JCJC - SHS 2 – DynaMov

Dynamics of movement patterns: Expertise and behavioural variability

Summary

The *DynaMov* project was funded by the French National Agency of Research over 4 years (between 2013 and 2017) under the following reference: ANR-JCJC-SHS-2-2013. This project proposes a multi-disciplinary approach to the analysis of human movement to explore behavioural adaptability as a determinant property of expertise (Davids et al., 2012; Seifert et al., 2013a). It combines knowledge and methodologies in the human movement sciences, computer sciences and applied mathematics. The primary aim is to investigate the functional role of movement variability in natural contexts where uncertainty and pressure are high, requiring that individuals constantly adapt their behaviours in order to respond to existing dynamical and interactive constraints. Studying the functional role of movement variability involves assessing how adaptive is human behaviour by analysing the balance between movement pattern stability (i.e., persistent behaviour) and flexibility (i.e., variable behaviour) relative to a performance context (Davids et al., 2003; Newell and Slifkin, 1998; Warren, 2006). Specifically, our project explores how experienced and inexperienced individuals in work and sport, such as firemen and athletes, adapt their motor behaviours in various performance contexts, i.e., when the environmental properties are stable or in unstable or transitional regions where movement patterns co-exist (technically known as a metastable region) (Kelso, 2012). The experimental aims include exploring how environmental properties (performance in stable vs. meta-stable region) influence behavioural adaptability, when inexperienced firemen and athletes are trained either in a stable environmental constraint or in meta-stable performance regions. This part of the project involves researchers from the CETAPS (University of Rouen, France), CESAMS (University of Caen, France), CSER (Sheffield Hallam University, UK), Queensland University of Technology (Australia), University of Otago (New Zealand).

Society demands the rapid and effective minimization and management of high risk performance situations. Hence, training in meta-stable performance regions is particularly relevant in order to facilitate those tasked with responding to high levels of uncertainty and temporal pressure (Hristovski et al., 2009; Pinder et al., 2012). Therefore, the findings of the project could provide useful knowledge to design training programmes requiring continuous motor adaptation, including exploration and escape

strategies (i.e., a fall back to safer or more reliable movement patterns). To permit the analysis of motor behaviour adaptability, the objective for computer sciences and applied mathematics relate to the development of movement pattern recognition software in order to track human behaviour in space-time dynamics by identifying “attractors” (i.e. stable movement patterns) and transitions between attractors. An additional focus will be on critical points of the dynamics of movement patterns by analysing and modelling global and local variability of the time-series. This part of the project involves researchers from Laboratory Jean Kuntzman (University of Grenoble, France), LITIS (National Institute of Applied Science of Rouen, France). This cooperation between computer sciences and applied mathematics and human movement sciences would enable the development of a multi-disciplinary team of research, across regional, national and international levels.

In summary, this research proposal describes a developmental experimental approach, whereby the main technical challenge is to develop a measurement system capable of capturing human behaviour in natural performance contexts using embedded sensors. Concurrently a method is developed for the analysis of human movement data using a small number of parameters. The project attempts to use inertial measurement units, which associate 3D accelerometer, 3D gyroscope and a 3D magnetometer. This project proposes the use of MotionPod3 by MOVEA (Movea©, Grenoble, France, http://movea.com/) who contribute as a partner in the project.

Main scientific and technical objectives

This project concerns a multi-disciplinary approach of human movement analysis to explore the motor behaviour adaptability as a determinant property of expertise. This project combines human movement sciences and computer sciences and applied mathematics. The primary aim of this project involves investigating the functional role of movement variability in natural contexts where uncertainty and temporal pressure are high by essence, requiring that individuals constantly adapt their behaviour in order to respond to existing dynamical and interactive constraints. Studying the functional role of movement variability means to assess how adaptive is the human behaviour by analysing the balance between movement pattern stability (i.e., persistent behaviour) and flexibility (i.e., variable behaviour) relative to the performance context. Specifically, our project explores how experienced and inexperienced firemen and athletes adapt their motor behaviour in various performance contexts, i.e., when the environmental properties are stable or with meta- stable performance regions (i.e., unstable region or transition region where movement patterns co-exist). Experimental aims include exploring how environmental properties (stable vs. meta-stable region) influence behavioural adaptability, when inexperienced firemen and athletes are trained either in a stable environmental constraint or in meta-stable performance regions. The main scientific lock in human movement science is to explore how meta-stable region can lead to functional variability of movement and individual creativity. In the same vein, the next scientific lock is to investigate the interest of training in met-stable region vs. in a stable context as it could lead to greater richness and creativity in behaviour (e.g., exploration and escape strategies) – a question which could be assessed through a transfer test.

This research programme involves experimental development whereby the main technical challenge is to track human behaviour using embedded sensors in order to capture human movement by a small number of parameters in a natural context. The project attempts to use inertial measurement units (IMU) which associate 3D accelerometer, 3D gyroscope and 3D magnetometer, called MotionPod3 by MOVEA© (Figure 1), which is a private company nested from CEA-LETI lab that is partner of this current project.

Figure 1. IMU used for climbing (limbs and hip)

One pragmatic challenge is to accurately put the sensors on the body in order to be sure to minimize inter-trial and inter-individual variability to assess movement pattern.

From there, in computer science, scientific locks belong to automatic recognition of movement patterns (i.e., attractors) through time-series. The IMU enables the calculation of several types of data (e.g., Euler angle, rotation matrix and quaternion) and numerous parameters to characterize movement pattern. Pilot studies and literature review invited us to reduce the number of dimensional characteristics toward a small number of macroscopic parameters, for instance by analysing inter-limb coordination. The two other scientific and technical issues for computer sciences and applied mathematics are to analyse: (i) the movement patterns coordination dynamics and the temporal dynamics of learning by Hidden Markov Model (HMM) and inter-individual variability by clustering analysis to determine profile, and; (ii) the global and local movement variability according to environmental properties (stable vs. meta-stable performance region). Local variability analysis corresponds to the detection of multivariate change points within angular time series in our case.

Work plan

Concerning human movement sciences, three specific actions are selected to study multi-articular movement coordination in experienced and inexperienced firemen and athletes: climbing stairs, ladder and indoor climbing wall. All actions are analysed in their natural performance context, with uncertainty introduced by setting up a meta-stable performance region. For instance, when climbing stairs, the height of the steps could be increased until the individual can't climb up using only his/her legs (bipedal climbing), but must also use his/her arms (quadrupedal climbing). Crucial works by Warren (1984) analysed the perceptual boundary between "climbable" and "unclimbable" stairs, by varying riser height with respect to leg length. From there, a meta-stable region corresponding to the boundary between bipedally-climbable and quadrupedally- climbable could be designed by taking in account individuals' leg length in the definition of riser height. This would complement Warren's pioneering work, which used verbal judgments in the context of a single action mode (bipedal climbing), by analysing motor coordination in the context of two contingent action modes (bipedal and quadrupedal climbing). A similar process could be conducted for climbing a ladder: the stance between two ladder rungs could be increased beyond the size of one arm so that individual cannot reach the next rung in one shot. Thus, depending of the stance between two rungs, individual can reach next rung by alternating hands on each rung or by putting both hands on each rung. Finally, when climbing on the indoor climbing wall, the hold orientation (vertical vs. horizontal) and the grasping-ability of the holds could be changed through the climbing wall to induce uncertainty in the grasping pattern. The comparison between a stable and meta-stable performance condition seems particularly relevant because firemen and athletes mostly encountered complex situation with high degree of unpredictability where they must overcome risk without mistake. The use of meta-stable performance region invites individuals to explore with the option to fall back toward a safer movement pattern. From there, the first experiment consists of comparison between experienced and inexperienced firemen and athletes when climbing stairs, ladder and indoor climbing wall in stable and meta-stable performance region. The second experiment corresponds to a training protocol (i.e., 10 weeks with 2 training sessions of 3 climbing ascent/week; each climbing session duration is around 30min/participant), with post-test, re-test and transfer test to explore the interest of training in a variable context.

For data analysis and data processing, we will mostly use computer sciences and applied mathematics. Movement pattern recognition will be based on i) the upper and lower limbs orientation through the 3D rotation matrix; (ii) trunk (at pelvis and shoulder level) inclination and orientation from Euler angle; (iii) pelvis acceleration and displacement. Dynamical analysis of movement pattern will consist in (i) analyse chain of limb movements by Hidden Markov Modelling (HMM) within and between trials, to (ii) analyse inter-individual variability in order to detect any individual strategy and movement pattern profiles, to (iii) analyse local variability that provides meaningful findings about the structure of the variability as it enables the detection of multiple change points.

This work plan is schedule on 4 years. First year is dedicated to design the protocol and testing apparatus, then a pilot study. Data collection for experiments 1 and 2 will be done during the second year. In the same time, movement pattern recognition, dynamical analysis and local variability analysis will be achieved for pilot stud and experiment 1. Years 3 and 4 are dedicated to movement pattern recognition, dynamical analysis and modelling, and local variability analysis for experiment 2.

Scientific, economic and technical contributions

CETAPS laboratory has taken predominantly a qualitative approach to assess coordination dynamics and global indicators of movement variability. The novelty of this project is that in addition to taking a qualitative approach, a quantitative approach will be used to enrich our existing methods. This complimentary approach is particularly appropriated to big data (e.g., long time-series, numerous events, numerous constraints), in order to provide modelling and clustering of human motor behaviour. From there, this project can bring three scientific contributions:

First, we aim at providing an algorithm to recognise the movement patterns used by experienced and inexperienced firemen and athletes to climb up stairs, ladder and indoor climbing wall according to a stable vs. meta-stable performance region. Previous studies have previously been done under the task representing the highest degree of complexity: climbing up an indoor climbing wall (Seifert et al., 2014, 2013c). Tri-dimensional rotation matrix (in x, y and z axes) was exported from the IMU to identify and recognize a given limb pattern according to a rotation matrix of reference with a total of 17 possible patterns. This pilot work offers proof of concept favouring the use of data from rotation matrix for human movement analysis and clustering. It is planed to share a patent about pattern recognition through tri-dimensional rotation matrix algorithm between MOVEA and CETAPS.

Second, we are also looking to provide a tool for modelling the temporal dynamics of the movement patterns. Based on the previous literature, the use of Hidden Markov Model (HMM) can provide accurate indicators of gait detection and chain of movement patterns analysis. This deliverable is very useful to reveal exploration and escape strategies (i.e., fallback toward safer movement pattern).

Third, novelty in this project is also reflected in the analysis of local variability (i.e., the structure of variability), whereby approaches for a deeper level of analysis into the temporal dynamics of movement patterns will be developed. As stated previously, this new step would enable to detect exploration and escape strategies. A publication led by some participants of the current project supported the efficacy of this approach (Seifert et al., 2013b). Three novelties are provided by our analysis: (i) to take into account the dynamics of the time series by using change point analysis of the series, (ii) to apply the change point analysis to circular data. Indeed, they are working with series of angles, (iii) to adapt a new method for change point detection, so called Filtered Derivative with p-values (FDpV) for detecting changes on the Euclidean mean.

Last, this project offers economic and technical contributions. Indeed, this project reflects a branching out of CETAPS lab toward a pluri-disciplinary approach of human movement sciences that lead to building a strong regional network of young and promising researchers with repercussion at national and international levels. Finally, this project fosters a close relationships with industry partners - a private company (MOVEA), born from LETI-CEA labs, with an existing scientific culture open to building strong relationships with universities for research & development purposes.

Leader of the project:
Ludovic Seifert, CETAPS (University of Rouen, France): ludovic.seifert@univ-rouen.fr

Participants:
Regis Thouvarecq, CETAPS (University of Rouen, France): regis.thouvarecq@univ-rouen.fr
Maxime L'hermette, CETAPS (University of Rouen, France): maxime.lhermette@univ-rouen.fr
Dominic Orth, CETAPS (University of Rouen, France), Queensland University of Technology (Australia): dominic.orth1@univ-rouen.fr
John Komar, CETAPS (University of Rouen, France): john.komar@univ-rouen.fr
Romain Hérault, LITIS (National Institute of Applied Science of Rouen, France): romain.herault@insa-rouen.fr
Nicolas Delestre, LITIS (National Institute of Applied Science of Rouen, France): Nicolas.delestre@insa-rouen.fr
Jean François Coeurjolly, Laboratory Jean Kuntzman (University of Grenoble, France): jean-francois.coeurjolly@upmf-grenoble.fr
Chris Button, University of Otago (New Zealand): chris.button@otago.ac.nz
Keith Davids, CSER (Sheffield Hallam University, UK): k.davids@shu.ac.uk
Bruno Mantel, CESAMS (University of Caen, France): bruno.mantel@unicaen.fr
Yanis Caritu, (Movea, Grenoble, France, http://movea.com/): ycaritu@movea.com
Jeremie Boulanger, CETAPS (University of Rouen, France): jeremie.boulanger@gmail.com

Bibliography

Davids, K., Araújo, D., Hristovski, R., Passos, P., Chow, J.Y., 2012. Ecological dynamics and motor learning design in sport. In: Hodges, N.J., Williams, A.M. (Eds.), Skill Acquisition in Sport: Research, Theory and Practice. Routledge (taylor and francis Group), New York, NY, USA, pp. 112–130.

Davids, K., Glazier, P.S., Araújo, D., Bartlett, R.M., 2003. Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. Sports Med. 33, 245–60.

Hristovski, R., Davids, K., Araújo, D., 2009. Information for regulating action in sport: metastability and emergence of tactical solutions under ecological constraints. In: Araujo, D., Ripoll, H., Raab, M. (Eds.), Perspectives on Cognition and Action in Sport. pp. 1–15.

Kelso, J.A.S., 2012. Multistability and metastability: understanding dynamic coordination in the brain. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 367, 906–18.

Newell, K.M., Slifkin, A.B., 1998. The nature of movement variability. In: Piek, J.P. (Ed.), Motor Behavior and Human Skill: A Multidisciplinary Approach. Human Kinetics, New York, NY.

Pinder, R.A., Davids, K., Renshaw, I., 2012. Metastability and emergent performance of dynamic interceptive actions. J. Sci. Med. Sport 1–7.

Seifert, L., Button, C., Davids, K., 2013a. Key properties of expert movement systems in sport : an ecological dynamics perspective. Sports Med. 43, 167–78.

Seifert, L., Coeurjolly, J.F., Hérault, R., Wattebled, L., Davids, K., 2013b. Temporal dynamics of inter-limb coordination in ice climbing revealed through change-point analysis of the geodesic mean of circular data. J. Appl. Stat. 40, 2317–2331.

Seifert, L., Orth, D., Boulanger, J., Dovgalecs, V., Hérault, R., Davids, K., 2014. Climbing skill and complexity of climbing wall design: assessment of jerk as a novel indicator of performance fluency. J. Appl. Biomech. 30, 619–25.

Seifert, L., Orth, D., Hérault, R., Davids, K., 2013c. Affordances and grasping patterns variability during rock climbing. In: Davis, T., Passos, P., Dicks, M., Weast-Knapp, J. (Eds.), Studies in Perception and Action XII: Seventeenth International Conference on Perception and Action. Psychology Press, Taylor & Francis, Estoril, Portugal, pp. 114–118.

Warren, W.H., 2006. The dynamics of perception and action. Psychol. Rev. 113, 358–89.