Effectiveness of Three-Dimensional Kinematic Biofeedback on the Performance of Scapula-focused Exercises

Ana Antunes[1], Inês Filipe[1], Sara Cordeiro[1], Joana Rosa[1], Filomena Carnide[1] and Ricardo Matias[1,2,3]
[1]*Neuromechanics of Human Movement Research,*
Group of the Interdisciplinary Centre for the Study of Human Performance, University of Lisbon, Lisbon, Portugal
[2]*School of Healthcare, Setúbal Polytechnic Institute, Campus do IPS, Estefanilha - Edifício da ESCE, Setúbal, Portugal*
[3]*Pattern and Image Analysis Group of the Instituto de Telecomunicações, Instituto Superior Técnico,*
University of Lisbon, Lisbon, Portugal

Keywords: Biofeedback, Scapulothoracic Stability, Motor Relearning, Physiotherapy.

Abstract: Three-dimensional (3D) kinematic biofeedback can help identify scapular movement disorders and assist the subjects' motor relearning process by facilitating changes in physiological and biomechanical function through real-time knowledge of performance and result during or immediately after a task execution. This study assessed the effectiveness of 3D kinematic biofeedback on the quality of the scapula-focused exercises execution, and motor learning transfer during shoulder flexion and a daily activity. Thirty healthy adults with no history of shoulder pain or dysfunction were randomly distributed into two groups. Skin-mounted sensors allowed tracking of the thorax, scapula and humerus, and scapulothoracic and glenohumeral 3D angles were computed after reconstructing upper-extremity motions during daily activities and exercises for different phases of a motor relearning process. The results of this study demonstrate that the execution quality of scapula-focused exercises benefits of real-time 3D kinematic biofeedback and that transfer of learning occurs with a specific motor training intervention.

1 INTRODUCTION

Shoulder pain and dysfunction are among the most frequent problems of patients with mechanical musculoskeletal disorders seeking health professionals (e.g. Physical therapists), which usually affect functional ability and life quality, resulting in a significant economic impact (Cunha-Miranda *et al.*, 2010).

Scapular dysfunction (or dyskinesis) seems to be a common denominator across the most prevalent shoulder dysfunctions. Although a consistent body of literature addresses how shoulder impingement symptoms are affected by scapular dysfunction, the role of the latter is not clearly defined in creating or exacerbating shoulder dysfunctions (Kibler *et al.*, 2013; Struyf *et al.*, 2013). Potential biomechanical contributors have been divided into two main groups: musculoskeletal alterations at rest (postural) and movement alterations (dynamic); such as pain, soft tissue tightness, muscle dynamics, muscle strength imbalances and fatigue, and thoracic posture (Michener *et al.*, 2003).

Some emerging evidence suggests that a scapula-focused treatment is effective to restore an accurate scapular motion and stability, considered essential for a normal shoulder function (Hanratty *et al.*, 2012; Kibler *et al.*, 2013; Struyf *et al.*, 2013). The conclusions on the effectiveness of exercise in the treatment of people with shoulder dysfunctions are challenged by the heterogeneity of the exercise interventions. Still, it has been extensively accepted the assumption that these patients need to go through a motor relearning process such as the proposed by Fitts and Posner (1967). Real-time biofeedback has been used to enhance the learning ability of an individual (Holtermann *et al.*, 2008). 3D kinematic biofeedback is a valid method that can reliably identify scapular movement disorders (Tate *et al.*, 2009) and can facilitate the physiological and biomechanical function through the reception of feedback information in real-time during or immediately after a task (Vedsted *et al.*, 2011).

Antunes A., Filipe I., Cordeiro S., Rosa J., Carnide F. and Matias R..
Effectiveness of Three-Dimensional Kinematic Biofeedback on the Performance of Scapula-focused Exercises.
DOI: 10.5220/0004928701730178
In *Proceedings of the International Conference on Physiological Computing Systems* (PhyCS-2014), pages 173-178
ISBN: 978-989-758-006-2

The biofeedback is effective in multiple contexts, showing satisfactory results by obtaining maximum performance (Egner and Gruzelier, 2003; Huang et al., 2013; Markovska-Simoska et al., 2008; Pop-Jordanova and Cakalaroska, 2008; Tsao and Hodges, 2007). Scapula motion analysis contributes to the understanding of the shoulder dysfunction and has been considered very suitable to the daily clinical context (Tate et al., 2009).

The aim of this study was to assess the effectiveness of 3D kinematic biofeedback during scapula-focused exercises on: (i) motor learning transfer during shoulder flexion task and one daily activity (simulating drinking a glass of water); (ii) the quality of the exercise execution during a cognitive phase and (iii) associative phase of a shoulder motor relearning process.

2 MATERIALS AND METHODS

2.1 Participants

A non-probabilistic sample of 30 participants (10 male and 20 female), 26 right-handed and 4 left-handed. Subjects were randomly and equally distributed into two groups: control (CG) and experimental (EG) groups. The mean age was 21.57 ± 4.14 years, with a mean weight and height of 63 ± 10.37 kg and 1.68 ± 0.08 m, respectively.

Participants were selected following specific criteria (checklist), applied by physical therapists properly instructed and aware of the study purposes. Healthy young participants were included with no history of pain or dysfunction of the shoulder. The exclusion criteria were: to be aged over 60 years; to have signs of complete rupture of the rotator cuff tendon or acute inflammation; to have been submitted to a physical therapy or any other treatment during the study and/or in the past 12 months that could have effect on dependent variables; to perform regular sport activity in the last six months (at least three times per week); to have diagnosis of cervical radiculopathy or neurological changes, visceral or systemic pain, positive Thoracic Outlet syndrome, any rheumatic diseases, history of shoulder, neck or spine high surgery and history of dislocation, subluxation or shoulder fractures.

The ethics committee of the School of Healthcare, Setúbal Polytechnic Institute, approved the study and all participants gave their written informed consent.

2.2 Instrumentation

Bony segment landmarks 3D coordinates were collected using an electromagnetic system trackSTAR (Ascension Technology, Burlington, Vermont) and "The MotionMonitor" software (Innovative Sports Training, Chicago, Illinois). This allowed synchronising the tracking of four sensors with a sampling rate of 100 Hz per sensor. Static accuracy has been reported at 1.8 mm and 0.5° (Milne *et al*., 1996).

2.3 Procedures

All research procedures were conducted by two experienced and trained physical therapists. After reading a letter explaining the study procedures and goals, data collection began with a questionnaire of the subject characteristics, including age, gender, height, weight and dominant side. The participants were randomly distributed in CG and EG. The figure 1 summarises the study procedure.

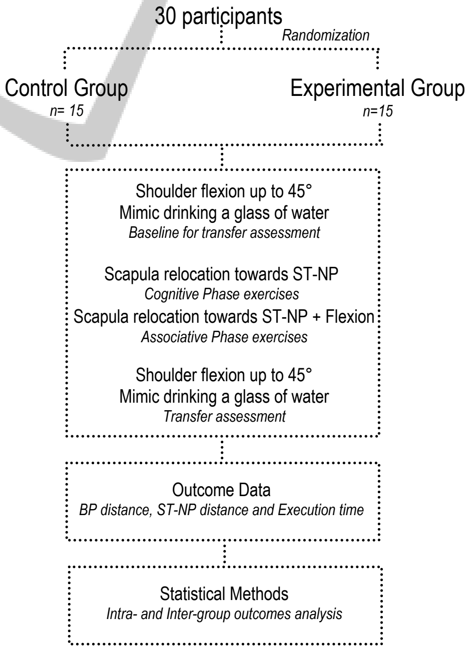

Figure 1: Study flow chart.

TrackSTAR sensor 1 was attached on a transparent acrylic – stylus - and three electromagnetic sensors were attached over the skin: of the spinous process of the first thoracic vertebra (sensor 2); of the flat surface on the superior acromion (sensor 3) and on the lateral side of the humerus (sensor 4), using double-sided tape. The humeral sensor fixation was reinforced with a velcro strap. Tape was also placed strategically over the sensor cables to reduce any motion artefacts.

The protocol of 3D kinematics data collection of the thorax, scapula and humerus followed previously published procedures (Matias and Pascoal, 2006) and the International Society Biomechanics recommendations for reporting upper extremity joints motion (Wu *et al*., 2005).

Scapulothoracic neutral position (ST-NP) was defined according to Mottram (1997) and scapula's Euler angles (internal rotation, upward rotation and posterior tilt) recorded.

ST-NP was set out for each subject, providing visual and tactile feedback. This position was assumed as the ST target position during the exercises.

Each subject performed the following sequence of movements:

a) Shoulder flexion up to 45°;
b) Mimic drinking a glass of water;
c) From the initial (postural) position relocate the scapula towards the ST-NP;
d) From the initial (postural) position relocate the scapula towards the ST-NP and while holding this position preform shoulder elevation in the scapular plane;
e) Repeat a);
f) Repeat b).

This exercise sequence was intended to study the effectiveness of 3D kinematic biofeedback on the performance of scapula-focused exercises in a cognitive (c) and associative (d) phases of motor relearning and if any immediate transfer occurs to an control shoulder flexion task (e) and to a daily activity task (f).

In each movement, a set of trigger signals synchronised with the kinematic data were used to identify (i) the beginning of data collection, (ii) when the subject verbalised that it reached the ST-NP and (iii) after 3 seconds from the latter.

In the experimental group, participants were asked to focus on the data show to access the biofeedback information.

This process happens in real-time, where the patient tries to move the yellow cross (that responds instantaneously to the shoulder movements, represented in Figure 2) into a static square (Figure 2), which appears always in the same position, according to the number of variables (coordinates) relevant to the study.

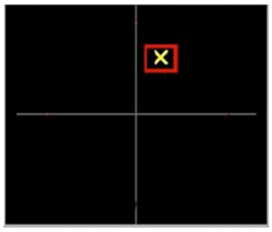

Figure 2: Example of Biofeedback display.

In the control group (group 1) participants have not access to the biofeedback system information. For both cases, the exercise ended when the participants reached the goal (i.e. when the ST reached the NZ) or after 15 seconds even if the participant could not achieved the objective.

Five repetitions for each exercise were performed, with an established interval of two minutes rest between them, in order to prevent muscle fatigue (Wilmore *et al*., 2008). The same physiotherapist provided a verbal instruction for each repetition.

The effectiveness of the exercise execution was determined by the following parameters:
-The distance to the BP: computed as the mean of the root mean square distances of scapula orientation values in each time frame to the BP;
-The distance to the ST-NP: transformed by the mean of the root mean square distances of the scapula orientation values, also in each time frame to the ST-NP.
-Execution time: time spends from the first to the second trigger.

2.4 Statistical Methods

All data were analysed using the MATLAB (version 2012a) and IBM-SPSS (version 21.0).

A visual pre-screening of the records was made, to rule out abnormal data acquisition sessions for a Gaussian distribution and additionally tested with the Shapiro-Wilk test. Appropriate descriptive statistics were calculated for each variable (mean, standard deviation and mode).

Differences between groups were performed through Student's t or Mann Whitney tests (when normal distribution was not verified). The within-groups association analysis was calculated with paired t-test's or Wilcoxon's test (for non-normal distribution of variables). The level of significance used in this study was set for $p < 0.05$ (two-tailed).

3 RESULTS

It was found statistical significant differences within the experimental group on the Euclidean distance to the best path results (z= -2.22; *p*= 0.027), with an execution quality increased by 1.25º when compared to the pre-exercise condition (table 1).

Table 1: Descriptive statistics (mean±sd) and associations test results between pre and pos- exercise conditions (FLEX- flexion; ADL-activity daily living).

n=30			Pre exercise	Pos exercise
FLX	Distance to the BP	CG	8.41±3. 48	9.21±3.33
		EG	9.16±3.04	8.22±2.43 *
	Distance to the ST-NP mode	CG	8.07±4.76	7.79±4.37
		EG	9.73±6.54	9.33±7.06
ADL	Distance to the BP	CG	5.11±1.27	4.79±1.40
		EG	4.73±1.52	4.89±1.68
	Distance to the ST-NP mode	CG	8.41±4.52	8.16±6.20
		EG	9.49±7.16	9.56±7.33

**p*<0.05

No statistical significant differences were found in any of the measured variables related to the cognitive phase exercises. On the contrary, for the associative phase exercises, statistical significant differences were found between groups in Euclidean distance to the best path results (t= 3.91; *p*= 0.001), and the mean Euclidean distance to the ST neutral position (u= 58.0; *p*= 0.014) (table 2).

Table 2: Descriptive statistics (mean±sd) and associations tests results between control and experimental groups.

n=30	CG	EG
COGNITIVE		
Distance to the BP	1.56±0.81	1.70±0.86
Distance to the ST-NP	3.44±2.00	2.95±1.88
Time	3.25±1.25	3.93±1.25
ASSOCIATIVE		
Distance to the BP	4.19±1.17	2.68±0.89*
Distance to the ST-NP	5.00±2.00	3.63±1.63*
Time	2.81±0.66	2.62±1.00

*p<0.05

4 DISCUSSION

In a motor relearning process the variability of the practice consists in repeating variations of the same task in which the parameters are changed, providing variations around the same skill. This study rely its intervention model in the extensive known, considering three stages motor relearning process that consists on the sequential cognitive, associative and autonomous phases (Fitts and Posner, 1967). The duration of the first phase is limited from a few minutes to a few days, while the second learning phase can last for weeks or even months (Schmidt, 2003; Sherwood and Lee, 2003; Summers and Anson, 2009) . According to this model for patients to improve their motor performance the exercise intervention must go through scapula-focused exercises aiming the awareness of the scapulothoracic neutral zone and normalisation of the scapulohumeral rhythm, by facilitating the central nervous system's ability to efficiently control the inter-segmental motion of the upper limb (Hess, 2000; Cools et al., 2003; Cowan et al., 2003).

In this study the exercise exposure period was the same of an average time of a physiotherapy session at an early stage of motor relearning process with emphasis on the cognitive and associative stages.

The results of this study demonstrate that real-time 3D kinematic biofeedback is an effective solution to correctly perform scapula-focused exercises during the progressive phases of learning a new skill, notably when the complexity of the task increases (Jones and French, 2007). The latter become particularly relevant to the associative phase where the quality of the movement becomes more important than the amount of practice itself (Schmidt, 2003; Sherwood and Lee, 2003; Summers and Anson, 2009). The results also provide preliminary evidence that after one physiotherapy session, immediate transfer of learning (Issurin, 2013; Maslovat et al., 2009) occurs when performing a similar task, with an increase in the execution quality. Given the obtained results, we believe that successful learning can be more expressive if we raise the time and volume of practice.

These preliminary findings corroborate other published results on the immediate effect of a specific motor training intervention (Tsao and Hodges 2007; Sturmberg et al. 2013).

Future studies are needed to address the effect of exercises volume and specificity on the execution performance quality, and its effects on the learning retention and transfer. In addition, it would be relevant to determine whether the magnitude of these changes are clinical meaningful, particularly in patients' functionality.

5 CONCLUSIONS

The real-time 3D kinematic biofeedback, proved to be an effective tool for improving the quality of the exercises' execution. Based on this study results subjects who had access to kinematic biofeedback improved 3D motion control of the ST during the analyzed tasks, corroborating results from previous studies. Such a tool can help subjects achieve rehabilitation motor (re)learning goals, and improve rehabilitation decision-making process by quantifying human movement performance.

ACNOWLEDGEMENTS

This study was a non-profit project and had no financial support. The authors would like to acknowledge all the participants that kindly accepted to participate in this study.

REFERENCES

Cools, A. M., Witvrouw, E. E., Declercq, G.A., Danneels, L. A., Cambier, D. C., 2003. Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms. *Am. J. Sports Med.* 31, 542–549.

Cowan, S. M., Bennell, K.L., Hodges, P.W., Crossley, K. M., McConnell, J., 2003. Simultaneous feedforward recruitment of the vasti in untrained postural tasks can be restored by physical therapy. *J. Orthop. Res. Off. Publ. Orthop. Res. Soc. 21*, 553–558.

Cunha-Miranda, L., Carnide, F., Lopes, M.F., 2010. Prevalence of rheumatic occupational diseases - PROUD study. Acta Reum. Port. 35, 215–226.

Egner, T., Gruzelier, J. H., 2003. Ecological validity of neurofeedback: modulation of slow wave EEG enhances musical performance. *Neuroreport 14*, 1221–1224.

Fitts, P.M., Posner, M.I., 1967. Human performance. Brooks/Cole Pub. Co.

Hanratty, C.E., McVeigh, J.G., Kerr, D.P., Basford, J.R., Finch, M.B., Pendleton, A., Sim, J., 2012. The effectiveness of physiotherapy exercises in subacromial impingement syndrome: *a systematic review and meta-analysis*. Semin. Arthritis Rheum. 42, 297–316.

Hess, S.A., 2000. Functional stability of the glenohumeral joint. Man. Ther. 5, 63–71.

Holtermann, A., Søgaard, K., Christensen, H., Dahl, B., Blangsted, A.K., 2008. The influence of biofeedback training on trapezius activity and rest during occupational computer work: a randomized controlled trial. Eur. *J. Appl. Physiol.* 104, 983–989.

Huang, H.-Y., Lin, J.-J., Guo, Y. L., Wang, W.T.-J., Chen, Y.-J., 2013. EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement. J. Electromyogr. Kinesiol. Off. J. Int. Soc. Electrophysiol. Kinesiol. 23, 267–274.

Issurin, V. B., 2013. Training transfer: scientific background and insights for practical application. Sports Med. Auckl. NZ 43, 675–694.

Jones, L. L., French, K. E., 2007. Effects of contextual interference on acquisition and retention of three volleyball skills. Percept. Mot. Skills 105, 883–890.

Kibler, W. B., Ludewig, P. M., McClure, P.W., Michener, L. A., Bak, K., Sciascia, A .D., Bak, K., Ebaugh, D., Kibler, W.B., Ludewig, P., Kuhn, J., McClure, P., Mazzocca, A., Michener, L., Bailey, L., Sciascia, A. D., Borstad, J., Seitz, A., Cools, A., Uhl, T., Cote, M., 2013. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the "scapular summit". Br. *J. Sports Med.* 47, 877–885.

Markovska-Simoska, S., Pop-Jordanova, N., Georgiev, D., 2008. Simultaneous EEG and EMG biofeedback for peak performance in musicians. Pril. Makedon. Akad. Na Nauk. Umet. Oddelenie Za Biološki Med. Nauki Contrib. Maced. Acad. Sci. Arts Sect. *Biol. Med. Sci.* 29, 239–252.

Maslovat, D., Brunke, K. M., Chua, R., Franks, I.M., 2009. Feedback effects on learning a novel bimanual coordination pattern: support for the guidance hypothesis. J. Mot. Behav. 41, 45–54.

Matias, R., Pascoal, A.G., 2006. The unstable shoulder in arm elevation: a three-dimensional and electromyographic study in subjects with glenohumeral instability. *Clin. Biomech. Bristol Avon 21 Suppl* 1, S52–58.

Michener, L.A., McClure, P.W., Karduna, A.R., 2003. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. Clin. Biomech. Bristol Avon 18, 369–379.

Milne, A.D., Chess, D.G., Johnson, J.A., King, G.J., 1996. Accuracy of an electromagnetic tracking device: a study of the optimal range and metal interference. *J. Biomech.* 29, 791–793.

Mottram, S .L., 1997. Dynamic stability of the scapula. Man. Ther. 2, 123–131.

Pop-Jordanova, N., Chakalaroska, I., 2008. Comparison of Biofeedback Modalities for Better Achievement in High School Students.

Schmidt, R.A., 2003. Motor schema theory after 27 years: reflections and implications for a new theory. Res. Q. Exerc. Sport 74, 366–375.

Sherwood, D.E., Lee, T.D., 2003. Schema theory: critical review and implications for the role of cognition in a new theory of motor learning. Res. Q. Exerc. Sport 74, 376–382.

Struyf, F., Nijs, J., Mollekens, S., Jeurissen, I., Truijen, S., Mottram, S., Meeusen, R., 2013. Scapular-focused treatment in patients with shoulder impingement syndrome: a randomized clinical trial. Clin. Rheumatol. 32, 73–85.

Sturmberg, C., Marquez, J., Heneghan, N., Snodgrass, S., van Vliet, P., 2013. Attentional focus of feedback and instructions in the treatment of musculoskeletal dysfunction: A systematic review. Man. Ther.

Summers, J.J., Anson, J.G., 2009. Current status of the motor program: Revisited. Hum. Mov. Sci. 28, 566–577.

Tate, A.R., McClure, P., Kareha, S., Irwin, D., Barbe, M.F., 2009. A clinical method for identifying scapular dyskinesis, part 2: validity. J. Athl. Train. 44, 165–173.

Tsao, H., Hodges, P.W., 2007. Immediate changes in feedforward postural adjustments following voluntary motor training. Exp. Brain Res. Exp. Hirnforsch. Expérimentation Cérébrale. 181, 537–546.

Tsao, H., Hodges, P.W., 2007. Immediate changes in feedforward postural adjustments following voluntary motor training. Exp. Brain Res. Exp. Hirnforsch. Expérimentation Cérébrale 181, 537–546.

Vedsted, P., Søgaard, K., Blangsted, A.K., Madeleine, P., Sjøgaard, G., 2011. Biofeedback effectiveness to reduce upper limb muscle activity during computer work is muscle specific and time pressure dependent. J. Electromyogr. Kinesiol. Off. J. Int. Soc. Electrophysiol. Kinesiol. 21, 49–58.

Wilmore, J.H., Costill, D.L., Kenney, W.L., 2008. Physiology of Sport and Exercise. Human Kinetics.

Wu, G., van der Helm, F.C.T., Veeger, H.E.J.D., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., Werner, F.W., Buchholz, B., International Society of Biomechanics, 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. J. Biomech. 38, 981–992.