DIFFERENZE NEL CONTROLLO NEUROMUSCOLARE TRA ORTESI PER GINOCCHIO E CAVIGLIA TRADIZIONALI E ORTESI DI NUOVA GENERAZIONE

DIFFERENCES IN NEUROMUSCULAR CONTROL BETWEEN CONVENTIONAL AND NEW-GENERATION ORTHOSES FOR KNEE AND ANKLE JOINTS
INTRODUCTION AND AIM
Proprioception and muscle force control are important determinants of joint stability. The former can be viewed as the cumulative neural input to the central nervous system from specialized nerve endings called mechanoreceptors, located in joint capsules, ligaments, muscles, tendons, and skin. Proprioception is generally divided into two components: kinesesthesia that is defined as the awareness of joint movement (dynamic phenomenon), and joint position sense that is restricted to the awareness of the position of a joint in space (static phenomenon). Besides proprioception, adequate control of submaximal muscle forces is especially important in activities of daily living that are normally executed at a fraction of the available maximal muscle strength. Accuracy (precision) and steadiness (variability) of force production are the two most commonly forms of muscle force control that can be easily evaluated during static and dynamic contractions. Knee and ankle orthoses are generally prescribed to orthopedic patients with the objective to improve joint stability. However, the influence of different orthosis designs on lower limb neuromuscular control are poorly known. The main aim of this study was to compare knee and ankle joints proprioception (kinesthesia and joint position sense) and muscle force control (accuracy and steadiness) between two different experimental conditions: use of conventional orthoses vs. use of new-generation orthoses (elastic ankle/knee brace with carbon fiber yarn and integrated taping system).
The experiments described in the following were performed at the Neuromuscular Research Laboratory, Schulthess Clinic, Zurich (Switzerland).
Sixteen healthy subjects (whose characteristics are reported in Table 1) participated in a 90 min familiarization session, followed by a 150 min experimental phase in which orthoses type, order of tests and joints (knee or ankle) were individually and meticulously randomized. All the orthoses were made by Tenortho (Tenorthosrl, Biassono, Italy). The conventional models NEOMESH (knee, Fig. 1) and GAMMA (ankle, Fig. 2) were compared to the experimental LINE C models, CKNEE (knee, Fig. 3) and CANKLE (ankle, Fig. 4).

**Table 1**

<table>
<thead>
<tr>
<th>Caratteristiche</th>
<th>Dati medi ± deviazione standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>N° (uomini/donne)</td>
<td>16 (8/8)</td>
</tr>
<tr>
<td>Età (anni)</td>
<td>27.9 ± 5.9</td>
</tr>
<tr>
<td>Peso (Kg)</td>
<td>68.8 ± 9.8</td>
</tr>
<tr>
<td>Altezza (cm)</td>
<td>174.1 ± 6.6</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>22.6 ± 2.1</td>
</tr>
<tr>
<td>Circonferenza ginocchio (cm)</td>
<td>36.9 ± 2.5</td>
</tr>
<tr>
<td>Circonferenza caviglia (cm)</td>
<td>25.1 ± 2.7</td>
</tr>
</tbody>
</table>

Demographic and anthropometric data of the subjects.

**Table 1**

<table>
<thead>
<tr>
<th>Sample characteristics</th>
<th>Mean ± standard deviation</th>
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</thead>
<tbody>
<tr>
<td>N° (males/females)</td>
<td>16 (8/8)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>27.9 ± 5.9</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>68.8 ± 9.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.1 ± 6.6</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>22.6 ± 2.1</td>
</tr>
<tr>
<td>Knee circumference (cm)</td>
<td>36.9 ± 2.5</td>
</tr>
<tr>
<td>Ankle circumference (cm)</td>
<td>25.1 ± 2.7</td>
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</tbody>
</table>
Abbiamo realizzato le seguenti valutazioni oggettive di vari aspetti del controllo proprio-cettivo:

1) senso di forza,
2) senso di posizione,
3) senso di movimento,
4) equilibrio statico.

Abbiamo inoltre quantificato: 5) il feeling soggettivo (comfort generale, stabilità articolare e preferenza) legato all’utilizzo dei due tutori.

Nelle pagine che seguono, presentiamo la descrizione della metodologia utilizzata nei vari test e i principali risultati corredati da analisi statistica (test t di Student per dati appaiati, test a due code, livello di significatività p<0.05), al fine di appurare eventuali differenze significative tra tutore convenzionale e tutore sperimentale.

The following objective assessments of different proprioception components were performed:

1) Muscle force control,
2) Joint position sense,
3) Kinesthesia,
4) Static balance.

Moreover, we quantified: 5) Subjective feeling (general comfort, joint stability and preference) using different orthoses.

In the following pages, we describe materials and methods used for each test and the principal outcome measures, accompanied by statistical analysis (Student’s t-test for paired samples, two-tailed test, significance level p<0.05), in order to verify possible significant differences between conventional and experimental orthoses.

Figura 1. NEOMESH

Figure 1. NEOMESH
Figura 2. GAMMA

Figura 3. CKNEE
Elastic knee brace with carbon fiber yarn and integrated TAPING system.

Figura 4. CANKLE
Elastic ankle brace with carbon fiber yarn and integrated TAPING system.
RESULTS

1. Muscle force control

Muscle force control/sense was measured as the accuracy (difference between actual and target force in percentage error) during submaximal quadriceps (knee) and triceps surae (ankle) contractions, performed in static (isometric: 45° knee flexion and 0° plantar flexion) and dynamic conditions (concentric and eccentric: 10°/s angular velocity with 80° range of motion for knee joint and 50° range of motion for ankle joint) using an isokinetic dynamometer.

Figure 5 shows the mean error (with standard deviation) in the three conditions (isometric, concentric and eccentric) for conventional and experimental orthoses and for the two joints (knee and ankle). Using the conventional orthosis, a significantly higher error was detected (i.e., better accuracy with experimental orthosis) in static conditions for the knee joint and in dynamic conditions for the ankle joint.

RISULTATI

1. Senso di forza

Il senso/controllo della forza muscolare è stato misurato in termini di accuratezza (differenza tra forza prodotta e forza richiesta, sotto forma di errore percentuale) durante contrazioni sottomassimali del quadriceps (ginocchio) e del tricipite surale (caviglia) realizzate in condizioni statiche (isometriche, ad un angolo pari a 45° di flessione del ginocchio e 0° di flessione plantare) e dinamiche (concentriche ed eccentriche, ad una velocità angolare di 10 °/s e con un range of motion di 80° per il ginocchio e di 50° per la caviglia) su un ergometro isocinetico.

La Figura 5 riporta l’errore medio (con la deviazione standard) registrato nelle tre condizioni (isometriche, concentriche ed eccentriche) per i due tipi di tutore (convenzionale e sperimentale) e per le due articolazioni considerate (ginocchio e caviglia). Si è evidenziato un errore significativamente più elevato con il tutore convenzionale (ossia, migliore accuratezza con il tutore sperimentale) in condizioni statiche per l’articolazione del ginocchio e in condizioni dinamiche per la caviglia.

Figure 5. Force accuracy during submaximal contractions of the quadriceps (knee) and triceps surae (ankle) muscles in static, eccentric, and concentric conditions with conventional and experimental orthoses. Mean values and SD bars are reported. Significant difference between the two conditions: * P<0.05.
2. Joint position sense

Joint position sense was measured, using the isokinetic dynamometer, as the ability to reposition the knee or ankle joints (difference between the actual and target positions) at three predetermined positions: extended (15° knee flexion, 15° ankle dorsiflexion), neutral (45° knee flexion, 0° ankle plantar flexion/extension) and flexed (75° knee flexion, 15° ankle plantar flexion).

Figure 6 shows the mean error (with standard deviation) in the three joint positions (extended, neutral and flexed) with conventional and experimental orthoses and for the two joints (knee and ankle). No significant differences were measured between conventional and experimental orthoses for both knee and ankle joint.

Figura 6. Senso di posizione nelle tre posizioni articolari (estesa, neutra e flessa) di ginocchio e caviglia con tutori convenzionale e sperimentale. Sono riportati i valori medi e la SD.

Figure 6. Position sense for the three positions (extended, neutral and flexed) of the knee and ankle joints with conventional and experimental orthoses. Mean values and SD bars are reported.
3. Kinesthesia

Kinesthesia was measured, using the isokinetic dynamometer, as the detection threshold of a passive extension movement at a very low angular velocity: 0.1°/s (difference between detected and real movement) at three predetermined joint positions: extended (15° knee flexion, 15° ankle dorsiflexion), neutral (45° knee flexion for the ginocchio e 0° ankle plantar flexion/extension) and flexed (75° knee flexion, 15° ankle plantar flexion).

Figure 7 shows the mean error (with standard deviation) in the three joint positions (extended, neutral and flexed) with conventional and experimental orthoses and for the two joints (knee and ankle). Using the conventional orthosis a significantly higher error was detected (i.e., better accuracy with experimental orthosis) in flexed position for the knee joint.

### Table: Error in Joint Positions

<table>
<thead>
<tr>
<th>Joint</th>
<th>Error - extended position (deg)</th>
<th>Error - joint neutral (deg)</th>
<th>Error - flexed position (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Orthosis</td>
<td>KNEE</td>
<td>ANKLE</td>
<td>KNEE</td>
</tr>
<tr>
<td>Experimental Orthosis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figura 7.** Cinestesia nelle tre posizioni articolari (estesa, neutra e flessa) di ginocchio e caviglia con tutori convenzionali e sperimentali. Sono riportati i valori medi e la SD. Differenze significative tra le due condizioni: *P<0.05.
4. Static balance
Balance was evaluated by stabilometry in a single limb stance, without visual feedback. Sway area and length, and mean sway velocities were calculated from the center of pressure movements on the stabilometric platform. Figure 8 shows the mean stabilometric parameters (with standard deviation) with conventional and experimental orthoses and for the two joints (knee and ankle). No significant differences were measured between conventional and experimental orthosis, for both knee and ankle joint.

![Figure 8. Stabilometric parameters for the knee and ankle joints with conventional and experimental orthoses. Mean values and SD bars are reported.](image-url)
5. Subjective feeling

Comfort sensation and joint stability perceived by participants during different tests were evaluated through 0-10 scoring scale, where 0 indicates the worst score and 10 the best one. In addition, at the end of each test the subjects were requested to express their preference for one of the two orthoses (conventional or experimental).

Figure 9 shows the mean subjective variables (with standard deviation) as well as the preference (in percentage) for conventional or experimental orthoses and for the two joints (knee and ankle). Using the experimental orthosis a significantly higher comfort score, for both knee and ankle, was observed while no difference in joint stability was detected. The number of participants who preferred the experimental orthosis was higher than those who preferred the conventional orthosis, particularly for the knee joint.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Comfort (0 = worst; 10 = best)</th>
<th>Stability (0 = worst; 10 = best)</th>
<th>Preference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee</td>
<td><img src="image1" alt="Bar chart" /></td>
<td><img src="image2" alt="Bar chart" /></td>
<td><img src="image3" alt="Bar chart" /></td>
</tr>
<tr>
<td>Ankle</td>
<td><img src="image4" alt="Bar chart" /></td>
<td><img src="image5" alt="Bar chart" /></td>
<td><img src="image6" alt="Bar chart" /></td>
</tr>
</tbody>
</table>

* Significant difference between the two conditions: *P* < 0.05.
Rispetto ai tutori convenzionali, i tutori sperimentali hanno permesso di ottenere un miglior controllo propriocettivo a livello dell’articolazione del ginocchio e della caviglia in termini di senso di movimento (cinestesia) e, soprattutto, di senso di forza.

I soggetti hanno percepito una sensazione di comfort superiore durante l’utilizzo del tutore sperimentale rispetto a quello convenzionale, ed in generale hanno dichiarato di preferire il modello sperimentale, soprattutto per l’articolazione del ginocchio.

Il senso di posizione, l’equilibrio statico e la sensazione di stabilità articolare non sono risultati differenti tra le due condizioni.

Compared with conventional orthosis, experimental orthosis allowed a better proprioceptive control for knee and ankle joints regarding kinesthesia and muscle force control.

Subjects perceived higher comfort sensation using the experimental orthosis compared to the conventional one, and in general they declared to prefer the experimental model, particularly for the knee joint.

No differences between the two conditions were detected concerning joint position sense, static balance and joint stability sensation.