A dynamic systems approach to bimanual coordination in stroke: implications for rehabilitation and research

Rita Sleimen-Malkoun, Jean-Jacques Temprado, Eric Berton
UMR 6233 Institut des Sciences du Mouvement E. J. Marey, CNRS & Université de la Méditerranée, Marseille, France

Key words: *stroke; bimanual coordination; dynamical systems; rehabilitation.*

Summary. *During the last 30 years, the dynamic systems approach to coordination patterns contributed to shed new lights on the principles governing interlimb coordination, its dynamics, and its neural basis, predominantly in healthy people.*

In the present paper, we aim to show how these concepts could provide a theoretical and a methodological framework to address bimanual coordination dysfunction and rehabilitation in stroke patients. Compared to conventional approaches to research and rehabilitation in stroke, the one proposed in this paper is original since it seeks to assess and improve the impaired limb through (and in) coordination tasks. We concretely envisage a number of implications of the "dynamic systems" view to understand the behavioral consequences of intrinsic asymmetries (due to central nervous system injury) on bimanual dynamics in stroke and to identify how to exploit the central nervous system plasticity and self-organizing properties for recovering more adaptive coordinated movements.

We conclude that more interest should be accorded to bimanual coordination assessment and rehabilitation in stroke. In this respect, the dynamical systems approach provides interesting insights and valuable tools. Experimental and clinical studies are still needed in order to elaborate frm and founded guidelines for therapy.

Introduction

Stroke is characterized by a partial (or total) paralysis of one side of the body induced by a monohemispheric cerebral vascular accident (CVA). It results in an important chronic functional limitation of upper limb and daily living functions, even after several months of rehabilitation (1, 2). For a long time, therapeutic interventions as well as research protocols in stroke have been focusing on the isolated dynamics of the impaired limb. Consequently, existing data on bimanual coordination deficits following CVA are sparse, and evidence is still lacking when it comes to multiple key points (how, why, and when bimanual coordination is impaired after stroke).

During the last three decades, movement scientists working in the theoretical context of dynamical systems devoted their efforts to understand the mechanisms and principles underlying the emergence, stabilization, destabilization, and changes of coordination patterns. The "synergetic approach" (3) and the paradigm of rhythmic bimanual coordination (4–6) have provided new grounds to address these issues and allowed the conceptualization and modeling of both spontaneous and directed nature of interlimb synergies. As a result, a basic understanding of coordination dynamics and its neural basis has begun to emerge (7, 8). However, since the dynamic theory of coordination patterns has primarily focused on nondisabled individuals, its possible applications to motor deficits and therapeutic interventions have been rarely envisaged (9–15), and it has been even more scarcely proposed as an interesting background to explore and re-establish disturbed bimanual synergies (16). Thus, it remains unclear for researchers and clinicians how approach may provide an adequate theoretical framework along with valuable methods to address the issue of bimanual coordination in a pathological context (such as stroke). More importantly, it is unclear how this approach may provide clinical guidelines to improve the effectiveness of rehabilitation protocols.

In the present paper, we mainly aim to draw research directions to clear up how the basic coordination principles (coordination patterns, coupling, symmetry-breaking, etc.) established in the undamaged neuro-musculo-skeletal system (NMSS) might offer a conceptual and methodological framework for understanding and rehabilitating bimanual coordination in stroke.

Discussion

Compared to conventional approaches in stroke, which are predominantly centered on unimanual rehabilitation, the originality of a dynamic system-inspired approach is to assess and improve the paretic

---

Correspondence to R. Sleimen-Malkoun, Institut des Sciences du Mouvement E. J. Marey, Faculté des Sciences du Sport, 163 Avenue de Luminy, BP 910, 13288 Marseille, France.
E-mail: rita.sleimen-malkoun@univmed.

Adresas susirašinėti: R. Sleimen-Malkoun, Institut des Sciences du Mouvement E. J. Marey, Faculté des Sciences du Sport, 163 Avenue de Luminy, BP 910, 13288 Marseille, France
El. paštas: rita.sleimen-malkoun@univmed.

limb function by exploiting the coupling principles of bimanual coordination that have been established by the dynamic approach in healthy individuals. The guiding thread consists in using the behavioral signatures introduced by the dynamic systems approach as a window into the neural and functional alterations after stroke.

This section is divided into two parts. In the first part, we present a brief review of the fundamental concepts and findings of the dynamical systems approach to bimanual coordination. In the second part, we explore those principles in the context of research and rehabilitation in stroke. We concretely envisaged a number of implications of the "dynamic systems" view to understand bimanual coordination in stroke patients and to ensure the recovery of more adaptive coordinated movements.

1. Dynamical systems approach to bimanual coordination in the undamaged neuro-musculo-skeletal system

1.1. ***Self-organizing and coupling properties.*** In contrast with the prevailing classical approaches that reduce bimanual coordination to a preplanned behavior couched in motor programs and internal models, the dynamical systems approach emphasizes the self-organizing character of movement patterns formation and reorganization. Inspired by the oscillator theory, this approach assumes that basic coordination patterns emerge, spontaneously, under certain conditions, as the result of self-organization and coupling influences between interacting components at multiple levels of the NMSS. Indeed, nonlinear dynamical systems are highly interconnected systems composed of many interacting parts, capable of constantly changing their state of organization. The spontaneous patterns can be further stabilized or overcame through intention, attention, or learning, which accounts for the directed aspect of interlimb synergies.

Accordingly, in cyclic bimanual coordination, the coupling interactions (at different levels of the NMSS) can be captured by a low dimensional order parameter, which is the relative phase between limbs. This so-called collective variable allowed the characterization of two preferred patterns of coordination (5): the "inphase" mode (0° of relative phase) and the "antiphase" mode (180° of relative phase). The inphase pattern is classically defined as involving symmetric movements of the limbs in opposite direction, while the antiphase pattern consists in parallel movements in the same direction. These emergent "default" patterns have a different stability that could be measured by the relative phase variability. Actually, regardless of the task, the "inphase" pattern showed to be the most stable one, whereas an unavoidable switch (transition) occurs from antiphase to inphase pattern each time the oscillation frequency (control parameter) exceed a given critical threshold.

The dynamics of spontaneous bimanual coordination has been formalized by the HKB model (6). In this model, the relative phase, capturing the inherent properties of the NMSS, at a behavioral level, is formulated by the following equation of motion:

$$\dot{\phi} = -a\sin\phi - 2b\sin 2\phi + \sqrt{Q}\varepsilon$$

The a and b parameters reflect the coupling strength, and the change in their ratio (b/a) mimics the effect of the control parameter (its decrease corresponds to an increase in movement frequency and consequently to a destabilization of the antiphase pattern). "$Q\varepsilon$" represents the constant fluctuations due to noise. Based on this model, the dynamics of bimanual coordination is represented by the landscape of the potential function (Fig. 1).

In Fig. 1, the two valleys of different depth represent the default coordination patterns of different stability (located at 0° and 180°). An overdamped particle moving freely in this landscape represents the current coordination state of the system. Thus, depending on its initial state, the system is attracted to one of the two valleys. The relative depths of the two valleys may vary as a function of b/a (oscillation frequency), thus modifying the attractive strength of the stable states and eventually leading to a monostable landscape (phase transition).

The attractive properties of stable states (0° and 180° of relative phase) result from the nonlinear coupling existing between limbs, that is, to the informational flow that links the system's components and captures the multiple interactions on various levels (neural, musculo-skeletal, vascular, etc.; see also Bingham et al. (17)). The neural basis of bimanual coupling is determined by the bilateral interactions and information flows circulating essentially between the two hemispheres and resulting in what is called the neural crosstalk occurring at dif-

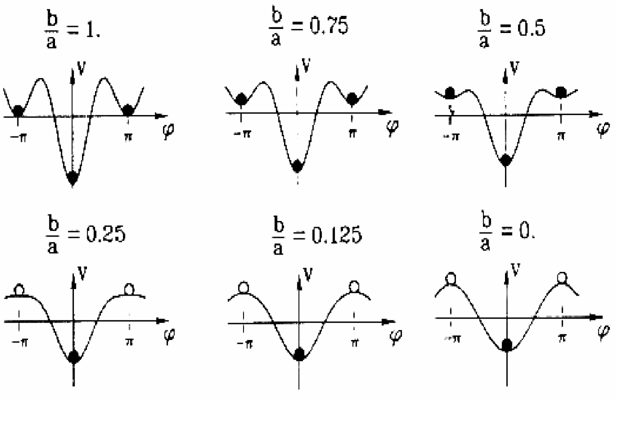

Fig. 1. HKB potential function on the interval (–180°, 180°) for different values of b/a

ferent levels of the central nervous system (CNS) (18–21).

1.2. ***Symmetry-breaking phenomena.*** By definition, coordination consists in establishing stable and accurate spatiotemporal relationships between (among) two (or more) components. These components might be relatively similar (bimanual coordination) or structurally different (speech). To take into account the neuroanatomical differences along with differences in intrinsic frequency proper to each component, a "broken symmetry" term ($\delta\omega$) has been added to the HKB model (22). Therefore, "relative coordination" was introduced into coordination dynamics. In contrast with "absolute coordination" (phase locking), relative coordination reflects a less rigid and more realistic behavior. At very low values of asymmetry ($\delta\omega \approx 0$), one could obtain phase locking as in the original symmetric coordination model but with a slight shift from the initial patterns (relative coordination). However, with increasing asymmetry, the attractors are weakened and eventually disappear (loss of synchronization, see Fig. 2). Interestingly, the modified version of the phase dynamics accounts for both asymmetry magnitude (represented by the added $\delta\omega$ term) and coupling strength (represented by b/a ratio). In other terms, the onset of the running solution depends upon both "$\delta\omega$" and "b/a" values.

The "symmetry-breaking" concept introduced by Kelso et al. (22) is considered as a kind of perturbation of the initial dynamic repertoire of the system. Later on, Fuchs and Jirsa (23) introduced an additional form of symmetry breaking, which rather modulates the available dynamic repertoire. This latter form of asymmetry reflects a different type of mechanisms that could not be understood in the framework of Kelso et al. (22). It is more related to the functional aspects of the perception-action cycle rather then biomechanical ones. Fuchs and Jirsa's parameter "σ" allows the coordinating system to interchange the position of the attractors, e.g. for $\sigma=1$, the potential landscape becomes totally reversed so that the inphase pattern becomes the less stable pattern and increasing the oscillation frequency would give rise to a transition to the antiphase pattern (as observed in Carson et al., (24)). More interestingly, for intermediate values of σ ($\sigma \approx 0.5$), the potential curve looses its stable fixed points, leading to a total absence of coordination (components act independently, see Fig. 3). The mechanisms giving rise to such symmetry breaking are probably related to the nature of the neural coupling underlying the coordination dynamics.

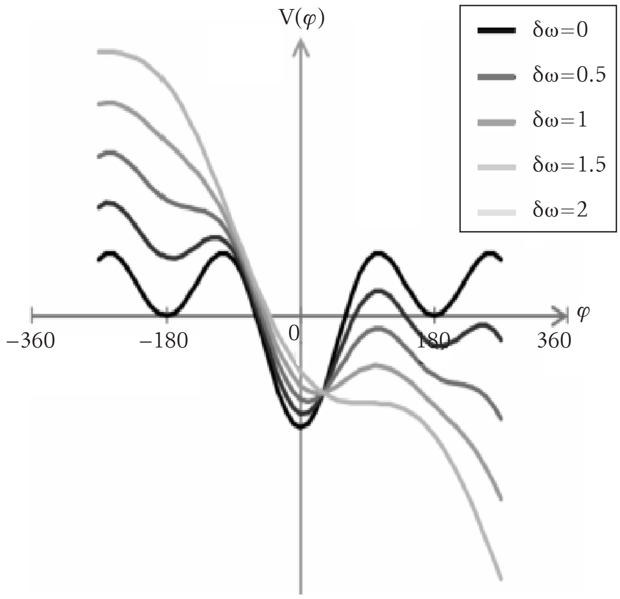

Fig. 2. Representation of the potential V(φ) of coordination dynamics with broken symmetry

The increase of $\delta\omega$ induces a progressive vanishing of the stable fixed points ($\varphi=0$, ±180°) together with a shifting away from the pure 0° and 180° patterns.

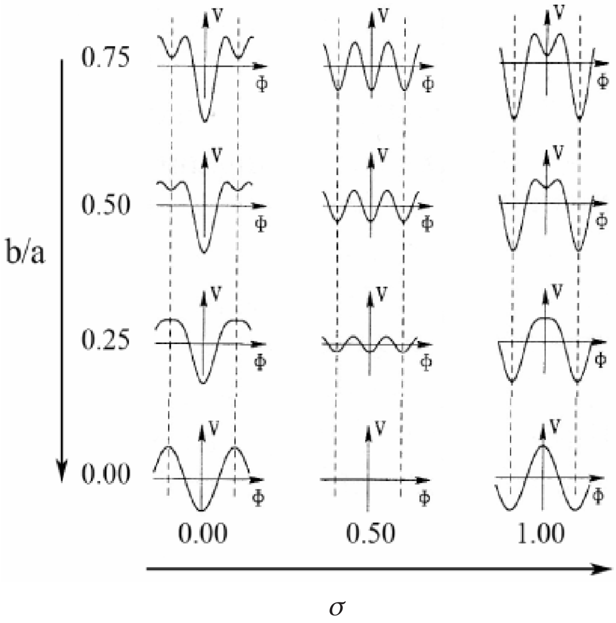

Fig. 3. Potential function from Fuchs-Jirsa's extension of the HKB equation for different values of "b/a" and "σ"

Both aspects of asymmetry, neuromechanical ($\delta\omega$) and perceptual-motor (σ), contributed to a better understanding of the coordination dynamics, along with providing a more realistic representation of coordinative behavior. These symmetry-breaking phenomena are of a particular importance when addressing the dynamics of a perturbed system, i.e. where asymmetries are accentuated by a central or peripheral pathology.

In analogy to the HKB model of rhythmic coordination patterns, Schöner (25) proposed a dynamical model to capture the synchronization/desynchronization tendencies observed in discrete bimanual coordination (26, 27). Synchronization tendency results from the coupling effects constraining limbs to act as a single unit under functional synergies. It consists in mutual temporal entrainment leading to a common behavior even if the constraints imposed to each of the limbs are different (28). The same coupling could be observed on a spatial level where limbs are constrained to share a common trajectory (29). The model proposed by Schöner (25) predicts that depending on the asymmetry between limbs, bimanual coordination may (or not) be dominated by one component, and coupling may (or not) be strong enough to lead to synchronization. The breaking of synchronization between limbs is associated to a sequential initiation of discrete movements.

More recently, a unifying perspective to continuous and discrete movements has been offered by Huys et al. (30) using the first established principles in dynamic system theory. In summary, the excitatory model (31) proposes that movements, independently of the discrete or continuous nature of the adopted regime, can be described by a flow field in the state (or phase) space. The description of movement patterns via phase flows offer a powerful theoretical tool to descried and understand dynamics patterns and coordination dynamics (see Jirsa and Kelso (31) for more details).

In the following section, we argue on how the conceptual framework of the synergetic approach (6, 25, 31) could provide some interesting insights to investigate coupling alterations after stroke along with inspiring new rehabilitation strategies directed toward the recovery of an efficient coordinative behavior.

2. New directions to bimanual coordination in stroke offered by the dynamic systems approach

2.1. Two coordinated hands are more than the addition of "one plus one." Most daily living activities require the simultaneous use of both hands involving symmetrical (moving a large box) and asymmetrical (opening a jar) movements. With age, we become even more dependent of bimanual movement (32), which is particularly handicapping for persons who have impaired (or no) manual control, as stroke patients. In this respect, it is known that, even after a long rehabilitation period, over 50% of patients suffer from long-term impaired upper limb function compromising their autonomy and quality of life (2). Consequently, over the two decades, researchers and clinicians concentrated their efforts both on the understanding of manual deficits due to stroke and on the development of new rehabilitation strategies (e.g. constraint-induced movement therapy, robot-assisted training, bimanual arm therapy, see Oujama et al. (33) for a review). Nonetheless, an important fact was often omitted concerning that functional abilities (essentially bimanual) are not a simple addition or combination of one-handed skills. Actually, from the point of view of dynamic systems, bimanual behavior is considered as the result of a task-specific functional pattern (synergy), where the two components (upper limbs) act as a single unit. Therefore, characterizing unimanual impairments is not sufficient to determine the extent of bimanual deficits, and by the same logic, rehabilitating unimanual control would not ensure the improvement of the bimanual one.

Several studies have examined reaching behavior in stroke. However, the majority of these studies used the bimanual behavior as a specific context to characterize the kinematical performance of the paretic limb and compare it to the unimpaired limb. Authors mainly reported a decrease in peak velocity, a decrease in movement amplitude with an increase in trajectory curvature, and an increase in off-axis forces against the support surface, moreover a segmentation in movement with a decrease in movement smoothness (leading to multiple peak velocities during the same movement cycle) (34, 35).

In stroke rehabilitation literature, alterations of bimanual coordination are usually considered as the consequence of the paretic arm impairment. Undeniably, motor deficits in the paretic arm constitute a major obstacle to the recovery of bimanual coordinated movements, most likely because they introduce an asymmetry between the two-hand kinematics. The dynamic systems approach to bimanual coordination suggests that bimanual asymmetry could be attenuated, at least in part, through coupling interactions between limbs. Thus, investigating how coordination principles persist or are eventually lost in stroke patients may constitute a promising, though indirect, window into brain/behavior dynamic relationships when various components of the NMSS are (more or less severely) altered. A careful analysis of the literature suggests however that the status of bimanual coordination in stroke rehabilitation remains ambiguous (36–39). Although most authors often underlined the importance of bimanual coordination recovery for stroke patients, bilateral arm training strategies (BATRAC, APBT, BIT, etc.) have been proposed as a tool for improving, quasi-exclusively, the individual performance of the paretic limb. Accordingly, impairment levels along with the response to therapy (recovery) were always measured by using motor scores and dexterity index tests, and in order to satisfy the therapists concerns for daily living activities, qualitative functional assessments were often used (Fugl-Meyer Assessment Score, Action Research Arm Test, Wolf Motor Function Test, etc.). Unfortunately, on the one hand, all of these tests do not provide any information about the possible causes for deficient task performance, in particular those resulting from alterations in bimanual coupling. Moreover, on the other hand, none of them is trained-task specific, i.e., none is directed toward the assessment of the task(s) used for rehabilitation.

2.2. ***Clinical assessment through the use of specific functional neurobehavioral variables.*** Concerning assessment strategies and methods, the attention of therapists should be drawn on several important points arising from the dynamic systems approach to coordination patterns: (a) the assessment of the persistence of the basic bimanual movements repertoire could be a preliminary step toward a better understanding of the NMSS dysfunctions; (b) deficits or gains in bimanual coordination do not automatically arise from impairments or progress in unimanual control instead, they must be looked at as specific synergies; and (c) restoring the default mode of interlimb coupling may be indicative of an ongoing re-learning process, which is of potential benefit for stroke patients.

Assessing bimanual coordination performance and interlimb coupling, in order to quantify and qualify the nature of coordination deficits in stroke, requires the identification of the appropriate "collective" variables. Relative phase and relative timing between limbs, which are the order parameters of coordination dynamics according to the dynamic systems approach (respectively in rhythmic and discrete coordination tasks), are good candidates to capture changes in bimanual coordination accuracy and stability in stroke (15, 40). Such variables could be looked at as behavioral signatures providing an effective and accessible tool to assess coordination and coupling impairments after a CVA. Moreover, it could also be used to evaluate recovery during and following rehabilitation without having to use "heavy" or invasive techniques. However, these variables do not replace functional scores and kinematical tests; instead they provide a complementary outcome measure specific to the assessment of the spatiotemporal relationships between coordinated components, which are often the primary locus for dysfunctions in pathological movement disorders.

It can be hypothesized that the unilateral hemispheric lesion in stroke patients might disturb the connectivity scheme within the CNS, which will affect the coupling strength and consequently the stability of coordination patterns. Theoretically, such hypothesis is supported by Banerjee and Jirsa's dynamical model (21) on the influence of neural connectivity and time delays of information flows on the stability of inphase and antiphase coordination patterns. This model is based on the neural crosstalk concept (18, 19), which gives rise to the bimanual functional coupling scheme. According to Banerjee and Jirsa (21), the increase in variability of bimanual coordination patterns can be predicted and explained by the alterations of neural connectivity (which mimics the changes in coupling strength in the HKB model) and also by an increase in time delays of information circulation and information processing in the nervous system. However, existing data are spare in this respect since researchers were primarily interested in accuracy of bimanual performance rather than in movement variability. Actually, although the variability has been considered as a very important parameter in the dynamic systems approach to coordination patterns, it is still far from being generally integrated into therapeutic practice (41). Recently, though not in the theoretical context of the dynamic pattern theory, few studies have been carried out to assess stability, accuracy of preferred patterns (i.e. phase and antiphase) and, eventually, phase transitions (in rhythmic and discrete coordination tasks) in hemiparetic patients. In general, they reported a decrease in consistency, accuracy, speed, and synchrony of bimanual movements (40, 42, 43). Obviously, researchers and therapists should accord more attention to the intraindividual variability of coordination patterns. It is a significant indicator of the processes underlying movement production. More specifically, it provides interesting insights on the stability of neurobehavioral coordination patterns as well as indirect information about the interlimb coupling strength.

2.3. ***Clinical intervention through the manipulation of specific constraints.*** According to the dynamic systems approach, stable bimanual coordination patterns emerge as the result of a coalition of internal (i.e. brain connectivity and neural dynamics) and external (i.e. task and environmental) constraints. Consequently, when internal constraints are altered due to a given pathology, e.g., stroke, the adaptation of the external constraints imposed to the system during rehabilitation becomes of a fundamental importance. More precisely, to enhance recovery through inducing plastic changes at different levels of the CNS, the adopted neurorehabilitation strategy should be able to adapt task and environmental constraints in order to compensate for the dysfunctional internal constraints. The cornerstone of a "dynamical strategy" to rehabilitation lies in the exact identification, the appropriate setting, and the adequate manipulation of different external constraints, which facilitate the production of adaptive coordinated behavior. By conjugating (a) scaling control parameters of the coordination pattern (e.g. movement speed, physical support, etc.), (b) providing behavioral information (e.g. instruction on movement goal, augmented auditory or visual feedback, guiding metronome, etc.), and (c) practicing a single or multiple coordination task across multiple training sessions, therapists may expect to obtain both short-term and delayed effects on coordinated behavior, as a result of stabilized CNS adaptations. Short-term effects would result from the transient effects of control parameters and behavioral information. Long-term effects would result from the repetitive practice in specific conditions. Here, an important message arising from the dynamic systems approach is that, for a given coordination pattern, the inappropriate scaling of the control parameter (e.g. movement speed) may preclude or, conversely, facilitate the production of an adaptive coordinated behavior.

2.4. ***Exploiting symmetry-breaking phenomena.*** The importance we accord to external constraints scaling is inspired and supported by the broken-symmetry principle. Actually, we consider coordination impairment in stroke partially resulting from a symmetry-breaking phenomenon in the coordination dynamics. According to Schöner's (25) model of discrete bimanual coordination, it can be hypothesized that relative timing between limbs expresses the effects of two types of factors: (a) biomechanical factors, such as neuromuscular stiffness of the paretic limb (spasticity), and (b) neural coupling factors (cross-talk). Thus, each of these factors could be the source of a certain amount of asymmetry that will shape the potential landscape of the coordination dynamics. Currently, we are conducting several experiments in order to determine the respective effects of each of these asymmetry sources, both in healthy individuals (by manipulating informational and mechanical constraints) and stroke patients (with different types of lesions and severity levels). We are particularly interested in exploring whether (more or less severely impaired) stroke patients are able to perform synchronized (relatively stable) bimanual patterns when asymmetry between limbs is attenuated by specific manipulations of constraints on either the nonparetic (e.g. progressive mechanical and/or informational loading) or the paretic arm (focus of attention, reduction of spasticity). An eventual tendency to resynchronization when asymmetry is attenuated would correspond to a transition from antiphase to inphase pattern. Moreover, at a given level of dissimilarity between limbs, we expect to observe a transient loss of coordination characterized by a complete independence of the limbs. In the extended version of the HKB model, such situation has been simulated thanks to a frequency detuning parameter (22). This parameter acts as a local mechanism on individual states thereby resulting in changes in the directional bias of phase transitions (antiphase to inphase) and occurrence of phase wrapping (no coordination or relative coordination). In Fuchs and Jirsa's extension, the symmetry breaking parameter acts as a global mechanism affecting the entire dynamic repertoire by modulating the stability of all coordination patterns. In Schöner's model, however, increasing temporal asymmetry between limbs is not predicted to give rise to relative coordination but instead, to abrupt transition from synchronized to desynchronized pattern. Thus, if relative coordination was observed, an extension should be added to Schöner's model in the spirit of Fuchs and Jirsa's model (23) and would correspond, in our experimental paradigm, to a transition from desynchronization to synchronization tendency when temporal asymmetry between limbs is attenuated. Since neural coupling is presumably altered as a consequence of CVA lesion (attention deficits, time delays in the information exchange, etc.), the type of symmetry breaking following Fuchs and Jirsa offers itself as a candidate mechanism. The effects of reducing spasticity of the paretic limb on bimanual coordination will also be of particular interest to distinguish the respective effects of neuromuscular factors and neural coupling. Finally, one can hypothesize that behavioral expressions of asymmetries and relative coordination caused by CVA lesions might depend on multiple factors, e.g. the location of the lesion (dominant/nondominant hemisphere), the age of the patient, and the constraints of the task.

From a therapeutic point of view, we are used to consider coupling as functional only when it permits to create a "positive entrainment effect" that is, when temporal and/or spatial features of the nonparetic arm trajectory interfere with the paretic arm trajectory thereby improving its performance. Such reasoning encouraged researchers and therapists to examine and develop the use of bimanual training in rehabilitation (37, 44). However, the predictions that in two-handed conditions, the paretic limb movement will be faster, more accurate, and smoother were rarely verified in the existing literature. Yet, from an objective point of view, coupling exists as long as there are spatial and temporal interferences, i.e., even an asymmetric influence of the paretic limb toward the nonparetic one indicates the persistence of bimanual coupling. The results observed in the literature, both in healthy (26, 28) and stroke participants (43–47), suggest a predominant, asymmetric coupling effect from the slower (i.e. paretic) to the faster (i.e. nonparetic) limb. Therapeutic interventions should then focus on training bimanual coordination in specific conditions that reduce interlimb asymmetries. For instance, one can propose to do so by: (a) adapting mean movement time, (b) reducing effective asymmetry between limbs (e.g. by loading the arm, reducing spasticity, etc.), (c) changing asymmetry through changes in informational constraints, (d) changing attentional conditions of the task either by instructing participants to allocate more attention to the paretic arm or by reorganizing the starting point and targets locations (see (48, 49)).

Conclusion

No doubt, the dynamic systems approach to research can significantly contribute to assessment and rehabilitation in stroke. In the present paper, we intended to provide a new conceptual and methodological framework to approach a bimanual coordination study and rehabilitation in stroke. In this respect, we focused on how cerebral vascular accident-induced alterations and functional recovery of coordinated behaviors can be understood as the result of complex interactions among multiple constraints arising at different levels of the neuro-musculo-skeletal system. By reviewing and illustrating the elementary principles of coordination dynamics in both cyclic and discrete movement tasks, we concretely envisaged a number of implications to understand how one might exploit self-organizing properties and coupling principles in order to assess bimanual behavior and stimulate the recovery of more adaptive coordinated movements.

The suggestions made in the current paper open doors for new perspectives in research and new strategies for clinical practice. However, before making formal recommendations, experimental and clinical studies are still necessary. In particular, further studies are still needed in order to elaborate founded guidelines to improve the efficacy of upper limb rehabilitation strategies regarding the recovery bimanual coupling. Such a program is currently in progress in our laboratory. It should help to determine how bimanual coordination training could take part of a global and comprehensive neurorehabilitation strategy. Nevertheless, even in absence of firm recommendations, we encourage researchers and clinicians to include the promising concepts and methods of the dynamic systems approach into their reasoning and practice.

Dinaminių sistemų pritaikymas sutrikus abiejų rankų koordinacijai po insulto. Reikšmė reabilitacijai ir moksliniams tyrinėjimams

Rita Sleimen-Malkoun, Jean-Jacques Temprado, Eric Berton
Valstybinio mokslinių tyrimų centro ir Viduržemio jūros universiteto E. J. Marey judėjimo mokslų institutas, Marselis, Prancūzija

Raktažodžiai: insultas, abiejų rankų koordinacija, dinaminės sistemos, reabilitacija.

Santrauka. Per pastaruosius 30 metų sukurtos dinaminių sistemų metodikos padėjo išsiaiškinti principus, kaip vykdoma tarpgalūninė koordinacija, jos dinamiką bei nervinės reguliacijos principus sveikiems žmonėms. Šio tyrimo tikslas – parodyti, kaip šios dinaminės sistemos gali pagelbėti kuriant teorines ir metodines priemones, taikytinas asmenims, turintiems abiejų rankų koordinacijos sutrikimų po insulto, bei jų reabilitacijai. Lyginant su įprastiniais metodais šis originalus tuo, jog galima vertinti ir pagerinti sutrikusią galūnių koordinaciją. Numatome dinaminių sistemų pritaikymų naudingumą siekiant suprasti elgsenos pasekmes, esant centrinės nervų sistemos pažeidimui, abiejų rankų dinamikai po insulto, taip pat nusakoma, kaip panaudoti centrinės nervų sistemos plastiškumą bei saviorganizuojančius procesus, siekiant atkurti koordinuotus judesius.

Išvados. Esant sutrikusiai abiejų rankų koordinacijai po insulto, naudinga dinaminių sistemų metodika. Reikalingi eksperimentiniai ir klinikiniai tyrimai, siekiant sukurti ir patvirtinti reikalingas nuorodas gydymui.

References

1. Kwakkel G, Kollen BJ, van der Grond J, Prevo AJ. Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. Stroke 2003;34:2181-6.
2. Verbunt JA, Seelen H AM, Ramos FP, Michielsen BHM, Wetzelaer WL, Moennekens M. Mental practice-based rehabilitation training to improve arm function and daily activity performance in stroke patients: a randomized clinical trial. BMC Neurol 2008;8:7.
3. Haken H. Synergetics: an introduction. 3rd ed. Berlin: Springer-Verlag; 1983.
4. Kelso JAS. On the oscillatory basis of movement. Bull Psychon Soc 1981;18:63.
5. Kelso JA. Phase transitions and critical behavior in human bimanual coordination. Am J Physiol 1984;246:R1000-4.
6. Haken H, Kelso JAS, Bunz H. A theoretical model of phase transition in human hand movements. Biol Cybern 1985;51:347-56.
7. Kelso JAS. Dynamic patterns: the self-organization of brain and behavior. Cambridge: MIT Press; 1995.
8. Kelso JAS. Coordination dynamics. In encyclopedia of complexity and systems science. Meyers RA, editor. Springer; 2009.
9. Fonseca RT, Holt KG, Saltzman E, Fetters L. A dynamical model of locomotion in spastic hemiplegic cerebral palsy:

influence of walking speed. Clin Biomech (Bristol, Avon) 2001;16(9):793-805.
10. Fonseca ST, Holt KG, Fetters L, Saltzman E. Dynamic resources used in ambulation by children with spastic hemiplegic cerebral palsy: relationship to kinematics, energetics, and asymmetries. Phys Ther 2004;84(2):344-54.
11. Holt KG, Fonseca ST, LaFiandra ME. The dynamics of gait in children with spastic hemiplegic cerebral palsy: theoretical and clinical implications. Hum Mov Sci 2000;19:375-405.
12. Schalow G. Stroke recovery induced by coordination dynamic therapy and quantified by the coordination dynamic recording method. Electromyogr Clin Neurophysiol 2002;42(2):85-104.
13. Schalow G. Symmetry diagnoses and treatment in coordination dynamics therapy. Electromyogr Clin Neurophysiol 2006;46(7-8):421-31.
14. Scholz JP. Dynamic pattern theory: some implications for therapeutics. Phys Ther 1990;70(12):827-43.
15. Emmerik (van) REA. The functional role of movement variability in movement coordination and disability. In: Davis WE and Broadhead GD, editors. Ecological task analysis: Looking back, thinking forward. Champaign. Ill: Human Kinetics; 2004.
16. Sleimen-Malkoun R, Temprado JJ, Jirsa VK, Berton E. New directions offered by the dynamical systems approach to bimanual coordination for therapeutic intervention and research in stroke. Nonlinear Dynamics Psychol Life Sci 2010; in press.
17. Bingham GP, Schmidt RC, Turvey MT, Rosenblum LD. Task dynamics and resource dynamics in the assembly of a coordinated rhythmic activity. J Exp Psychol Hum Percept Perform 1991;17(2):359-81.
18. Cardoso de Oliveira S. The neuronal bases of bimanual coordination: recent neurophysiological evidence and functional models. Acta Psychol (Amst) 2002;110(2-3):139-59.
19. Carson RG. Neural pathways mediating bilateral interactions between the upper limbs. Brain Res Rev 2005;49(3):641-62.
20. Carson RG, Kelso JAS. Governing coordination: behavioural principles and neural correlates. Exp Brain Res 2004;154:267-74.
21. Banerjee A, Jirsa VK. How do neural connectivity and time delays influence bimanual coordination? Biol Cybern 2007;96(2):265-78.
22. Kelso JAS, Delcolle JD, Schöner G. Action-perception as a pattern formation process. In: Jeannerod M, editor. Attention and performance XIII. Hillsdale, NJ: Erlbaum; 1990. p. 139-69.
23. Fuchs A, Jirsa VK. The HKB model revisited: how varying the degree of symmetry controls dynamics. Hum Mov Sci 2000;19(4):425-49.
24. Carson RG, Riek S, Smethurst CJ, Párraga JF, Byblow WD. Neuromuscular-skeletal constraints upon the dynamics of unimanual and bimanual coordination. Exp Brain Res 2000;131(2):196-214.
25. Schöner G. A dynamic theory of coordination of discrete movement. Biol Cybern 1990;53(4):257-70.
26. Kelso JAS, Putnam CA, Goodman D. On the space-time structure of human interlimb co-ordination. Q J Exp Psychol A 1983;35(2):347-75.
27. Corcos DM. Two-handed movement control research. Res Q Exerc Sport 1984;55(2);117-22.
28. Kelso JAS, Southard DL, Goodman D. On the coordination of two-handed movements. J Exp Psychol Hum Percept Perform 1979;5:229-38.
29. Franz EA, Zelaznik HN, McCabe G. Spatial topological constraints in a bimanual task. Acta Psychol (Amst) 1991;77:137-51.
30. Huys R, Studenka BE, Rheaume NL, Zelaznik HN, Jirsa VK. Distinct timing mechanisms produce discrete and continuous movements. PLoS Comput Biol 2008;4(4).
31. Jirsa VK, Kelso JAS. The excitator as a minimal model for the coordination dynamics of discrete and rhythmic movement generation. J Mot Behav 2005;37(1):35-51.
32. Kitbreath SH, Heard RC. Frequency of hand use in healthy older persons. Aust J Physiother 2005;51(2):119-22.
33. Oujamaa L, Relave I, Froger J, Mottet D, Pelissier JY. Rehabilitation of arm function after stroke: literature review. Ann Phys Rehabil Med 2009;52:269-93.
34. Krebs HI, Aisen ML, Volpe BT, Hogan N. Quantization of continuous arm movements in humans with brain injury. Proc Natl Acad Sci USA 1999;96:4645-9.
35. Kamper DG, McKenna-Cole AN, Kahn LE, Reinkensmeyer DJ. Alterations in reaching after stroke and their relation to movement direction and impairment severity. Arch Phys Med Rehabil 2002;83(5):702-7.
36. Cauraugh JH, Summers JJ. Neural plasticity and bilateral movements: a rehabilitation approach for chronic stroke. Prog Neurobiol 2005;75(5):309-20.
37. McCombe Waller S, Whitall J. Bilateral arm training: why and who benefits? NeuroRehabilit 2008;23(1):29-41.
38. Stewart KC, Cauraugh JH, Summers JJ. Bilateral movement training and stroke rehabilitation: a systematic review and meta-analysis. J Neurol Sci 2006;244(1-2):89-95.
39. Stoykov ME, Corcos D. A review of bilateral training for upper extremity hemiparesis. Occup Ther Int 2009;16(3-4):190-203.
40. Ustinova KI, Fung J, Levin MF. Disruption of bilateral temporal coordination during arm swinging in patients with hemiparesis. Exp Brain Res 2006;169(2):194-207.
41. Harbourne RT, Stergiou N. Movement variability and the use of nonlinear tools: principles to guide physical therapist practice. Phys Ther 2009;89(3):267-82.
42. McCombe Waller S, Whitall J. Fine motor control in adults with and without chronic hemiparesis: baseline comparison to nondisabled adults and effects of bilateral arm training. Arch Phys Med Rehabil 2004;85(7):1076-83.
43. Rose DK, Winstein CJ. The co-ordination of bimanual rapid aiming movements following stroke. Clin Rehabil 2005;19(4):452-62.
44. Harris-Love ML, McCombe Waller S, Whitall J. Exploiting interlimb coupling to improve paretic arm reaching performance in people with chronic stroke. Arch Phys Med Rehabil 2005;86:2131-7.
45. Garry ME, van Steenis RE, Summers JJ. Interlimb coordination following stroke. Hum Mov Sci 2005;24(5-6):849-64.
46. Lewis GN, Byblow WD. Bimanual coordination dynamics in poststroke hemiparetics. J Mot Behav 2004;36(2):174-88.
47. Messier S, Bourbonnais D, Desrosiers J, Roy Y. Kinematic analysis of upper limbs and trunk movement during bilateral movement after stroke. Arch Phys Med Rehabil 2006;87(11):1463-70.
48. Sherwood DE. Distance and location assimilation effects in rapid bimanual movement. Res Q Exerc Sport 1991;62(3):302-8.
49. Riek S, Tresilian JR, Mon-Williams M, Coppard VL, Carson RG. Bimanual aiming and overt attention: one law for two hands. Exp Brain Res 2003;153(1):59-75.

Received 17 May 2010, accepted 7 June 2010
Straipsnis gautas 2010 05 17, priimtas 2010 06 07