Design of a mechatronic device for learning a gesture and strengthening specific muscles.

MONNET Tony, EON Antoine, DECATOIRE Arnaud

Abstract

The objective of this project is to create a mechatronic device that can assist in motor learning. The device will facilitate interaction between a human and a robot, taking into account the kinematics and dynamics of the movement that the human is trying to learn. The potential applications of this development range from learning high-level sports movements to rehabilitating motor skills after trauma or surgery.

Context

This thesis is part of the three themes of the RoBioSS team: 'Dynamics of motion', 'Physical and systemic interactions', and 'Mechatronics and cobotics'. The acquisition of motor skills, ranging from everyday movements to technical gestures and movements leading to high-level sporting performance, is based on two main processes: trajectory learning and dynamic adaptation [16].

We will use the term 'global movement' to refer to the movement of the entire body when performing a gesture (see Figure 1a). We will also use the term 'isolated movement' to refer to the movement of a single joint, which is identical (from a kinematic perspective) to the joint movement performed during the global movement, but without involving the other joints of the body (see Figure 1b).

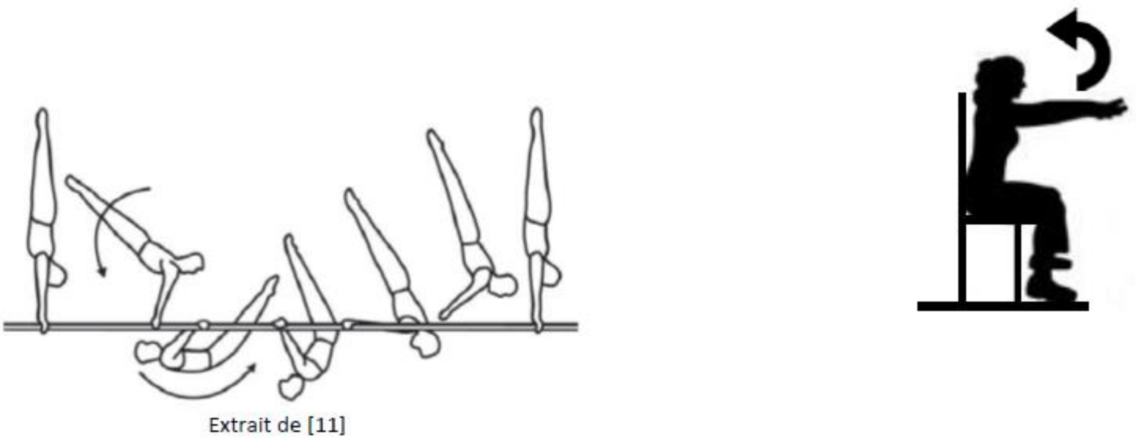

Figure 1: Difference between an antepulsion performed during a "global movement" (a) and during an "isolated movement" (b).

Learning joint kinematics can be initiated by mimicking in a single joint the movements to be performed. However, this approach has limitations when considering the dynamic aspects of the movement. Performing adduction of the right arm in a standing position does not generates the same joint torque in the shoulder as performing it in a backward salto, even though the joint kinematics are identical [13]. Similarly, reproducing flexion-extension movements at knee with feet in the air when sitting on a rehabilitation table generates less joint effort compared to supporting your body weight while walking on the ground.

The use of robotic systems to aid trajectory learning (guidance) has shown no real direct benefits [8,14]. On the other hand, robotic guidance can be useful be useful when the movement involves several joints and/or several tasks, as it can free up attention from some aspects of the movement to focus on others [9].

With regard to dynamic adaptation, recent research [5,17] has shown that the process of dynamic adaptation process was based on the errors observed during the previous movement. By applying a force, via a robotic device, proportional to the observed deviation from the desired trajectory, it is then possible to correct the trajectory ("Error-based learning"). A mathematical model of this principle was proposed by [4] and tested with subjects walking on a treadmill. However, the question of the trade-off between of learning and the amount of assistance to be provided.

Coaches and technicians have long applied this principle, using their imagination imagination to devise simple devices. For example, hang a bucket from the end of a rope rope and asking a gymnast learning to do pommel circles to place his or her feet in the bucket (Figure 2), allows the gymnast to create the external effort needed to keep his or her feet feet above the ground.

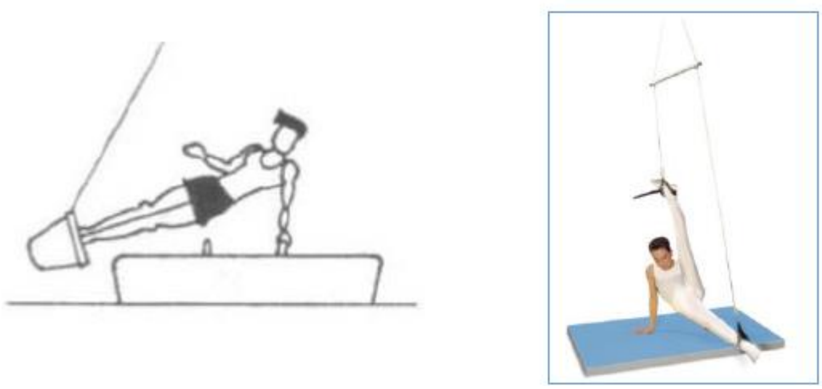

Figure 2: Learning device for pommel ring kinematics.

While this device proves effective at the beginning of the learning phase, facilitating the gestures, its prolonged use quickly becomes counter-productive, as it encourages the development of joint efforts that are very different from those that the gymnast will have to provide. At What happens when the bucket is removed, thus removing the possibility of creating an external effort on the feet? the feet? The use of this type of device therefore calls into question the ability to transfer of learning.

The same analysis can be made for all kinds of assistance provided by a trainer, robotic device (such as an exoskeleton [10]) or even a physiotherapist during the performing a gesture. In reality, these are more assistance than learning devices, in the in the sense that they compensate for a deficit in effort.

Another robotic assistance strategy, called the "error-augmentation strategy", was then studied by [15]. It consists in having a robotic device apply a force opposite to that which should be applied to correct any deviations in trajectory. If this strategy initially leads to greater trajectory deviations, when the applied force disappears an "after-effect" is observed, leading the subject to follow the desired trajectory perfectly with appropriate muscle activation.

Most of the existing mechanical/mechatronic devices related to movement have been developed for studies in the field of motor control (Figure 3a and 3b), movement analysis and simulation (Figure 3c and 3d), or for rehabilitation programs (Figure 3e). Few are designed to teach specific movements or strengthen muscles. The design of today's ergometers requires the user/athlete to master gestures so that the efforts felt are perceived as realistic. There are no ergometers equipped with a biomechanical movement simulation model that model, taking into account the subject's anthropometric characteristics, which enable to learn how to develop the necessary articular efforts, with feedback on the quality of the kinematics achieved. The general scientific problem proposed by this research program research program is to develop this type of ergometer, whose use can be extend from the field of functional rehabilitation to that of high-level sports performance.

a) Contrôle du poignet lors du putt au golf.

b) BioMotionBot pour l'analyse de tâches sensori-motrices

c) Ergomètre Kayak instrumenté pour la simulation de gestes sportifs (RoBioSS)

d) Ergocycle instrumenté pour l'analyse du mouvement de pédalage (RoBioSS)

e) Dispositif iso-cinétique destiné à la rééducation
Extrait de https://www.medimex.fr/humac-norm-by-csmi.html

Figure 3: Examples of mechanical and mechatronic devices related to human movement (a from [12]; b from [1]).

Objectives

The objectives of this project are to develop a mechatronic device that will allow :

- Learn to achieve a target joint kinematics during an isolated movement WHILE

- Learn to produce, during an isolated movement, the articular efforts developed for this kinematics during the global movement. These efforts will be obtained by optimizing the movement according to the subject's anthropometric characteristics and physical capabilities.

- Define the ideal opposing force to be applied so that it is acceptable to the user.

- Take into account the level of learning and expertise in robotic assistance.

- Define different forms of feedback to optimize learning without making learners dependent.

Bibliography
1 *Bartenbach V, Sander C, Pöschl M, Wilging K, Nelius T, Doll F, Burger W, Stockinger C, Focke A, Stein T.* The BioMotionBot: A robotic device for applications in human motor learning and rehabilitation. J Neurosci Methods 2013; 213: 282–297

2 *Blandin Y, Toussaint L, Shea CH.* Specificity of Practice: Interaction between concurrent sensory information and terminal feedback. Journal of Experimental Psychology: Learning, Memory and Cognition 2008; 34: 994–1000
3 *Boutin L, Eon A, Zeghloul S, Lacouture P.* From human motion capture to humanoid locomotion imitation Application to the robots HRP-2 and HOAP-3. Robotica 2011; 29: 325–334
4 *Emken JL, Benitez R, Reinkensmeyer DJ.* Human-robot cooperative movement training: Learning a novel sensory motor transformation during walking with robotic assistance-as-needed. J NeuroEngineering Rehabil 2007; 4: 8
5 *Emken JL, Benitez R, Sideris A, Bobrow JE, Reinkensmeyer DJ.* Motor Adaptation as a Greedy Optimization of Error and Effort. J Neurophysiol 2007; 97: 3997–4006
6 *Eon A.* Contribution à la génération de mouvements dynamiques pour les robots humanoïdes et au dimensionnement de leurs actionneurs. Université de Poitiers 2009;
7 *Fohanno V, Begon M, Lacouture P, Colloud F.* Estimating joint kinematics of a whole body chain model with closed-loop constraints. Multibody Syst Dyn 2014; 31: 433–449
8 *Gillespie RB, O'Modhrain M, Tang P, Zaretzky D, Pham C.* The virtual teacher. Proc ASME Dyn Syst Control Div 1998; 64: 171–178
9 Griffiths PG, Gillespie RB. Sharing Control Between Humans and Automation Using Haptic Interface: Primary and Secondary Task Performance Benefits. Hum Factors J Hum Factors Ergon Soc 2005; 47: 574–590
10 *Hayes S, White M, White H, Vanicek N.* Biomechanical profiles of able-bodied robotic exoskeleton gait and normal walking. Gait & Posture 2018; 65: 33–35
11 *Hiley MJ, Yeadon MR.* The effect of cost function on optimum technique of the undersomersault on parallel bars. J Appl Biomech 2012; 28: 10–19
12 *Kümmel J, Kramer A, Gruber M.* Robotic guidance induces long-lasting changes in the movement pattern of a novel sport-specific motor task. Hum Mov Sci 2014; 38: 23–33
13 *Monnet T., Decatoire A., Lacouture P.* Comparison of shoulder's net moment between practice and real condition. Comput Methods Biomech Biomed Engin 2005; 8: 197–198

14 *O'Malley M, Gupta A, Gen M, Li Y.* Shared control in haptic systems for performance enhancement and training. J Dyn Syst Meas Control Trans ASME 2006; 128: 75–85
15 *Patton JL, Mussa-Ivaldi FA.* Robot-assisted adaptive training: custom force fields for teaching movement patterns. Biomed Eng IEEE Trans On 2004; 51: 636–646
16 *Reinkensmeyer DJ, Patton JL.* Can Robots Help the Learning of Skilled Actions? Exerc Sport Sci Rev 2009; 37: 43–51
17 *Scheidt RA, Dingwell JB, Mussa-Ivaldi FA.* Learning to Move Amid Uncertainty. J Neurophysiol 2001; 86: 971–985
18 *Scotto Di Cesare C, Bringoux L, Bourdin C, Sarlegna FR, Mestre DR.* Spatial localization investigated by continuous pointing during visual and gravitoinertial changes. Experimental Brain Research 215: 173–182
19 *Seguin P, Bessonnet G, Sardain P.* A Parametric Optimization Approach to Walking Pattern Synthesis. The International Journal of Robotics Research 2005; 24: 523–536
20 *Vulliez M, Zeghloul S, Oussama K.* Design strategy and issues of the Delthaptic, a new 6-DOF parallel haptic device. Mechanism and Machine Theory 2018; 128: 395–411
21 *Vulliez P, Gazeau JP, Laguillaumie P, Mnyusiwalla H.* Focus on the mechatronics design of a new dexterous robotic hand for inside hand manipulation. Robotica 2018; 36: 1206–1224