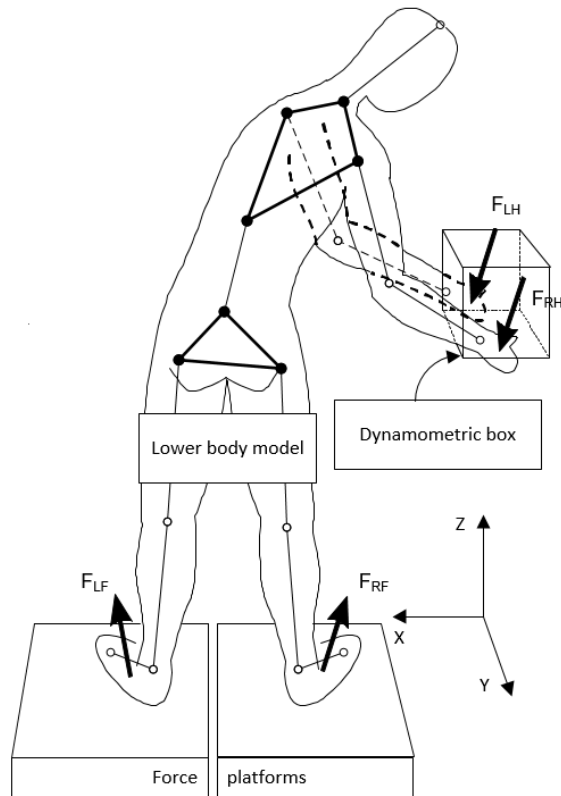
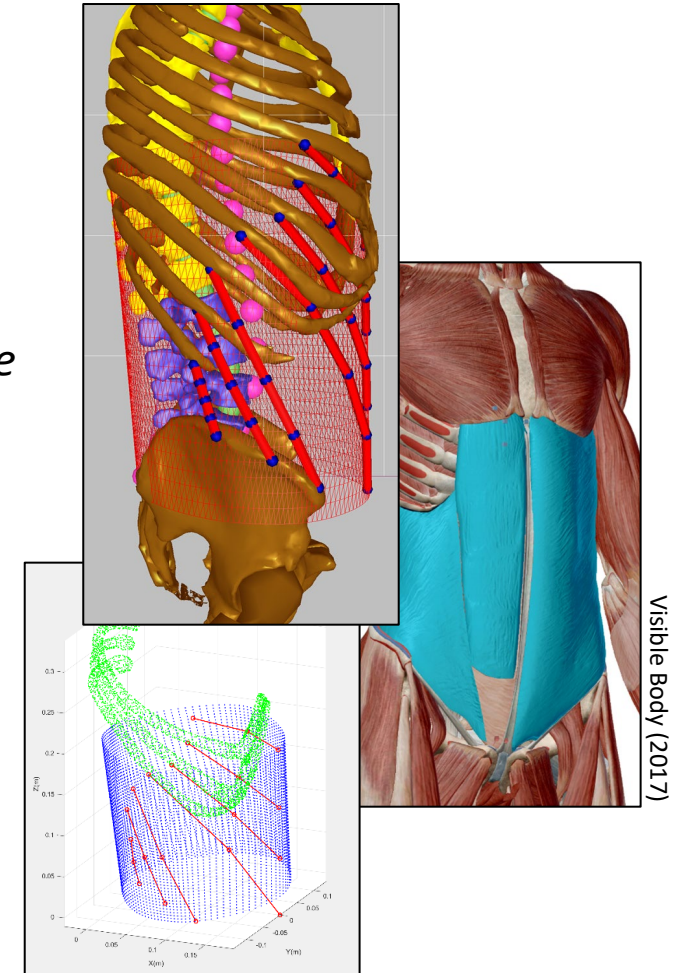


Modélisation biomécanique du dos guidée par des mesures expérimentales non invasives



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Objectifs de l'exposé

- *Illustrer le fonctionnement d'un modèle musculosquelettique de la colonne vertébrale lombaire guidé par des mesures expérimentales non invasives*
- *Présenter des résultats obtenus avec ce modèle tirés de deux études portant sur le travail de manutentionnaires et d'une étude sur la méthode de résolution multiarticulaire adoptée*



An improved multi-joint EMG-assisted optimization approach to estimate joint and muscle forces in a musculoskeletal model of the lumbar spine

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Méthode

ARTICLE INFO

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Trunk muscle forces
Dynamics
EMG
Optimization
Compression and shear

ABSTRACT

Muscle force partitioning methods and musculoskeletal system simplifications are key modeling issues that can alter safety professional muscle forces lumbar spine optimization n at all lumbar j conventional s same lumbar contributions joint methods muscle forces spine joints cr to balance the forces at differ its single-joint biological inte



A comparison of lumbar spine and muscle loading between male and female workers during box transfers

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Étude 2

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ABSTRACT

There is a clear relationship between lumbar spine loading and back musculoskeletal disorders in manual materials handling. The incidence of back disorders is greater in women than men, and for similar work demands females are functioning closer to their physiological limit. It is crucial to study loading on the spine musculoskeletal system with actual handlers, including females, to better understand the risk of back disorders. Extrapolation from biomechanical studies conducted on unexperienced subjects (mainly males) might not be applicable to actual female workers. For male workers, expertise changes the lumbar spine flexion, passive spine resistance, and active/passive muscle forces. However, experienced females select similar postures to those of novices when spine loading is critical. This study proposes that the techniques adopted by male experts, male novices, and females (with considerable experience but not categorized as experts) impact their lumbar spine musculoskeletal systems differently. Spinal loads, muscle forces, and passive resistance (muscle and ligamentous spine) were predicted by a multi-joint EMG-assisted optimization musculoskeletal model of the lumbar spine. Expert males flexed their lumbar spine less (avg. 21.9° vs 30.3–31.7°) and showed decreased passive internal moments (muscle avg. 8.9% vs 15.9–16.0%; spine avg. 4.7% vs 7.1–7.8%) and increased active internal moments (avg. 72.9% vs 62.0–63.9%), thus producing a different impact on their lumbar spine musculoskeletal systems. Experienced females sustained the highest relative spine loads (compression avg. 7.3 N/BW vs 6.2–6.4 N/BW; shear avg. 2.3 N/BW vs 1.7–1.8 N/BW) in addition to passive muscle and ligamentous spine resistance similar to novices. Combined with smaller body size, less strength, and the sequential lifting technique used by females, this could potentially mean greater risk of back injury. Workers should be trained early to limit excessive and repetitive stretching of their lumbar spine passive tissues.

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A biomechanical comparison between expert and novice manual materials handlers using a multi-joint EMG-assisted optimization musculoskeletal model of the lumbar spine

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Étude 1



ARTICLE INFO

Article history:

ABSTRACT

Expertise is a key factor modulating the risk of low back disorders (LBD). Through years of practice in the workplace, the typical expert acquires high level specific skills and maintains a clean record of work-related injuries. Ergonomic observations of manual materials handling (MMH) tasks show that expert techniques differ from those of novices, leading to the idea that expert techniques are safer. Biomechanical studies of MMH tasks performed by experts/novices report mixed results for kinematic/tic variables, evoking potential internal effect of expertise. In the context of series of box transfers lated by actual workers, detailed internal loads predicted by a multiple-joint EMG-assisted optimization lumbar spine model are compared between experts and novices. The results confirmed that the lution of internal moments are modulated by worker expertise. Experts flexed less their lumbar e and exerted more active muscle forces while novices relied more on passive resistance of the cles and ligamentous spine. More specifically for novices, the passive contributions came from global hstor muscles, selected local extensor muscles, and passive structures of the lumbar spine (ligaments discs). The distinctive distribution of internal forces was not concomitant with a similar effect on forces, these forces being dependent on external loading which was equivalent between experts novices. From a safety standpoint, the present results suggest that experts were more efficient than ces in partitioning internal moment contributions to balance net (external) loading. Thus, safer lifting practices might be seen as a result of experts' experience.

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Introduction

- *Il est reconnu que des charges élevées et/ou répétitives agissant sur les structures (os et disques) de la colonne vertébrale et les tissus (muscles, ligaments, etc.) qui la soutiennent représentent un facteur de risque pour les maux de dos.*
- *Dans un contexte de prévention et de réadaptation des travailleurs, la connaissance de l'amplitude et de la distribution des forces internes exercées sur la colonne vertébrale lors d'activités de travail représente un prérequis pour comprendre les effets associés à différents modes opératoires.*
- *Il est important d'étudier des manutentionnaires des deux sexes possédant différents niveaux d'expertise (peu d'études sur de réels travailleurs).*
- *Les manutentionnaires experts utiliseraient des techniques différentes de celles des novices et ces techniques seraient plus sécuritaires.*
- *Une seule approche non invasive permet d'estimer les charges sur les structures internes de la colonne vertébrale : la modélisation musculosquelettique.*

But et hypothèses

- *Comparer des hommes novices et experts et des femmes expérimentées en manutention sur la base du chargement lombaire, des forces musculaires et de la résistance passive de la colonne*
- *Il est postulé que les experts utilisent des modes opératoires plus sécuritaires et efficaces :*
 - *en sollicitant moins la force musculaire passive et la résistance passive de la colonne vertébrale (H1);*
 - *en utilisant davantage la composante active (contractile) de la force musculaire (H2);*
 - *en supportant de plus petites forces articulaires relatives (H3).*

Méthodologie

- *Sujets et tâches*
 - *Étude 1 : Experts vs Novices*
 - *Étude 2 : Experts vs Novices vs Femmes*
- *Instrumentation*
- *Modèle musculosquelettique (MMS) de la colonne vertébrale lombaire*
 - *Principales caractéristiques*
 - *Diagramme*
 - *Optimisation multiarticulaire assistée par l'EMG (M-EMGAO)*
 - *Importance de l'approche multiarticulaire*
 - *Obtention des moments internes normalisés*
- *Statistiques*

Étude 1 : Experts vs Novices

Variables	Experts (n = 10)		Novices (n = 10)	
	\bar{x}	SD	\bar{x}	SD
Age (années)	39.1	10.0	23.3	3.2
Masse (kg)	71.8	9.5	69.0	7.3
Taille (m)	1.72	0.08	1.74	0.05

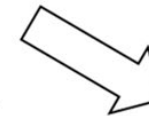
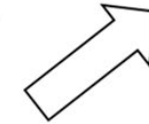
Lifting phase



Top of the pile



H4



H1

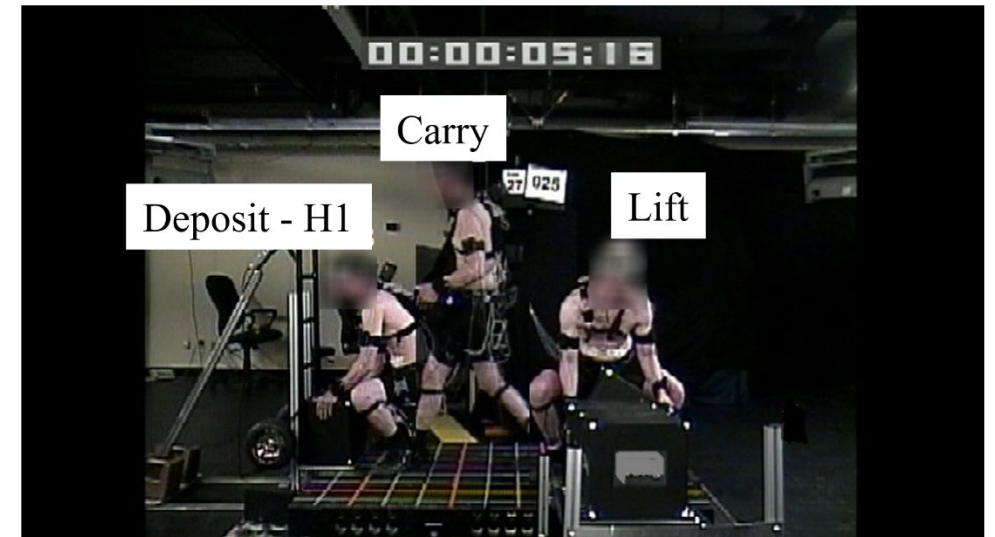
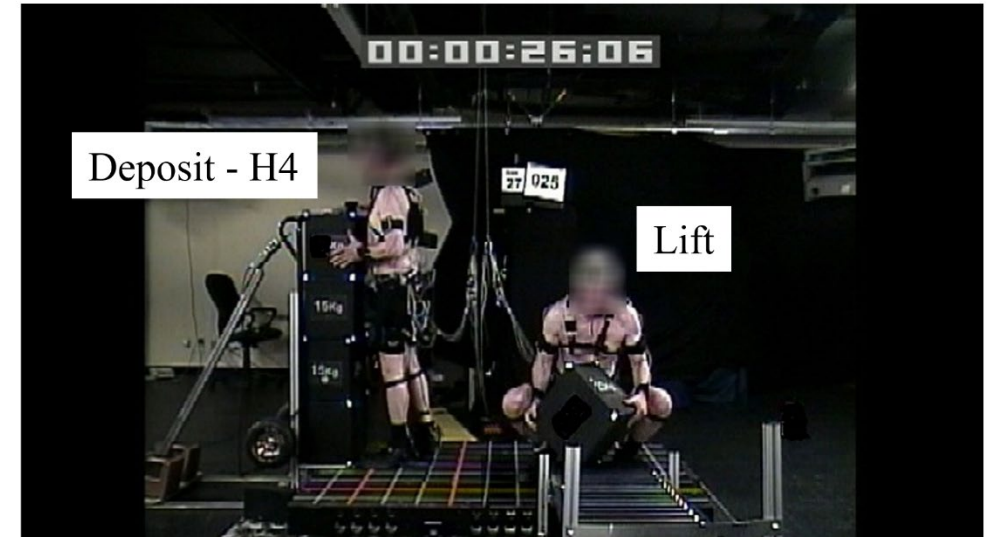
Floor

20 sujets x 2 réps x 2 boîtes x 2 hauteurs = 160 essais
10 653 postures analysées (Experts : 5 447; Novices : 5 206)

Étude 2 : Experts vs Novices vs Femmes

Variables	Experts (n=10)		Novices (n=10)		Femmes (n=10)	
	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD
Age (années)	39.1	10.0	23.3	3.2	40.7	9.4
Masse (kg)	71.8	9.5	69.0	7.3	65.6	10.1
Taille (m)	1.72	0.08	1.74	0.05	1.63	0.08

30 sujets x 2 réps x 2 hauteurs = 120 essais
6490 postures analysées
(Experts : 2 218; Femmes : 2 264;
Novices : 2 008)



Instrumentation



Cinématique 3D

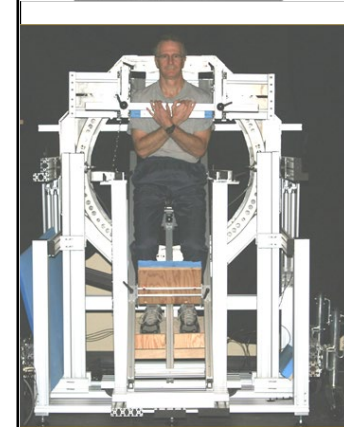
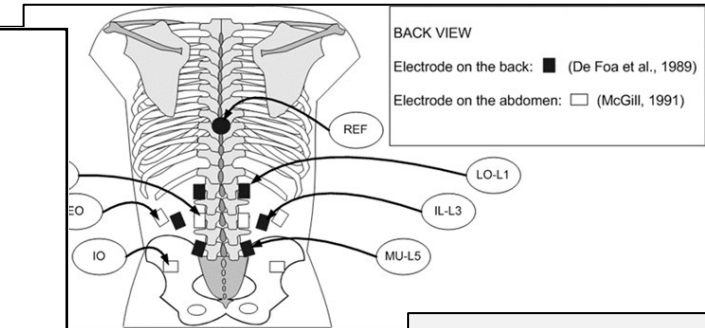
- 12 grappes de DELs (48 marqueurs)
- 4 senseurs OptoTrak
- Enregistrement à 30 Hz

Forces au sol

- Grande plateforme
- Enregistrement à 1024 Hz

Dynamique inverse

- Des forces au sol vers la colonne vertébrale



EMG

- 12 électrodes DelSys
- Gain 1 000
- Enregistrement à 1 024 Hz
- Filtre passe-bande (ordre 8, 20-450 Hz)
- Signal redressé
- Enveloppe linéaire (3 Hz Butterworth)

Dynamométrie

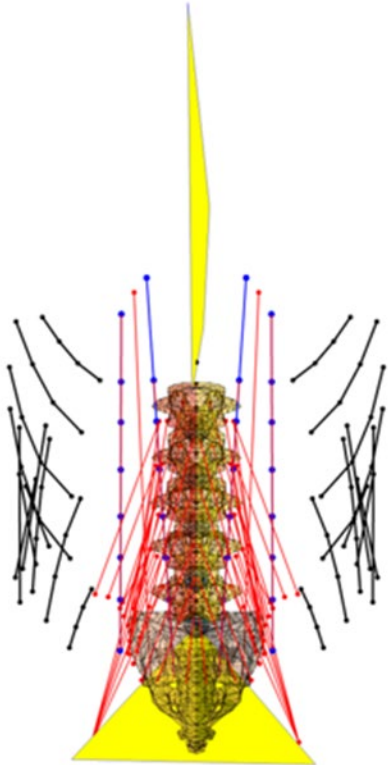
- Efforts statiques en rampe
- Enregistrement à 1 024 Hz
- Posture neutre
- CMV dans chaque plan anatomique (6 directions) avec rétroaction visuelle (meilleur effort toutes directions confondues pour la normalisation)

MMS : principales caractéristiques

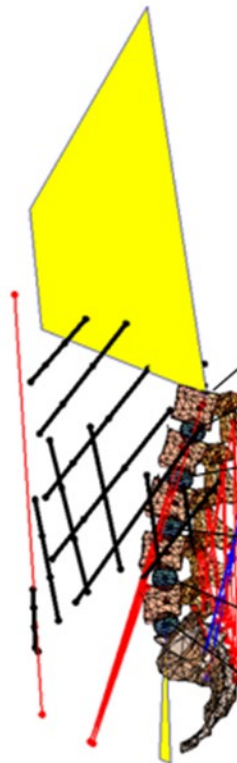
Architecture

- 6 articulations (T12-L1 to L5-S1)
- 76 fascicules (30 globaux et 46 locaux)

Frontal View



Sagittal View



46 local fascicles

musculaires ajustées

omment représenté

sacrum, thorax)
S1)
colonne
ques) et muscles
nalisé (0-1)

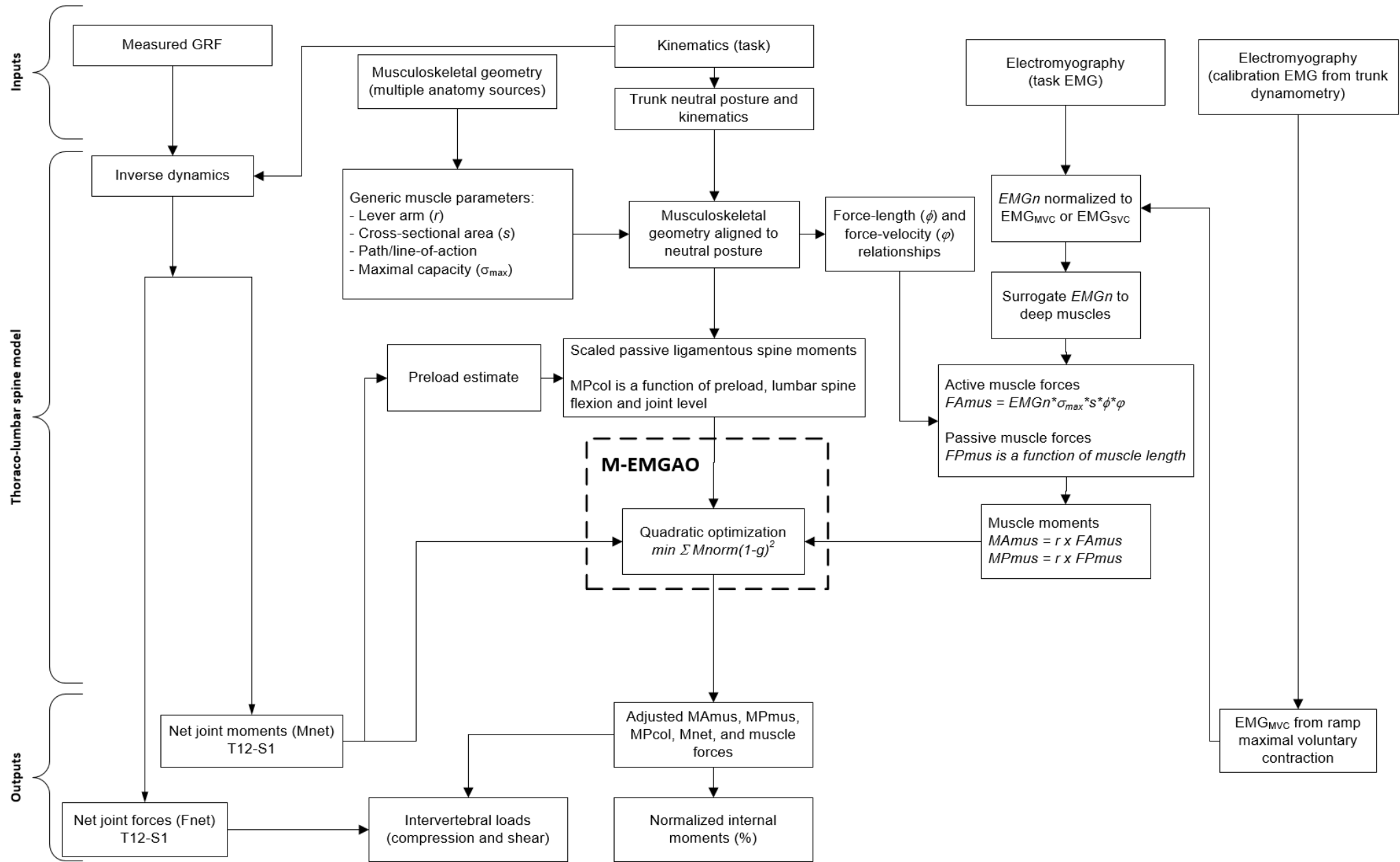
ajustement
aire guidée par

es forcés à
ctivation

x. : 0.7 MPa

ctifs, passifs),
ts et forces

MMS: diagramme



MMS : optimisation multiarticulaire assistée par l'EMG (**M-EMGAO**)

Objectif

$$\min \sum_{i=1}^{176} Mnorm_i (1 - g_i)^2 \quad (1)$$

$$Mnorm_i = \sqrt{\sum_j Mr_{i,j}^2} \quad (2)$$

$$Mr_{i,j} = \sqrt{M_{L(i,j)}^2 + M_{S(i,j)}^2 + M_{T(i,j)}^2} \quad (3)$$

Contraintes d'égalité

$$\left\{ \begin{array}{l} \sum_{i=1}^{N_j} (g_i M_{Amus_{L(i,j)}} + g_i M_{MPmus_{L(i,j)}}) + g_i M_{Pcol_{L(j)}} \pm g_i M_{Merr_{L(j)}} - g_i M_{net_{L(j)}} = 0 \\ \sum_{i=1}^{N_j} (g_i M_{Amus_{S(i,j)}} + g_i M_{MPmus_{S(i,j)}}) + g_i M_{Pcol_{S(j)}} \pm g_i M_{Merr_{S(j)}} - g_i M_{net_{S(j)}} = 0 \\ \sum_{i=1}^{N_j} (g_i M_{Amus_{T(i,j)}} + g_i M_{MPmus_{T(i,j)}}) + g_i M_{Pcol_{T(j)}} \pm g_i M_{Merr_{T(j)}} - g_i M_{net_{T(j)}} = 0 \end{array} \right. \quad (4)$$

Bornes

$$\left\{ \begin{array}{l} \left(\frac{M_{AmusMax_i}}{M_{Amus_i}} \right) \geq g_i \geq 0.5 \text{ (or 0) for MAmus} \\ 1.05 \geq g_i \geq 0.5 \text{ for MPmus} \\ 1.05 \geq g_i \geq 0.95 \text{ for MPcol} \\ 1.05 \geq g_i \geq 0.95 \text{ for Mnet} \\ 1 \geq g_i \geq 0 \text{ for Merr} \end{array} \right. \quad (5)$$

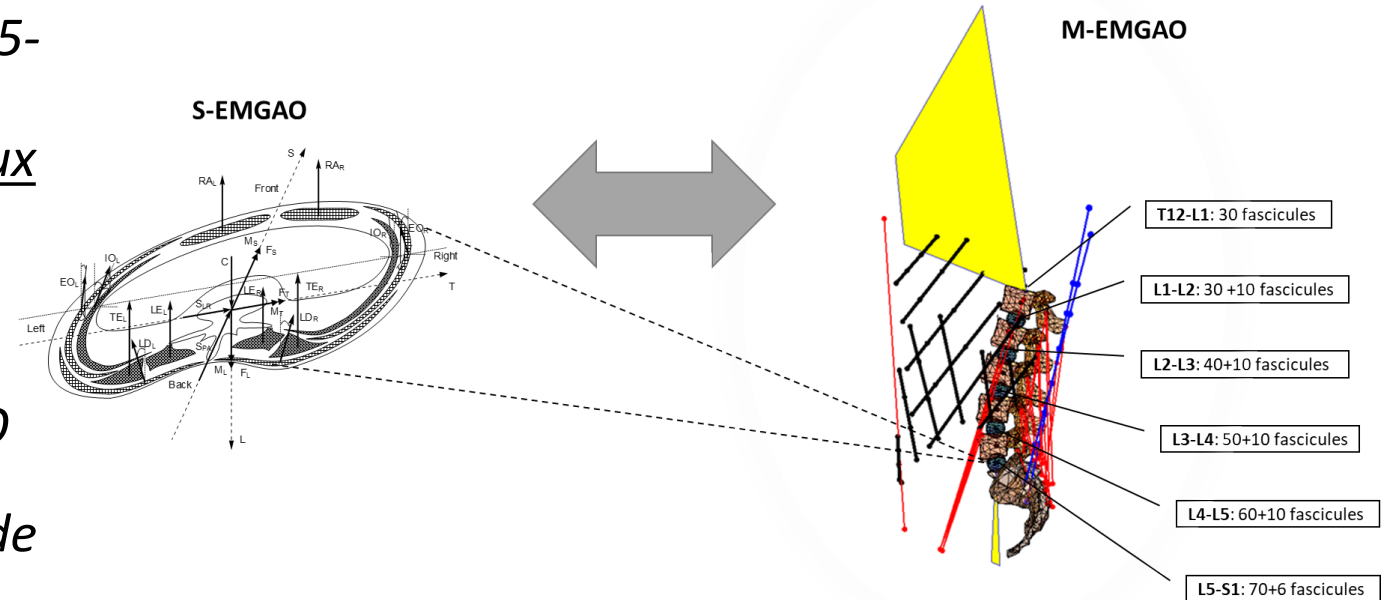
MMS : importance de l'approche multiarticulaire

- *Comparaisons :*

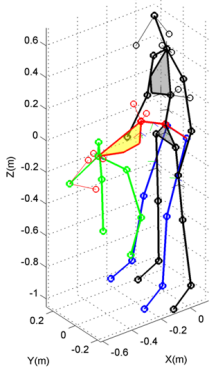
- Une seule coupe transversale (L5-S1; S-EMGAO)
- Considération de tous les niveaux simultanément (T12-S1; M-EMGAO)

- *Principaux résultats :*

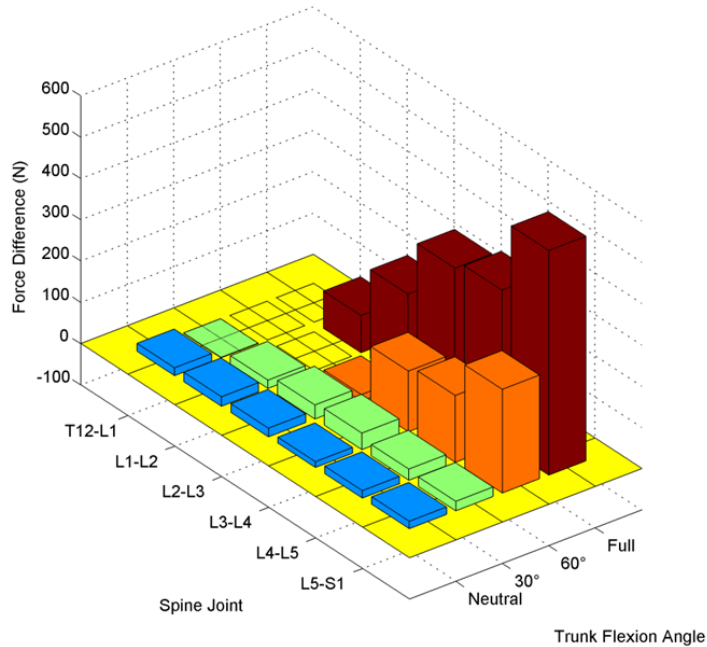
- Forces musculaires de S-EMGAO ne respectent pas l'équilibre mécanique aux autres niveaux de la colonne vertébrale.
- Les stratégies musculaires obtenues sont différentes.
- Les chargements articulaires sont différents.



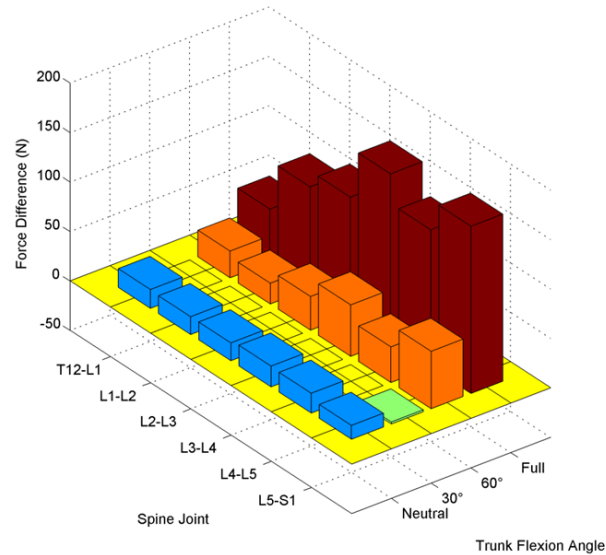
MMS : tâche symétrique (S-EMGAO vs M-EMGAO)



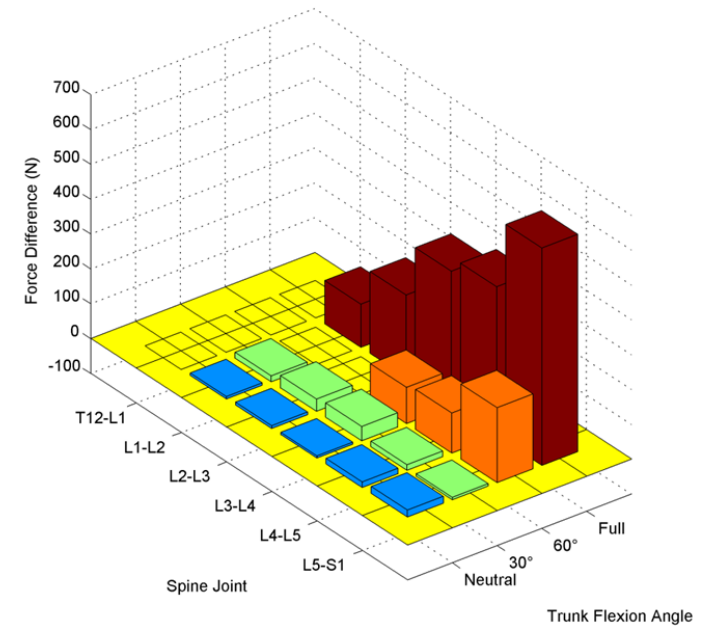
Compression



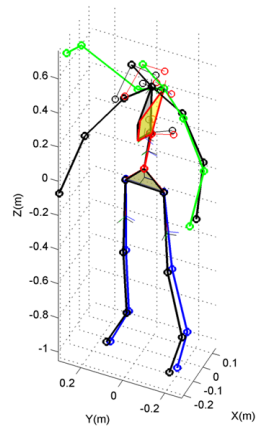
Cisaillement



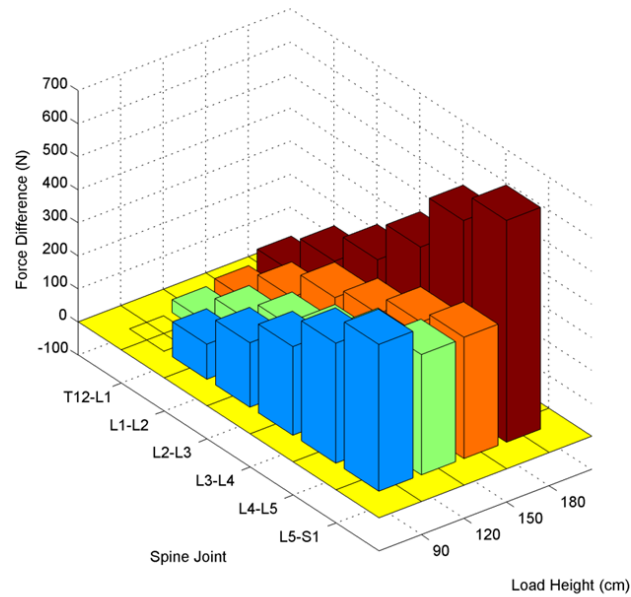
Muscles locaux



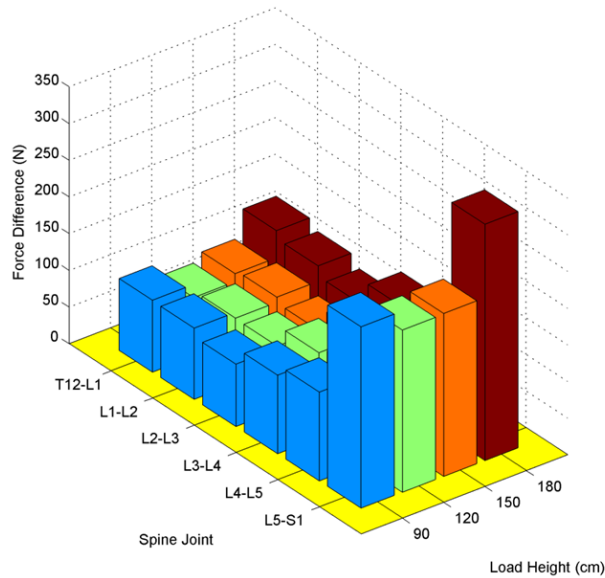
MMS : tâche asymétrique (S-EMGAO vs M-EMGAO)



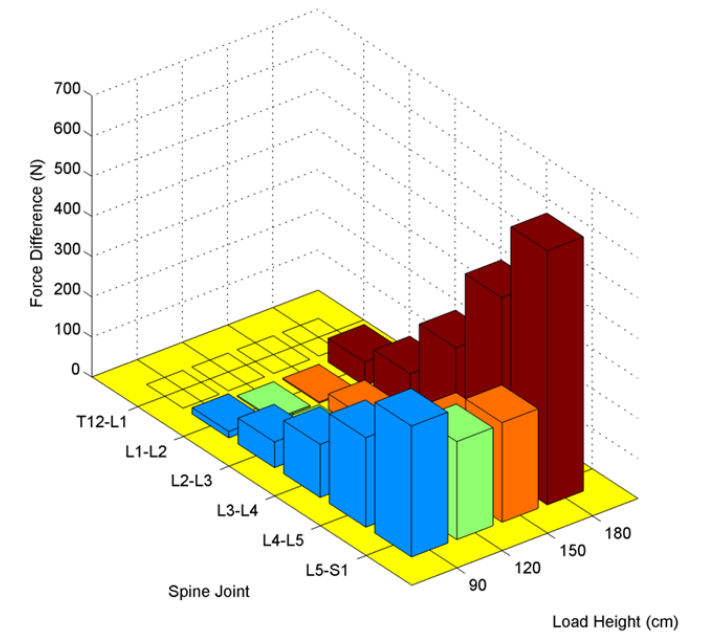
Compression



Cisaillement

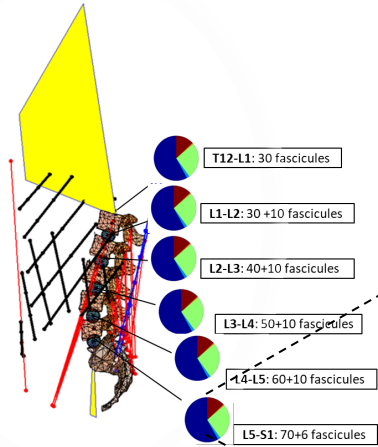


Muscles locaux

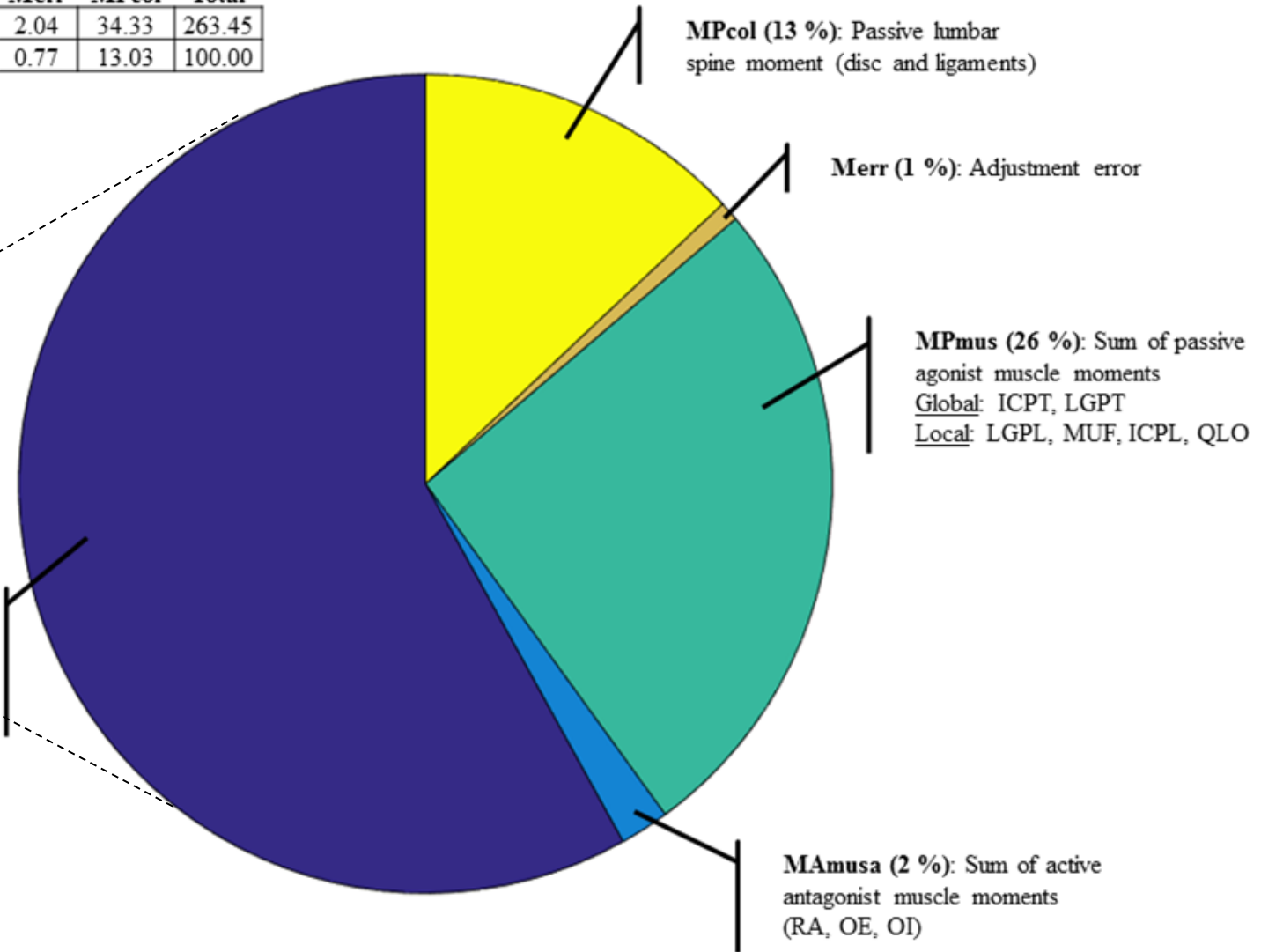


MMS : obtention des moments internes normalisés

	MAmus	MAmusa	MPmus	Merr	MPcol	Total
Nm	152.99	5.16	68.93	2.04	34.33	263.45
%	58.07	1.96	26.17	0.77	13.03	100.00



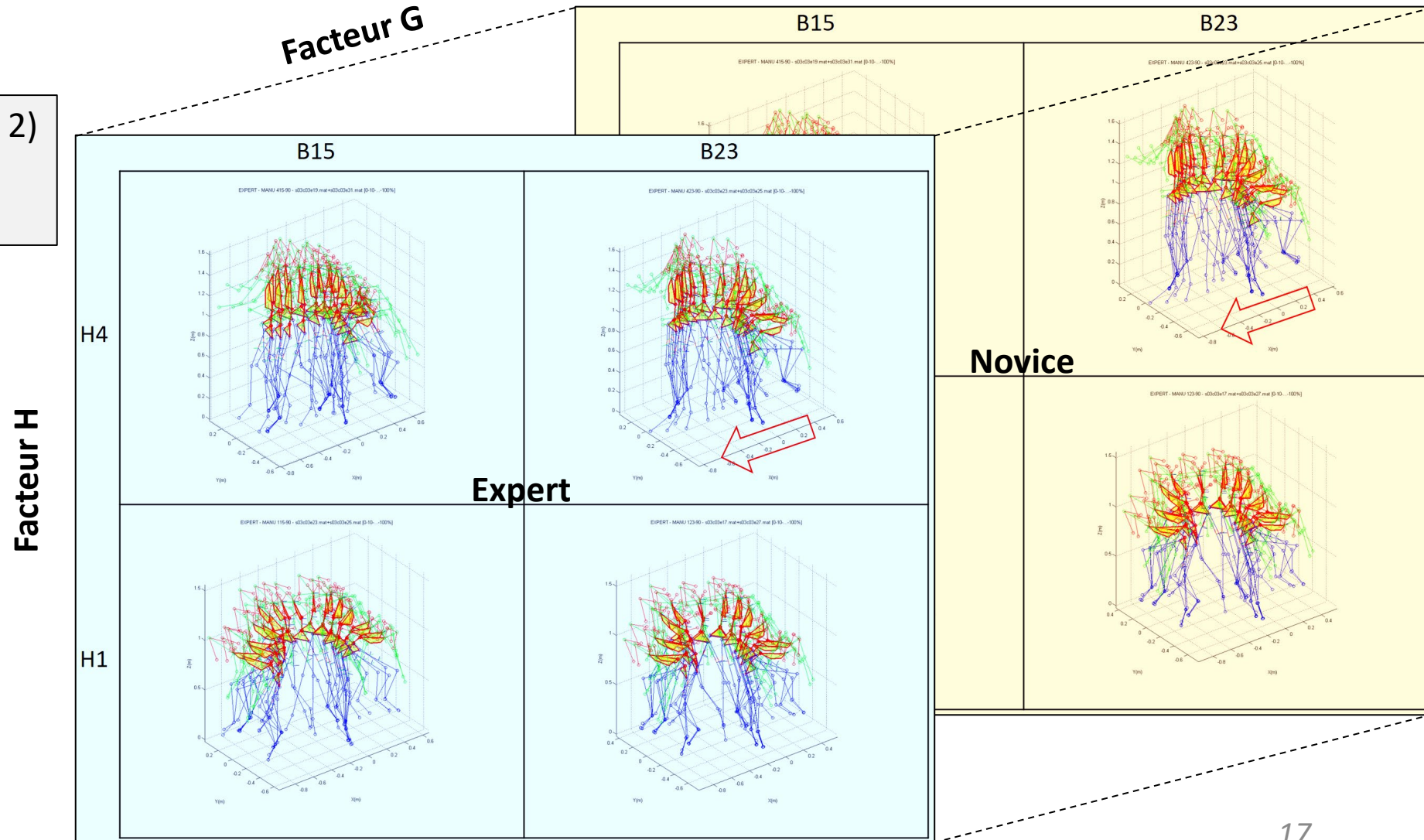
MAmus (58 %): Sum of active agonist muscle moments
Global: ICPT, LGPT
Local: LGPL, MUF, ICPL, QLO



Statistiques - Étude 1 : E vs N

Facteur B

ANOVA G x B x H (2 x 2 x 2)
Facteurs B et H répétés
Interactions GB et GH



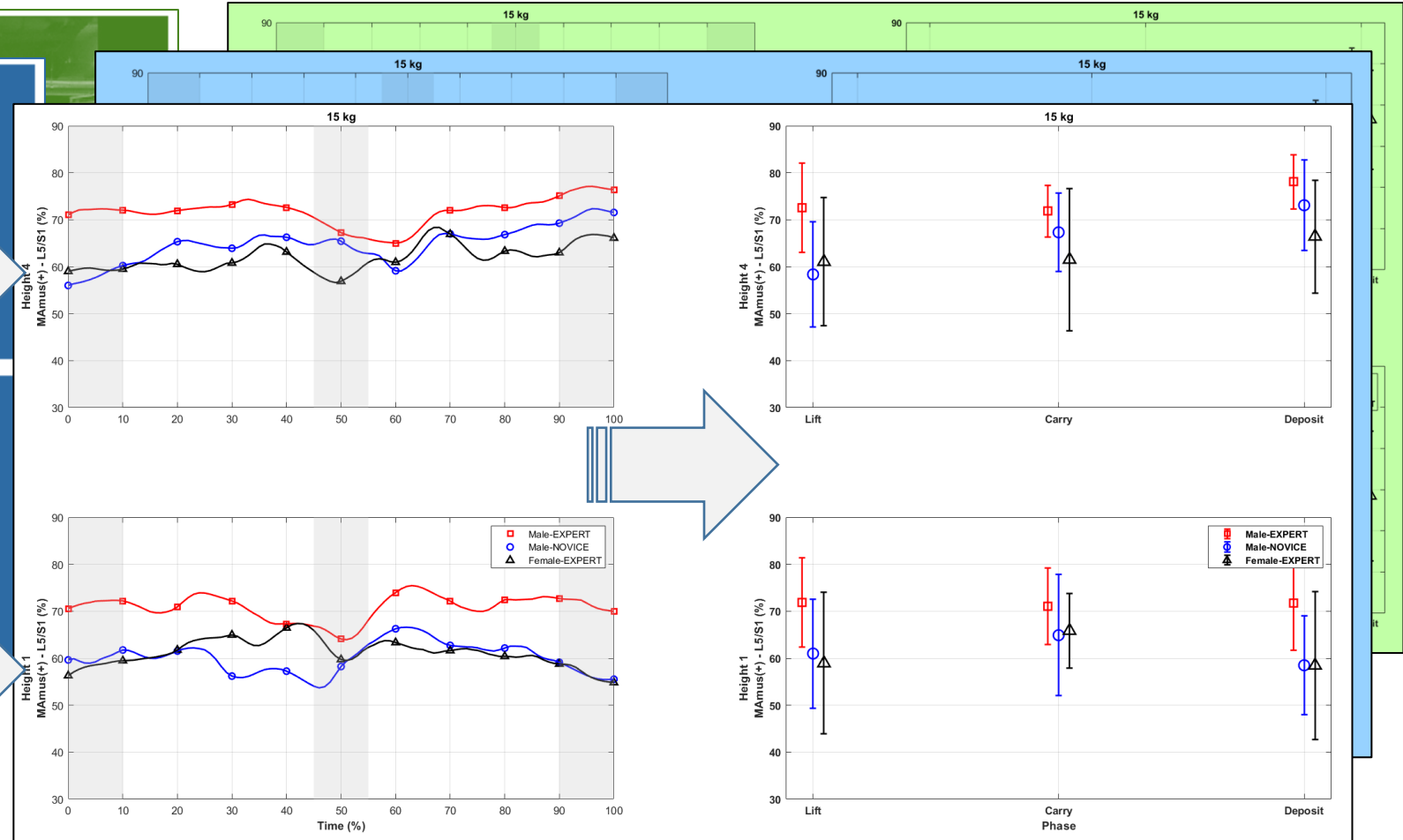
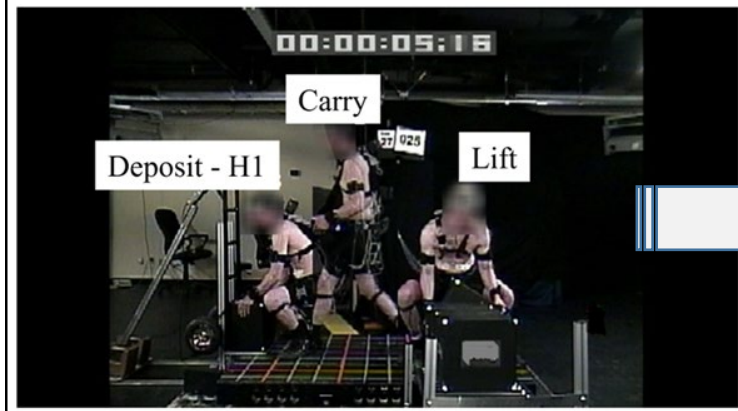
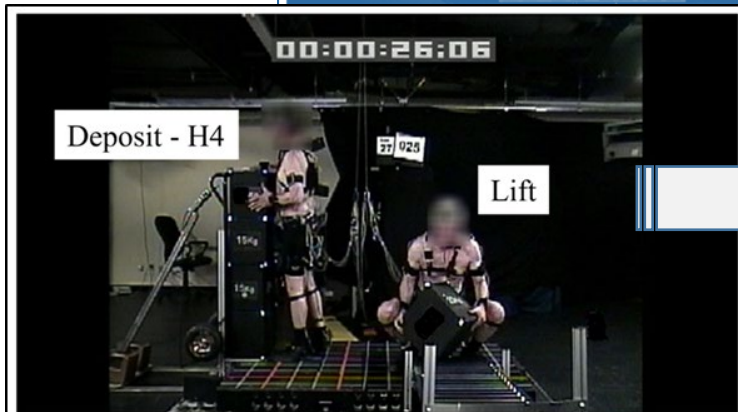
Statistiques - Étude 2 : E vs N vs F

ANOVA G x H x P (3 x 2 x 3)
Facteurs H et P répétés
Interactions GH et GP

Femme

Novice

Expert



Résultats - Étude 1 : E vs N

- *Moments internes*
- *Moments musculaires*
 - *Extenseurs globaux*
 - *Extenseurs locaux*
 - *Fléchisseurs globaux*
- *Effet de l'expertise (soulèvement)*

Résultats - E vs N : moments internes

Moments	Lift Phase (from conveyor)					
	Expertise		Box Mass		Deposit Height	
	Expert	Novice	15 kg	23 kg	Floor (H1)	Top (H4)
MAmus	74.9 (10.1)	64.7 (11.9)	68.0 (12.5)	71.6 (11.6)	70.1 (12.1)	69.5 (12.3)
MAmusa	6.8 (3.2)	5.7 (3.8)	7.2 (4.1)	5.3 (2.6)	6.3 (3.1)	6.2 (4.0)
MPmus	14.6 (8.1)	23.4 (10.4)	20.4 (10.7)	17.7 (9.7)	19.2 (10.4)	18.9 (10.2)
MPcol	8.5 (3.2)	11.6 (3.7)	10.5 (3.9)	9.6 (3.6)	10.5 (3.9)	9.6 (3.7)
Deposit Phase (to hand trolley)						
MAmus	76.5 (7.9)	68.3 (11.5)	71.5 (11.2)	73.3 (10.0)	68.6 (12.0)	76.2 (7.3)
MAmusa	14.4 (10.1)	16.4 (14.3)	15.3 (11.7)	15.5 (13.1)	6.1 (3.2)	24.7 (11.1)
MPmus	8.6 (8.8)	14.1 (12.7)	11.6 (11.1)	11.1 (11.4)	19.9 (9.8)	2.7 (2.5)
MPcol	4.4 (4.3)	7.3 (5.7)	6.0 (5.3)	5.7 (5.1)	9.8 (3.8)	2.0 (3.0)

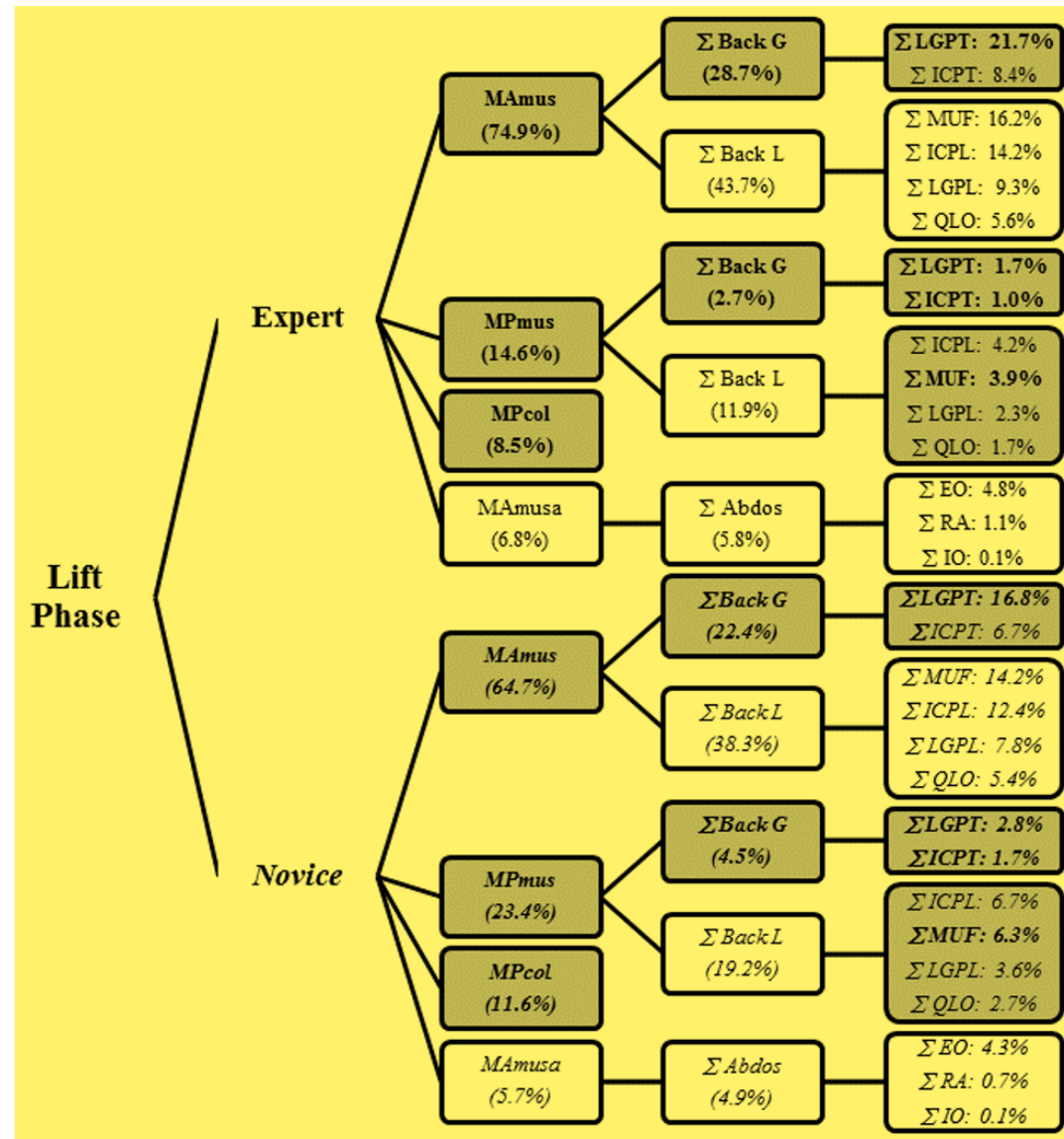
Résultats - E vs N : extenseurs globaux

Muscles	Lift Phase (from conveyor)			
	Expertise			
	Expert		Novice	
	Active	Passive	Active	Passive
Σ ICPT	8.4 (3.2)	1.0 (0.4)	6.7 (3.7)	1.7 (0.8)
Σ LGPT	21.7 (5.7)	1.7 (0.6)	16.8 (5.6)	2.8 (1.2)
Σ Back G	28.7 (7.0)	2.7 (0.9)	22.4 (6.7)	4.5 (1.9)
	Deposit Phase (to hand trolley)			
Σ ICPT	6.6 (3.2)	0.6 (0.5)	7.6 (4.4)	1.1 (0.8)
Σ LGPT	23.2 (6.7)	1.0 (0.7)	20.0 (6.3)	1.9 (1.5)
Σ Back G	29.2 (7.9)	1.6 (1.2)	26.0 (8.1)	3.0 (2.2)

Résultats - E vs N : extenseurs locaux

Muscles	Lift Phase (from conveyor)			
	Expertise			
	Expert		Novice	
	Active	Passive	Active	Passive
Σ LGPL	9.3 (2.3)	2.3 (1.4)	7.8 (2.3)	3.6 (1.8)
Σ MUF	16.2 (3.1)	3.9 (2.0)	14.2 (2.7)	6.3 (3.0)
Σ ICPL	14.2 (2.9)	4.2 (3.0)	12.4 (5.1)	6.7 (3.2)
Σ QLO	5.6 (0.8)	1.7 (1.4)	5.4 (1.6)	2.7 (1.4)
Σ Back L	43.7 (7.8)	11.9 (7.7)	38.3 (7.3)	19.2 (9.3)
Deposit Phase (to hand trolley)				
Σ LGPL	9.5 (2.1)	1.3 (1.4)	8.1 (2.1)	2.1 (2.0)
Σ MUF	20.3 (6.2)	2.2 (2.5)	18.4 (6.4)	3.7 (3.7)
Σ ICPL	13.5 (2.5)	2.4 (2.8)	11.4 (3.3)	4.0 (3.9)
Σ QLO	4.3 (1.6)	0.9 (1.2)	3.9 (1.4)	1.6 (1.6)
Σ Back L	45.3 (6.6)	6.8 (7.7)	40.0 (7.3)	11.2 (10.9)

Résultats - E vs N : effet de l'expertise (soulèvement)



Résultats - Étude 2 : E vs N vs F

- *Forces articulaires*
- *Moments internes*
- *Moments musculaires*
 - *Extenseurs globaux*
 - *Extenseurs locaux*
 - *Fléchisseurs globaux*

Résultats - E vs N vs F : forces articulaires

Dependent Variable	Group (G)			Post hoc G
	Expert (E)	Novice (N)	Female (F)	
<i>A. Joint forces, lumbar flexion angle and net joint moment</i>				
Fcomp (N/BW)	6.4 (1.9)	6.2 (1.8)	7.3 (1.8)	F > E,N
Fshear PA (N/BW)	1.7 (0.7)	1.8 (0.7)	2.3 (0.7)	F > E,N
Lumbar Flexion (°)	21.9 (16.6)	30.3 (19.6)	31.7 (20.0)	E < F,N
Mnet (Nm)	122.3 (66.9)	125.3 (68.9)	103.1 (57.5)	F < E,N

Résultats - E vs N vs F : moments internes

Dependent Variable	Group (G)			Post hoc G
	Expert (E)	Novice (N)	Female (F)	
<i>B. Internal moments</i>				
MAmus (%)	72.9 (8.3)	63.9 (11.6)	62.0 (13.3)	E > F,N
MAmusa (%)	12.0 (8.7)	10.4 (9.6)	13.2 (12.4)	
MPmus (%)	8.9 (7.9)	15.9 (11.6)	16.0 (13.1)	E < F,N
MPcol (%)	4.7 (4.2)	7.8 (5.3)	7.1 (4.3)	E < F,N

Résultats - E vs N vs F : moments musculaires

Dependent Variable	Group (G)			Post hoc G
	Expert (E)	Novice (N)	Female (F)	
<i>C. Muscle moments: Extensors (global, local) and global flexors</i>				
Σ Back G_{ac} (%)	26.3 (6.1)	21.8 (7.8)	21.4 (7.1)	E > F,N
Σ Back L_{ac} (%)	42.2 (6.5)	37.1 (7.6)	35.9 (11.0)	E > F,N
Σ Back G_{pc} (%)	1.7 (1.2)	3.3 (2.2)	2.6 (1.9)	E < F,N
Σ Back L_{pc} (%)	7.1 (7.1)	12.7 (9.9)	13.2 (11.2)	E < F,N
Σ Abdo $_{ac}$ (%)	8.9 (8.5)	7.5 (8.8)	10.3 (12.2)	

Résultats - E vs N vs F : extenseurs globaux

Dependent Variable	Group (G)			Post hoc G
	Expert (E)	Novice (N)	Female (F)	
<i>D. Detailed muscle moments: Global extensors</i>				
Σ LGPT _{ac} (%)	20.2 (6.0)	16.7 (5.9)	16.7 (5.5)	E > F,N
Σ LGPT _{pc} (%)	1.0 (0.7)	2.1 (1.5)	1.7 (1.3)	E < F,N
Σ ICPT _{ac} (%)	6.1 (3.1)	5.1 (3.6)	4.6 (3.0)	E > F
Σ ICPT _{pc} (%)	0.6 (0.5)	1.2 (0.8)	0.9 (0.7)	E < N

Résultats - E vs N vs F : extenseurs locaux

Dependent Variable	Group (G)			Post hoc G
	Expert (E)	Novice (N)	Female (F)	
<i>E. Detailed muscle moments: Local extensors</i>				
Σ LGPL _{ac} (%)	8.4 (2.0)	7.3 (2.1)	7.3 (2.6)	
Σ LGPL _{pc} (%)	1.4 (1.3)	2.4 (1.8)	2.5 (2.0)	E < F,N
Σ ICPL _{ac} (%)	12.4 (3.3)	10.1 (3.3)	9.9 (4.1)	E > F,N
Σ ICPL _{pc} (%)	2.5 (2.6)	4.4 (3.5)	4.6 (4.0)	E < F,N
Σ MUF _{ac} (%)	17.4 (5.6)	15.9 (5.9)	14.9 (5.8)	
Σ MUF _{pc} (%)	2.3 (2.1)	4.2 (3.2)	4.3 (3.5)	E < F,N
Σ QLO _{ac} (%)	4.0 (1.7)	3.8 (1.5)	3.7 (1.5)	
Σ QLO _{pc} (%)	1.0 (1.1)	1.7 (1.4)	1.8 (1.7)	

Résultats - E vs N vs F : fléchisseurs globaux

Dependent Variable	Group (G)			Post hoc G
	Expert (E)	Novice (N)	Female (F)	
<i>F. Detailed muscle moments: Global flexors</i>				
ΣRA_{ac} (%)	1.5 (1.4)	1.2 (1.5)	2.4 (3.2)	F > N
ΣEO_{ac} (%)	7.2 (7.7)	6.3 (7.2)	7.4 (9.8)	
ΣIO_{ac} (%)	0.2 (0.4)	0.3 (0.8)	0.6 (1.7)	

Discussion - Manutention

Comment le groupe (Expert vs Novice vs Femme) influence-t-il la distribution des contributions internes et le chargement articulaire?

- *Les Novices et les Femmes font plus appel à la contribution passive des muscles extenseurs (globaux et locaux) et la résistance passive de la colonne vertébrale lombaire (ligaments et disques) - H1 acceptée.*
- *Les Experts utilisent plus la contribution active (contractile) musculaire - H2 acceptée.*
- *Les forces articulaires normalisées (compression, cisaillement) sont supérieures chez les Femmes - H3 partiellement acceptée.*

Discussion - Modélisation

- *L'approche de modélisation (M-EMGAO) joue un rôle déterminant dans la capacité de prédire des forces musculaires cohérentes (respect de l'intégrité mécanique et biologique du système musculosquelettique).*
- *L'ajustement (scaling du MMS) au gabarit et au sexe de chaque sujet constitue une amélioration importante qui est envisagée. Selon Ghezelbash et al. (2016), la mise à l'échelle augmente le chargement lombaire chez les Femmes, ce qui aurait accentué les effets observés dans l'Étude 2.*

Conclusion

- *Les Experts sont plus efficaces que les Novices et les Femmes quant à la distribution des moments internes (forces internes) pour équilibrer le chargement externe :*
 - *Les méthodes de manutention plus sécuritaires des Experts peuvent être le résultat de leur grande expérience (nombre d'années).*
 - *L'utilisation réduite des tissus passifs de la colonne vertébrale par les Experts concorde avec leur bon dossier sur le plan des blessures au dos.*
- *Les Femmes supportent un chargement lombaire relatif supérieur tout en exploitant plus la contribution passive des muscles ainsi que la résistance passive de la colonne vertébrale :*
 - *Une technique de soulèvement séquentielle (genou, hanche et colonne) au lieu de synchrone des Femmes et leur plus petit gabarit pointe vers un risque accru de blessure au dos.*
- *Les manutentionnaires auraient avantage à être exposés dès que possible à des principes, instructions et méthodes visant à limiter l'utilisation répétitive des tissus passifs.*

Remerciements

Collaborateurs

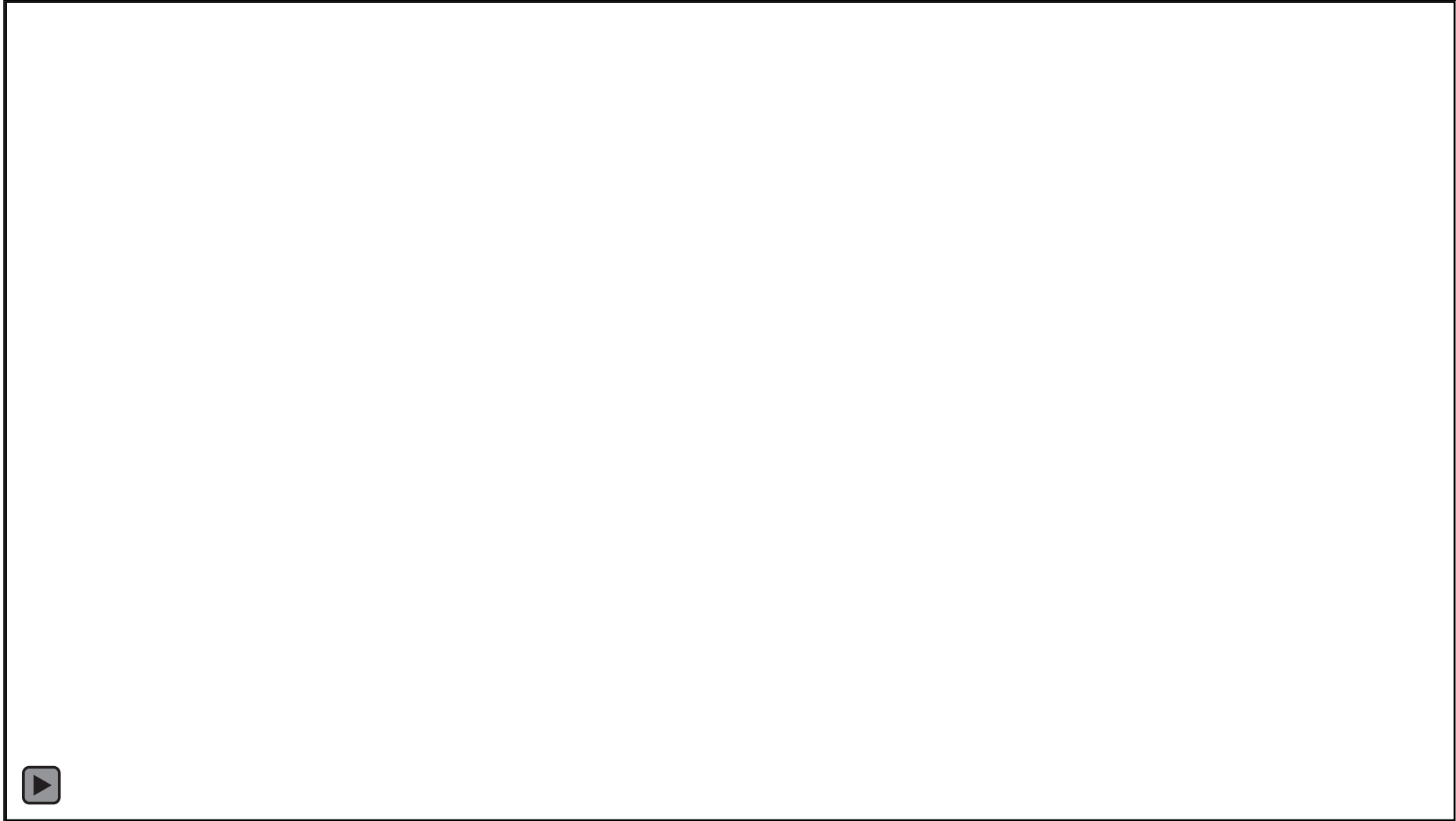
- *André Plamondon, Ph. D., IRSST*
- *Christian Larivière, Ph. D., IRSST*
- *Aboulfazl Shirazi-Adl, Ph. D., Polytechnique Montréal*
- *Navid Arjmand, Ph. D., Sharif University of Technology*

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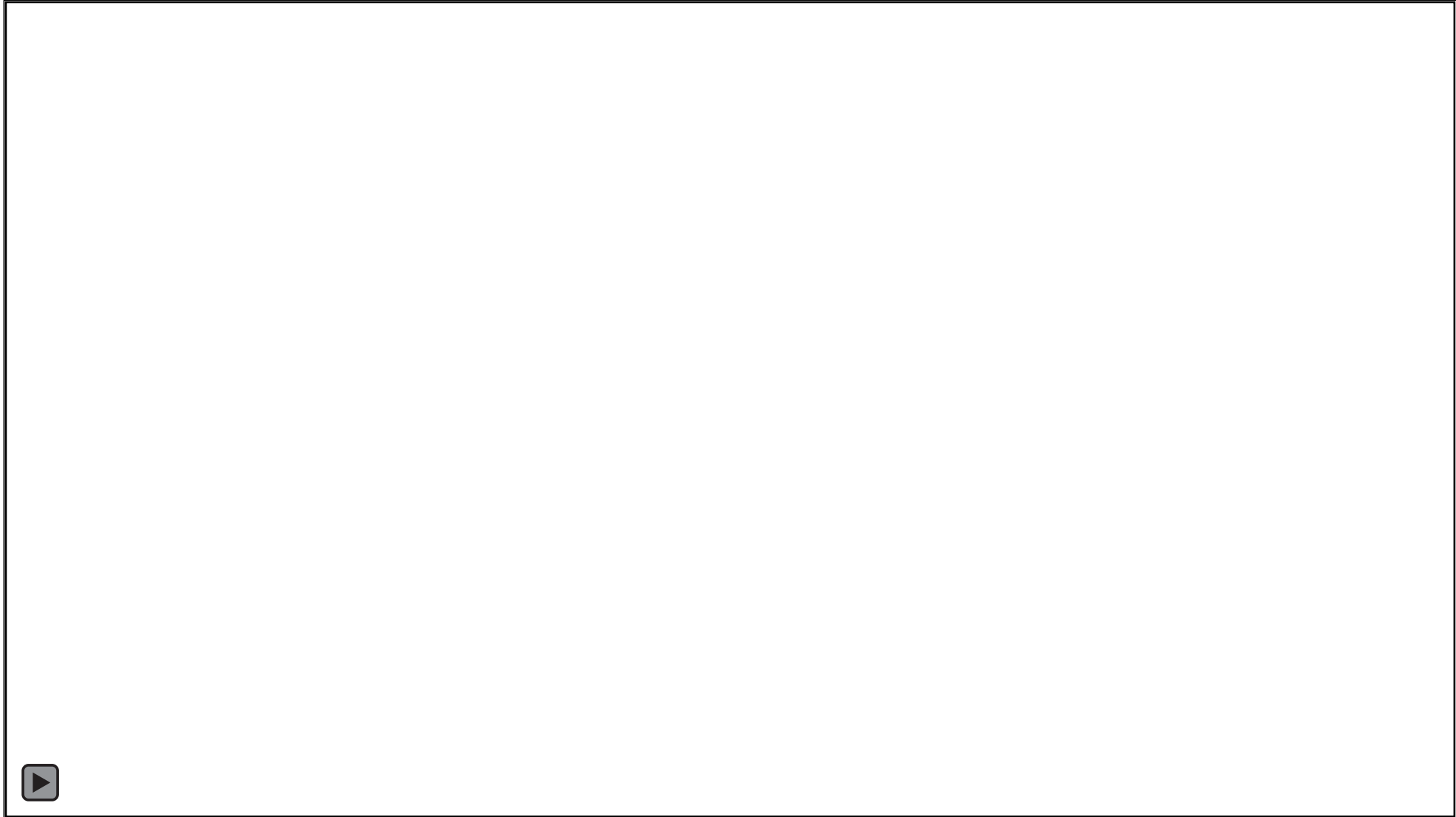
- *CRSNG*
- *IRSST*

Matériel additionnel

Méthodologie : expert # 13



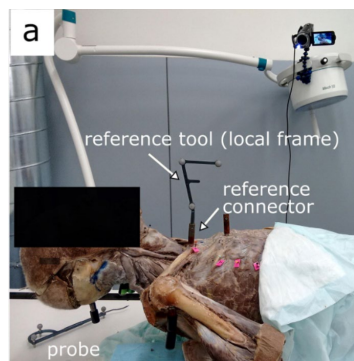
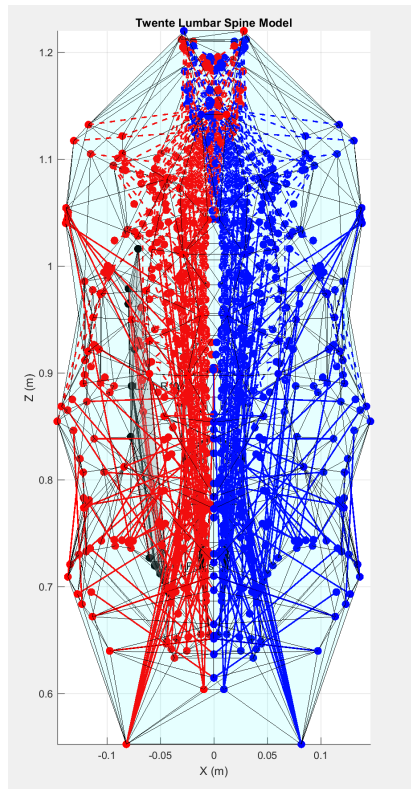
Méthodologie : expert # 27



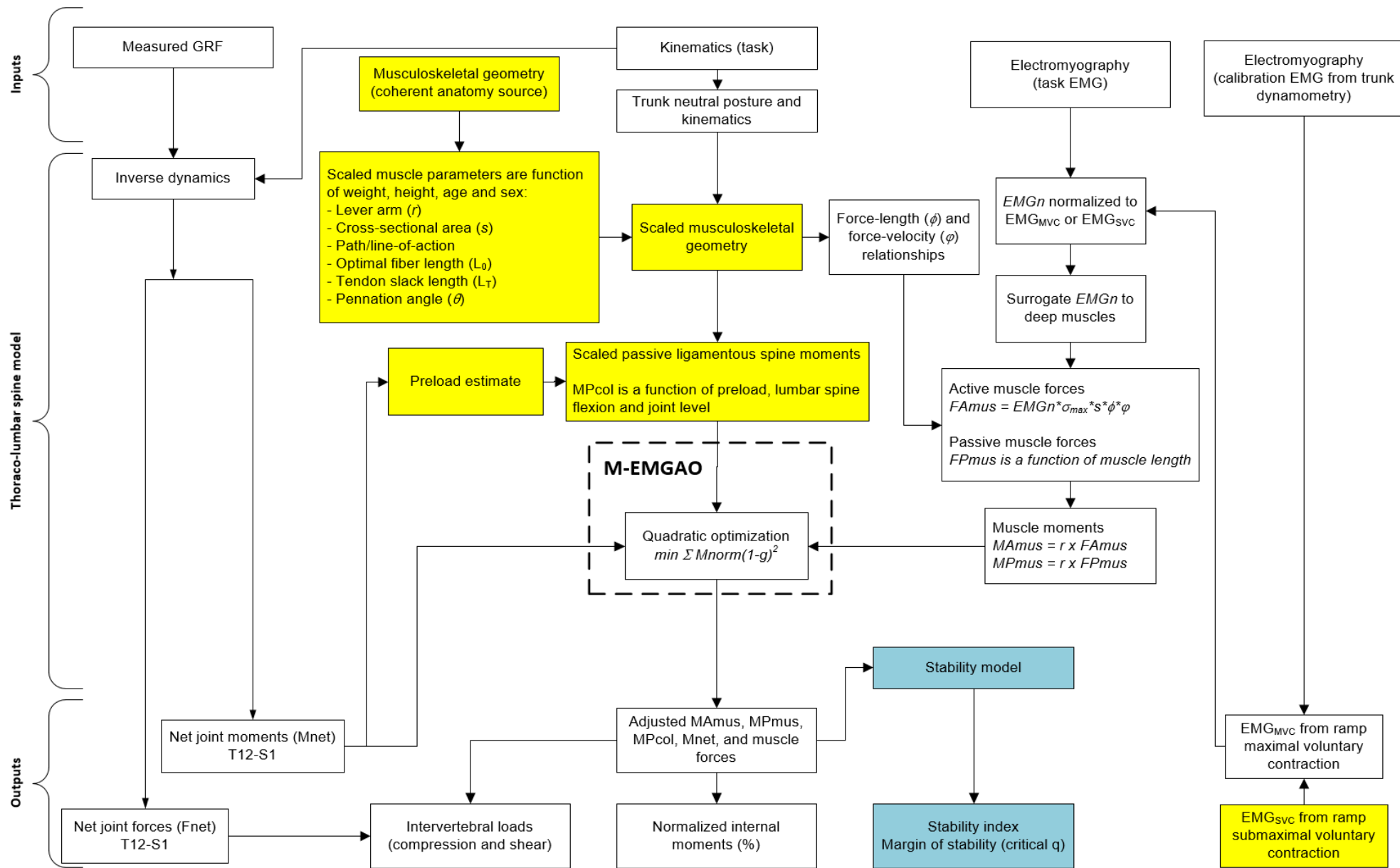
Supp. JoB 2018

Abbreviations

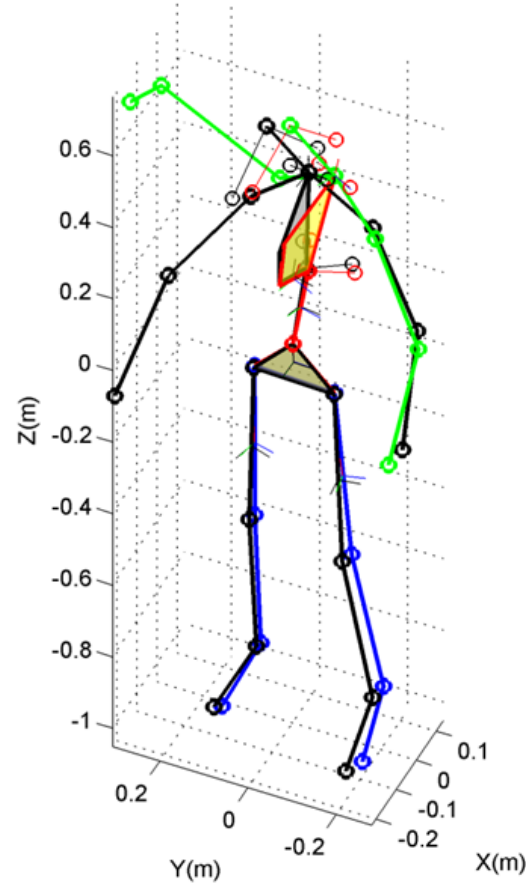
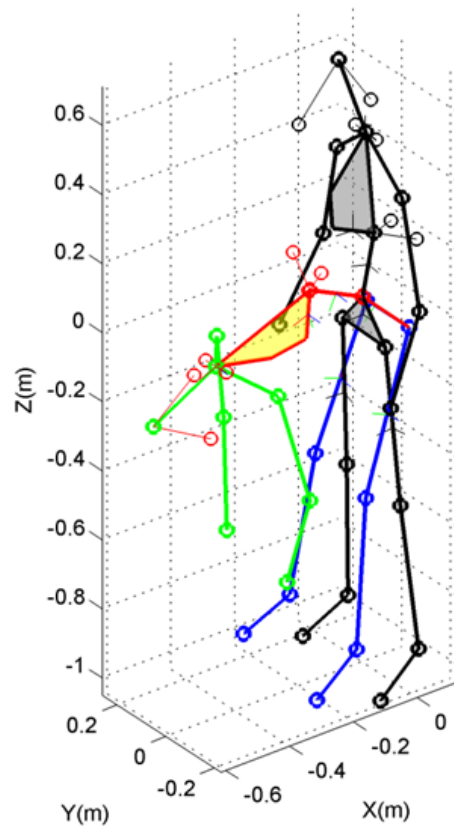
Abbreviation	Definition (units)
Joint forces	
F _{comp}	Joint compression force (N)
F _{shear}	Joint shear force (N)
Moments	
M _{Amus}	Active muscle moment (Nm)
M _{AmusMax}	Maximal active muscle moment about a lumbar joint for a given posture (Nm)
M _{err}	Adjustment error moment (Nm)
M _{net}	Net (external) joint moment (Nm)
M _{norm}	Euclidean norm of the resultant moment(s) about relevant joint(s) (Nm)
M _{Pcol}	Passive ligamentous spine (resistance) moment (Nm)
M _{Pmus}	Passive (agonist) muscle moment (Nm)
M _L , M _S , M _T , M _r	Longitudinal (L), sagittal (S), transverse (T), and resultant moment about a joint (Nm)
Dependent variables	
F _{shear PA} , F _{shear ML}	Postero-anterior and medial-lateral shear joint force (N/Body weight)
M _{Amus}	Normalized agonist muscle moment (%)
M _{Amusa}	Normalized antagonist muscle moment (%)
M _{Pcol}	Normalized passive ligamentous spine moment (%)
M _{Pmus}	Normalized passive muscle moment (%)
Σ Abdo	Sum of global flexor normalized moments: EO, IO, RA (%)
Σ Back L	Sum of local extensor normalized moments: LGPL, MUF, ICPL, QLO (%)
Σ Back G	Sum of global extensor normalized moments: ICPT and LGPT (%)
Σ EO	Sum of external oblique normalized moments (%)
Σ ICPL	Sum of iliocostalis pars lumbaris normalized moments (%)
Σ ICPT	Sum of iliocostalis pars thoracis normalized moments (%)
Σ IO	Sum of internal oblique normalized moments (%)
Σ LGPL	Sum of longissimus pars lumbaris normalized moments (%)
Σ LGPT	Sum of longissimus pars thoracis normalized moments (%)
Σ MUF	Sum of multifidus normalized moments (%)
Σ QLO	Sum of quadratus lumborum normalized moments (%)
Σ RA	Sum of rectus abdominis normalized moments (%)



Bayoglu et al., 2017



Tâches (2011)



Sujet

- Homme : 1.75 m, 68.4 kg

Flexion sagittale complète

- Aucune charge externe
- 3 essais : le plus sagittal conservé

Soulèvement asymétrique

- Membre supérieur droit
- Masse de 5.2 kg
- Maintien à 4 hauteurs p/r au sol : 90, 120, 150 et 180 cm
- 3 essais : celui conservant le mieux un même bras de levier (charge-sacrum) conservé

Validation : tâche symétrique

Posture	Variable	Muscle or Joint	M-EMGAO	S-EMGAO						
			T12-S1	L5-S1	L4-L5	L3-L4	L2-L3	L1-L2	T12-L1	
60°		RA	102	97	109	102	110	114	116	
		EO	75	15	15	17	21	25	33	
		IO	11	5	6	7	8	9	3	
		ICPT	205	216	199	204	207	215	239	
		LGPT	236	236	236	236	236	236	236	
		ΣF_{mus}	629	569	565	566	582	599	627	
		C/S	T12-L1	768/224						782/197
			L1-L2	1001/226					1043/205	
			L2-L3	1285/155				1268/122		
			L3-L4	1666/256			1520/204			
		L4-L5	1934/158		1771/122					
		L5-S1	2009/524	1758/466						

Validation : tâche asymétrique

Load Height	Variable	Muscle or Joint	M-EMGAO	S-EMGAO					
			T12-S1	L5-S1	L4-L5	L3-L4	L2-L3	L1-L2	T12-L1
90 cm		RA	6	6	6	6	6	6	6
		EO	305	14	13	16	19	23	32
		IO	86	91	70	56	51	53	62
		ICPT	8	16	17	18	19	21	23
		LGPT	75	99	169	201	226	262	352
		^a ΣF _{mus}		480	226	275	297	321	365
	^b C°/S	T12-L1	743/-24						759/-122
		L1-L2	830/-46					724/-143	
		L2-L3	895/-75				701/-160		
		L3-L4	978/44			710/-63			
		L4-L5	1069/105		706/-16				
		L5-S1	1119/415	675/168					

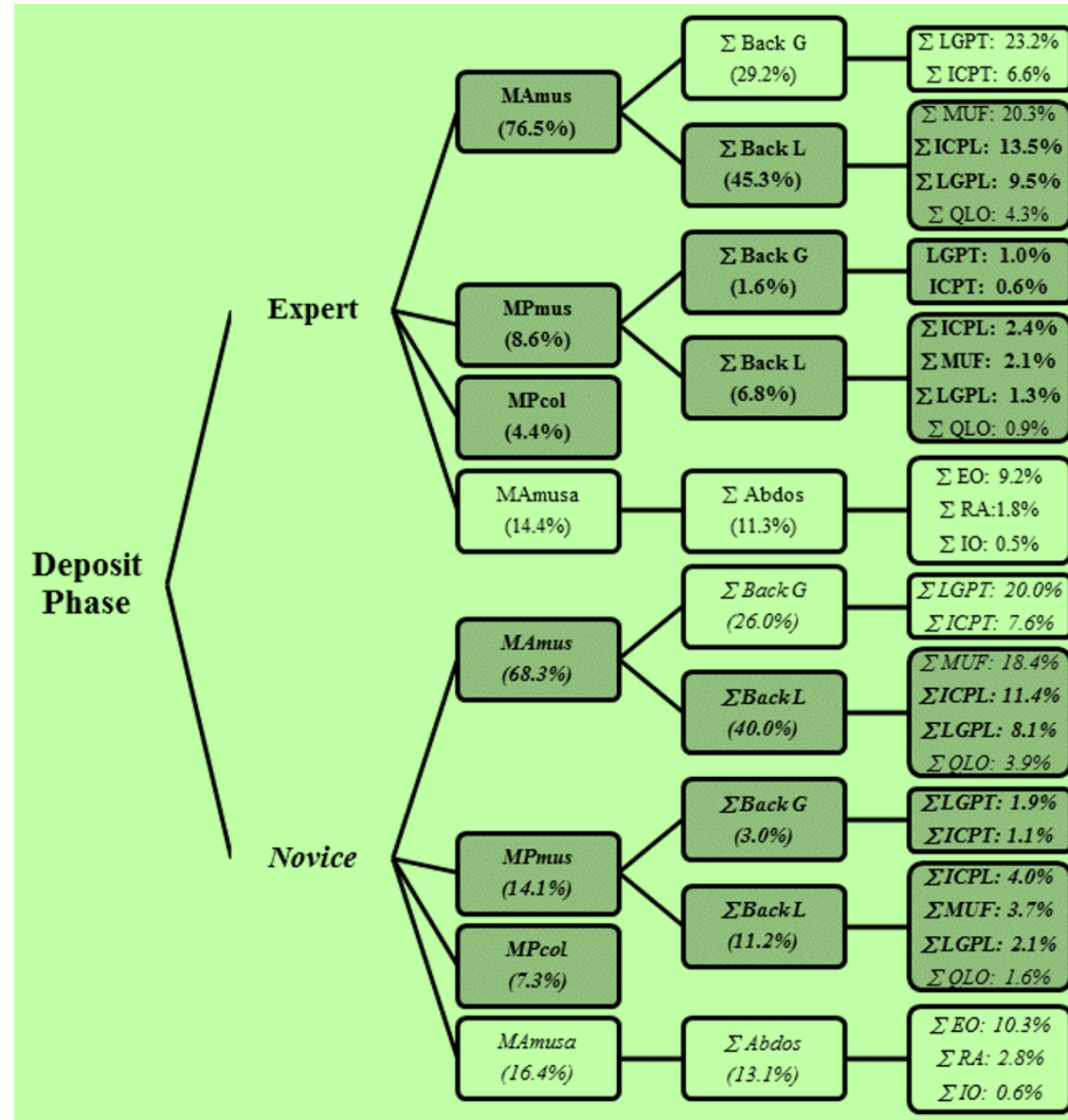
Résultats - E vs N : extenseurs globaux

Muscles	Lift Phase (from conveyor)											
	Expertise				Box Mass				Deposit Height			
	Expert		Novice		15 kg		23 kg		Floor (H1)		Top (H4)	
	Active	Passive	Active	Passive	Active	Passive	Active	Passive	Active	Passive	Active	Passive
Σ ICPT	8.4 (3.2)	1.0 (0.4)	6.7 (3.7)	1.7 (0.8)	6.3 (2.3)	1.4 (0.7)	8.8 (4.1)	1.4 (0.7)	7.5 (3.3)	1.4 (0.7)	7.7 (3.7)	1.4 (0.7)
Σ LGPT	21.7 (5.7)	1.7 (0.6)	16.8 (5.6)	2.8 (1.2)	18.9 (5.8)	2.3 (1.2)	19.5 (6.5)	2.1 (1.0)	18.8 (6.3)	2.2 (1.1)	19.6 (6.0)	2.3 (1.1)
Σ Back G	28.7 (7.0)	2.7 (0.9)	22.4 (6.7)	4.5 (1.9)	24.0 (6.1)	3.7 (1.9)	27.1 (8.5)	3.4 (1.6)	25.2 (7.1)	3.5 (1.7)	25.9 (8.0)	3.6 (1.8)
	Deposit Phase (to hand trolley)											
Σ ICPT	6.6 (3.2)	0.6 (0.5)	7.6 (4.4)	1.1 (0.8)	6.9 (4.2)	0.9 (0.6)	7.3 (3.4)	0.9 (0.7)	6.1 (2.9)	1.4 (0.6)	8.1 (4.4)	0.4 (0.3)
Σ LGPT	23.2 (6.7)	1.0 (0.7)	20.0 (6.3)	1.9 (1.5)	20.7 (6.7)	1.5 (1.3)	22.4 (6.6)	1.4 (1.2)	19.1 (5.1)	2.3 (1.2)	24.1 (7.1)	0.6 (0.6)
Σ Back G	29.2 (7.9)	1.6 (1.2)	26.0 (8.1)	3.0 (2.2)	26.3 (8.4)	2.3 (1.9)	28.8 (7.7)	2.2 (1.9)	24.3 (6.2)	3.6 (1.7)	30.8 (8.6)	0.9 (1.7)

Résultats - E vs N : extenseurs locaux

Muscles	Lift Phase (from conveyor)											
	Expertise				Box Mass				Deposit Height			
	Expert		Novice		15 kg		23 kg		Floor (H1)		Top (H4)	
	Active	Passive	Active	Passive	Active	Passive	Active	Passive	Active	Passive	Active	Passive
Σ LGPL	9.3 (2.3)	2.3 (1.4)	7.8 (2.3)	3.6 (1.8)	8.5 (2.5)	3.2 (1.8)	8.6 (2.3)	2.7 (1.6)	9.0 (2.8)	2.9 (1.7)	8.0 (1.9)	2.9 (1.7)
Σ MUF	16.2 (3.1)	3.9 (2.0)	14.2 (2.7)	6.3 (3.0)	15.4 (3.5)	5.4 (2.9)	15.0 (2.6)	4.8 (2.7)	15.5 (3.2)	5.2 (3.0)	14.9 (3.0)	5.1 (2.7)
Σ ICPL	14.2 (2.9)	4.2 (3.0)	12.4 (5.1)	6.7 (3.2)	12.9 (3.4)	5.9 (3.5)	13.7 (4.9)	5.0 (3.2)	13.2 (3.3)	5.5 (3.4)	13.4 (5.1)	5.4 (3.4)
Σ QLO	5.6 (0.8)	1.7 (1.4)	5.4 (1.6)	2.7 (1.4)	5.4 (0.9)	2.3 (1.6)	5.6 (1.6)	2.0 (1.4)	5.5 (1.1)	2.2 (1.5)	5.5 (1.5)	2.1 (1.5)
Σ Back L	43.7 (7.8)	11.9 (7.7)	38.3 (7.3)	19.2 (9.3)	40.7 (8.6)	16.7 (9.6)	41.3 (7.4)	14.5 (8.8)	41.8 (8.1)	15.7 (9.5)	40.3 (7.9)	15.4 (9.2)
	Deposit Phase (to hand trolley)											
Σ LGPL	9.5 (2.1)	1.3 (1.4)	8.1 (2.1)	2.1 (2.0)	8.6 (2.3)	1.7 (1.7)	9.0 (2.2)	1.6 (1.8)	7.8 (1.9)	2.9 (1.6)	9.8 (2.1)	0.4 (0.4)
Σ MUF	20.3 (6.2)	2.2 (2.5)	18.4 (6.4)	3.7 (3.7)	19.7 (6.9)	3.0 (3.1)	19.0 (5.7)	2.9 (3.3)	14.2 (3.3)	5.4 (2.9)	24.5 (3.7)	0.6 (0.7)
Σ ICPL	13.5 (2.5)	2.4 (2.8)	11.4 (3.3)	4.0 (3.9)	12.3 (3.5)	3.2 (3.4)	12.7 (2.6)	3.1 (3.5)	12.3 (2.7)	5.7 (3.3)	12.7 (3.4)	0.7 (0.6)
Σ QLO	4.3 (1.6)	0.9 (1.2)	3.9 (1.4)	1.6 (1.6)	4.1 (1.6)	1.3 (1.4)	4.1 (1.5)	1.2 (1.5)	5.2 (0.7)	2.3 (1.4)	3.0 (1.3)	0.2 (0.2)
Σ Back L	45.3 (6.6)	6.8 (7.7)	40.0 (7.3)	11.2 (10.9)	42.3 (7.5)	9.2 (9.5)	43.0 (7.4)	8.8 (9.9)	38.7 (7.3)	16.2 (9.0)	46.6 (5.0)	1.9 (1.9)

Résultats - E vs N : effet de l'expertise (dépôt)

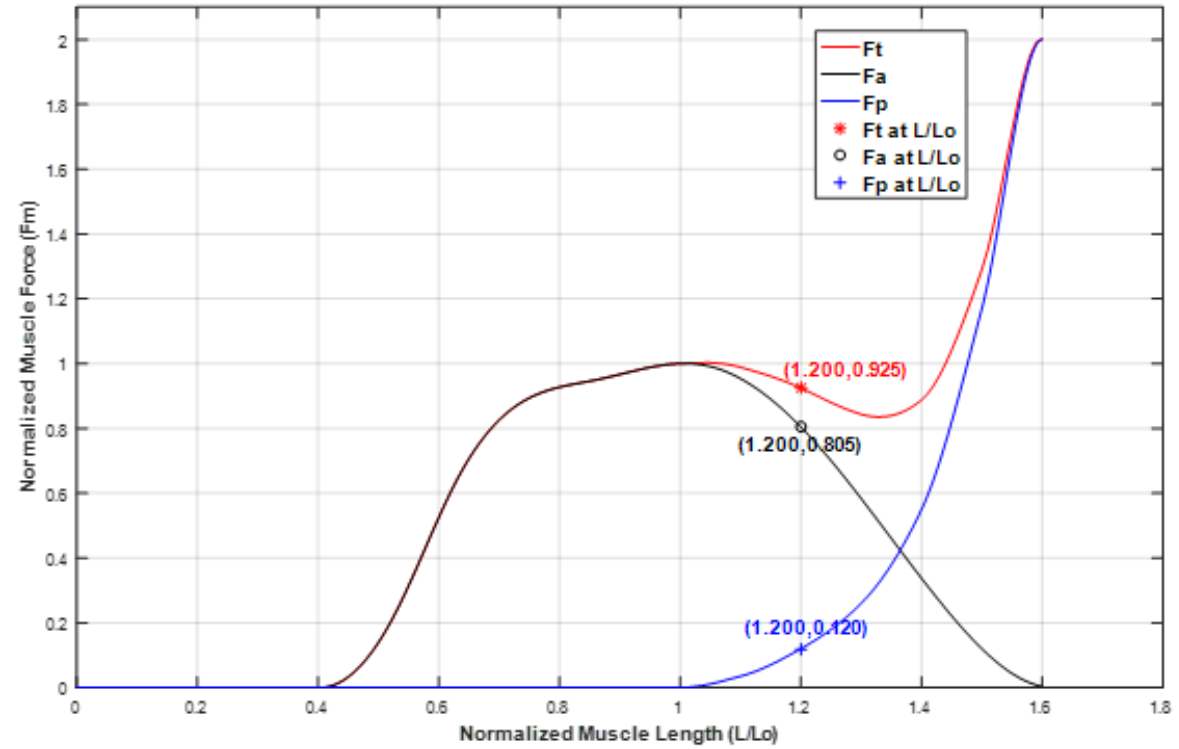


Discussion - Influence M-EMGAO

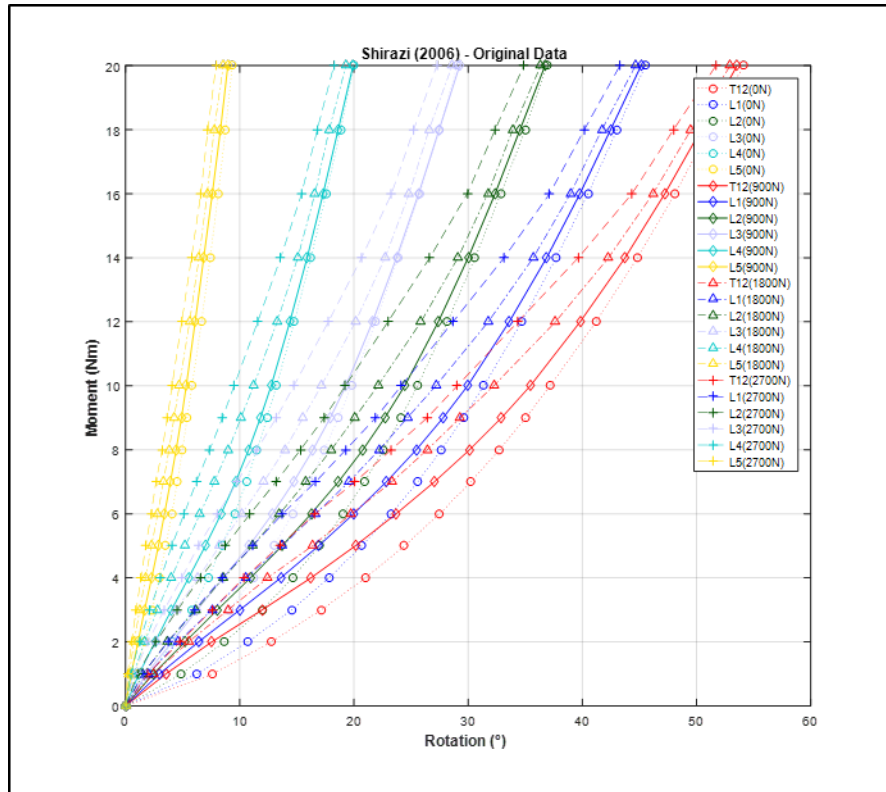
Comment le degré de cohérence de la méthode de résolution guidée par EMG (S-EMGAO vs M-EMGAO) influence-t-il les prédictions du modèle musculosquelettique?

- Les forces résolues à un seul niveau (p. ex. : S-EMGAO à L5-S1) ne parviennent pas à respecter l'équilibre mécanique aux autres niveaux de la colonne (L4-L5 à T12-L1).*
- Les stratégies musculaires (ensemble de forces activées et leur intensité) diffèrent entre S-EMGAO et M-EMGAO.*
- Le chargement articulaire prédit diffère entre S-EMGAO et M-EMGAO.*

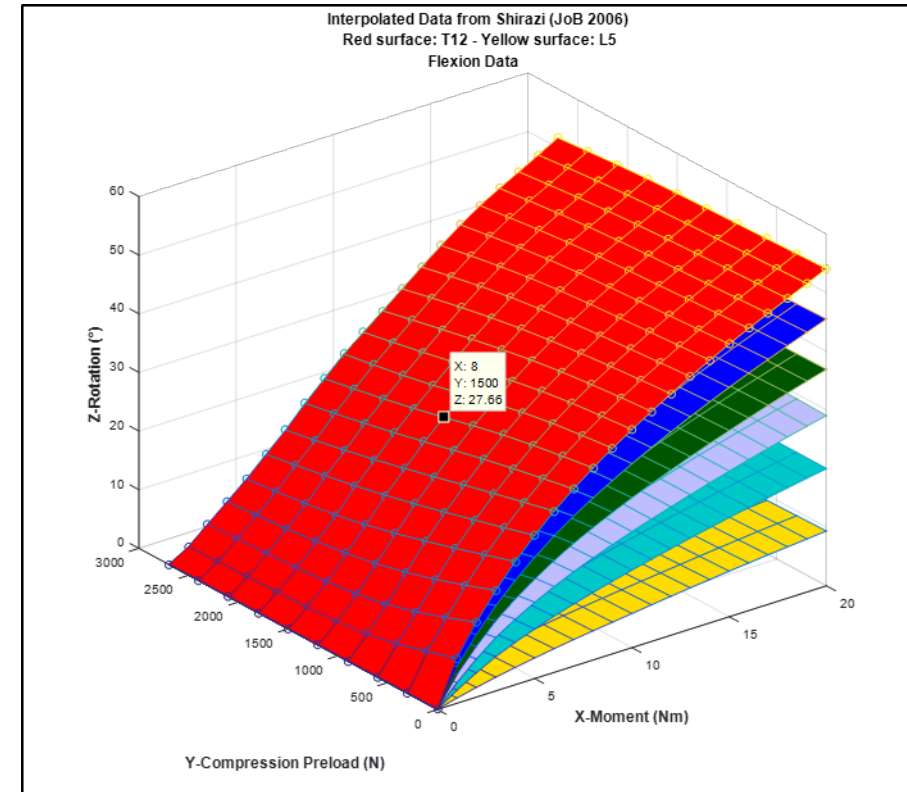
Force musculaire passive (ϕ pour MPmus; φ négligé)



Résistance passive de la colonne lombaire (MPcol)



Shirazi-Adl (2006)



Fonctionnement de l'optimisation (EMGAO) : 1 de 4

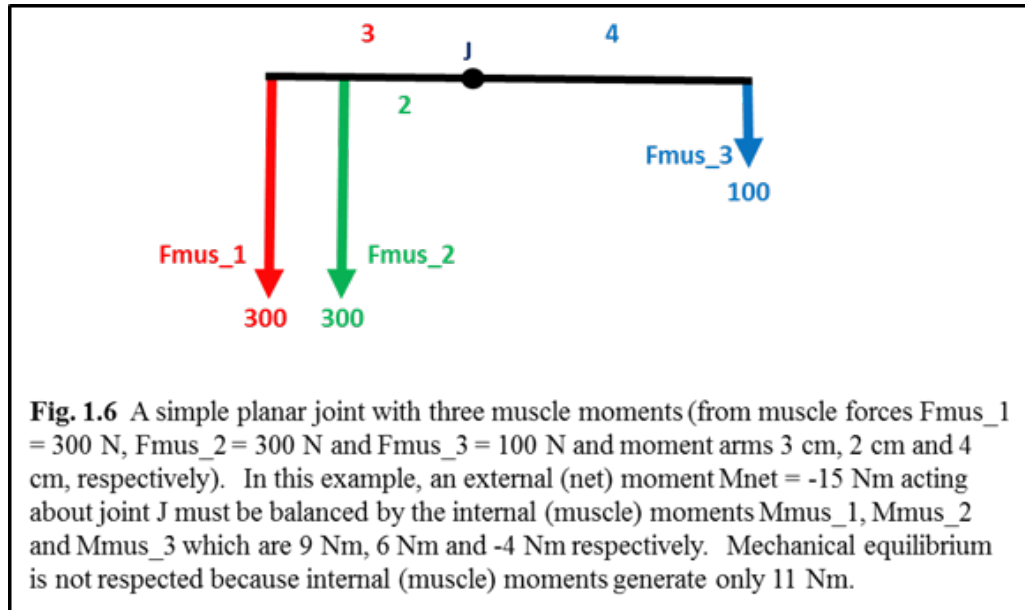


Table 1.6

Input forces vs output optimal forces and gains $g(i)$ for example in Fig 1.6

	Input	$g(i)$	Output

Case 1 (original)			
F1	300.00	1.21	363.16
F2	300.00	1.21	363.16
F3	100.00	0.79	78.95

Case 2 (F1 modified)			
F1	360.00	1.11	398.08
F2	300.00	1.11	331.73
F3	100.00	0.89	89.42

Case 3 (F1 and F2 modified)			
F1	360.00	1.05	376.36
F2	360.00	1.05	376.36
F3	100.00	0.95	95.45

Case 4 (F1, F2 and F3 modified)			
F1	360.00	1.03	370.00
F2	360.00	1.03	370.00
F3	90.00	0.97	87.50

Case 5 (Case 4 + forces bounded 0.8 to 1)			
F1	360.00	1.00	360.00
F2	360.00	1.00	360.00
F3	90.00	0.83	75.00

Case 6 (Case 5 + Mnet bounded 0.8 to 1)			
F1	360.00	1.00	360.00
F2	360.00	1.00	360.00
F3	90.00	0.97	87.10

Fonctionnement de l'optimisation (EMGAO) : 2 de 4

Table 1.6A
Example solution - M-EMGAO (T12-S1) - Equilibrium at L5-S1

#	Muscle	Moment (Nm)							
		Force (N)		Mmus (L)		Mmus (S)		Mmus (T)	
		Pre	Opt	Pre	Opt	Pre	Opt	Pre	Opt
1	RAg-Thor	3	1	0.0	0.0	0.1	0.1	-0.3	-0.2
2	EOg-1-TA	0	0	0.0	0.0	-0.0	-0.0	-0.0	-0.0
3	EOg-2-TA	0	0	0.0	0.0	0.0	0.0	-0.0	-0.0
4	EOg-3-TA	0	0	0.0	0.0	0.0	0.0	-0.0	-0.0
5	EOg-4-TA	0	0	0.0	0.0	0.0	0.0	-0.0	-0.0
6	EOg-5-TA	8	0	0.7	0.0	0.8	0.0	-0.6	-0.0
7	EOg-6-TA	8	0	0.7	0.0	0.8	0.0	-0.3	-0.0
8	IOg-1-AI	0	0	-0.0	-0.0	0.0	0.0	-0.0	-0.0
9	IOg-2-AI	0	0	-0.0	-0.0	0.0	0.0	-0.0	-0.0
10	IOg-3-TI	0	0	-0.0	-0.0	0.0	0.0	-0.0	-0.0
11	IOg-4-TI	5	12	-0.1	-0.4	0.6	1.4	-0.1	-0.2
12	IOg-5-TI	4	7	-0.0	-0.1	0.4	0.6	0.0	0.0
13	IOg-6-TI	4	10	-0.1	-0.2	0.3	0.7	0.1	0.3
14	ICPTg-Thor	86	94	0.2	1.3	1.9	3.4	1.3	1.8
15	LGPTg-Thor	236	421	0.2	1.3	1.9	6.2	3.7	9.8
16	ICPLg-L1	14	10	0.0	0.0	0.4	0.2	0.3	0.2
17	IPg-L1F	5	10	0.1	0.1	0.4	0.8	-0.2	-0.4
18	LGPLg-L1	15	10	0.1	0.0	0.4	0.2	0.3	0.2
19	MUFg-L1	31	20	0.3	0.1	0.6	0.3	0.7	0.3
20	QLOg-L1	12	6	0.1	0.0	0.5	0.1	0.2	0.0
21	ICPLg-L2	20	30	0.1	0.2	0.5	1.1	0.4	1.0
22	IPg-L2F	2	6	0.0	0.0	0.1	0.4	-0.1	-0.2
23	LGPLg-L2	18	23	0.1	0.1	0.4	0.8	0.4	0.6
24	MUFg-L2	45	17	0.4	0.0	0.8	0.0	0.9	0.0
25	QLOg-L2	11	7	0.1	0.1	0.4	0.2	0.1	0.1
26	ICPLg-L3	24	36	0.1	0.2	0.6	1.4	0.5	1.1
27	IPg-L3F	3	9	0.0	0.1	0.2	0.6	-0.1	-0.3
28	LGPLg-L3	20	23	0.1	0.1	0.5	0.7	0.4	0.6
29	MUFg-L3	68	26	0.6	0.0	0.8	0.0	1.4	0.0
30	QLOg-L3	10	9	0.1	0.1	0.3	0.3	0.1	0.1
31	ICPLg-L4	25	44	0.1	0.3	0.7	1.9	0.4	1.2
32	IPg-L4F	2	3	0.0	0.0	0.1	0.2	-0.1	-0.1
33	LGPLg-L4	21	39	0.1	0.2	0.5	1.3	0.4	1.0
34	MUFg-L4	60	78	0.5	1.0	0.4	0.7	1.3	2.4
35	QLOg-L4	9	16	0.0	0.1	0.2	0.6	0.1	0.4
36	IPg-L5F	1	2	0.0	0.0	0.0	0.1	-0.0	-0.0
37	LGPLg-L5	22	41	0.1	0.3	0.4	1.2	0.3	0.8
38	MUFg-L5	43	66	0.2	0.4	0.1	0.1	1.1	2.4

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Table 1.6A (suite 1)

#	Muscle	Moment (Nm)							
		Force (N)		Mmus (L)		Mmus (S)		Mmus (T)	
		Pre	Opt	Pre	Opt	Pre	Opt	Pre	Opt
39	RAd-Thor	3	1	0.0	0.0	-0.1	-0.1	-0.3	-0.2
40	E0d-1-TA	0	0	-0.0	-0.0	0.0	0.0	-0.0	-0.0
41	E0d-2-TA	0	0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
42	E0d-3-TA	0	0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
43	E0d-4-TA	0	0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
44	E0d-5-TI	5	13	-0.3	-0.7	-0.6	-1.6	-0.3	-0.8
45	E0d-6-TI	7	13	-0.3	-0.5	-0.9	-1.8	-0.1	-0.1
46	I0d-1-AI	0	0	0.0	0.0	-0.0	-0.0	-0.0	-0.0
47	I0d-2-AI	0	0	0.0	0.0	-0.0	-0.0	-0.0	-0.0
48	I0d-3-TI	0	0	0.0	0.0	-0.0	-0.0	-0.0	-0.0
49	I0d-4-TI	5	3	0.4	0.2	-0.6	-0.3	0.1	0.0
50	I0d-5-TI	5	0	0.4	0.0	-0.5	-0.0	0.2	0.0
51	I0d-6-TI	4	0	0.3	0.0	-0.3	-0.0	0.3	0.0
52	ICPTd-Thor	106	157	-0.0	-0.8	-3.2	-6.1	1.8	3.5
53	LGPTd-Thor	370	629	0.1	-0.2	-3.8	-8.6	5.9	14.2
54	ICPLd-L1	17	7	-0.0	-0.0	-0.4	-0.1	0.5	0.1
55	IPd-L1F	5	0	-0.0	-0.0	-0.3	-0.0	-0.2	-0.0
56	LGPLd-L1	24	10	-0.0	-0.0	-0.5	-0.2	0.6	0.2
57	MUFd-L1	41	41	-0.3	-0.3	-0.7	-0.9	1.0	1.2
58	QLOd-L1	14	9	-0.1	-0.1	-0.5	-0.3	0.3	0.2
59	ICPLd-L2	25	6	-0.0	-0.0	-0.6	-0.0	0.6	0.0
60	IPd-L2F	2	0	-0.0	-0.0	-0.1	-0.0	-0.1	-0.0
61	LGPLd-L2	28	7	-0.0	-0.0	-0.6	-0.0	0.6	0.0
62	MUFd-L2	60	70	-0.4	-0.7	-1.0	-1.5	1.4	2.2
63	QLOd-L2	13	3	-0.0	-0.0	-0.4	-0.0	0.2	0.0
64	ICPLd-L3	29	7	0.0	0.0	-0.7	-0.0	0.7	0.0
65	IPd-L3F	4	0	-0.0	-0.0	-0.2	-0.0	-0.1	-0.0
66	LGPLd-L3	32	8	-0.0	-0.0	-0.7	-0.0	0.6	0.0
67	MUFd-L3	91	152	-0.6	-1.5	-1.0	-2.6	2.1	5.3
68	QLOd-L3	12	3	-0.0	-0.0	-0.3	-0.0	0.2	0.0
69	ICPLd-L4	31	25	0.1	0.0	-0.8	-0.7	0.6	0.5
70	IPd-L4F	2	0	-0.0	-0.0	-0.1	-0.0	-0.1	-0.0
71	LGPLd-L4	34	34	0.0	0.0	-0.7	-0.7	0.6	0.6
72	MUFd-L4	80	144	-0.4	-1.3	-0.5	-1.4	1.9	5.3
73	QLOd-L4	11	9	0.0	0.0	-0.3	-0.2	0.2	0.2
74	IPd-L5F	1	0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
75	LGPLd-L5	36	15	0.0	0.0	-0.7	-0.3	0.5	0.2
76	MUFd-L5	58	99	-0.0	-0.0	-0.1	-0.2	1.4	3.8
Fmus Tot		1991	2540						

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Table 1.6A (suite 2)

	Moment (Nm)							
	Force (N)		Mmus (L)		Mmus (S)		Mmus (T)	
	Pre	Opt	Pre	Opt	Pre	Opt	Pre	Opt
Avg	33	48						
SD	62	107						
Min	0	0						
Max	370	629						
MAmus (+)			7.2	5.9	16.8	24.7	36.4	60.3
MAmus (-)			-3.4	-6.8	-20.9	-26.9	-3.0	-2.5
MPmus (+)			0.3	0.3	1.0	1.0	1.4	1.4
MPmus (-)			-0.1	-0.1	-0.7	-0.6	0.0	0.0
MAmus Total			3.7	-0.8	-4.1	-2.2	33.4	57.8
MPmus Total			0.3	0.3	0.3	0.4	1.4	1.4
Mmus (MAmus+MPmus)			4.0	-0.5	-3.8	-1.8	34.8	59.2
Mnet (External)				-13.6		-3.9		60.3
MPcol (Spine)				11.9		1.4		-0.0
Merr (Adjust)				-1.2		-0.7		1.1
Equilibrium: Mmus-Mnet-Mcol+Merr				0.0		0.0		-0.0
Gains g(i) - Stats for Force Opt >= 1 N								
	MAmus	MPmus	MPcol	Mnet				
Avg	1.39	0.78	1.02	0.97				
SD	1.05	0.16	0.05	0.02				
Min	0.00	0.50	0.95	0.95				
Max	3.76	1.05	1.05	1.00				