Does neuromuscular taping influence hand kinesiology? A pilot study on Down's Syndrome

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Introduction

In everyday activities we depend on signals coming from our moving bodies enabling us to respond to the space around us and to react rapidly in continuing changing circumstances (1). The information coming from the periphery contributes making us aware of our position and the movement of our limbs during any action: this feedback is necessary to adjust the posture and the trajectory of the part of the body that we are moving. This helps us during the execution of any particular preprogrammed task or to deal with unexpected variations or perturbations during a designated task.

One of the most important afferent information of the body is proprioception. During limb movements and postural changes, body tissues (such as skin, muscles, tendons, fascia, joint capsules and ligaments around the relevant joints involved in that action) are subject to deformations (1, 2). Different receptors capture the information concerning kinesthetia in a specific environment during the execution of a task, sending to the CNS afferent sensorial feedback signals providing a real-time description of the motion that we are performing. The so-called kinesthetic sensors include muscle spindles, skin and joint receptors and Golgi tendon organs. They are excited under different stimulations, providing the sense of kinesthesia.

An exhaustive review by Proske and Gandevia (1) reported that afferent signals coming from muscle spindles and skin receptors play a significant role in kinesthesia and they contribute to the sensation of movement and position perceived by the subject.

Muscle spindles constitute the intrafusal muscle fibers and they are embedded in extrafusal muscle fibers: when the extrafusal fibers are stretched, the muscle spindles give rise to afferent signals directed to the CNS, contributing to the proprioception sense.

Moreover, when movement is performed, the skin surface is deformed: this deformation is captured by the mechanoreceptors of the skin and sent to CNS, giving rise to afferent signals also contributing to proprioception.

There are literature debates on the key role played by muscle spindles and by skin receptors in kinesthesia: a previous work (3) showed also that, avoiding muscle spindles stimulation, the skin receptors can produce the perception of illusory movements using an adhesive tape at the elbow, indicating that the two kinds of receptors contribute with the same weight to change proprioception at distal joints. However, the contribution of skin receptors to positional sense at the most proximal joint is likely to be less important than the action coming from muscle spindles (1).

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Taking into account these relevant results documented in previous literature and studies which and focused on the sense of kinesthesia in normal subjects, as well as the importance of the kinesthetic afferent signals in the development and learning stage of motor control in a bottom-up approach (4), we focused our study on a pathology characterized by poor or missing sensorimotor integration mechanisms (5-7): the Down syndrome.

As literature extensively reported, a pervasive feature of motor skill performance in Down Syndrome (DS) subjects is "clumsiness", which commonly implies an ample set of movement characteristics, such as slow movements with unusual and less efficient coordination patterns, high rates of failure (8, 9), slower reaction times (10), reduced muscle tone and higher ligament laxity (11, 12), poorer control of timing and difficulty to modulate actions under changing task conditions (13-16) and changing sensory information (14, 16, 17). Recent literature on DS pointed out that clumsiness might be mainly a product of different sensorial integration, more than a product of biomechanical constraints due to the typical features of this syndrome (7, 18). Frith and Frith (19) attributed motor clumsiness to a general deficit in developing motor programing. Other authors have attributed these changes to more specific impairments of somatosensory function (20), decision making processes (21) or timing of motor sequences (22, 20). Since appropriate proprioceptive information is of fundamental importance to the preparation and for correct execution of movements, the lack of elaboration of feedback signals could be responsible for the poorer capacity of movement organization and coordination that subjects with DS show when carrying out complex motor tasks.

Moreover in every learning stage, the impairments the peripheral level could alter the afferent signals, giving rise to a different proprioception and consequently to a modified development of motor strategies.

In this sense, biomechanical aspects have been recently linked to the specific sensory, motor, cognitive and perceptual impairments of DS, but it remains unclear how these localized deficits impact on perceptual-motor processing and function (18, 20, 23, 24).

Understanding the mechanisms of these alterations, that could generate different afferent signals and consequently modify the development of usual motor pathways, becomes fundamental in order to modify, in a rehabilitative context, the motor potentiality and the possibility to obtain relevant benefits for a more focused treatment. For example, DS, as previously reported, are characterized by hypotonia and ligament laxity: the muscle spindles and the Golgi tendon receptors could have different threshold excitability resulting in delayed activation or neural silence. In this case, the perception relies on other afferent signals that could become more important and could probably contribute to the changes observed in acquired motor schemes.

Given the importance of proprioception in motor control, we arranged our work in order to analyse if modification of a proprioceptive signal, through the application of Neuromuscular Taping (NMT), could generate a modification in motor behaviour.

In our pilot study we analysed the movement during a drawing test in 5 participants with DS pre and post the application of NMT. The small number of cases studied will not produce significant statistical verification but will indicate a tendancy that may be further studied with a larger case group.

Over the last 5 years in Europe, proprioceptive NMT technique has become a mainstream treatment protocol in post-operative, oncological, neurological care of patients as well in sports medicine (25).

This innovative NMT application is based on eccentric stimulation of the skin, muscle tissue, tendons, neurological vessels, lymphatic and vascular pathways improving their functioning. NMT provides passive stretching through the application of a tape creating eccentrical stimulation encouraging flexibility and coordination and bettering range of movement (26). It has been claimed that the effects are possibly due to modifications of the sensorimotor and proprioceptive feedback mechanisms. It has been hypothesized that the application of NMT is able to stimulate or activate cutaneous mechanoceptors.

Given the known background on the kinesthetic sense and on the sensorimotor deficits in DS, the aim of this pilot study is to use motion analysis approach to quantify the alterations in a drawing test induced by the application of NMT: the drawing test permitted the participants to focus their attention on a distal joint, in which the contribution of skin receptors in kinesthesia assumes major relevance, as previously mentioned.

Materials and methods

Subjects

5 participants with DS (5DS) were enrolled for this study: the subjects and their legal guardians gave their informed written consent to the study. The study was approved by the ethical committee in accordance with the ethical principles of the Declaration of Helsinki.

The chronological mean age was 21 ± 3.81 years old. The inclusion criteria for DS were a regular school frequency and education, no orthopaedic problems that could restrict upper limbs motion, low to medium intelligence quotient (IQ) and no clinical sign of dementia.

Information and data for the 5 DS participants were collected pre and post NMT application.

This information was compared with the data acquired from two other DS groups: a pathological group (DSG) composed of 23 participants with DS (mean age 14.9 ± 4.6) and a control group (CG) composed of 13 healthy subjects (mean age 9.0 ± 2.1 years old), that underwent the same protocol baseline acquisition.

Treatment

The tape was applied in a particular way that characterized the NMT application with the aim to raise the skin in a wave, amplifying the stretching/contraction effect of the skin itself during movement.

NMT was applied by the same physical therapist over the cervical spine bilaterally, over the shoulder and over the extensors of the hand and fingers on the same dominant writing side (Fig. 1).

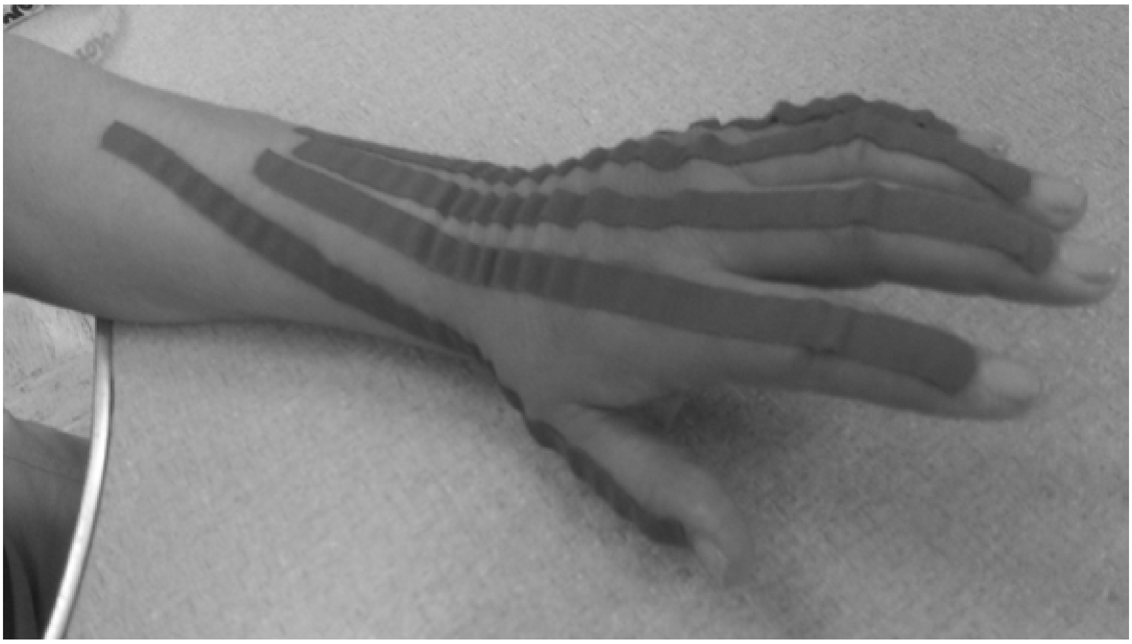

Fig. 1. An example of NMT application on dorsal hand of a DS participant aimed to rise the skin in a wave, amplifying the stretching/contraction effect of the skin itself.

The cervical applications were bilateral (cervical spine standard treatment protocol) and consisted of four tapes of 20 cm in length and 1.25 cm width applied laterally to the spine from the hair line in the occipital area to the 4° thoracic vertebra with the patient maintaining an anterior head flexion at 45° in a sitting position; each tape is applied with 0% tension over the skin in a stretched position. While for the shoulder (double fan shoulder decompression standard treatment protocol) the application was made using two tapes, 25cm in length cut into a fan cut with 5 strips each 1cm wide, applying the anterior fan over the anterior segment of the shoulder and brachial plexus with the upper limb and shoulder in extension (posterior) and external rotation while the posterior fan applied over the posterior segment of the shoulder and brachial plexus with the upper limb in flexion and internally rotated, both applications are applied with 0% tension to the tape over the skin in a stretched position. The hand extensors application (standard hand extensors protocol) was applied with five tapes cut 25cm in length and 1cm in width applied over the dorsal aspect of the fingers, hand and forearm with the hand fisted and wrist in a flexed position; each tape is applied with 0% tension over the skin in a stretched position (27, 28). The NMT was applied constantly and changed every 3 days by the same physiotherapist for total 5 applications; the patient was invited to normally move during this period without changing their habits. No additional rehabilitative treatment was done during this period.

The motion analysis acquisition was conducted at the time of enrolment before the application of NMT and was repeated at the end of the treatment cycle (two weeks for a total of 5 applications)

Methods

The graphic gesture was acquired with an optoelectronic system (acquisition frequency was set at 200Hz) equipped with six cameras (SMART-D BTS; Italy) and with an integrated video system (Vixta, BTS, Italy) for video-recording. The optoelectronic system is an instrument that measures the 3D coordinates (X, Y, Z) of reflective markers through time. The markers were of diameter=10mm and were used in the configurations described in the work by Ancillao and colleagues (29).

The participants are seated comfortably on an adjustable chair, in front of a desk. Their height respect to the desk was regulated to allow easy and comfortable drawing. They were given a paper sheet with a printed figure (a circle, an equilateral cross and a square) and were asked to “copy the illustrated figure” with their dominant hand. The figures were presented one per time. After drawing the first figure, the child was presented with the second and then with the third. Three acquisitions (one for each drawing) were recorded for each child. Children were given a modified ink pen with markers on the cap that allowed the reconstruction of the trace drawn by the children.

The pen tip coordinates were reconstructed (Pen tip reconstructed) and it was possible to obtain the digitalized drawing trace (i.e., the drawn figure) and the trace of the pen lifts.

Markers were also put on the body of the subject. Landmarks on the body were chosen in order to minimize the effect of the skin artefacts. In particular, markers were put on the head, shoulders, trunk, elbow, wrist and hand on the side of hand dominance.

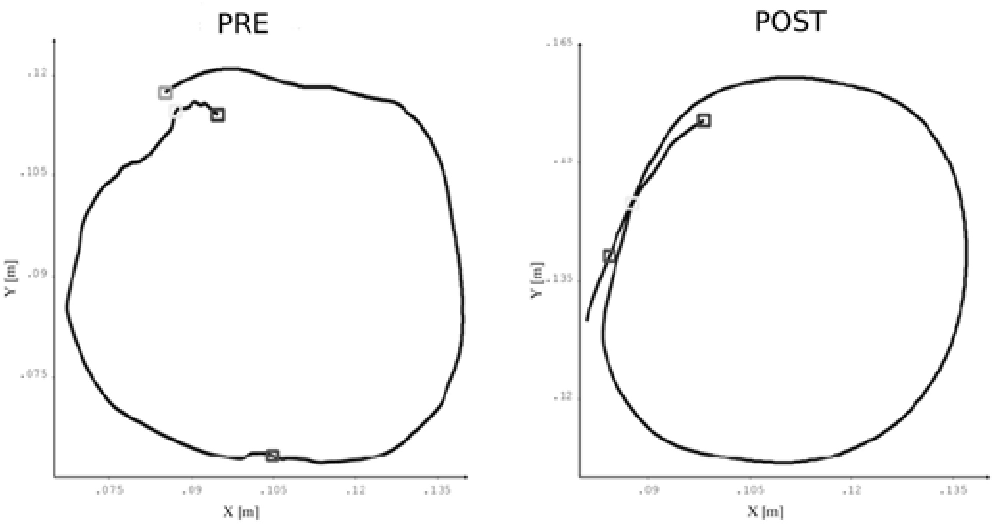

Fig. 2. An example of circle drawing test captured with motion system in PRE (left side) and POST (right side) session for a particicipant with DS.

The drawing test was acquired in two different session for the 5DS: PRE and POST NMT application (Fig. 2).

Parameters

After reconstructing the 3D coordinates of the markers, the following parameters were computed. To characterize the position of the subject's head during the drawing, the maximum and minimum projections of the central head marker on the table were computed and the difference between these two values was named head-table distance (H-T dist) (m), documenting the view of the participants focused on the copying sheet and consequently his reliance on proprioception during drawing.

To characterize the movement of the upper limb, the elbow angle was defined as the acute angle between the markers positioned on the shoulder, elbow and wrist. The wrist angle was defined as the acute angle between the markers positioned on the elbow, wrist and hand. The ranges of motion (ROMs) of these two angles were computed from the coordinates of the external markers.

To characterize the drawing traces of the different figures the following parameters were calculated.

Circle drawing

The drawing features of the circle were characterized by:

- length of the drawing track (Length) (cm), drawing time (Time) (s) and drawing mean velocity (MeanVel) (cm/s);
- horizontal and vertical diameters lengths (H_Dm, V_Dm) (cm);
- Drawing accuracy was evaluated by the parameter of eccentricity (Ecc) (1):

$$Ecc=\left|1\quad\frac{V\_Dm}{H\_Dm}\right|(1)$$

The more the drawn figure is close to a perfect circle, the more the parameter approaches a 0 value.

Cross drawing

The drawing features of the cross were characterized by:

- drawing time (Time) (s) and drawing vertical and horizontal meanvelocity (Mean VVeland Mean HVel) (cm/s);
- length of the horizontal and vertical sides (H_side, V_side) (cm);
- Drawing accuracy was evaluated by the cross side error parameter(side-ɛ), chosen to assess the tendency to draw irregular cross bars (2):

$$side\_\quad=\left|1\quad\frac{H\_Side}{V\_Side}\right|(2)$$

The closer the value is to 0, the more precise is the drawing, i.e. the sides have more similar lengths(equilateral cross);

Square drawing

The drawing features of the square were characterized by:

- drawing time (Time) (s);
- length of the upper, lower, left and right sides (S1, S2, S3, S4) (cm);

Drawing accuracy was evaluated by two parameters, chosen to assess the tendency to draw an irregular polygon:

square sides error (s- ε) (cm) (3):

$$s\quad=\left|S1\quad S2\right|+\left|S3\quad S4\right|(3)$$

The closer the value is to 0, the more precise is the drawing, i.e. the sides have more similar lengths.

square to rectangle error (str-**ε**) (4):

$$str \quad = \left|1 \quad \frac{W}{H}\right| (4)$$

where W is the square's width, calculated as Max (S1, S2) and H is the square's height, calculated as Max (S3, S4). The closer the parameter is to 0, the closer the drawing is to a square.

These parameters were chosen to assess the tendency to draw irregular parallelepiped rather than squares.

Statistics

Data was collected for each subject and tabulated in order to compare overall results from PRE and POST treatment conditions and to compare the previously analysed DS and CG group. The median, 25° and 75° percentile values and parameter were computed for each group. The non-parametrical Mann-Whitney U-test was used to verify the presence of statistically significant differences between the PRE and POST conditions versus DSG and CG groups.

The non-parametrical Kruskall-Wallis test was used to verify the presence of statistically significant differences between the PRE and POST conditions in 5DS. Differences were considered significant at a p-value<0.05.

Results

Table 1 presents the statistical differences in this pilot study for drawing kinematics and drawing accuracy in 5DS in PRE and POST NMT treatment, together with DSG and CG subjects.

As presented in table 1 for circle drawing there are no differences between 5DS PRE and DSG: the differences reported between DSG and CG represented the drawing characterization by the DS pathology. The DS participants in general are characterized by higher value of mean velocity: in the treatment group after three weeks of NMT application, even though not statistically significant, the 5DS POST showed a mean velocity reduction, closer to CG data. Moreover, the H-T dist evidenced no statistical difference between 5DS POST and CG, while there is statistical difference between 5DS PRE compared to CG.

Concerning the cross drawing, the comparison between PRE and POST condition pointed out statistical differences in time, mean vertical velocity and H-T dist, with values closer to CG for POST condition. Also in this test the H-T dist presented higher values in POST condition.

As reported in Table 1, no statistical differences between PRE and POST condition were found in the squared test.

*Table 1. Median (25° percentile, 75° percentile) values for the drawing features and drawing accuracy parameters for the 5DS in PRE and POST conditions, and DSG and CG groups. (p-value<0.05: *DSG vs CG; + 5DS PRE vs 5DS POST; § 5DS PRE vs DSG; ° 5DS POST vs DSG; ^ 5DS PRE vs CG; # 5DS POST vs CG).*

	5DS PRE	**5DS POST**	**DSG**	**CG**	
Parameter	**Median (25°, 75°)**	**Median (25°, 75°)**	**Median (25°, 75°)**	**Median (25°,75°)**	**p**
	Circle drawing				
Time (s)	4.93 (2.66,5.4)	3.97 (2.94,5.52)	2.92 (2.11,5.70)	6.48 (5.12,9.07)	^*#
Mean Vel (cm/s)	3.20 (2.40,4.20)	2.80 (2.30,2.90)	4.20 (3.20,5.70)	1.90 (1.67,2.65)	*
H-T dist (cm)	1.60 (0.50,1.60)	2.30 (1.40,2.50)	1.55 (1.00,2.22)	2.95 (2.62,7.83)	^*
	Cross drawing				
Time (s)	3.54 (2.88,3.76)	4.89 (3.75,4.92)	3.31 (2.07,4.88)	6.66 (4.94,8.35)	+*
Mean VVel (cm/s)	4.10 (3.70,4.90)	3.50 (3.10,3.70)	4.40 (2.80,6.73)	2.50 (1.70,3.25)	+*
H_side (cm)	7.10 (5.80,7.70)	5.80 (3.80,7.30)	4.15 (2.77,5.00)	5.85 (5.05,6.40)	*§
V_side (cm)	7.50 (7.20,8.10)	7.70 (6.70,8.10)	5.60 (4.50,6.52)	6.05 (5.35,6.50)	^§°
s_ε	0.21 (0.04,0.45)	0.053 (0.04,0.72)	0.26 (0.12,0.39)	0.15 (0.07,0.19)	*
H-T dist (cm)	1.20 (1.00,1.70)	3.30 (2.50,4.50)	1.10 (1.00,3.00)	4.55 (2.55,7.00)	+^*
	Squaredrawing				
Time (s)	7.53 (5.73,8.64)	11.9 (8.99,12.60)	7.87 (4.68,12.53)	10.01 (9.14,11.9)	+
S1 (cm)	6.70 (5.60,6.80)	6.85 (5.07,8.93)	4.50 (4.05,5.58)	4.60 (4.40,5.00)	^§
S3 (cm)	5.30 (4.00,7.60)	5.80 (5.00,6.60)	4.95 (4.05,5.90)	4.10 (3.80,4.50)	*
S4 (cm)	5.50 (3.80,6.50)	6.00 (05.70,7.30)	5.30 (4.43,5.75)	4.40 (4.20,4.80)	*
s_ε	0.01 (0.01,0.02)	0.01 (0.00,0.04)	0.01 (0.01,0.02)	0.00 (0.00,0.01)	*
str_ε	0.15 (0.14,0.33)	0.33 (0.33,0.45)	0.21 (0.11,0.23)	0.06 (0.01,0.11)	#*

Discussion

During every day activities our body completes many actions without the awareness of the mechanisms that are being activated for the correct execution of a particular gesture.

The process of voluntary movement begins with the intention to move, leading to motor command generation and its efference copy: that copy takes into account both motor and sensory signals cemented in the past experience of doing that particular action. Motor and sensory signals, learned and optimized, compose the movement strategy for the execution of a particular task: the way in which the different submovements are coordinated to finalize the action and the predicted sensory signals creates the final precise gesture. The forward model uses the efference copy to compute the expected outcome o outcomes, and, during the performance, the expected outcomes are compared with the real-time input (feedback circuit), generated by all the reafferent signals coming from the periphery (with or without awareness). Hence the capacity to quantify the discrepancy between what we planned and what we were really executing. In term of sensory signals, this discrepancy determines what we perceive (1, 30).

The underlying idea of the sensory model proposed by Bays and Wolpert (30) is that we perceived the sensory discrepancy alone. Therefore, based on that model, if the predicted and actual sensory feedback match, no sensation rises and the entire forward model for that type of task remains unchanged. Otherwise if the sensory discrepancy persists during the execution of a task, the forward model needs to be regularly updated over both short and long time scales (1).

The application of the NMT probably produces an external influence that should provoke a sensory discrepancy, as the difference between the predicted sensory signals, which normally accompany a specific task, and the actual sensory signals, coming from periphery during the task. The sensory discrepancy should arise and the plan of the movement should undergo an altered change in order to modify and reduce that discrepancy. In this way the subject could probably update the forward model shaping it according to the new sensory feedback created by the NMT taping in decompression and with eccentric properties: this change in the forward model of the sensory system could imply a modification also in the forward models for physiological motor control.

In any learned motor task, we carry out the action without thinking about it, unaware of its predictability. But the term “learned” implies that there is a learning stage to the task where feedback is used to fine-tune its execution (1).

As previously reported, the application of NMT lasted for three weeks (each application reapplied 5 times during the 3 week session) in which the five analysed subjects carried out all the everyday activitiese could hypothesise that the sensory discrepancy introduced by the “new” sensorial signals, produced by the Neuromuscular Taping, coming from the stimulated skin receptors should gradually decrease while supported by the learning stage of the induced change in sensory efference copy. Considering our everyday behaviors, we should imagine constantly shifting strategies in the coordination of internally generated actions to actions dominated by feedback from the periphery (1). Reducing that sensory discrepancy should imply changing of the forward models for physiological motor control. The data recorded at the end of the three weeks support this hypothesis: the documented higher values of H-T dist are linked to a higher reliance on visual attention on copying sheet and consequently more reliance on proprioceptive signal on the drawing sheet during the trials.

Limits of this pilot study are the limited number of treated DS participants. Future studies will be enlarged to cater for a sigfnificant subject group also dividing the DS participants in two subgroups testing also placebo effects. Moreover, we could introduce modifications to the motion capture system acquisition protocol in order to better control other variables such as eye movements.

The results from this pilot study further opens discussion concerning the proprioception signal in a pathological context: as reported, feedback signals are used to fine tune the execution of a particular task in a learning stage. This feedback assumes a critical role in the bottom up theory: modifying the signal coming from periphery could alter motor pathways and consequently map the motor cortex in an alternate or different way.

Moreover, it is of interest to underline the role of movement in Down syndrome. Understanding the different proprioceptive signals arising in kinesthesia will consequently able us to better reorganise and focus rehabilitative programs. Directly acting on feedback signals could influence indirectly forward models for physiological motor control.

Declaration of Interest

The authors declare that no commercial, or financial conflict of interest exists for any of them, in connection with the submission of the present draft. The authors alone are responsible for the content and writing of this paper.

References

1. Proske U, Gandevia SC. The proprioceptive senses: their role in signaling body shape, body position and movement, and muscle force. Physiol Rev2012; 92:1651-97
2. Grigg P. Peripheral neural mechanisms in proprioception. Journal of Sport R ehabilitation 1994; 3:2–17
3. Collins DF, Refshauge KM, Todd G, Gandevia SC. Cutaneous receptors contribute to kinesthesia at the index finger, elbow, and knee. J Neurophysiology 2005; 94:1699–706
4. Avanzino L, Pelosin E, Abbruzzese G, Bassolino M, Pozzo T, Bove M. Shaping motor cortex plasticity through proprioception. Cerebral Cortex 2013; doi: 10.1093
5. Latash ML, Almeida GL, Corcos DM. Preprogrammed reactions in individuals with Down syndrome: the effects of instruction and predictability of the perturbation. Arch Physical Med Rehab 1993; 74:391-9
6. Almeida GL, Corcos DM, Latash ML. Practice and transfer effects during fast single-joint elbow movements in individuals with Down syndrome. Physical Therapy 1994; 74:1000-12

7. Latash ML. Learning motor synergies by persons with Down syndrome. Journal of IntellectDisabil Res 2007; 51:962-71
8. Rigoldi C, Galli M, Albertini G. Gait development during lifespan in subjects with Down syndrome. Res Developm Disabilities 2011; 32:158-63
9. Galli M, Cimolin V, Patti P, et al. Quantifying established clinical assessment measures using 3D-movement analysis in individuals with Down syndrome. Disability & Rehabilitation 2010; 32:1768-74
10. Anson JG. Down syndrome: neuromotor programming and fractionated reaction time. In: Latash, ML (Eds.), Motor Control in Down Syndrome 1989; 6-ll
11. Morris AF, Vaughan SE, Vaccaro P. Measurements of neuromuscular tone and strength in Down's syndrome children. J Mental Deficiency Res 1982; 26:41-6
12. Galli M, Rigoldi C, Brunner R, Virji-Babul N, Albertini G. Joint stiffness and gait pattern evaluation in children with Down syndrome. Gait & Posture 2008; 28:502-6
13. Cole KJ, Abbs JH, Turner GS. Deficits in the production of grip forces in Down syndrome. DevelopmMed Child Neurol 1988; 30:752-8
14. Shumway-Cook A, Woollacott MH. Dynamics of postural control in the child with Down syndrome. Physical Ther 1985; 65:1315-22
15. Davis WE, Kelso JA. Analysis of "invariant characteristics" in the motor control of down's syndrome and normal subjects. J Motor Behav1982; 14:194-12
16. Latash ML, Corcos DM. Kinematic and electromyographic characteristics of single-joint movements of individuals with Down syndrome. Am J Ment Retard 1991;96:189-201
17. Rigoldi C, Galli M, Mainardi L, et al. Postural control in children, teenagers and adults with Down syndrome. Res Developmental Disabil 2011; 32:170-5
18. Virji-Babul N, Brown M. Stepping over obstacles: anticipatory modifications in children with and without Down syndrome. Exp Brain Res 2004; 159:487-90
19. Frith U, Frith CD. Specific motor abilities in Down's syndrome. J Child Psychology and Psychiatry 1974; 15:293-301
20. Chiarenza GA, Stagi P. Neurophysiological correlates of perceptual-motor behavior in Down syndrome. In: Weeks, DJ, Chua, R, & Latash, ML (Eds.), Perceptual-motor behavior in Down syndrome. Champaign: Human Kinetics; 2000; 321-47
21. Almeida GL, Corcos DM, Hasan Z. Horizontal-plane arm movements with direction reversals performed by normal individuals and individuals with Down syndrome. J Neurophysiology 2000; 84:1949-60
22. Henderson SE, Illingworth SM, Allen J. Prolongation of simple manual and vocal reaction times in Down syndrome. Adapted Physical Activity Quarterly 1991; 8:234-41
23. Vimercati SL, Galli M, Rigoldi C, et al. Obstacle avoidance in Down syndrome. J Electromyogr Kines 2013; 23:483-9
24. Vimercati SL, Galli M, Rigoldi C, et al. Motor strategies and motor programs during an arm tapping task in adults with Down Syndrome. ExpBrain Res 2013; 225:333-8
25. Costantino C, Licari O, Granella F, Sghedoni S. Neuromuscular taping in multiple sclerosis: A pilot study. Acta Biomedica 2012; 83:103–7
26. Camerota F, Galli M, Cimolin V, Celletti C, Ancillao A, Blow D, Albertini, G. Neuromuscular taping for the upper limb in Cerebral Palsy: A case study in a patient with hemiplegia. Develop Neurorehabil 2013; DOI: 10.3109/17518423.2013.830152
27. Blow D. NeuroMuscular Taping: From Theory to Practice. Milano: Edi Ermes. 2012
28. Blow D. (Taping NeuroMuscolare trattamento delle edemi, ematomi e cicatrice. Milano: Edi Ermes, 2013
29. Ancillao A, Galli M, Vimercati SL, et al. An optoelectronic based approach for handwriting capture. Computer Meth Programs Biomed 2013; 111:357-65
30. Bays PM, Wolpert DM. Computational principles of sensorimotor control that minimize uncertainty and variability. J Physiology 2007; 578:387–96