Impedance-controlled, minimally-assistive robotic training of severely impaired hemiparetic patients

Maura Casadio, Pietro Morasso, and Vittorio Sanguineti

Neurolab - DIST
University of Genova
Via Opera Pia 13, 16145 Genova, Italy
maura.casadio@dist.unige.it

Psiche Giannoni
ART Education and Rehabilitation Center
Piazza di Soziglia 1/5
16123 Genova, Italy
psichegi@tin.it

* This work is partially supported by the Italian Ministry of University and Research and by the Italian Multiple Sclerosis Foundation

Abstract – The paper describes a pilot study in the robotic training of severely impaired hemiparetic patients. It provides arguments in favor of impedance control, with a backdrivable manipulandum characterized by a very low level of the intrinsic mechanical impedance, and proposes a method of minimally assistive robotic training that focuses on outward reaching movements of large amplitude. This type of training is well accepted by the patients and appears to help them decrease the dominating flexion patterns that characterize their pathology.

Index Terms – Robot therapy; Haptic interface; Impedance control; Hemiplegic patients; Motor learning.

I. INTRODUCTION

Personal assistant robots for severely disabled individuals have been studied in the last 25 years and in the last decade a significant body of clinical experimental evidence has been collected for understanding how to match the technical features of robotic manipulanda or robotized haptic interfaces with the disability-related requirements of effective rehabilitation protocols [1,2,3,4,5]. Thus robotic devices for movement therapy are moving closer to becoming practical tools in the rehabilitation of stroke survivors and persons with other sensorimotor disabilities. Robotic technology offers indeed a range of functions that are likely to augment current clinical practice by leveraging therapists’ time, cost effectively extending therapy programs, providing new measures of impairment, and offering new insights in the recovery process.

On the other hand, the extreme variability of clinical syndromes does not allow to identify a single recipe, but even in a narrower category of patients, such as hemiparetic stroke survivors, a consensus has yet to be reached on many strategic points. As a contribution to the current debate, we report on a pilot study that focuses on two aspects: 1) the type of control (impedance vs. admittance control) and 2) the type of robotic intervention (assistive vs. resistive).

II. MATERIALS & METHODS

A. The Robotic Manipulator

In the reported experiments we used the robotic manipulator Braccio di Ferro (see fig. 1) that has been designed explicitly for robotic therapy [6] and is characterized by the following features:

- large planar workspace (80x40 cm ellipse) that can be rotated around a horizontal axis in order to train the subjects in different planes (we did not exploit this feature in the present study);
- very good rigidity of the structure;
- direct drive of the manipulandum by means of two brushless motors, thus eliminating any backlash in the force/motion transmission and minimizing the overall inertia at the Haptic Interaction Point (HIP): it is less than 1 kg;
- very low frictional forces (less than 0.06 N);
- very good spatial resolution (0.024 mm);
- uniform manipulability index (0.2257 \pm 0.0195);
- uniform force/torque ratio (2.21 \pm 0.19 N/Nm);
- large available force at the HIP (continuous force > 50 N; peak force > 200 N);
- high frequency control (16 kHz for the current loop and 1 kHz for the impedance control).

The manipulator is operated according to the impedance control scheme:

\[ T_m = J(q)^T \cdot F_h(x, \dot{x}, \ddot{x}) \]  

where \( T_m \) is the torque vector to be transmitted to the two motors via direct current drive, \( J \) is the Jacobian matrix of the manipulator, and \( F_h \) the desired force at the HIP, calculated according to the haptic interaction model as a function of the position of the HIP \( (x) \) and its time derivatives. In this design there is no need of a force sensor at the HIP because the extremely low friction and the low inertia allow us to estimate the interaction forces directly.

Figure 1: Braccio di Ferro
from the motor currents.

B. The patients

For this pilot study we chose three patients who were characterized by a similar pathological condition of the affected upper limb: a massive flexion scheme, which is a common feature in hemiparetic patients and in practice makes the hand unusable even in the most simple activities of daily life. In most recent studies of robot therapy for hemiparetic patients, such as [2,3,5], the occurrence of this scheme is usually an exclusion criterion, because the patients are supposed to be able to carry out reaching movements, although with some difficulty, in all directions. The selected patients, on the contrary, are unable to perform outward reaching movements, particularly in selected directions, whereas have little difficulty for inward movements that indeed are aided by the pathological condition. Table I lists the relevant features of the patients (S1, S2, S3), including the initial Fugl-Meyer score for the hand section that expresses numerically the selection criterion stated above. The training sessions were carried out at the Neurolab of the Department of Informatics, Systems, and Telecommunications of the University of Genova, under the supervision of a physical therapist. The research conforms to ethical standards laid down in the 1964 Declaration of Helsinki that protect research subjects. Before beginning, each subject signed a consent form that protected research subjects.

C. The experimental setup and protocol

The main purpose of the experiments was to facilitate the active execution of outward reaching movements of large amplitude, in order to progressively free the patients from the dominating flexion patterns. For achieving this goal, the subjects were requested to reach visual/haptic targets in the workspace under control of the manipulandum that acted, at the same time, as provider of facilitating actions and monitor of the on-going performance. It is important to note that we kept the level of assistance as low as possible, in order to be sure that the observed responses were mainly driven by active patterns, not by robot actions.

The subjects sat in a chair, with their chest and wrist restrained by means of suitable holders, and grasping the handle of Braccio di Ferro. A light support was connected to the forearm that allowed low-friction sliding on the horizontal surface of a table. Therefore, only shoulder and elbow could move and motion was restricted to the horizontal plane, with no influence of gravity. The height of the seat was adjusted so that the arm was kept horizontally, at the level of the shoulder joint. The position of the seat was also adjusted in such a way that, with the hand positioned in the center of the workspace, the elbow and the shoulder joints were flexed about 90° and 45°, respectively.

Braccio di Ferro generated the force fields implied by the haptic interaction model by transmitting the forces to the handle. The targets were located on three layers (fig. 2): near layer (A), middle layer (B), and far layer (C). The subjects were positioned in such a way that C-targets could be reached with an almost fully extended arm. The distance between adjacent layers was 20 cm; between targets on the same layer was 6.26 cm (layer A), 8.77 cm (layer B), 5.65 cm (layer C). The target radius was 1 cm. The targets were represented visually on a computer screen in front of the subject and haptically by the force field generated by the robot. Moreover, C-targets were located on a virtual wall (implemented with a stiff virtual boundary: 1000 N/m) in order to further reinforce the feedback about the successful achievement of the outward reaching movements.

The haptic representation of the target was a force field directed from the current position of the HIP to the designated target. The amplitude of the field grows smoothly with a selected force level: we used a ramp with a rise time of 1 s and the force levels that turned out to be appropriate for the subjects were 6, 9, 12, 15 N. We added to this attractive force field a resistive force field, proportional to the movement velocity that had the purpose of damping small oscillations, particularly in the initial and final part of the movements. In summary, the impedance control scheme applied in our experiments can be expressed as follows

\[
T_n = J^T \begin{pmatrix} \rho(F) (x_T - x_H) \\ \|x_T - x_H\| \end{pmatrix} \begin{bmatrix} B & 0 \\ 0 & B \end{bmatrix} \begin{bmatrix} \dot{x}_H \\ \ddot{x}_H \end{bmatrix}
\]

where \(\rho(F)\) is the saturated ramp with the final force level \(F\), \(x_T\) is the target position, \(x_H\) is the current hand position, \(\dot{x}_H\) is the hand velocity vector, \(B = 12\) N is the viscous coefficient. In this way the assistance provided by the haptic interaction scheme is very smooth and is meant to elicit an active movement, not to determine a passive one.
The force level of the robot facilitation was selected by the physical therapist as the minimum value that evoked a functional response, i.e. a movement in the intended direction, independently of the target reaching time or the fact that the target could not be reached at all, as in the early phase of learning.

The basic trial consisted of the following steps (fig. 3):
1) from a starting position in the A layer, random select one of three C-targets (forward-left, forward, forward-right); turn on the visual and haptic representations of the targets at the same time; when the target is reached, give an acoustic feedback, switch off the target (visually and haptically) and wait for a given time;
2) random select one of the B targets; turn it on; switch it off when is reached and wait for a given time;
3) random select one of the A targets; turn it on; switch it off when is reached and wait for a given time.

The duration of the wait and rise times was 1 s. The basic trial was repeated several times, in such a way to have 3 presentations of the seven C-targets, with a total of 21+21+21=63 movements in a given block of trials.

In the return movements (C→B and B→A) the force field could be turned off in most of the cases, even in the early phase of learning, but we chose to keep it running because the patients need a protocol as uniform as possible in order to focus their attention on the task and progressively release the pathological flexion pattern. We introduced in the protocol two types of trials, with open or closed eyes, respectively. In the latter case, the subjects could feel the target via the proprioceptive channel and the purpose was indeed to enhance the role of proprioception, which is likely to have a beneficial effect in the further reduction of the pathological patterns.

The overall protocol consisted of four blocks of trials: open eyes, closed eyes, open eyes, closed eyes, using the same level of force. This lasted about one hour in the early phase of training and less in the later phases. In the later phase of learning the therapist could decide, in accordance with the subject, to extend the session with additional blocks characterized by lower levels of force. In any case, the sessions never lasted more than one hour. The training sessions took place one or two times per week, while the patients received their standard physiotherapy treatment.

### III. RESULTS

Figure 4 shows a typical example of basic trial in the early phase of training (subject 3, force level 12 N): in the upper panel there is the trajectory to three targets in the three layers of the workspace (A→C→B→A) and in the lower panel there is the corresponding time plot of the magnitude of the force field and the velocity trace of the hand. It clearly appears that the outward reaching movement (A→C) is segmented into a sequence of submovements, the first of which only covers part of the total distance, thus leaving a residual error that must be corrected by subsequent commands. The inward reaching movements, on the contrary, are carried out with a single command, which is characterized by a higher peak: as a consequence, the duration of forward reaching is much longer than inward reaching. The experimental data also show that the segmentation pattern is greatly dependent on movement direction, as a consequence of the individual specific impairment: figure 5 illustrates this fact, by showing typical velocity profiles of the same subject to the 7 targets of the C layer: this subject clearly has more difficulty in the right part of the workspace than in the left part. Nonetheless, the basic movements exhibit the typical bell-shaped velocity profile and this is important for two reasons: 1) it makes us confident that, in spite of the severity of the impairment, the subjects exhibit an underlying potential of recovery because the basic control patterns are still there, though “hidden” by the dominating pathological scheme; 2) it assures us that for the selected level of assistance the observed movements are mainly determined by active motor patterns and thus are not the passive responses to the robot action.

Figure 6 shows, for the same subject, the same typical experimental trial, in a later phase of learning and with a reduced level of assistance. Figure 7 shows the speed profiles to the 7 targets of the C layer. It is apparent that there were remarkable improvements: 1) the reaching time is decreased; 2) the segmentation in sub-movements of outward reaching is reduced as well as the residual error after the first sub-movement; 3) the reaching patterns to the different C-targets are more uniform.

As already mentioned, during a given training session the therapist decided which level of force was more appropriate in the given conditions and, if appropriate, asked the subjects to perform more trials with reduced levels of force. As a consequence, different subjects follow slightly different protocols and this does not allow the use of traditional statistical tools for the evaluation of the outcome. However, personalization of the treatment, in close cooperation with the human physical therapist, is a condition sine qua non for a successful employ of the “robotic therapist”. Moreover, it is also ethically unacceptable to force on all the subjects the same protocol, which may be too demanding for some subjects and insufficient for others and may vary in different training sessions, because these patients are persons, not experimental animals, and the chosen experimental conditions must aim at maximizing their physical/psychological benefit.

Tables II, III, IV summarize the sequence of trials adopted for the different subjects in the different training sessions. Tables V, VI, VII show two performance indicators (the reaching time T to the C-targets and the residual error E after the first sub-movement) in a representative subset of the trials for the three subjects.

Alternating OE and CE trials was well accepted by the subjects, although they reacted in a different way, in particular in the early phase of training: subject 1 performed better without vision, whereas subject 3 exhibited the opposite behavior and in subject 2 the performance was about the same. In the later training phases the OE/CE difference was attenuated and this is clearly a positive clinical sign, because it means that an effect of training is also a recalibration of the sensory channels that are crucial for carrying out purposive motor actions. In any case, it is remarkable the subject were indeed capable to operate at all only on the basis of proprioceptive cues.
The tables also show that subject 1 had more difficulty to carry out movements to the left part of the workspace, whereas subject 2 and 3 had more difficulty in the right part. Such direction-dependent disuniformity tends to be reduced during the training, clearly another positive clinical sign. Figure 8 shows, for the three subject, the variation of the reaching time, as a function of the number of training session, for the same level of force level (9 N).

IV. DISCUSSION

The first topic we wish to address in this section is related to the choice between impedance and admittance control.
In the impedance control paradigm, the robot operates as a “force generator” (by using the direct current drive of the motors) and this force can either resist or assist the movement of the user as a function of the movement kinematics. In order to work properly, the intrinsic mechanical impedance of the impedance-controlled manipulandum (in particular the intrinsic inertial and frictional forces) must be very small and this requires a very careful mechanical design and a direct coupling of the motors to the mechanical linkage, thus allowing an intrinsic back-drivability of the system.

In the admittance control paradigm, the robot operates as a “displacement generator” (by using a suitable feedback positional controller) and the desired displacements can be made dependent upon the interaction force measured by a force sensor mounted in the handle. In this case, there is no specific need of a small intrinsic mechanical impedance of the manipulandum and in fact a typical solution is to use a Cartesian structure with a ball screw connection to the motors that is typically non back-drivable and may have a rather large inertia and friction.

The admittance control scheme is clearly simpler and is very well suited for interaction paradigms that are compatible with the intrinsic positional control mechanism, for example with a rehabilitation approach which relies on passive motions of the joints. However, this is of no clinical relevance for the category of patients that were considered in this pilot study. The type of haptic targets that were used in the study cannot be implemented in an acceptable way (i.e. guaranteeing stability and low levels of noise) in an admittance control scheme with a non back-drivable manipulandum. Therefore, the technical solution that is mandated by this kind of robot therapy is impedance-control with back-drivable manipulandum characterized by a very low level of the intrinsic mechanical impedance.

The second topic that we address is the type of robotic intervention (assistive vs. resistive). In the study by Stein et al [2], a comparison is made between the improvements of performance that can be obtained by means of progressive resistive training vs. active-assisted robot-aided exercises. In that study, which only includes subjects who are able to execute reaching movements in all directions without robot intervention, the difference between the two protocols does not appear to be significant. On the other hand, the study by Patton et al [5] suggests a different message. In that study, which addressed a similar category of patients, the authors were interested to see if hemiparetic patients retained the ability of healthy controls to adapt to curvy, velocity dependent force fields. In fact, they found that subjects could adapt, as evidenced by significant after effects that were not correlated with the clinical scores. This supports the assumption that the fundamental neural plasticity that characterizes normals is preserved in these subjects, a prerequisite for designing successful rehabilitation paradigms. They also found that significant improvements occurred only when the training forces magnified the original errors, and not when the training forces reduced the errors or were zero. This suggests that error-enhancing therapy (as opposed to guiding the limb closer to the correct path) to be more effective than therapy that assisted the subject. However, both studies do not pay sufficient attention to the level of assistive forces. It is clear, indeed, that if assistance is too large it is equivalent to force passive movements on the patients.

In any case, the reported findings may be relevant for the further development of the pilot study if we succeed to transfer the improvements due to the robotic training into functional improvements related to the activities of daily life. For our category of patients this requires a careful integration of robotic and human therapy. Moreover, the study supports the working hypothesis of using a minimal assistive intervention in the initial phase of training. Among the many open questions is the critical role of proprioception. Our patients, although severely impaired, exhibited a degree of proprioceptive competence and their performance was characterized by a significant capability to learn. Is this plasticity still available if the proprioceptive channel is ineffective?

REFERENCES

Table I: subject data

<table>
<thead>
<tr>
<th>Age (s)</th>
<th>Sex</th>
<th>Months</th>
<th>post-injury</th>
<th>Affected hand</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>F-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>57</td>
<td>M</td>
<td>42</td>
<td>L</td>
<td>170</td>
<td>74</td>
<td>11</td>
</tr>
<tr>
<td>S2</td>
<td>30</td>
<td>F</td>
<td>13</td>
<td>L</td>
<td>168</td>
<td>61</td>
<td>11</td>
</tr>
<tr>
<td>S3</td>
<td>34</td>
<td>F</td>
<td>23</td>
<td>R</td>
<td>179</td>
<td>72</td>
<td>11</td>
</tr>
</tbody>
</table>

OE/CE: Open/Closed Eyes; Fxx: force level (N); T: reaching time

OE E 15.4 10.9 5.8 2.4 3.4 3.2 2.6
OE E 22.3 15.8 11.9 11.4 7.6 5.9 4.7
OE E 13.2 9.8 6.9 7.9 7.3 8.0 6.4
OE E 1.0 4.3 4.1 4.6 5.3 5.1 6.8
OE E 3.8 3.6 3.0 3.1 5.8 6.0 15.0
OE E 3.6 4.7 4.4 3.6 4.2 4.7 6.4
OE E 7.8 6.0 6.6 5.4 8.5 9.5 9.9
OE E 2.9 5.2 4.8 5.3 5.2 5.9 6.0
OE E 6.0 4.8 4.3 6.0 11.5 15.8 30.0
OE E 3.8 1.4 4.0 5.0 6.0 5.9 7.3
OE E 3.7 7.4 4.8 5.9 8.9 10.3 30.5
OE E 0.2 2.3 4.8 5.0 6.0 7.4 10.3
OE E 1.2 2.3 1.4 1.8 2.7 4.8 5.4
OE E 0.9 1.1 0.5 1.7 1.8 1.7 4.8
OE E 1.3 1.3 1.3 2.5 3.0 2.9 6.2
OE E 1.0 0.6 0.4 2.5 2.3 1.6 2.1
OE E 2.6 4.0 2.3 4.3 3.2 5.8 9.7
OE E 1.8 1.7 2.4 4.5 1.7 4.4 7.4
OE E 2.8 2.8 2.5 6.8 3.1 3.3 13.1
OE E 1.8 2.3 2.2 4.3 2.2 0.3 2.1
OE E 5.6 2.7 2.6 2.3 3.5 3.4 8.7
OE E 2.8 2.1 0.4 0.4 0.3 4.1 7.4

Table II: Subject 1: Trials for each training session (TS)

<table>
<thead>
<tr>
<th>TS</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F15</td>
<td>F15</td>
<td>F12</td>
<td>F12</td>
<td>F12</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
</tr>
<tr>
<td>2</td>
<td>F15</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
</tr>
<tr>
<td>3</td>
<td>F15</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
</tr>
<tr>
<td>5</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
</tr>
<tr>
<td>7</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
</tr>
</tbody>
</table>

Table III: Subject 2: Trials for each training session

<table>
<thead>
<tr>
<th>TS</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
</tr>
<tr>
<td>2</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
</tr>
<tr>
<td>3</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
</tr>
<tr>
<td>4</td>
<td>F9</td>
<td>F9</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
</tr>
<tr>
<td>5</td>
<td>F9</td>
<td>F9</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
</tr>
<tr>
<td>6</td>
<td>F9</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F6</td>
<td>F5</td>
<td>F5</td>
<td>F5</td>
</tr>
</tbody>
</table>

Table IV: Subject 3: Trials for each training session

<table>
<thead>
<tr>
<th>TS</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
<th>OE</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F8</td>
<td>F8</td>
</tr>
<tr>
<td>2</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F8</td>
<td>F8</td>
</tr>
<tr>
<td>3</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F8</td>
<td>F8</td>
</tr>
<tr>
<td>4</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F8</td>
<td>F8</td>
</tr>
<tr>
<td>5</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F8</td>
<td>F8</td>
</tr>
<tr>
<td>6</td>
<td>F12</td>
<td>F12</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F9</td>
<td>F8</td>
<td>F8</td>
</tr>
</tbody>
</table>

Table V: Subject 1. TG (1-7): targets in the C layer; OE/CE: Open/Closed Eyes; Fxx: force level (N); T: reaching time (s); E: residual error after the first sub-movement (cm)

<table>
<thead>
<tr>
<th>TS</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
<th>OE</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG 1</td>
<td>T</td>
<td>32.1</td>
<td>20.8</td>
<td>14.4</td>
<td>16.0</td>
<td>16.0</td>
<td>13.1</td>
<td>13.6</td>
<td>T</td>
<td>13.2</td>
<td>9.8</td>
<td>6.9</td>
<td>7.9</td>
<td>7.3</td>
<td>8.0</td>
<td>6.4</td>
<td>T</td>
<td>1.0</td>
</tr>
<tr>
<td>TG 2</td>
<td>E</td>
<td>6.7</td>
<td>6.6</td>
<td>5.3</td>
<td>5.3</td>
<td>3.8</td>
<td>5.9</td>
<td>4.6</td>
<td>T</td>
<td>39.9</td>
<td>14.7</td>
<td>15.4</td>
<td>13.0</td>
<td>15.7</td>
<td>10.8</td>
<td>5.3</td>
<td>T</td>
<td>22.3</td>
</tr>
<tr>
<td>TG 3</td>
<td>E</td>
<td>13.1</td>
<td>10.0</td>
<td>5.2</td>
<td>0.7</td>
<td>3.4</td>
<td>5.4</td>
<td>2.6</td>
<td>T</td>
<td>9.5</td>
<td>6.6</td>
<td>4.9</td>
<td>3.9</td>
<td>5.0</td>
<td>6.3</td>
<td>5.4</td>
<td>T</td>
<td>15.4</td>
</tr>
<tr>
<td>TG 4</td>
<td>E</td>
<td>29.7</td>
<td>6.1</td>
<td>13.1</td>
<td>8.5</td>
<td>7.6</td>
<td>8.6</td>
<td>8.2</td>
<td>T</td>
<td>12.5</td>
<td>7.1</td>
<td>13.0</td>
<td>7.9</td>
<td>6.8</td>
<td>6.3</td>
<td>5.4</td>
<td>T</td>
<td>36.0</td>
</tr>
<tr>
<td>TG 5</td>
<td>E</td>
<td>8.2</td>
<td>9.0</td>
<td>6.6</td>
<td>4.3</td>
<td>3.8</td>
<td>4.1</td>
<td>3.9</td>
<td>T</td>
<td>15.7</td>
<td>11.1</td>
<td>6.2</td>
<td>1.3</td>
<td>3.3</td>
<td>1.9</td>
<td>2.8</td>
<td>T</td>
<td>9.5</td>
</tr>
<tr>
<td>TG 6</td>
<td>E</td>
<td>15.4</td>
<td>10.9</td>
<td>5.8</td>
<td>2.4</td>
<td>3.4</td>
<td>3.2</td>
<td>2.6</td>
<td>T</td>
<td>8.2</td>
<td>9.0</td>
<td>6.6</td>
<td>4.3</td>
<td>3.8</td>
<td>4.1</td>
<td>3.9</td>
<td>T</td>
<td>15.7</td>
</tr>
<tr>
<td>TG 7</td>
<td>E</td>
<td>12.5</td>
<td>7.1</td>
<td>13.0</td>
<td>7.9</td>
<td>6.8</td>
<td>6.3</td>
<td>5.4</td>
<td>T</td>
<td>36.0</td>
<td>5.0</td>
<td>14.0</td>
<td>5.0</td>
<td>4.5</td>
<td>3.8</td>
<td>5.0</td>
<td>T</td>
<td>8.2</td>
</tr>
</tbody>
</table>