3. Results

Table III and figure 2 demonstrates reliability between raters and show agreement of measures in-vitro.

Absolute agreement between the two raters to measure inclinations was excellent: the ICC reached 0.985 (Table III), indicating that these parameters were highly reproducible. The standard error of measurement was 1.07 degrees for the inclination parameter. The MDC95 value for this parameter did not exceed 2.97% supporting that relatively small changes need to be detected to confidently state that real changes had taken place (i.e., exceed the bounds of measurement error).

#### 2.5.4. Discussion

We demonstrated that this system valid and highly reliable in the laboratory environment, for measuring known inclinations. However, we now needed to test the system to get orientation data from unknown inclinations, and not only on static postures. That's why we discussed about the feasibility of our protocol on patients.

#### 2.6. Feasibility (Video 3)

Outside the laboratory, we tried to find the most appropriate tasks to record in the minimum amount of time to make our method feasible.

Lateropulsion behavior is mostly studied in static tasks on stroke patients (18), but studying dynamic tasks is necessary to understand the whole phenomenon. Indeed, after few weeks of recovery, some patients show a way much better static postural behavior, but the dynamic tasks are still risky due to this lateropulsion. That's why we decided not only to record the sitting and standing position, but also two other dynamic tasks: Sitting to standing position, and walking.

Perception of vision is also a critical point for patients with a pushing behavior: Closing patient's eyes tend to enhance the phenomenon of lateropulsion (10) and might be interesting to record. Preliminary testing of the device showed that we should select just a few of those parameters for our protocol, so that it would be as



Video 3

less time consuming as possible. Indeed, it took more than an hour to evaluate the whole tasks on a single patient for two operators. That is why all the selected tasks were performed eyes opened, and we kept four tasks: sitting position (SI), sitting to standing position (STS), standing position (ST), and walking (W). Another advantage of selecting fewer tasks is to reduce the risk to find a significant result by mistake.

The tasks were performed three times for each patient to improve reproducibility (30), and values of three trials were averaged. After that, the patient was asked to walk as far as possible straightforward. The final routine was the following: SI (60 sec) > STS > ST (20 sec) > SI (20 sec) > STS > ST (20 sec) > SI (20 sec) > STS > ST (20 sec) > W. We admitted that 20 seconds of recording for each static position was a good compromise to provide clinically accurate data while reducing patient global fatigue. The first task recording is longer than the others to investigate any drifting that might happen after a longer period of time. Patient was secured all the time by an operator and was given precise oral instructions before each task (Appendix 1). He was sitting on a physiotherapy examination table set to obtain a 100° knee flexion and the use of arms was not possible during sitting to standing task.

The duration of the procedure as well as patient complaints or possible adverse events were documented to analyze the feasibility of this method. We aimed to achieve a total duration of 30 minutes to perform this routine of tasks for both operators. After defining and applying the routine of tasks described above, we obtained good trials durations.

The inter-session interval was around one or two minutes. Setting up the patient and placement of sensors took about 10 min. The routine of tasks measured three times took 10 min for each rater. Computation of parameters and graph display took about 10 min. Sensors were well tolerated by participants during the trials. Acceptability was excellent: participants perceived the sensors' presence but none of them

complained about discomfort. They did not report issue regarding walking with the sensors either. Three participants experienced difficulties to walk and complete the gait task due to global weakness (Patients 1, 2, 5, Table I). No serious adverse event was reported.

Another limitation of this new method deals with the patient's abilities at the time of instrumental evaluation: In the first month following a stroke, some patients are still unable to walk properly, and we also failed to evaluate patients with strong cognitive disorders, such as attention disorders or comprehension aphasia. Most of them were unable to remain still while recording data. The limitations we encountered are detailed in a user guide detailed in Appendix 2, describing the most common errors of measures.

### 2.7. Parameters

For patients, the tilt of each body segment was assessed during static and dynamic tasks by measuring the average angle in the roll plane during all the trials. This main outcome measure was the most clinically accurate to describe the behavior of body segments for pusher patients. By convention, a negative value corresponded to a leftward tilt in patients.

As secondary outcome measures, we computed sensors data standard deviations, and maximum reached value for each trial. Those values were the most relevant to describe global instability and any risk of falling due to a sudden extreme inclination.

### 2.8. Data-processing

We enrolled an expert to help us to develop a custom script that automatically computes an output file of each trial including relevant graphs and charts from raw sensor data. The step-by-step data processing procedure is extensively detailed in



Appendix 3, and an example of data report is shown in Appendix 4. All computations were performed using the R language, v3.5.0 (<https://www.r-project.org>), which is a free and open source program.

As the aim of our study was to investigate body tilting, we did not include data measures in the pitch plane in our statistical analysis. It is known that backward disequilibrium might be caused by an abnormal perception of verticality, especially in the elderly (12). IMUs provide the ability to investigate orientation in the three planes, and the script we developed has enough flexibility to collect and organize other orientation values during recording. However, data processing involving more than one plane would require a specific software development team to optimize this workflow. A clinically relevant graphical user interface is yet to be developed, and could offer encouraging perspectives of biofeedback.

### 3. Application

#### 3.1. Clinical examples

While adjusting the steps of our protocol in our implementation process, we observed a lot of interesting preliminary outcomes on patients, leading to promising hypotheses.

##### 3.1.1. Bias in visual vertical perception and head orientation (Video 4)

We noticed a difference in lateral orientation of body segments during different tasks for stroke patients with a pusher behavior in comparison from other stroke patients: Especially for dynamic tasks, we observed that pusher patients presented a way more important deviation of the head segment in comparison to non-pusher patients (Patient 1 vs. Patient 2). Non-pushers tend to keep a horizontal gaze whereas lower



Video 4

body segments are bending due to contralateral muscle weakness (Video 3). This might be a direct consequence of the bias of perception of visual vertical for pusher patients, as previously suggested by two authors (19, 20).

The ipsilesional lateral tilt of the head is also dominant for static tasks and walking procedure for pusher patients included in the analysis (Patient 1 and 6), and for a single other pusher patient (evaluated a Day 90 post stroke, not included in the data analysis for being evaluated by just one rater). (Figure 4)

The dominant tilt of the head was again present for still tasks in the late evaluation of a pusher patient (Patient 6, Day 145 post stroke), whilst showing a better head postural control for walk and sit-to-stand task.

In early stages post stroke (Patient 1, Day 45 post stroke), deviation is that important that trunk segment would be almost as deviated as the head segment, increasing the risk of falling.

### 3.1.2. Patients follow-up (Video 5)

Patient 1 was evaluated twice: at Day 45 and Day 90 (not included in data analysis). Whereas postural control seems way much better for static tasks, late evaluation of dynamic tasks tends to show a major risk of fall, especially in sitting-to-standing task: Even at Day 145 (Patient 6) trunk orientation reached high maximum angle values (up to +14.5°) whereas external visual feedback would not spot a falling risk.

Repeating measures on same patients would help to understand the natural evolution of ipsilateral lateropulsion for patients undergoing specific physical therapy.

### 3.1.3. Gait analysis

Data obtained for walking task showed a surprising repetitive pattern that might be linked to gait characteristics of patients, especially for step counting. As a result, a



Video 5

step frequency could be obtained instantly, and a gait speed could be easily computed if walking task was executed for a predefined distance.

#### 3.1.4. Oscillations

We observed oscillations in static tasks for all patients. We observed different oscillation frequencies for patients depending on their medical condition. All stroke patients we evaluated presented an average trunk oscillation of 0.6 Hz in standing position at all times post hemispheric stroke. Likewise, we observed an oscillation in standing position that was close to 2.0 Hz (Patients 1, 2 and 6 ; Video 6). In both static position, cerebellar stroke patients showed a different pattern of oscillations with upper body segments oscillating at an average frequency of 3 Hz, in comparison to the pelvis oscillation that was ten times below this frequency (Patients 3 and 5). Patient 4 affected by Parkinson's disease showed a different oscillation pattern in all static tasks at 0.3 Hz. Those observations suggest the high potential of motion sensors abilities to characterize gait and posture impairments for patients suffering from neurological diseases.



Video 6

### 3.2. Inter-rater reliability on patients (unknown inclinations)

#### 3.2.1. Introduction

6 patients with admitted in a neuro-rehabilitation unit were evaluated in this study. Inclusion criteria were age 18 to 80 years, recent admission in a neuro-rehabilitation unit, ability to stand with the assistance of a physiotherapist, subjective posture disorder due to any medical condition, and absence of medical problems preventing a safe execution of the tasks. Participant demographic and clinical data are shown in Table I. Participants gave their informed consent in accordance with the Helsinki declaration and those who were filmed signed a model release form.

### 3.2.2. Methods

An experienced and an unexperienced rater assessed a convenience sample of 6 adults. The unexperienced practitioner was first instructed about the system characteristics and usage by the first rater. An instruction manual for measurement and calibration was used (Appendix 1). Each participant first stood still on the side of an examination table to perform sensors installation and calibration by each rater. The orientation data of motion sensors was recorded individually for each task. The order of raters was determined randomly by the observer so that the practitioner sequence differed with each patient.

As explained before, SEM and MDC95 were also computed. For the three first tasks in-vivo (SI, ST, STS), statistics were computed with a model 2.10 (consistency) because each parameter was the mean of 3 trials. ICC for walking task (W) was calculated with a model of absolute agreement.

### 3.2.3. Results

Table IV (a, b, c) and figure 3 (a, b, c) demonstrates reliability between raters and show agreement of measures in vivo.

We computed an analysis on patients' parameters for each task. Average inclination angles results were highly reproducible for sitting, standing, and sit-to-stand tasks (ICCs 0.77–0.95) Average inclination for walking task was moderately reproducible (ICC = 0,71 (0.37 ; 0.90)).

Measuring instability of each task using standard deviation of measures showed a poor reliability except for sit-to-stand task (ICC = 0.71 (0.37;0.88)).

Maximum inclinations measures of body segments were highly reproducible for sitting, standing, and sit-to-stand tasks (ICCs 0.83–0.93) except during walking (ICC = 0.58 (0.18;0.82)).

#### 3.2.4. Discussion

Reliability of this new technique for mean inclination measure was excellent for all static and dynamic tasks. It was also excellent to measure maximum inclinations except during the walking procedure.

The poor reliability for maximum inclination during walking procedure may have been due to a lack of participants, but also to the fact that this is the most energy consuming task, and global fatigue would tend to make the second walk trial more chaotic for patients. We might have been able to avoid this consequence by increasing the inter-trial time.

The excellent reproducibility for walking procedure is quite surprising according to the fact that it is the most difficult. We included in the analysis data from 2 patients who were unable to walk without a strong help from the operator, including intermittent shoulder contact, but this bias might have been cleared by the long period of recording.

Poor reliability on the statistical dispersion of measures, meant to represent global instability during tasks, is mostly due to the low number of participants, which is the main limitation of this study. Our results will need to be confirmed in a larger sample of patients, especially in the pushers group.

## **4. Prospects**

### 4.1. SCAlE for LAteropulsion (SCALA)

We already discussed about the fundamental need to assess lateropulsion after a stroke, which is known to be a primary cause of postural and gait disorders. SCALA is a new promising tool which is currently conceived by 21 international experts having clinical and scientific background of lateropulsion (27). Current lateropulsion evaluation tools tend to be outdated due to recent progress on posture concepts (18), and the rising of new smart and affordable technologies such as motion sensors.

Our implementation work will be part of upcoming work to validate this new tool. Our protocol will be used to bolster convergent validity of SCALA versus direct orientation data from motion sensors. Meanwhile, we also plan to assess statistical responsiveness of our measures which characterizes the ability of a measure to change over a pre-specified time frame. Additionally, a greater scale reliability analysis will soon be launched on pusher patients versus healthy subjects with twenty patients in each group. After three years of conceiving, this project is in the waiting line for ethics committee approval soon, and it has received the French national financial support of PHRC (Programme Hospitalier de Recherche Clinique). Validation of SCALA is part of a multi-centric global assignment aimed at studying neural mechanisms and recovery of the sense of verticality after stroke, in view of implementing a rehabilitation program dedicated to these troubles.

#### 4.2. Virtual Reality Glasses to Improve Lateropulsion and the post-stroke postural vertical (VIRGIL)

Recent breakthroughs in gait and posture concepts for stroke patients lead to conceiving new rehabilitation protocols aiming to recalibrate the sense of verticality. A recent work showed that a virtual reality environment could modulate visual vertical perception for healthy patients (28). Being immersed in a tilted environment induces a powerful bias in verticality perception. VIRGIL study is a research protocol which

aims at better understanding postural perception of verticality in a virtual reality environment both on stroke patients and on healthy subjects. This is an immediate application of our motion sensors implementation work for the year to come.

With the help of a virtual reality headset, patients will be immersed in a tilted 3D environment and whole-body orientation will be measured. Our hope is to prove that this method could recalibrate the intern perception of verticality and could produce enhancements of gait and posture patterns. As a consequence, the impact on disability, activity and participation would be major for patients.

#### 4.3. Further work

We mostly discussed about applications for stroke patients, but our system might be useful for Parkinson's disease research. Characterization of body kinematics on Parkinson's patients could be interesting to measure the effect of deep brain stimulation therapy after surgery, inside or outside the laboratory. This is even more relevant for patients affected with Pisa Syndrome that is almost observed in 10% of Parkinson's patients (26), for whom instability in the roll plane increases risk of falling.

Finally, we observed that our analysis could be helpful for gait assessment. We observed that we could already compute gait speed with footsteps frequency, but more promising data could be extracted from IMUs during our evaluation, especially to characterize gait asymmetry post-stroke (29).

## 5. Conclusion

Although body tilting measurement in the roll plane is important in neuro-rehabilitation, especially for individuals with stroke or Parkinson disease, there is a lack of a

standardized method. This study implements a new technic using wearable motion sensors, and starts the first investigations of its feasibility, reliability and validity.

After selecting the best motion sensors according to our clinical needs (Xsens Awinda), we tested its validity for measuring body orientation in the roll plane and defined 3 relevant body landmarks: Gonion, C7, S1. We had to solve the question of sensor's calibration for measuring absolute vertical orientation, and adopted the principle of collinearity between the 3 selected anatomical body landmarks. This set up was found highly reliable on a dummy. We then optimized the clinical procedure: number of conditions, duration and order of trials. The right balance between feasibility and a comprehensive data-set was reached step by step. The final protocol was completed in 20 minutes, comprising the following conditions in this order: Sitting, sitting to standing, standing, this sequence being repeated three times. The session ended by assessing whole-body orientation during gait on a few meters, once. Three criteria were measured per condition: The main criterion was the average tilt of the three segments (segmental and whole-body orientation). The two secondary criteria were: Maximum orientation and the standard deviation of measures during the tests (body stabilization). To easily compute and export data to display results of determined criteria, we worked with experts to craft a smart data processing script. The last step of this study consisted performing first tests of inter-rater reliability of the full procedure on six patients showing postural disorders due to neurological conditions. Average and maximal orientations were moderately to highly reliable for all conditions. Instability criterion was less reliable. These preliminary results need to be confirmed with a larger sample of patients, especially those showing lateropulsion after stroke. This will be done during the SCALA study, starting soon.



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## **Author contributions**

Study conception and design: SG and DP. Experimental conduct: SG. Data analyzes: IJ and SG. Statistical analysis: SG. Manuscript preparation: SG and DP.

Validity analysis : RG and SD.

## **Disclosure statement**

The authors declare no competing interests.

## Implementing inertial sensors to quantify whole-body orientation in the roll plane


### Conclusion

Although body tilting measurement in the roll plane is important in neuro-rehabilitation, especially for individuals with stroke or Parkinson disease, there is a lack of a standardized method. This study implements a new technic using wearable motion sensors, and starts the first investigations of its feasibility, reliability and validity.

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## Table captions

### **Table I. Patients characteristics:**

FIM: Functional Independence Measure (the higher, the more independent, maximum 126/126)

**Table II. Validity testing of motion sensor versus inclinometer:** Correlation coefficients (CC) were calculated between angles values measured on inclinometer and motion sensor.

**Table III. Reliability of measures for average body tilt in-vitro with motion sensors:** Correlation coefficients (CC) were calculated between two raters for angles values measured dummy body segments after calibrating the system for each.

**Table IVa, b, c. Reliability of measures for average body-tilt, instability and maximum values in-vivo with motion sensors:** Correlation coefficients (CC) were calculated between two raters for mean angles values (a), standard deviation (b) and maximum inclination (c) measured on patients' body segments after calibrating the system for each.

**Figure 1. Agreement between inclinometer and motion sensors**

**Figure 2. Agreement between both raters in body-tilt measurement on dummy**

**Figure 3a, b, c. Agreement between both raters in average body-tilt measurement (a), variability (b), and maximum angle (c)**

**Figure 4. Results for pusher and non-pushers patients in sitting task, showing a dominant head tilt for pusher patients**

X-axis : time (ms), Y-axis : angle values (degrees, positive value means right tilt by convention)



**Video 1. Motion sensors calibration procedure in-vitro**

Duration: 00'21"



**Video 4. Bias in horizontal gaze for pusher and non-pushers patients: side-to-side comparison**

Duration: 00'30"



**Video 2. Motion sensors calibration procedure in-vivo**

Duration: 00'40"



**Video 5. Follow-up for pusher patients**

Duration: 00'22"



**Video 3. Tasks data recording in vivo**

Duration: 00'40"



**Video 6. Oscillation frequency analysis**

Duration: 00'20"

**Table I.**

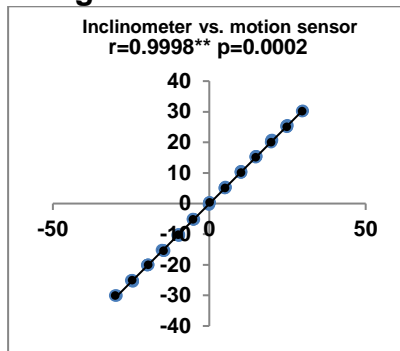
<b>Patient</b>	<b>Gender</b>	<b>Age</b>	<b>Pathology</b>	<b>Time from diagnosis to clinical evaluation</b>	<b>Pushing behavior</b>	<b>Spatial neglect</b>	<b>FIM</b>	<b>Cognitive disorders</b>
1	Male	73	Left ischemic hemispheric stroke (Middle cerebral artery)	45 days	Yes	Yes	57	Mild aphasia
2	Male	56	Right ischemic hemispheric stroke (Middle cerebral artery)	45 days	No	No	71	No
3	Male	49	Right ischemic cerebellar stroke (Posterior inferior cerebellar artery)	4 days	-	No	124	No
4	Female	70	Parkinson's disease	4 years	-	-	94	No
5	Female	65	Left ischemic cerebellar stroke (vertebra-basilar artery)	60 days	-	No	109	No
6	Male	66	Right ischemic hemispheric stroke (Middle cerebral artery)	145 days	Yes	Yes	84	Severe aphasia



**Table II.**

Measure instrument	Measured angles mean (SD)	Correlation coefficient ( <i>r</i> ) (p-value)
Inclinometer	0.05 (17.84)	$r=0.9998^{**}$
Motion sensor	0.13 (17.46)	$p=0.0002$

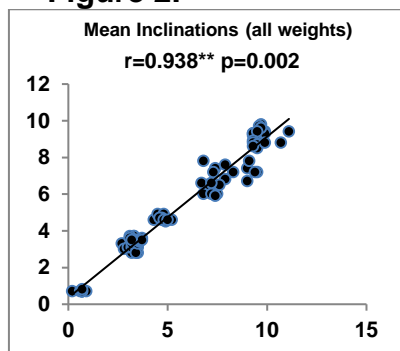
**Figure 1.**



**Table III.**

Dummy load	Sensor position	Observer 1 mean (SD)	Observer 2 mean (SD)	Correlation index ICC (SEM, MDC95)
2kg	Head	3.3 (0.14)	3.3 (0.28)	<b>0.985*</b> (1.073, 2.974)
	Thorax	3.1 (0.19)	3.2 (0.29)	
	Pelvis	0.7 (0.18)	0.7 (0.03)	
5kg	Head	8.3 (1.01)	7.3 (0.43)	
	Thorax	7.3 (0.36)	6.4 (0.42)	
	Pelvis	3.5 (0.17)	3.4 (0.23)	
7kg	Head	9.8 (0.51)	9.4 (0.22)	
	Thorax	9.6 (0.43)	8.9 (0.36)	
	Pelvis	4.6 (0.25)	4.7 (0.13)	

**Figure 2.**



**Table IVa.**

Patient (sitting)	Sensor position	Rater 1 Mean angle	Rater 2 Mean angle	Correlation index ICC(95% CI) (SEM, MDC95)	Patient standing	Sensor position	Rater 1 Mean angle	Rater 2 Mean angle	Correlation index ICC(95% CI) (SEM, MDC95)
1	Head	7,5	4,2	<b>0.88**</b> (0.70;0.95) (0.85, 2.35)	1	Head	2,5	5,1	<b>0.95**</b> (0.87;0.98) (1.02, 2.82)
	Thorax	3,6	2			Thorax	6,1	7,1	
	Pelvis	3,3	3,5			Pelvis	2,4	4,1	
2	Head	0,7	1,1		2	Head	-0,5	0,2	
	Thorax	2,6	2,2			Thorax	2,4	2,5	
	Pelvis	0,2	-0,4			Pelvis	-1,3	-0,5	
3	Head	1,5	3,2		3	Head	1,8	1,7	
	Thorax	-3,0	-2,3			Thorax	-3,4	-2,9	
	Pelvis	-0,5	-1,5			Pelvis	1,3	0,4	
4	Head	2,9	2,3		4	Head	0,1	-0,2	
	Thorax	5,4	4,3			Thorax	-3,6	-4,3	
	Pelvis	-1,0	-1,6			Pelvis	-6	-5,8	
5	Head	-0,9	-0,9		5	Head	-0,3	-1,6	
	Thorax	1,5	2,2			Thorax	1,9	1,9	
	Pelvis	0,3	0,3			Pelvis	0,3	0,2	
6	Head	-2,0	-2,5		6	Head	-2	-1,8	
	Thorax	0,5	-1,5			Thorax	1	1	
	Pelvis	0,9	-1,7			Pelvis	0,9	0	

Patient (sit to stand)	Sensor position	Rater 1 Mean angle	Rater 2 Mean angle	Correlation index ICC(95% CI) (SEM, MDC95)	Patient (walk)	Sensor position	Rater 1 Mean angle	Rater 2 Mean angle	Correlation index ICC(95% CI) (SEM, MDC95)
1	Head	9,1	0,2	<b>0.77**</b> (0.50;0.91) (1.44, 3.99)	1	Head	1,3	2,6	<b>0.71*</b> (0.37;0.90) (1.81, 5.00)
	Thorax	6,4	3,2			Thorax	-1,8	8	
	Pelvis	6,7	4,9			Pelvis	-3,6	-0,7	
2	Head	2,3	3,3		2	Head	0,1	1,6	
	Thorax	-2,9	-0,3			Thorax	8,9	2,9	
	Pelvis	-6,3	-4			Pelvis	0,1	-7,7	
3	Head	0,5	1,3		3	Head	-0,6	-1,4	
	Thorax	-3,6	-2,7			Thorax	-3,5	-3,9	
	Pelvis	3	1,8			Pelvis	2,6	0	
4	Head	0,1	-0,5		4	Head	2,8	3,9	
	Thorax	-2,8	-5			Thorax	-1,7	-5,5	
	Pelvis	-3,9	-3,1			Pelvis	-4,9	-4,1	
5	Head	-5,3	-3,4		5	Head	-4,1	-7,8	
	Thorax	8,8	9,4			Thorax	13	15,8	
	Pelvis	-3,4	0,3			Pelvis	-7,6	-2,4	
6	Head	0,2	0		6	Head	-1,7	-1,5	
	Thorax	2,9	4			Thorax	2,2	2,7	
	Pelvis	0,2	1,6			Pelvis	0,7	1,5	

Figure 3a.

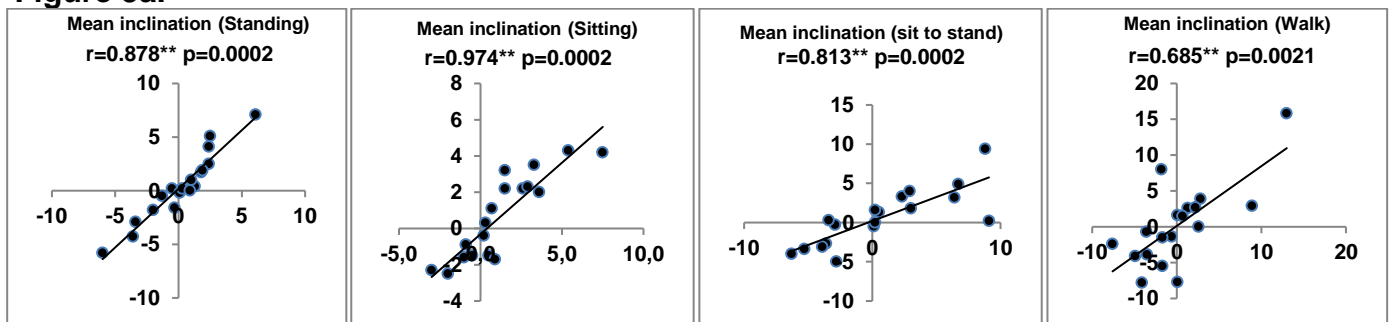


Table IVb.

Patient (sitting)	Sensor position	Rater 1 Standard deviation	Rater 2 Standard deviation	Correlation index ICC(95% CI) (SEM, MDC95)	Patient (standing)	Sensor position	Rater 1 Standard deviation	Rater 2 Standard deviation	Correlation index ICC(95% CI) (SEM, MDC95)
1	Head	2,7	1,2	0.30 (0.18;0.66) (0.19, 0.51)	1	Head	1,8	1,6	0.42 (0,04;0,73) (0.23, 0.64)
	Thorax	2,1	1			Thorax	2,8	1,6	
	Pelvis	0,5	0,4			Pelvis	1,2	0,9	
2	Head	1,3	1,9		2	Head	1	2,1	
	Thorax	0,4	1,3			Thorax	0,9	2	
	Pelvis	0,8	1,1			Pelvis	1,4	2,7	
3	Head	0,6	0,5		3	Head	0,6	0,4	
	Thorax	1,0	0,5			Thorax	0,4	0,6	
	Pelvis	0,4	0,3			Pelvis	0,5	0,4	
4	Head	1,1	1,1		4	Head	0,6	0,5	
	Thorax	1,2	1,8			Thorax	0,8	0,3	
	Pelvis	1,6	1,1			Pelvis	0,5	0,7	
5	Head	0,8	1,2	5	Head	0,9	0,4		
	Thorax	0,7	1,1		Thorax	2	0,5		
	Pelvis	0,4	1,2		Pelvis	1,3	0,7		
6	Head	0,9	1,2	6	Head	0,6	0,8		
	Thorax	1,5	0,9		Thorax	0,5	0,6		
	Pelvis	0,5	0,6		Pelvis	0,9	0,7		

Patient (sit to stand)	Sensor position	Rater 1 Standard deviation	Rater 2 Standard deviation	Correlation index ICC(95% CI) (SEM, MDC95)	Patient (walk)	Sensor position	Rater 1 Standard deviation	Rater 2 Standard deviation	Correlation index ICC(95% CI) (SEM, MDC95)
1	Head	4,3	1,6	0.71* (0.37;0.88) (0.37, 1.42)	1	Head	2,1	2,3	0.36 (0.11;0.70) (0.79, 2.19)
	Thorax	5	2,9			Thorax	2,3	2,8	
	Pelvis	2,1	1,4			Pelvis	1,5	3,2	
2	Head	2	1,9		2	Head	12,4	3,1	
	Thorax	5,2	2,9			Thorax	5,4	3,4	
	Pelvis	4,9	4,7			Pelvis	6,5	4,2	
3	Head	0,8	1,1		3	Head	1,3	0,8	
	Thorax	1,2	1			Thorax	1	0,9	
	Pelvis	1,8	2,3			Pelvis	1,2	1,5	
4	Head	2,4	1,8		4	Head	3	2,2	
	Thorax	3,5	2			Thorax	2,5	2,1	
	Pelvis	2,1	1,3			Pelvis	2,9	2,6	
5	Head	2,9	1,9	5	Head	4,7	4,7		
	Thorax	5,5	6,4		Thorax	8,4	3,2		
	Pelvis	4	1		Pelvis	3,4	3,5		
6	Head	3,1	2,2	6	Head	1,7	1,5		
	Thorax	4,2	4,1		Thorax	2,2	2,3		
	Pelvis	2,3	1,7		Pelvis	1,4	1,3		

Figure 3b.

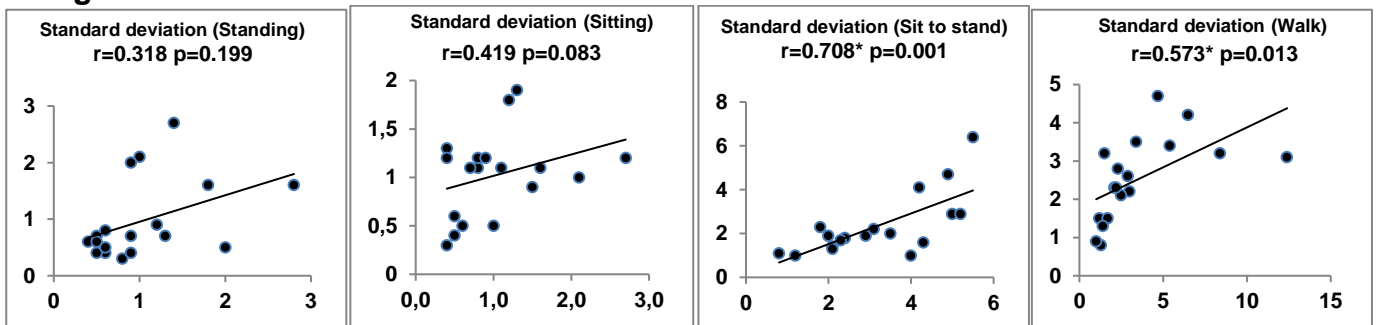


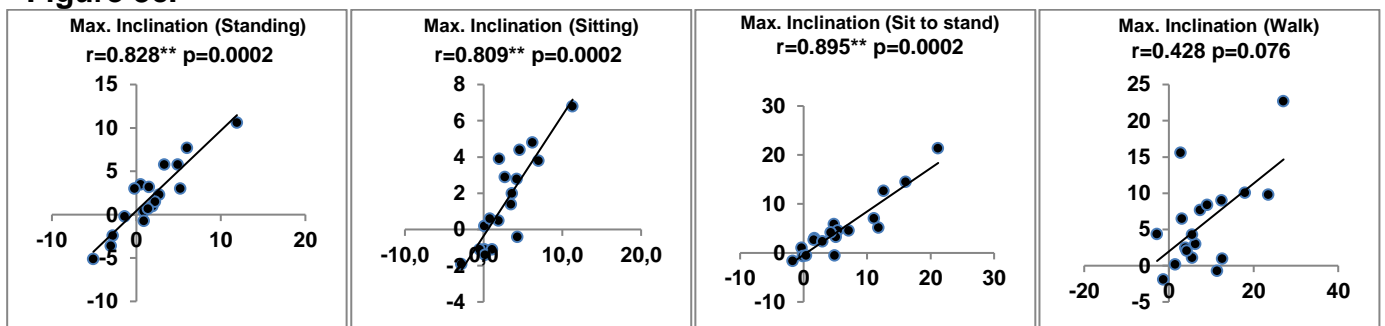
Table IVc.

Patient (sitting)	Sensor position	Rater 1 Max. angle	Rater 2 Max. angle	Correlation index ICC(95% CI) (SEM, MDC95)	Patient (standing)	Sensor position	Rater 1 Max. angle	Rater 2 Max. angle	Correlation index ICC(95% CI) (SEM, MDC95)
1	Head	11,3	6,8	<b>0.83**</b> (0.60;0.93) (1.03, 2.84)	1	Head	6	7,7	<b>0.91**</b> (0.79;0.96) (1.33, 3.68)
	Thorax	7,0	3,8			Thorax	11,9	10,6	
	Pelvis	4,6	4,4			Pelvis	4,9	5,8	
2	Head	3,5	1,4		2	Head	0,5	3,5	
	Thorax	3,6	2			Thorax	3,3	5,8	
	Pelvis	1,9	0,5			Pelvis	-0,2	3	
3	Head	2	3,9		3	Head	2,7	2,3	
	Thorax	-2,8	-1,9			Thorax	-2,8	-2,4	
	Pelvis	0,1	-1,1			Pelvis	1,9	1	
4	Head	4,2	2,8		4	Head	0,9	0,4	
	Thorax	6,2	4,8			Thorax	-3	-3,6	
	Pelvis	-0,5	-1,1			Pelvis	-5,1	-5,1	
5	Head	0,1	0,2	5	Head	0,9	-0,7		
	Thorax	2,7	2,9		Thorax	5,2	3		
	Pelvis	0,8	0,6		Pelvis	2,2	1,5		
6	Head	1,1	-1,1	6	Head	-1,4	-0,2		
	Thorax	4,3	-0,4		Thorax	1,5	3,2		
	Pelvis	0,2	-1,4		Pelvis	1,4	0,7		

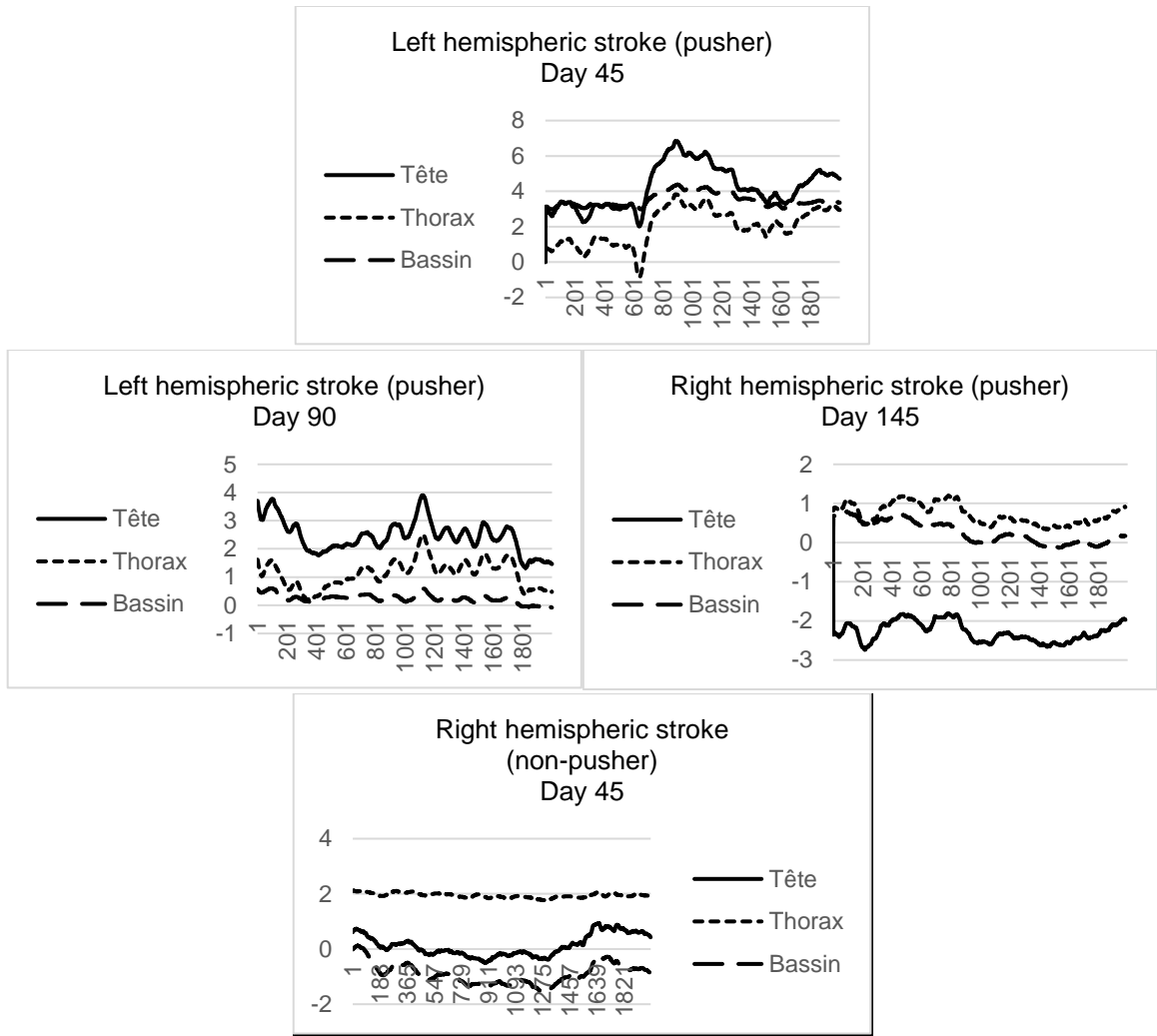
  

Patient (sit to stand)	Sensor position	Rater 1 Max. angle	Rater 2 Max. angle	Correlation index ICC(95% CI) (SEM, MDC95)	Patient (walk)	Sensor position	Rater 1 Max. angle	Rater 2 Max. angle	Correlation index ICC(95% CI) (SEM, MDC95)
1	Head	11,8	5,2	<b>0.93**</b> (0.82;0.97) (2.08, 5.77)	1	Head	7,4	7,7	0.58 (0.18;0.82) (2.49, 6.90)
	Thorax	12,6	12,7			Thorax	2,8	15,6	
	Pelvis	11,1	7,1			Pelvis	3,1	6,5	
2	Head	4,8	5,9		2	Head	23,5	9,8	
	Thorax	1,7	3			Thorax	18	10,1	
	Pelvis	-0,3	1,1			Pelvis	12,6	1	
3	Head	1,6	2,7		3	Head	1,5	0,2	
	Thorax	-1,7	-1,6			Thorax	-1,3	-1,9	
	Pelvis	5,4	4,6			Pelvis	6,3	3	
4	Head	5,1	3,3		4	Head	12,5	9	
	Thorax	4,9	-0,5			Thorax	11,4	-0,7	
	Pelvis	-0,1	-0,6			Pelvis	3,9	2,5	
5	Head	0,4	-0,5	5	Head	5,5	1,1		
	Thorax	21,2	21,4		Thorax	27,1	22,7		
	Pelvis	3	2,4		Pelvis	-2,8	4,4		
6	Head	7,1	4,6	6	Head	4,2	2,1		
	Thorax	16,1	14,5		Thorax	9,1	8,4		
	Pelvis	4,3	4,2		Pelvis	5,5	4,3		

**Figure 3c.**



**Figure 4.**



## **Appendixes**

- 1. Operators instructions booklet (setup, calibration, data recording and processing)**
- 2. Most common errors of measurements**
- 3. Data processing script**
- 4. Example of data report**

**Measuring lateropulsion  
using Xsens motion sensors**

***Operator's booklet***

Version 2.0 – Protocole SCALA – Août 2018

**Consignes aux opérateurs : Protocole de calibration et mesures Xsens**

Consignes opérateur 1  
Consignes opérateur 2

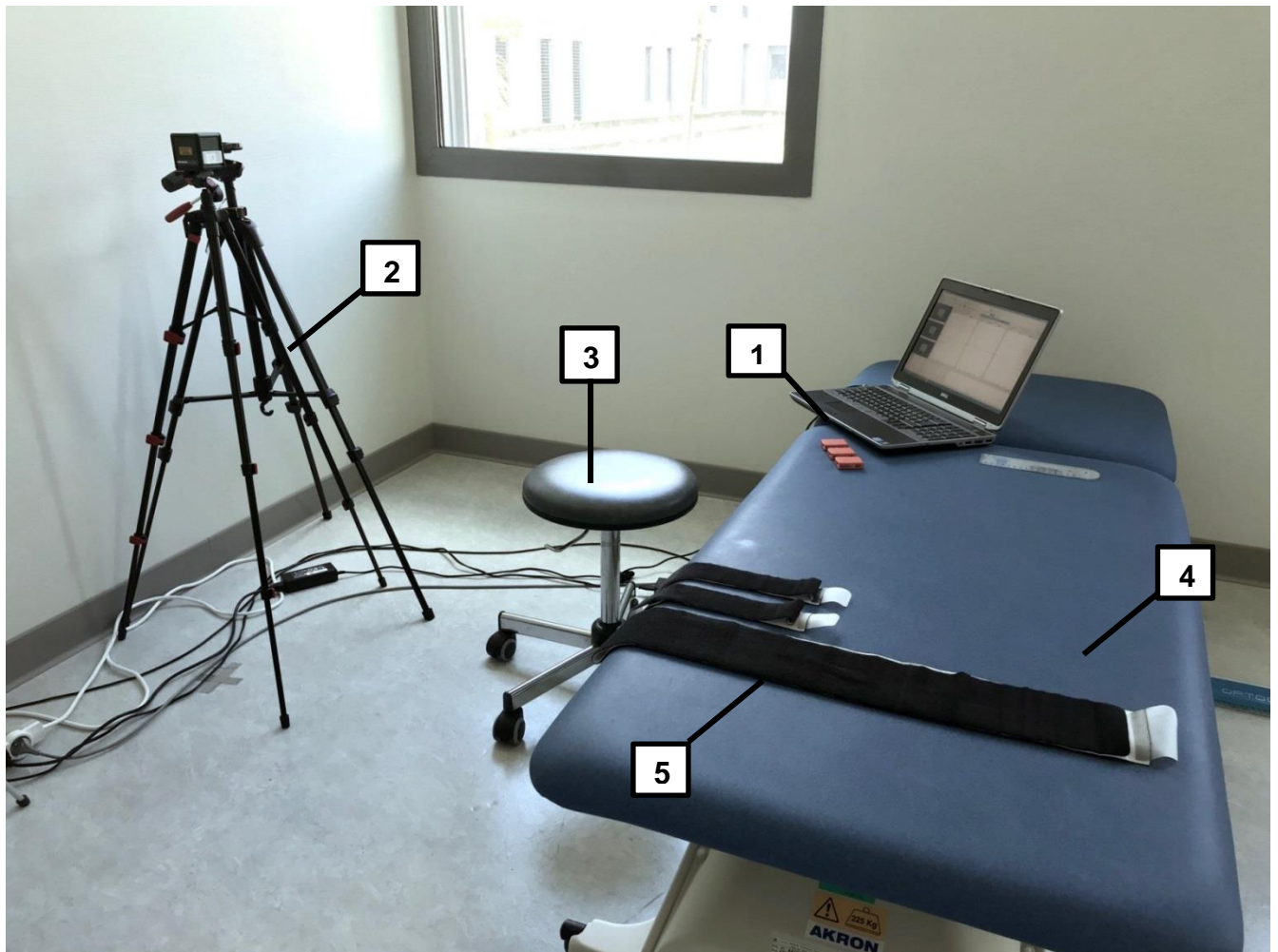
Page 2  
Page 3  
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**Enregistrement et traitement des données Xsens**

Procédure d'enregistrement  
Traitement général des données  
Traitement spécifique des données pour l'étude de la latéropulsion

Page 7  
Page 7  
Page 11  
Page 13

## Matériel pré-requis



1. Ordinateur portable, dongle USB de réception Xsens, Capteurs Xsens, Goniomètre
2. Laser et trépied
3. Tabouret de l'opérateur
4. Plan Bobath réglable
5. Bandes velcro

## Personnel requis

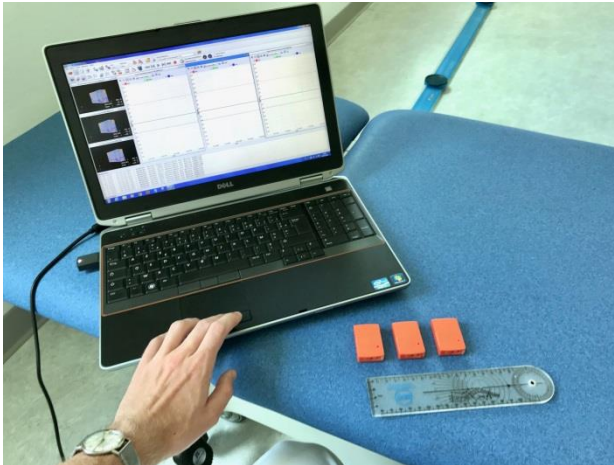
Opérateur 1

Opérateur 2

## Consignes Opérateur 1

1. Placer le patient assis sur le plan Bobath, dos face à l'examineur, avec réglage tel que les genoux soient à 100° de flexion. L'opérateur 1 est placé dos au patient, avec l'ordinateur à portée de main. Il reste assis tout au long de la procédure.





2. Placer les bandes et les capteurs sur le patient en regard de l'occiput, de l'épineuse C7 et du sacrum
3. Allumer le dispositif laser



4. Le faisceau laser atteint le dos du patient. Ajuster le faisceau vertical pour le centrer sur la marque du capteur du sacrum (S1).



5. A l'aide de l'opérateur 2, maintenir le patient redressé de telle sorte que les trois repères des trois capteurs passent par la ligne de référence verticale du faisceau laser



6. L'**opérateur 1** contrôle le bon alignement en balayant du regard l'alignement des repères faisceau laser
7. Une fois la position adéquate atteinte, l'opérateur 1 clique sur le bouton "Alignment reset"



8. L'**opérateur 2** peut lâcher le patient pour procéder à l'acquisition des données dans les différentes tâches

9. L'**opérateur 1** clique sur le bouton rouge pour procéder à l'enregistrement de chaque tâche. Un second clic stoppe l'enregistrement à la fin de chaque tâche.



## Consignes Opérateur 2

### 1. Consignes à dire à haute voix au patient :

Assis, 60 et 20 secondes, yeux ouverts :

**« A mon signal, veuillez rester assis en regardant droit devant vous. N'ayez pas peur, vous ne chuterez pas. »**

Transfert assis debout :

**« A mon signal, veuillez-vous mettre debout. N'ayez pas peur, vous ne chuterez pas. »**

Debout, 20 secondes, yeux ouverts :

**« A mon signal, veuillez rester debout en regardant droit devant vous. N'ayez pas peur, vous ne chuterez pas. »**

Marche :

**« A mon signal, nous allons essayer de marcher quelques mètres, je vous sécurise tout au long du chemin. N'ayez pas peur, vous ne chuterez pas. »**

### 2. Avant l'installation :

Aider l'**opérateur 1** à installer le patient sur le plan Bobath.

### 3. Pendant la calibration :

Rester debout devant le patient pour maintenir son tronc et sa tête dans l'axe pendant que l'**opérateur 1** calibre le matériel.

### 4. Pendant les enregistrements :

**Assis, Transfert, Debout :**

Se placer du côté pathologique du patient.

L'**opérateur 2** vérifie que les mains du patient soient placées de telle sorte que la main saine tient la main parétique. **Elles ne doivent pas toucher le plan de l'assise pendant le transfert.**

Le seul contact autorisé à l'**opérateur 2** est au niveau de la ceinture du patient : **Au choix :**

- Une main seule : Latérale : Retenir autant que possible le bassin sans le pousser.
- Deux mains : Une latérale, une **sous** la fesse : Ajoute une aide contre la rétropulsion, une poussée antérieure est autorisée lors du transfert. **Attention à ne pas toucher le capteur avec cette main.**

L'environnement visuel est contrôlé à l'aide d'un repère mural que le patient fixe pendant les enregistrements.

En position debout : S'assurer l'aplomb des épaules corresponde à la position au sol des pieds. Dans le cas inverse, rapprocher les pieds du patient après le transfert.



**Marche :**

Se placer en face ou côté à côté du patient et le suivre.

Le seul contact autorisé à l'**opérateur 2** est au niveau de la ceinture du patient :

Retenir sans pousser.

Penser à disposer d'une chaise en bout de parcours.

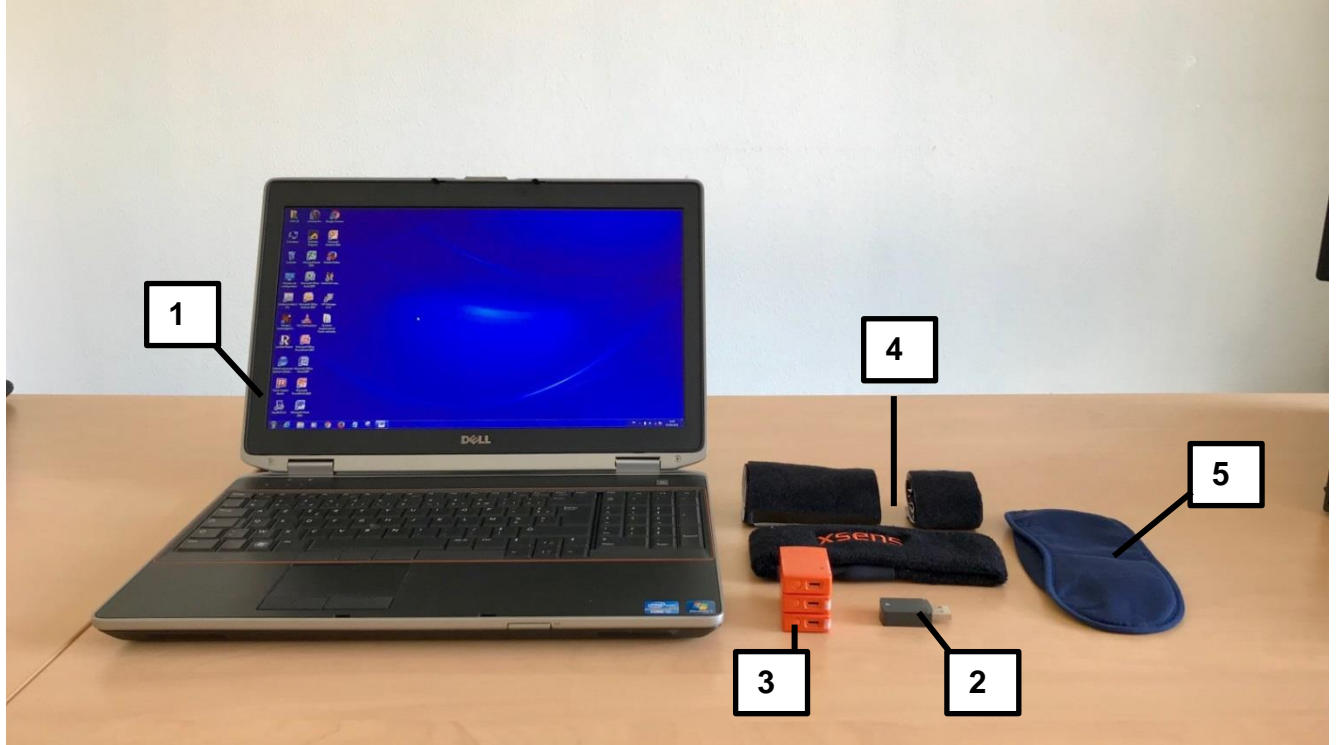
5. L'**opérateur 2** s'assure du bon enchaînement des enregistrements pour éviter les erreurs de traitement de données :

Assis 60 secondes ⇒ Transfert ⇒ Debout 20 secondes ⇒ Assis 20 secondes ⇒  
Transfert ⇒ Debout 20 secondes ⇒ Assis 20 secondes ⇒ Transfert ⇒ Debout 20  
secondes ⇒ Marche

# Enregistrement et traitement des données Xsens

Version 2.0 – Protocole SCALA – Août 2018

## Matériel pré-requis



1. Ordinateur portable (Uniquement Windows, **Logiciel MT Manager**, Logiciel **Rstudio** et fichier **Xsens\_Data\_Processing.rmd**)
2. Dongle USB de réception Xsens
3. Capteurs Xsens
4. Bandes velcro
5. Masque (optionnel)

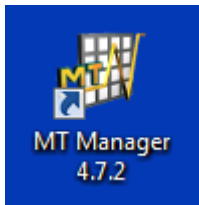
## Procédure d'enregistrement des données

1. Brancher le Dongle USB, et allumer les capteurs nécessaires (un appui long pour allumer, la led clignotte ; un appui très long pour éteindre, la led s'éteint)

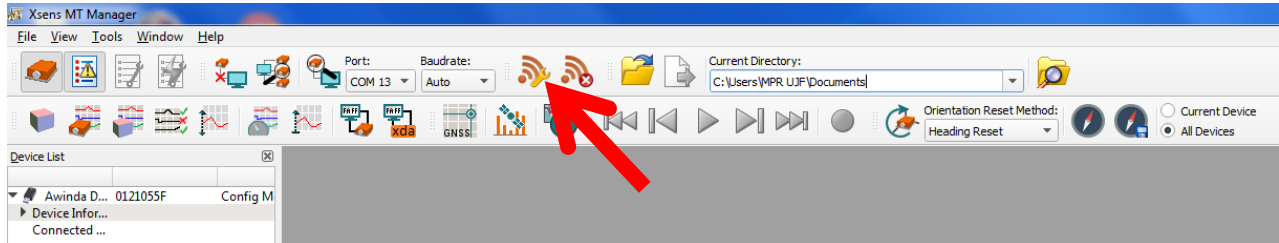


2. Lancer MT Manager





### 3. Cliquer sur le bouton Wireless Configuration

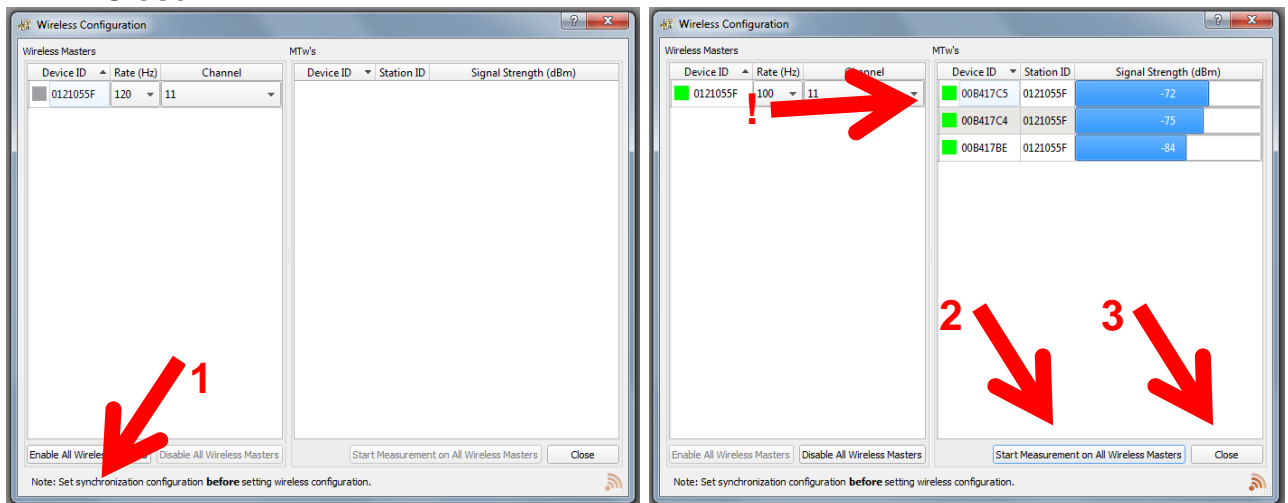


### 4. Cliquer sur **Enable All Wireless Masters** : A gauche du tableau, le récepteur reconnu s'active, puis quelques secondes sont nécessaires pour reconnaître les capteurs dans le tableau de droite.

Si les capteurs n'apparaissent pas à droite : Les agiter légèrement, vérifier leur mise sous tension, vérifier leur niveau de batterie.

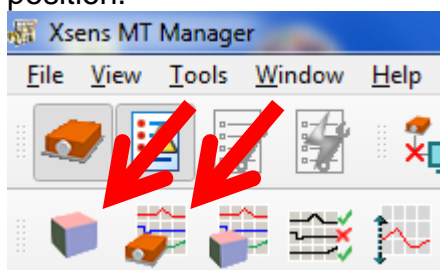
Bien repérer le nom (Device ID) des capteurs allumés.

Une fois détectés, cliquer **Start Measurement on All Wireless Masters** puis sur **Close**.

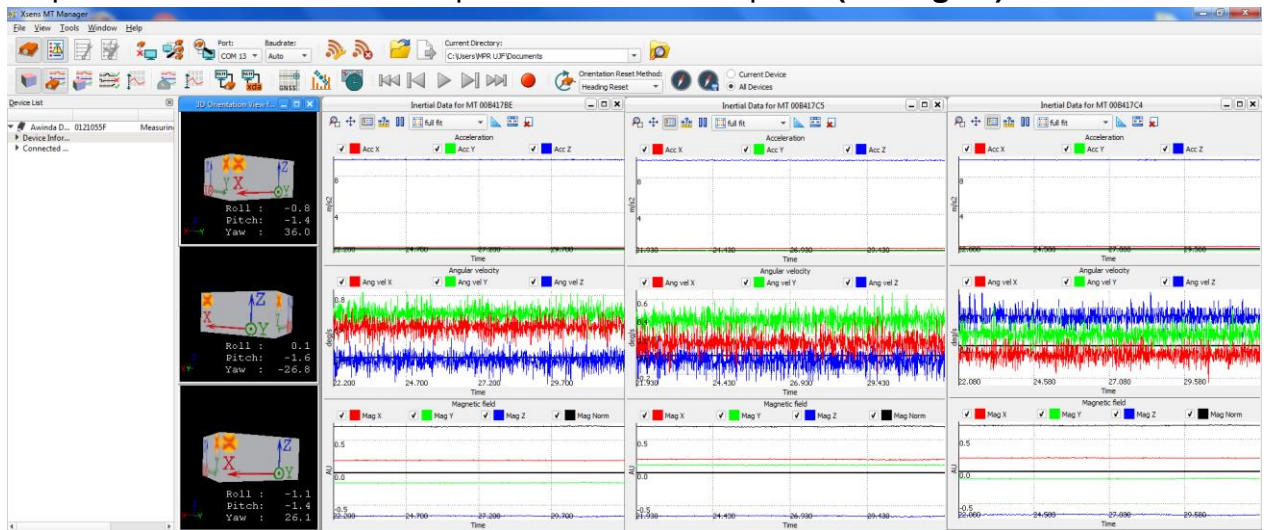


### 5. Cliquer sur le **3D View** et **Inertial Data** pour afficher les représentations des capteurs en marche (placer les fenêtres de la manière la plus intuitive en fonction de l'enregistrement prévu).

Bien repérer le nom de chaque capteur entre sa représentation à l'écran et sa position.

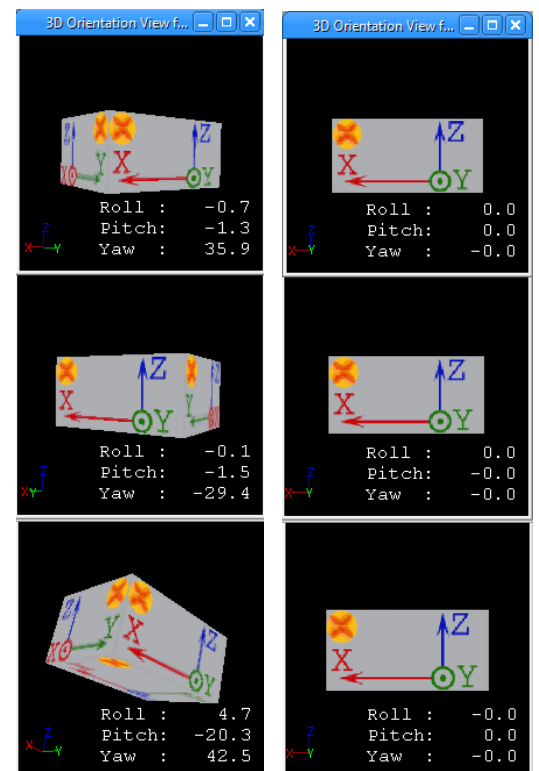


6. La procédure de calibration est prête à être mise en place (cf. Page 2)



7. Placer les capteurs sur le sujet, et procéder à la calibration des capteurs (cf. Page 2)

8. Choisir « **Alignment Reset** » dans le menu déroulant pour mettre à la fois à zéro l'inclinaison et l'orientation des trois capteurs simultanément.



A gauche, position des capteurs avant Alignment reset ; A droite, calibration effectuée

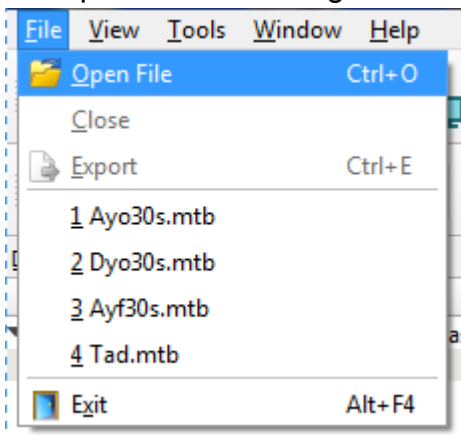
9. Placer le sujet dans un référentiel de base. Une fois prêt, cliquer sur le bouton.  
Les référentiels des trois capteurs sont désormais dans le même référentiel que celui indiqué par la verticale terrestre. **(Cf. Video de procédure de calibration)**
10. Un clic sur le bouton rouge lance l'enregistrement d'une série de données à 100Hz.  
Un second clic stoppe l'enregistrement.





## Traitement général des données

1. Récupération de l'enregistrement : File > Open

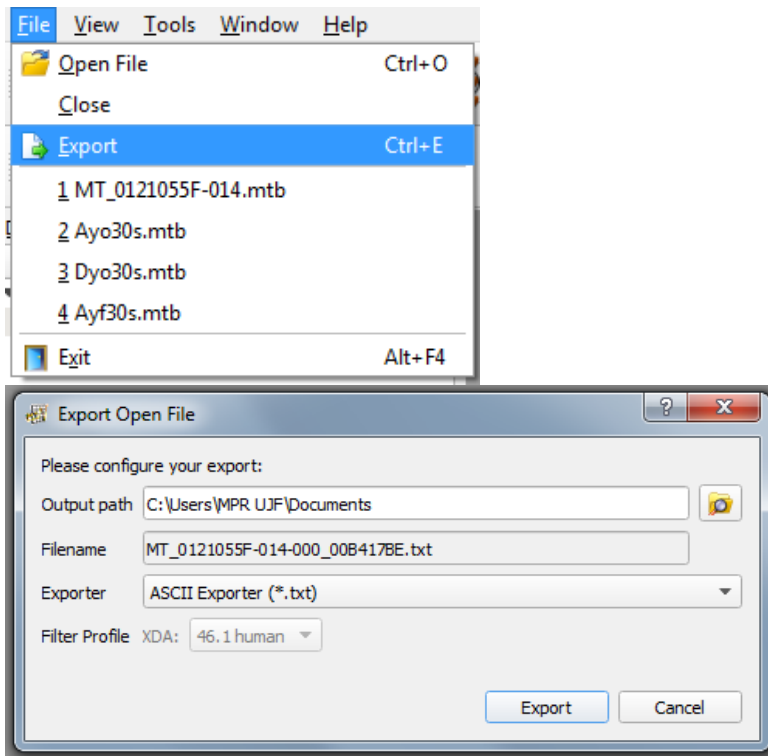


2. Ouvrir le fichier correspondant à l'enregistrement souhaité (l'heure d'enregistrement peut aider)

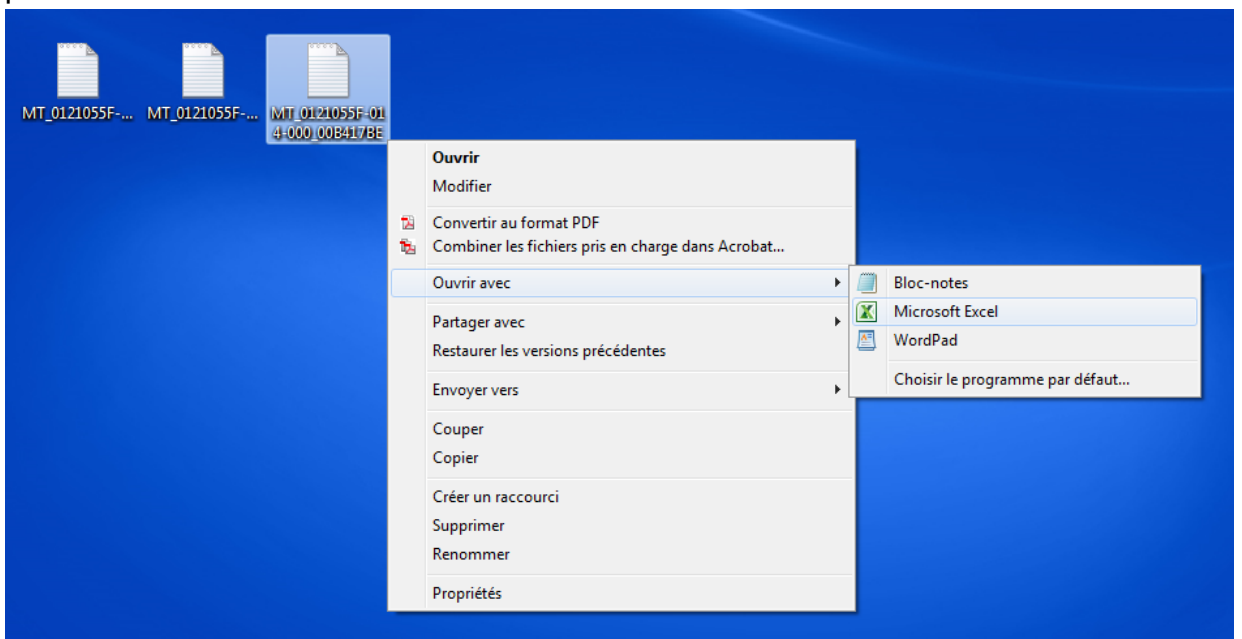
**Bibliothèque Documents**  
Inclut : 2 emplacements

Nom	Modifié le
EndNote	23/06/2011 17:26
MT_0121055F-014	07/03/2018 11:19
MT_0121055F-013	07/03/2018 11:19
MT_0121055F-012	15/07/2017 20:07
MT_0121055F-011	14/07/2017 19:33
MT_0121055F-010	14/07/2017 14:44
MT_0121055F-009	05/07/2017 14:18

3. Exporter les données à l'endroit souhaité  
**Ne pas hésiter à utiliser le raccourci Ctrl+E, et Entrée**



4. On obtient autant de fichiers que de capteurs en données brutes (fichiers .txt). Chaque fichier porte le nom du capteur associé. Ouvrir chaque fichier avec Microsoft Excel pour extraire les données nécessaires.



5. Extraire les colonnes de données souhaitées pour analyse statistique

The image shows a Microsoft Excel spreadsheet with a grid of data. The spreadsheet has columns labeled S through AK and rows numbered 1 through 41. The data is organized into columns with headers: FreeAcc\_X, FreeAcc\_Z, Gyr\_X, Gyr\_Y, Gyr\_Z, Mag\_X, Mag\_Y, Mag\_Z, Vellinc\_X, Vellinc\_Y, Vellinc\_Z, Ortrinc\_q0, Ortrinc\_q1, Ortrinc\_q2, Ortrinc\_q3, Pressure, Roll, Pitch, Yaw, Latitude, and Longitude. The first few rows contain comments starting with '//'. The main data starts from row 6. Two callout boxes are present: box 1 is a black box with the number '1' pointing to the 'PacketCount' column header, and box 2 is a black box with the number '2' pointing to the 'Yaw' column header.

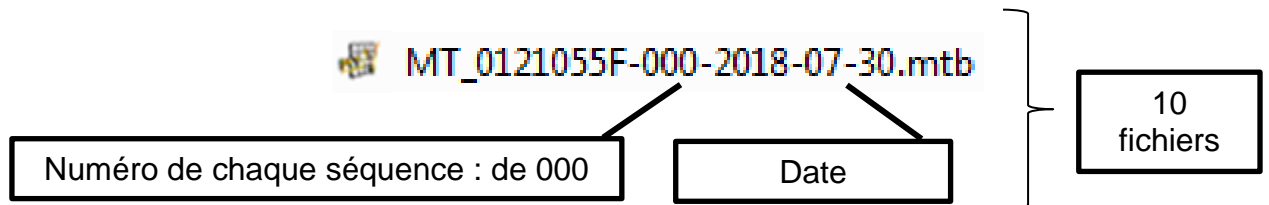
1. PacketCount (une unité équivaut à 1 milliseconde, enregistrement à 100Hz)
2. Valeurs d'orientation absolues dans les 3 axes. Récupérer les données de l'orientation voulue.
3. Autres données des capteurs, notamment Moment angulaire, Accélération, vitesse angulaire

## Traitement spécifique des données (Protocole de mesure de la latéropulsion)

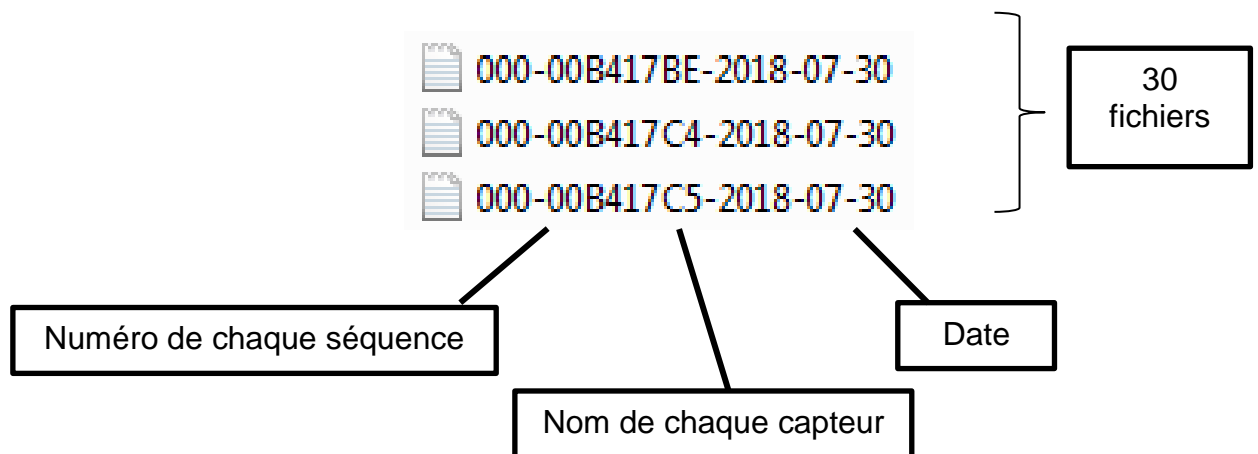
### 1. L'enregistrement de la séquence :

**Assis 60 secondes ⇒ Transfert ⇒ Debout 20 secondes ⇒ Assis 20 secondes ⇒ Transfert ⇒ Debout 20 secondes ⇒ Assis 20 secondes ⇒ Transfert ⇒ Debout 20 secondes ⇒ Marche**

Nous donne 10 fichiers distincts ayant pour nomenclature :



### 2. Après ouverture des dix fichiers et export (Ctrl + E, Entrée), on obtient 10x3 fichiers (nombre d'enregistrement x nombre de capteurs)



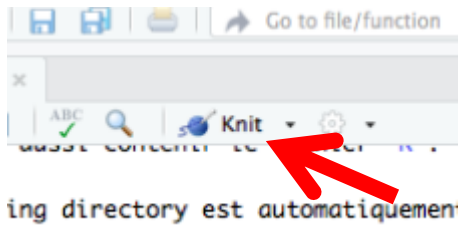
### Attention

La nomenclature des fichiers exportés doit absolument commencer par la séquence numérique de 000 à 009 correspondant respectivement aux enregistrements de la suite de séquences réalisée dans le bon ordre

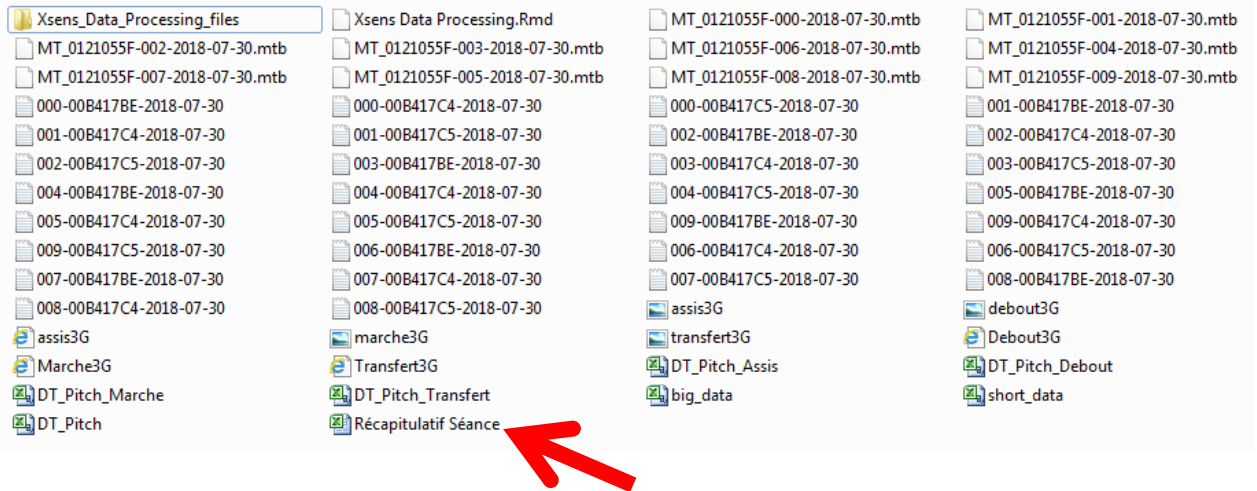
Si tel n'est pas le cas, il faut modifier les paramètres d'exportation des séquences dans MT Manager, tel que la nomenclature soit :  
<number of trial>-<sensor ID>-<date :YYYY-MM-DD>.txt

### 3. Copier le fichier « *Xsens\_data\_processing.rmd* » dans le dossier contenant ces 30 fichiers, puis double-cliquer dessus.

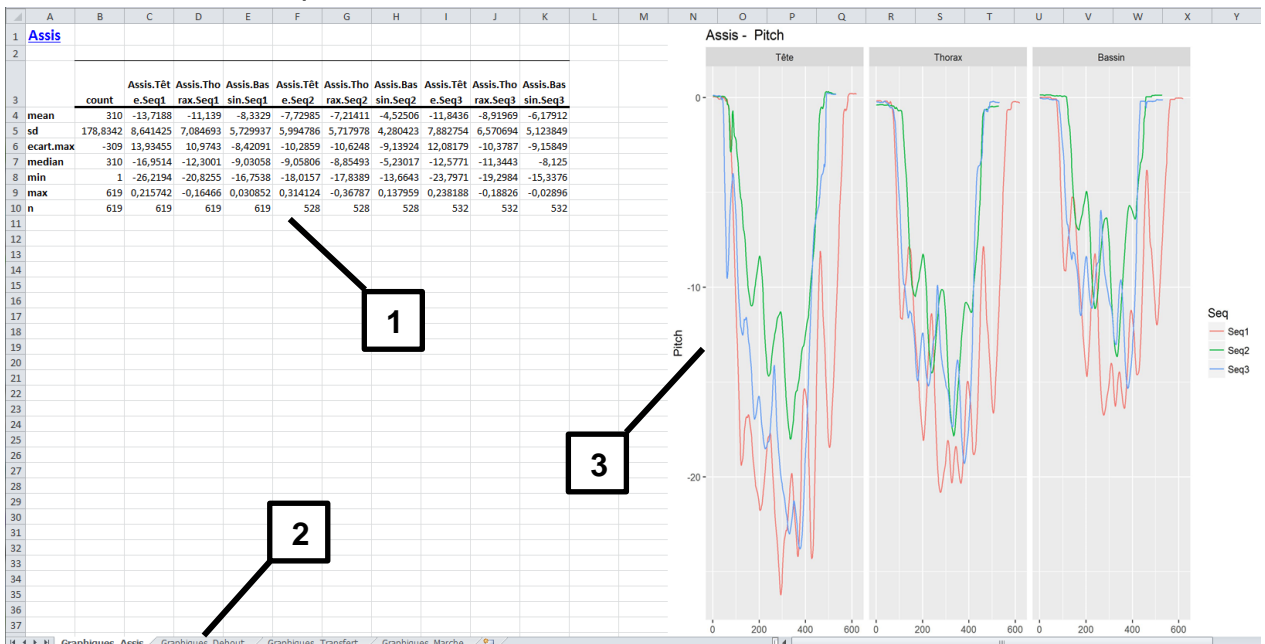
### 4. Rstudio s'ouvre. Cliquer sur « Knit ».



5. On obtient plusieurs fichiers récapitulatifs (tableaux Excel paginés et graphiques) dans ce même répertoire après un temps de traitement d'environ 30 secondes.



6. Visualisation du récapitulatif de la séance.



1. Statistiques descriptives pour chaque segment corporel avec : Moyenne de l'inclinaison, instabilité (écart-type), et angulations maximales
2. Une page de classeur par tâche (Assis, debout, transfert, marche)
3. Représentations schématiques de l'enregistrement de chaque séquence

Pour toute question concernant la procédure : [sgiroux@chu-grenoble.fr](mailto:sgiroux@chu-grenoble.fr)

**Measuring lateropulsion**  
using **Xsens** motion sensors

# ***Most common errors of measurements***

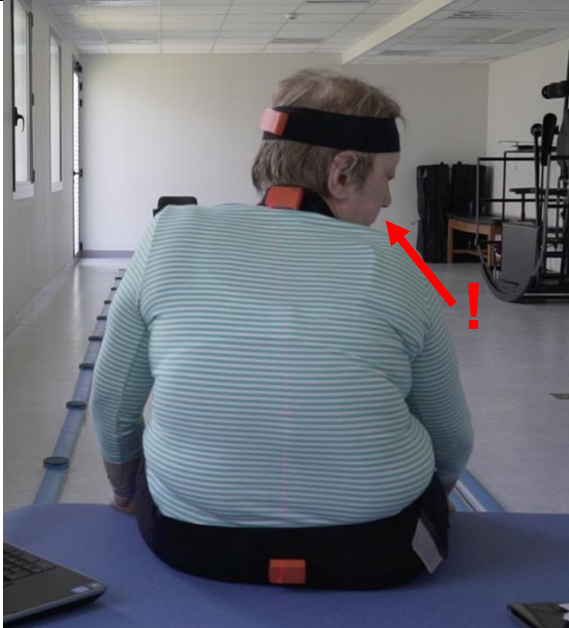
Version 2.0 – Protocole SCALA – Août 2018



## Erreurs de mesures habituelles - Xsens

Version 2.0 – Protocole SCALA – Août 2018

### Distraction du patient



En position assise ou debout :

- Bien que les mouvements involontaires influent peu sur les acquisitions :
- S'assurer que le patient ait le regard en direction d'un point fixe (bien lire à voix haute les consignes du guide de l'opérateur)
- Ne pas parler au patient pour éviter qu'il tourne la tête vers l'opérateur
- Il est difficile d'évaluer les patients aphasiques ou présentant des troubles de l'attention

### Aide de l'opérateur à l'exécution des tâches



Pendant les transferts ou la marche :

- Pas de main au contact du thorax ou des bras
- Contact au bassin autorisé (poussée postérieure ou maintien latéral)



## Contact involontaire des capteurs



Pendant le passage assis-debout :

- Ne pas aider le patient en tirant la ceinture ou en touchant les capteurs, au risque de fausser les mesures en cours et ultérieures pour ce capteur
- Si le contact se produit, recommencer la procédure de calibration
- La main aidante pousse sous la fesse si besoin mais ne tire pas vers le haut

## Transfert aidé des mains

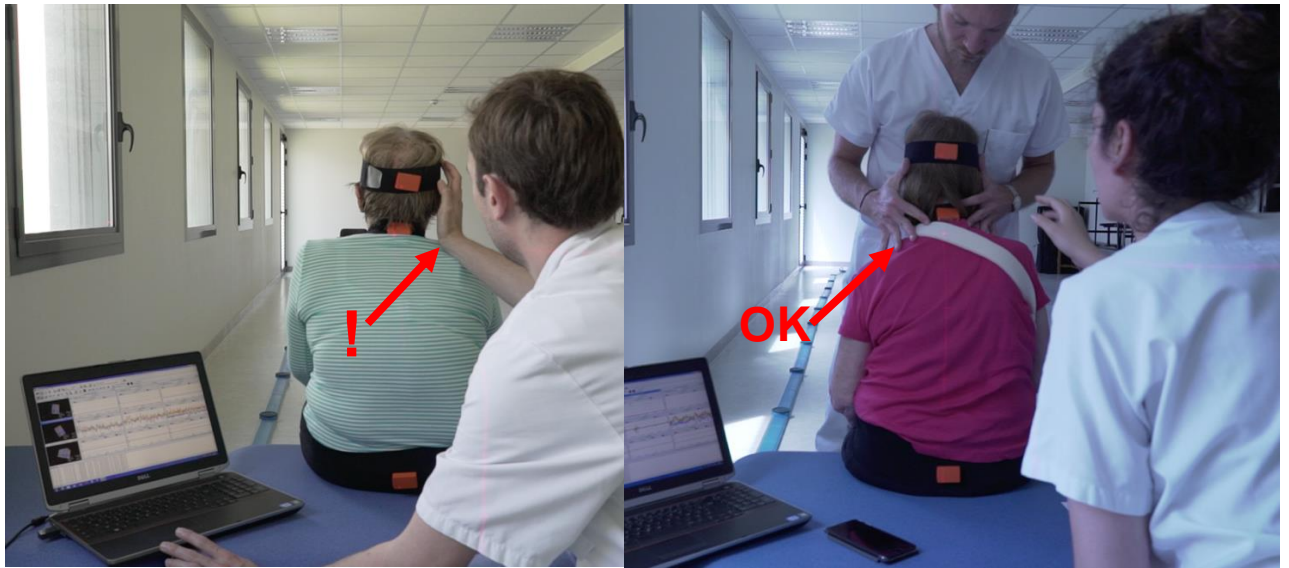


Pendant le passage assis-debout :

- Le patient ne doit pas s'aider de ses mains pour le transfert
- Les mains restent sur les genoux
- Si besoin, l'opérateur aide le patient par une poussée manuelle sous les fesses



## Erreurs de calibration



Pendant la calibration :

- Ne pas calibrer le système seul
- Calibrer à deux pour qu'un opérateur maintienne la position adéquate à deux mains comme ci-dessus
- L'autre opérateur a les mains libres pour utiliser l'ordinateur

# *An implementation in R Markdown of motion sensors inertial data*

*Iragaël Joly*

*06 juin, 2018*

Cette notice décrit le bout de code *R* pour :

1. l'importation des données après exportation de *Xsens* par l'utilisateur
2. La mise en forme des données, selon 2 objectifs :
  - la production d'un fichier *xls* adapté à l'utilisateur
  - permettre un premier traitement des données sous *R*
3. la production de quelques traitements avec *R* (statistiques descriptives et graphiques)
4. l'exportation de ces éléments sous format *html* et *xls*

## **Remarques préliminaires:**

- Le document peut être compilé avec Rstudio pour produire un document *html* et tous les fichiers de données et images
- Le document utilise *Rmarkdown* et nécessite pour l'édition du document *html* l'installation de deux packages: `install.packages("tuftes")` et `install.packages("knitr")`. D'autres packages sont utiles pour les manipulations de données, ils sont précisés plus loin.
- Attention les temps de calculs sont vite *longs* !

## *Mise en place de l'espace de travail*

### *Dossier de travail (working directory)*

Il s'agit de définir le dossier de travail qui contient les **fichiers à importer** et contiendra les **fichiers produits**.

Il doit aussi contenir le présent fichier *RMarkdown*: `xsens_data_analysis.rmd`.

Le working directory est automatiquement défini pour l'exécution du fichier *Rmd* comme le dossier contenant ce fichier.

Il peut être utilisé de spécifier le working directory de façon plus globale par l'instruction suivante:

```
rm(list = ls())  
setwd("C:\\Users\\ijoly.INRA\\Downloads\\Stanislas\\TEST")
```

### *Installation des packages*

On utilise par la suite les packages:

- xlsx pour l'export du résultat au format xls
- dplyr pour les fonctions avancées de manipulations de données
- ggplot2 pour les graphiques avancés
- hexbin pour les graphiques hexbin
- stringr pour les fonctions sur le texte

```
# install.packages("dplyr")
# install.packages("xlsx")
# install.packages("hexbin")
# install.packages("reshape2")
library(dplyr)
library(xlsx)
library(ggplot2)
library(hexbin)
library(knitr)
library(stringr)
library(reshape2)
library(gridExtra)
```

## *Vidange de l'environnement (uniquement les objets pouvant poser conflits)*

On supprime de l'environnement l'objet `big_data`, qui peut provenir de précédentes exécutions et qui poserait un conflit lors d'une nouvelle exécution.

```
rm(big_data)
## Warning in rm(big_data): objet 'big_data' introuvable
```

## *Importation des données depuis les exports Xsens au format .txt*

1. On crée une liste des fichiers d'extensions `.txt` présents dans le dossier de travail
2. On définit une fonction 'maison' : `read5()` pour lire les fichiers à partir de la ligne 5 ET pour supprimer les colonnes vides
3. On applique la fonction d'importation à chaque fichier présent dans le dossier, et on crée un *dataframe* pour chaque fichier importé

```
# import multiple files
## create list of files in WD with ".txt" extension
temp <- list.files(pattern="*.txt")
## create function to read from line 5
## AND to drop all NA columns (405 -> 28)
read5 <- function(x){
  y <- read.delim(x, skip=5)
  tempDF <- y[,which(unlist(lapply(y, function(x) !all(is.na(x)))))]
  return(tempDF)
}
# read5("o1 a1 MT_0121055F-007-000_00B417BE.txt")
## read all files into multiple dataframes
list2env(
  lapply(setNames(temp, make.names(gsub("*.txt$", "", temp))),
```

```
read5), envir = .GlobalEnv)
## <environment: R_GlobalEnv>
```

On crée une liste avec les *dataframe* pour les concatener toutes ensemble, sans devoir les lister à la main.

On peut ajouter un filtre pour sélectionner les dataframes selon leur noms. On utilise `ls()` pour lister les objets en mémoire et `mget()` pour chercher dans un ensemble ou un environnement et faire une liste du résultat.

La liste des objets considérés est présentée

```
## Create list of DF names given condition "o1."
# df_list_o1 <- mget(ls(pattern = "o.*"))
## Create list of DF names given condition "data.frame"
dfs <- Filter(function(x) is(x, "data.frame"), mget(ls()))
## tests
names(dfs)
## [1] "X000.00B417BE.2018.04.15" "X000.00B417C4.2018.04.15"
## [3] "X000.00B417C5.2018.04.15" "X001.00B417BE.2018.04.15"
## [5] "X001.00B417C4.2018.04.15" "X001.00B417C5.2018.04.15"
## [7] "X002.00B417BE.2018.04.15" "X002.00B417C4.2018.04.15"
## [9] "X002.00B417C5.2018.04.15" "X003.00B417BE.2018.04.15"
## [11] "X003.00B417C4.2018.04.15" "X003.00B417C5.2018.04.15"
## [13] "X004.00B417BE.2018.04.15" "X004.00B417C4.2018.04.15"
## [15] "X004.00B417C5.2018.04.15" "X005.00B417BE.2018.04.15"
## [17] "X005.00B417C4.2018.04.15" "X005.00B417C5.2018.04.15"
## [19] "X006.00B417BE.2018.04.15" "X006.00B417C4.2018.04.15"
## [21] "X006.00B417C5.2018.04.15" "X007.00B417BE.2018.04.15"
## [23] "X007.00B417C4.2018.04.15" "X007.00B417C5.2018.04.15"
## [25] "X008.00B417BE.2018.04.15" "X008.00B417C4.2018.04.15"
## [27] "X008.00B417C5.2018.04.15" "X009.00B417BE.2018.04.15"
## [29] "X009.00B417C4.2018.04.15" "X009.00B417C5.2018.04.15"
```

## Concaténation des bases

Plusieurs solutions existent. Ici on utilise la plus rapide **a priori**, avec `dplyr`

On concatène verticalement (les unes sur les autres) les bases de données en créant un identifiant de la dataframe d'origine: `dfo` rappelant pour chaque ligne le fichier d'origine.

```
# Create the big_data
## Solution 1:
# base option - slower but not extra dependencies
# big_data <- do.call(what = rbind, args = df_list)
#
## Solution 2:
# library(dplyr)
# data table and dplyr have nice functions for this
# they will be faster and can also add id columns to identify
# which list item they came from. They can also fill in
# missing values if some data frames have more columns than others
# big_data = data.table::rbindlist(df_list)
big_data <- dplyr::bind_rows(dfs, .id="dfo")
```

# Quelques vérifications

On explore le fichier: nombre de lignes par dfo ou fichier

```
#library(knitr)
kable( addmargins(table(big_data$dfo)))
```

Var1	Freq
X000.00B417BE.2018.04.15	619
X000.00B417C4.2018.04.15	619
X000.00B417C5.2018.04.15	619
X001.00B417BE.2018.04.15	678
X001.00B417C4.2018.04.15	678
X001.00B417C5.2018.04.15	678
X002.00B417BE.2018.04.15	427
X002.00B417C4.2018.04.15	427
X002.00B417C5.2018.04.15	427
X003.00B417BE.2018.04.15	528
X003.00B417C4.2018.04.15	528
X003.00B417C5.2018.04.15	528
X004.00B417BE.2018.04.15	378
X004.00B417C4.2018.04.15	378
X004.00B417C5.2018.04.15	378
X005.00B417BE.2018.04.15	811
X005.00B417C4.2018.04.15	811
X005.00B417C5.2018.04.15	811
X006.00B417BE.2018.04.15	532
X006.00B417C4.2018.04.15	532
X006.00B417C5.2018.04.15	532
X007.00B417BE.2018.04.15	367
X007.00B417C4.2018.04.15	367
X007.00B417C5.2018.04.15	367
X008.00B417BE.2018.04.15	601
X008.00B417C4.2018.04.15	601
X008.00B417C5.2018.04.15	601
X009.00B417BE.2018.04.15	665
X009.00B417C4.2018.04.15	665
X009.00B417C5.2018.04.15	665
Sum	16818

```
# df_list_o1 <- mget(ls(pattern = "o.*"))
```

*On crée les variables des classes*

- Obs: pour marquer les observateurs. On attend 2 observateurs identifiés par les caractères "o1" et "o2" dans le nom de fichier
- Post: pour marquer la posture. On attend : Assis -TransfertAssisDebout - Debout - Marche
- Seq: pour marquer la séquence. On attend : 1, 2, 3 pour les 3 postures et on note 4 pour la marche

```

# OBSERVATEUR
big_data$Obs <- NULL;
big_data$Obs <- factor( ifelse(grepl("o1",big_data$dfo),"OBS1",
                             ifelse(grepl("o2",big_data$dfo),"OBS2", "other") ) )
addmargins( table(big_data$Obs) )
##
## other Sum
## 16818 16818
# Posture et Sequence
# La séquence de mesure pour chaque observateur sera toujours : Assis1 > TransfertAssisDebout1 > Debout1
> Assis2 > TransfertAssisDebout2 > Debout3 > Assis3 > TransfertAssisDebout3 > Debout3 > Marche
# Donc ça donne dans le nom de fichier
# 10 séquences numérotées : 000 > 001 > 002 > 003 > 004 > 005 > 006 > 007 > 008 > 009
big_data$Post<- NULL
big_data$Seq<- NULL
# a1
big_data$Post[grepl("000",big_data$dfo)==TRUE] <- "Assis"
big_data$Seq[grepl("000",big_data$dfo)==TRUE] <- "Seq1"
# a2
big_data$Post[grepl("003",big_data$dfo)==TRUE] <- "Assis"
big_data$Seq[grepl("003",big_data$dfo)==TRUE] <- "Seq2"
# a3
big_data$Post[grepl("006",big_data$dfo)==TRUE] <- "Assis"
big_data$Seq[grepl("006",big_data$dfo)==TRUE] <- "Seq3"
# d1
big_data$Post[grepl("002",big_data$dfo)==TRUE] <- "Debout"
big_data$Seq[grepl("002",big_data$dfo)==TRUE] <- "Seq1"
# d2
big_data$Post[grepl("005",big_data$dfo)==TRUE] <- "Debout"
big_data$Seq[grepl("005",big_data$dfo)==TRUE] <- "Seq2"
# d3
big_data$Post[grepl("008",big_data$dfo)==TRUE] <- "Debout"
big_data$Seq[grepl("008",big_data$dfo)==TRUE] <- "Seq3"
# t1
big_data$Post[grepl("001",big_data$dfo)==TRUE] <- "Transfert"
big_data$Seq[grepl("001",big_data$dfo)==TRUE] <- "Seq1"
# t2
big_data$Post[grepl("004",big_data$dfo)==TRUE] <- "Transfert"
big_data$Seq[grepl("004",big_data$dfo)==TRUE] <- "Seq2"
# t3
big_data$Post[grepl("007",big_data$dfo)==TRUE] <- "Transfert"
big_data$Seq[grepl("007",big_data$dfo)==TRUE] <- "Seq3"
# d4
big_data$Post[grepl("009",big_data$dfo)==TRUE] <- "Marche"
big_data$Seq[grepl("009",big_data$dfo)==TRUE] <- "Seq4"
# vérif
addmargins( table(big_data$Post) )
##
## Assis Debout Marche Transfert Sum
## 5037 5517 1995 4269 16818
addmargins( table(big_data$Seq) )
##
## Seq1 Seq2 Seq3 Seq4 Sum

```

```
## 5172 5151 4500 1995 16818
# Identifier les CAPTEURS:
# les 3 capteurs seront toujours à la même position, soit B417C4 : Occiput (O1), B417C5 : Thorax (C7), et
B417BE : Sacrum (S1)
big_data$Capt[grepl("B417C4",big_data$dfo)==TRUE] <- "Tête"
big_data$Capt[grepl("B417C5",big_data$dfo)==TRUE] <- "Thorax"
big_data$Capt[grepl("B417BE",big_data$dfo)==TRUE] <- "Bassin"
big_data$Capt <- factor(big_data$Capt, levels = c("Tête", "Thorax", "Bassin" ))

# vérif
addmargins( table(big_data$Capt) )
##
## Tête Thorax Bassin Sum
## 5606 5606 5606 16818
```

## Mise en forme du tableau : Non Nécessaire a priori pour R

On veut 1 tableau par posture, composé de 9 colonnes de tailles variables: 3 Capteurs x 3 Séquences

- On créé un identifiant global *idg*
- On créé un facteur Combi combinant Posture, Capteur et Séquence
- On créé un identifiant par Combi : *count*
- On créé plusieurs tables pour passer du format *long* au format *wide* à destination d'*xls*

```
# réduction de la base aux colonnes utiles
short_data <- subset(big_data, select = c(Obs, Seq, Post, Capt, Pitch, PacketCounter))
# idg : Identifiant unique global
short_data$idg <- row.names(short_data)
# Combinaison des Facteurs
# Note the default separator of '.'
short_data$Combi <- with(short_data, interaction(Post, Capt, Seq))
kable( table(short_data$Combi))
```

Var1	Freq
Assis.Tête.Seq1	619
Debout.Tête.Seq1	427
Marche.Tête.Seq1	0
Transfert.Tête.Seq1	678
Assis.Thorax.Seq1	619
Debout.Thorax.Seq1	427
Marche.Thorax.Seq1	0
Transfert.Thorax.Seq1	678
Assis.Bassin.Seq1	619
Debout.Bassin.Seq1	427
Marche.Bassin.Seq1	0
Transfert.Bassin.Seq1	678
Assis.Tête.Seq2	528



<b>Var1</b>	<b>Freq</b>
Debout.Tête.Seq2	811
Marche.Tête.Seq2	0
Transfert.Tête.Seq2	378
Assis.Thorax.Seq2	528
Debout.Thorax.Seq2	811
Marche.Thorax.Seq2	0
Transfert.Thorax.Seq2	378
Assis.Bassin.Seq2	528
Debout.Bassin.Seq2	811
Marche.Bassin.Seq2	0
Transfert.Bassin.Seq2	378
Assis.Tête.Seq3	532
Debout.Tête.Seq3	601
Marche.Tête.Seq3	0
Transfert.Tête.Seq3	367
Assis.Thorax.Seq3	532
Debout.Thorax.Seq3	601
Marche.Thorax.Seq3	0
Transfert.Thorax.Seq3	367
Assis.Bassin.Seq3	532
Debout.Bassin.Seq3	601
Marche.Bassin.Seq3	0
Transfert.Bassin.Seq3	367
Assis.Tête.Seq4	0
Debout.Tête.Seq4	0
Marche.Tête.Seq4	665
Transfert.Tête.Seq4	0
Assis.Thorax.Seq4	0
Debout.Thorax.Seq4	0
Marche.Thorax.Seq4	665
Transfert.Thorax.Seq4	0
Assis.Bassin.Seq4	0
Debout.Bassin.Seq4	0
Marche.Bassin.Seq4	665
Transfert.Bassin.Seq4	0

---

```
# Max nb lignes par Combi
```

```
max_n <- max(table(short_data$Combi))
```

```
# ID par COMBI
```

```
short_data$count <- with(short_data, ave(seq_along(Combi), Combi, FUN=seq_along))
```

```
# verif
```

```
# by( short_data$count, short_data$Combi,max )
```



```

# Réorganisation en tableaux pour l'export 'xls'
DT_Pitch <- dcast(short_data, count ~ Combi, value.var = "Pitch")

DT_Pitch_Assis <- dcast(subset( short_data , short_data$Post=='Assis' ), count ~ Combi, value.var = "Pitch")

DT_Pitch_Debout <- dcast(subset( short_data , short_data$Post=='Debout' ), count ~ Combi, value.var =
"Pitch")

DT_Pitch_Transfert <- dcast(subset( short_data , short_data$Post=='Transfert' ), count ~ Combi, value.var =
"Pitch")

DT_Pitch_Marche <- dcast(subset( short_data , short_data$Post=='Marche' ), count ~ Combi, value.var =
"Pitch")
# Ces instructions pourront être utilisées en remplaçant 'Pitch' par 'Roll' ou 'Yaw'

```

## Quelques Graphiques à produire en lot

### Courbes par Posture (ici Assis)

```

# On crée une DF par Posture
Assis <- subset( short_data , short_data$Post=='Assis' )
Debout <- subset( short_data , short_data$Post=='Debout' )
Transfert <- subset( short_data , short_data$Post=='Transfert' )
myList <- list(Assis=Assis, Debout=Debout, Transfert=Transfert)
# Graphiques Individuels pour Assis - à automatiser pour autres postures ?
assis1 <- ggplot( Assis[ Assis$Capt=='Tête' , ] , aes(x=count , y=Pitch , colour=Seq, group=Seq)) +
geom_line() + ggtitle("Assis - Tête - Pitch")
assis2 <- ggplot( Assis[ Assis$Capt=='Thorax' , ] , aes(x=count , y=Pitch , colour=Seq, group=Seq)) +
geom_line() + ggtitle("Assis - Thorax - Pitch")
assis3 <- ggplot( Assis[ Assis$Capt=='Bassin' , ] , aes(x=count , y=Pitch , colour=Seq, group=Seq)) +
geom_line() + ggtitle("Assis - Bassin - Pitch")

# Triplets de 3 Graphiques pour Assis - à automatiser pour autres postures ?
assis3G <- short_data[ short_data$Post=='Assis', ] %>% ggplot(aes(x = count, y = Pitch, colour=Seq,
group=Seq)) + geom_line()+ facet_wrap( ~ Capt)+ ggtitle("Assis - Pitch")

debout3G <- short_data[ short_data$Post=='Debout', ] %>% ggplot(aes(x = count, y = Pitch, colour=Seq,
group=Seq)) + geom_line()+ facet_wrap( ~ Capt)+ ggtitle("Debout - Pitch")

transfert3G <- short_data[ short_data$Post=='Transfert', ] %>% ggplot(aes(x = count, y = Pitch, colour=Seq,
group=Seq)) + geom_line()+ facet_wrap( ~ Capt)+ ggtitle("Transfert - Pitch")

marche3G <- short_data[ short_data$Post=='Marche', ] %>% ggplot(aes(x = count, y = Pitch, colour=Seq,
group=Seq)) + geom_line()+ facet_wrap( ~ Capt)+ ggtitle("Marche - Pitch")

```

### Save des images en SVG et JPEG - A développer pour tous les graphiques ?

```

ggsave(filename="assis3G.jpeg", plot=assis3G, width=8 , height = 8)
ggsave(filename="debout3G.jpeg", plot=debout3G, width=8 , height = 8)
ggsave(filename="transfert3G.jpeg", plot=transfert3G, width=8 , height = 8)
ggsave(filename="marche3G.jpeg", plot=marche3G, width=8 , height = 8)
svg(filename = 'assis3G.svg', width=8 , height = 8) ; assis3G ; dev.off()
## png
## 2
svg(filename = 'Debout3G.svg', width=8 , height = 8) ; debout3G ; dev.off()
## png
## 2

```

```

svg(filename = 'Transfert3G.svg', width=8 , height = 8) ; transfert3G ; dev.off()
## png
## 2
svg(filename = 'Marche3G.svg', width=8 , height = 8) ; transfert3G ; dev.off()
## png
## 2

```

## Summary stat

```

## Summary table
# Reorder DT_Table
# order <- c( "count", "Assis.Occiput.Seq1", "Assis.Occiput.Seq2", "Assis.Occiput.Seq3" ,
"Assis.Sacrum.Seq1" , "Assis.Sacrum.Seq2", "Assis.Sacrum.Seq3", "Assis.Thorax.Seq1",
"Assis.Thorax.Seq2" , "Assis.Thorax.Seq3"
# )

# order <- c( 1, 2, 8, 5, 3, 9, 6, 4, 10, 7)
# DT_Pitch_Assis <- DT_Pitch_Assis[order]
# DT_Pitch_Debout <- DT_Pitch_Debout[order]
# DT_Pitch_Transfert <- DT_Pitch_Transfert[order]
# DT_Pitch_Marche <- DT_Pitch_Marche[c(1,3,4,2)]

myList <- list(DT_Pitch_Assis=DT_Pitch_Assis, DT_Pitch_Debout=DT_Pitch_Debout,
DT_Pitch_Transfert=DT_Pitch_Transfert, DT_Pitch_Marche=DT_Pitch_Marche)

# Calcul du plus grand écart avec son signe
# (DT_Pitch_Assis$Assis.Occiput.Seq1-mean(DT_Pitch_Assis$Assis.Occiput.Seq1))[
# which.max(abs( DT_Pitch_Assis$Assis.Occiput.Seq1 - mean(DT_Pitch_Assis$Assis.Occiput.Seq1)))]

max.ecart <- function(x){
  nax <- na.omit(x)
  (nax-mean(nax))[ which.max(abs( nax- mean(nax)))]
}

# Summary table
tmp <- function(x) {
  tab <- do.call(data.frame,
list(mean = apply(x, 2, mean,na.rm=TRUE),
sd = apply(x, 2, sd,na.rm=TRUE),
ecart.max = apply(x, 2, max.ecart ),
median = apply(x, 2, median,na.rm=TRUE),
min = apply(x, 2, min,na.rm=TRUE),
max = apply(x, 2, max,na.rm=TRUE),
n = apply(x, 2, function(y) length(which(!is.na(y)))) ))
return(t(tab))
}

StatA <- data.frame( tmp(DT_Pitch_Assis) )
StatD <- data.frame( tmp(DT_Pitch_Debout) )
StatT <- data.frame( tmp(DT_Pitch_Transfert) )
StatM <- data.frame( tmp(DT_Pitch_Marche) )

```

## Exportation du résultat

On exporte aux formats **xls** et **csv**

### Export en csv

```

myList <-
list(DT_Pitch_Assis=DT_Pitch_Assis,DT_Pitch_Debout=DT_Pitch_Debout,DT_Pitch_Transfert=DT_Pitch_Transfert,DT_Pitch_Marche=DT_Pitch_Marche, DT_Pitch=DT_Pitch, big_data=big_data, short_data=short_data)

mapply(write.csv, myList, file=paste0(names(myList), '.csv'))
## $DT_Pitch_Assis
## NULL
##
## $DT_Pitch_Debout
## NULL
##
## $DT_Pitch_Transfert
## NULL
##
## $DT_Pitch_Marche
## NULL
##
## $DT_Pitch
## NULL
##
## $big_data
## NULL
##
## $short_data
## NULL

```

## *Export des bases: big\_data et short\_data*

Rque: Impossible d'exporter par la liste big\_data est trop grosse et génère un problème de mémoire à l'exportation en xls. Mais il est possible de faire l'export individuellement

```

# list_of_datasets <- list(big_data, short_data)
# write.xlsx(list_of_datasets, file = "Initial_Data.xlsx")
# run out of memory...

```

```

wb<-createWorkbook(type="xlsx")
sheet = createSheet(wb, "big_data")
addDataFrame(big_data, sheet=sheet, startColumn=1, row.names=FALSE)
saveWorkbook(wb, "big_data.xlsx")
# run out of memory...

```

```

wb<-createWorkbook(type="xlsx")
sheet = createSheet(wb, "short_data")
addDataFrame(short_data, sheet=sheet, startColumn=1, row.names=FALSE)
saveWorkbook(wb, "short_data.xlsx")

```

## *Export des bases: DT\_Pitch et DT\_Pitch par posture*

*A exécuter pour préparer qq fonctions de mise en page sous xls*

```

xlsx.addTitle<-function(sheet, rowIndex, title, titleStyle){
  rows <-createRow(sheet,rowIndex=rowIndex)
  sheetTitle <-createCell(rows, colIndex=1)
  setCellValue(sheetTitle[[1,1]], title)
  setCellStyle(sheetTitle[[1,1]], titleStyle)
}

```

```

# create a new workbook for outputs
#++++++
# possible values for type are : "xls" and "xlsx"
wb<-createWorkbook(type="xlsx")

# Define some cell styles
#++++++
# Title and sub title styles
TITLE_STYLE <- CellStyle(wb)+ Font(wb, heightInPoints=16,
                                color="blue", isBold=TRUE, underline=1)
SUB_TITLE_STYLE <- CellStyle(wb) +
  Font(wb, heightInPoints=14,
        isItalic=TRUE, isBold=FALSE)

# Styles for the data table row/column names
TABLE_ROWNames_STYLE <- CellStyle(wb) + Font(wb, isBold=TRUE)
TABLE_COLNames_STYLE <- CellStyle(wb) + Font(wb, isBold=TRUE) +
  Alignment(wrapText=TRUE, horizontal="ALIGN_CENTER") +
  Border(color="black", position=c("TOP", "BOTTOM"),
        pen=c("BORDER_THIN", "BORDER_THICK"))
# write.xlsx(big_data, "StanFile.xlsx", sheetName="TABCOmplet",
#           col.names=TRUE, row.names=TRUE, append=FALSE)

sheet = createSheet(wb, "ToutesPostures")
addDataFrame(DT_Pitch, sheet=sheet, startColumn=1, row.names=FALSE)

sheet = createSheet(wb, "Assis")
addDataFrame(DT_Pitch_Assis, sheet=sheet, startColumn=1, row.names=FALSE)

sheet = createSheet(wb, "Debout")
addDataFrame(DT_Pitch_Debout, sheet=sheet, startColumn=1, row.names=FALSE)

sheet = createSheet(wb, "Transfert")
addDataFrame(DT_Pitch_Transfert, sheet=sheet, startColumn=1, row.names=FALSE)

sheet = createSheet(wb, "Marche")
addDataFrame(DT_Pitch_Marche, sheet=sheet, startColumn=1, row.names=FALSE)
saveWorkbook(wb, "DT_Pitch4_DATA.xlsx")
# Graphiques ASSIS
sheet = createSheet(wb, "Graphiques_Assis")
xlsx.addTitle(sheet, rowIndex=1, title="Assis",
              titleStyle = TITLE_STYLE)# Add a table into a worksheet
addDataFrame(StatA, sheet, startRow=3, startColumn=1,
             colnamesStyle = TABLE_COLNames_STYLE,
             rownamesStyle = TABLE_ROWNames_STYLE)
addPicture("assis3G.jpeg", sheet, scale = 1, startRow = 1,
           startColumn = 14)

# Graphiques DEBOUT
sheet = createSheet(wb, "Graphiques_Debout")
xlsx.addTitle(sheet, rowIndex=1, title="Graphiques_Debout",
              titleStyle = TITLE_STYLE)# Add a table into a worksheet
addDataFrame(StatD, sheet, startRow=3, startColumn=1,
             colnamesStyle = TABLE_COLNames_STYLE,
             rownamesStyle = TABLE_ROWNames_STYLE)
addPicture("debout3G.jpeg", sheet, scale = 1, startRow = 1,
           startColumn = 14)

# Graphiques TRANSITION
sheet = createSheet(wb, "Graphiques_Transfert")
xlsx.addTitle(sheet, rowIndex=1, title="Graphiques_Transfert",
              titleStyle = TITLE_STYLE)# Add a table into a worksheet

```

```

addDataFrame(StatT, sheet, startRow=3, startColumn=1,
             colnamesStyle = TABLE_COLNAMES_STYLE,
             rownamesStyle = TABLE_ROWNUMES_STYLE)
addPicture("transfert3G.jpeg", sheet, scale = 1, startRow = 1,
          startColumn = 14)

# Graphiques MARCHE
sheet = createSheet(wb, "Graphiques_Marche")
xlsx.addTitle(sheet, rowIndex=1, title="Graphiques_Marche",
             titleStyle = TITLE_STYLE)# Add a table into a worksheet
addDataFrame(StatM, sheet, startRow=3, startColumn=1,
             colnamesStyle = TABLE_COLNAMES_STYLE,
             rownamesStyle = TABLE_ROWNUMES_STYLE)
addPicture("marche3G.jpeg", sheet, scale = 1, startRow = 1,
          startColumn = 14)
saveWorkbook(wb, "DT_Pitch4_MOY.xlsx")

```

## Essai 2 Observateurs

```
# création d'un observateur fictif
```

```
New_data <- short_data
```

```
New_data$Obs <- 'OBS1'
```

```
New_data$Pitch <- New_data$Pitch- rnorm(length(New_data$Pitch), 0, 1)
```

```
shortDF <- rbind(short_data, New_data)
```

```
# plot(x=shortDF$Pitch[shortDF$Obs=='OBS1'], y=shortDF$Pitch[shortDF$Obs=='other'])
```

```
library(tidyr)
```

```
##
```

```
## Attaching package: 'tidyr'
```

```
## The following object is masked from 'package:reshape2':
```

```
##
```

```
## smiths
```

```
data_wide <- spread(shortDF, Obs, Pitch)
```

```
sps <- ggplot(data_wide, aes(x=other, y=OBS1)) + geom_point()
```

```
sps + geom_smooth()
```

```
## `geom_smooth()` using method = 'gam'
```

# Data report - Xsens

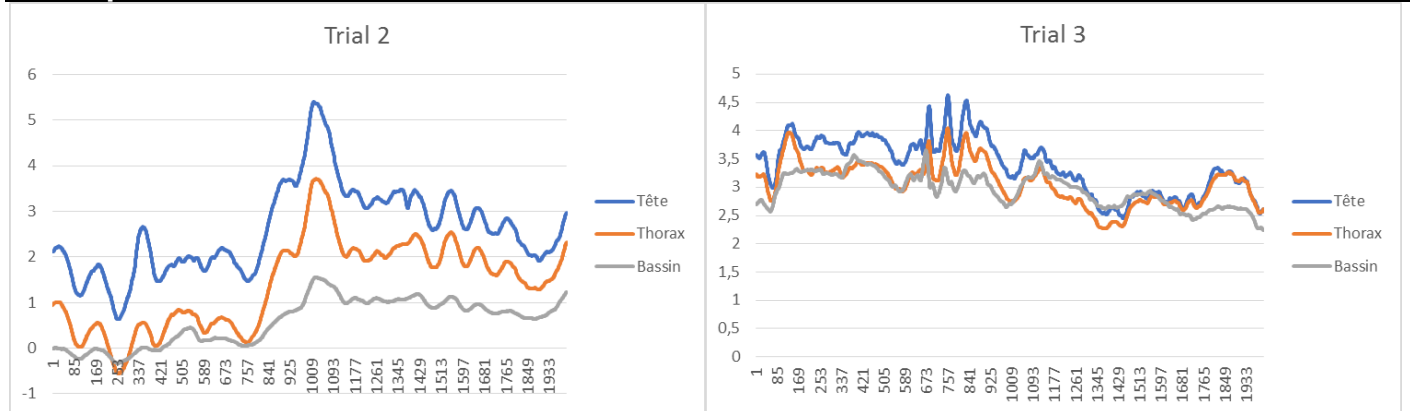
Version 1.0 – Protocole SCALA – July 2018

Patient ID : \_\_\_\_\_

Date of evaluation : \_\_\_\_\_

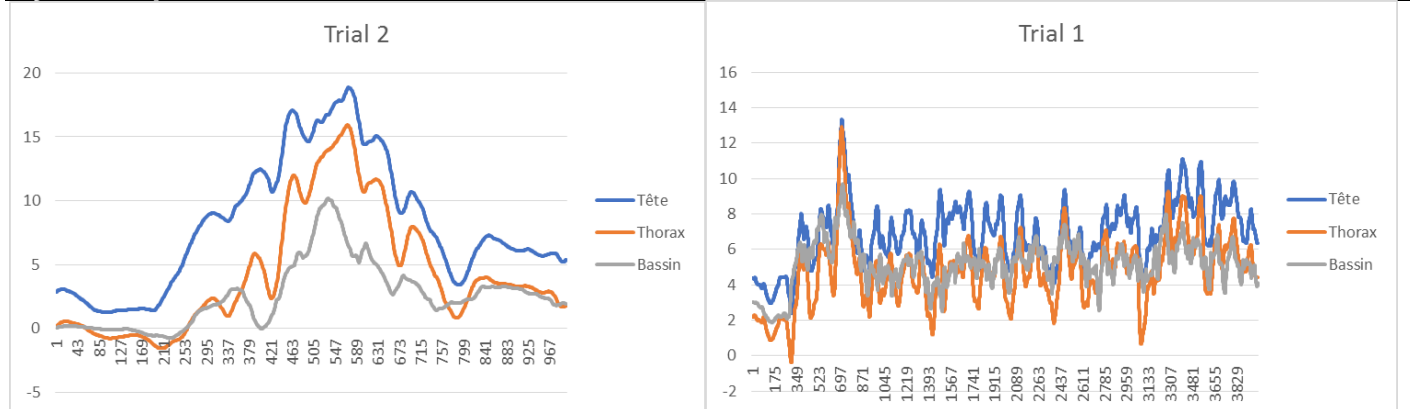
Operator : \_\_\_\_\_

## Static postures

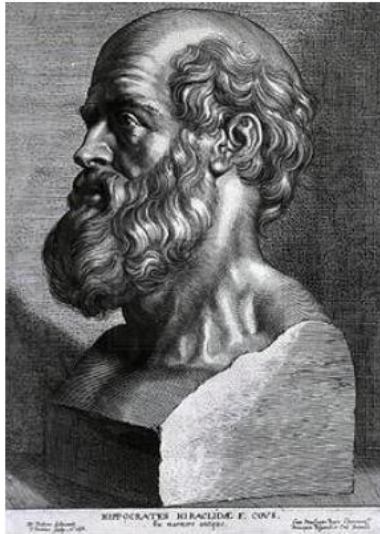


Tête		Tête	
Moyenne	2,3	Moyenne	4,4
Ecart type	0,8	Ecart type	1,0
Max	4,2	Max	5,7
Thorax		Thorax	
Moyenne	1,3	Moyenne	3,3
Ecart type	0,7	Ecart type	0,7
Max	2,9	Max	4,5
Bassin		Bassin	
Moyenne	0,2	Moyenne	3,4
Ecart type	0,5	Ecart type	0,7
Max	0,9	Max	3,9

## Dynamic postures



Tête		Tête	
Moyenne	5,7	Moyenne	6,9
Ecart type	4,0	Ecart type	1,8
Max	13,8	Max	13,3
Thorax		Thorax	
Moyenne	2,7	Moyenne	4,8
Ecart type	4,3	Ecart type	2,0
Max	12,6	Max	12,9
Bassin		Bassin	
Moyenne	1,6	Moyenne	5,1
Ecart type	3,0	Ecart type	1,3
	5,9		9,7



## **SERMENT D'HIPPOCRATE**

*En présence des Maîtres de cette Faculté, de mes chers condisciples et devant l'effigie d'HIPPOCRATE,*

*Je promets et je jure d'être fidèle aux lois de l'honneur et de la probité dans l'exercice de la Médecine.*

*Je donnerai mes soins gratuitement à l'indigent et n'exigerai jamais un salaire au dessus de mon travail. Je ne participerai à aucun partage clandestin d'honoraires.*

*Admis dans l'intimité des maisons, mes yeux n'y verront pas ce qui s'y passe ; ma langue taira les secrets qui me seront confiés et mon état ne servira pas à corrompre les mœurs, ni à favoriser le crime.*

*Je ne permettrai pas que des considérations de religion, de nation, de race, de parti ou de classe sociale viennent s'interposer entre mon devoir et mon patient.*

*Je garderai le respect absolu de la vie humaine.*

*Même sous la menace, je n'admettrai pas de faire usage de mes connaissances médicales contre les lois de l'humanité.*

*Respectueux et reconnaissant envers mes Maîtres, je rendrai à leurs enfants l'instruction que j'ai reçue de leurs pères.*

*Que les hommes m'accordent leur estime si je suis fidèle à mes promesses.*

*Que je sois couvert d'opprobre et méprisé de mes confrères si j'y manque.*