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L'acquisition des habiletés motrices complexes.

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L'approche dynamique a apporté, dans le domaine de l'apprentissage, un certain nombre de propositions novatrices. La première est que l'acquisition d'une coordination nouvelle ne se construit pas à partir de rien, ou d'un chaos initial, mais sur la base des coordinations initiales, ou spontanées, du système. Le comportement du débutant est alors conçu comme le reflet des tendances spontanées de coordination, dont les principes peuvent être définis à un niveau très général. Lorsque la coordination à apprendre diffère qualitativement de la coordination spontanée, l'apprentissage se caractérise par une transition de phase, c'est-à-dire qu'un nouvel attracteur va se substituer à l'attracteur initial. Les caractéristiques et les conditions d'émergence de cette transition sont cependant encore mal connues, ainsi que les moyens susceptibles d'en accélérer l'apparition.

Les communications de Pier Zanone, Jean-Jacques Temprado et Didier Delignières, Déborah Nourrit et Thibault Deschamps contribuent à illustrer ces principes. Zanone évoque notamment l'apprentissage de coordinations bimanuelles entrant en compétition avec le répertoire spontané. Ses travaux ont notamment montré les répercussions de l'acquisition d'une coordination nouvelle sur les coordinations initiales du système (déstabilisation temporaire de coordinations spontanées, stabilisation de coordinations non spécifiquement pratiquées,..). Temprado décrit des différences qualitatives entre les coordinations de débutants et d'experts dans le service au volley-ball. Ces différences suggèrent que l'accès à l'expertise est bien caractérisé par une transition de phase. Delignières, Nourrit et Deschamps présentent les résultats d'une étude longitudinale des effets de la pratique sur un simulateur de ski. Les résultats montrent que les sujets exploitent assez longtemps un premier type de coordination, qui leur permet de résoudre de manière satisfaisante les problèmes posés par la tâche. Puis au bout de quelques semaines, on observe une bifurcation vers un autre type de comportement, qui semble utiliser de manière plus optimale les caractéristiques du dispositif. L'expérimentation montre que cette bifurcation est progressive, et se réalise au cours d'une phase caractérisée par un régime bistable, où les deux comportements semblent simultanément disponibles.

La communication de Keith Davids et ses collaborateurs jette un regard nouveau sur un thème déjà largement débattu: l'aménagement de contraintes des tâches en vue d'optimiser l'apprentissage. On s'accorde généralement à considérer la simplification des tâches comme une aide essentielle à l'apprentissage: d'un point de vue cognitiviste, une telle stratégie permettrait de mettre la difficulté de la tâche à portée des capacités de traitement du sujet. Certains auteurs ont néanmoins évoqué les effets pervers d'une sur-simplification, sans cependant avancer d'explication satisfaisante. L'argumentation de Davids part des principes du couplage perception-mouvement: l'adéquation du comportement moteur aux contraintes environnementales repose sur une mise en relation étroite entre certaines données perceptives essentielles et le mouvement. Les auteurs suggèrent que ce couplage doit être préservé pour favoriser l'apprentissage. Or certaines stratégies didactiques (proposant par exemple de découper le geste en segments à travailler successivement) ne permettent manifestement pas aux sujets d'installer et l'exploiter ce couplage essentiel.

UNE PERSPECTIVE DYNAMIQUE DE L'ACQUISITION DE NOUVEAUX COMPORTEMENTS

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Mots-clés : Apprentissage, Développement, Posture graphique, Coordination bimanuelle

L'acquisition de nouveaux comportements est une problématique centrale en psychologie, et en psychologie du sport tout particulièrement. En dépit de son importance, son étude semble montrer deux limitations assez critiques. D'une part, cette acquisition a été le plus généralement évaluée en simples termes de changement/amélioration de la performance — un des paradigmes les plus usités en STAPS n'est-il pas la comparaison entre novices et experts ? —, négligeant quelque peu l'investigation des *mécanismes* sous-tendant le changement comportemental. D'autre part, la question a été traitée le plus souvent en isolation des processus d'acquisition se déroulant sur d'autres bases de temps, en particulier l'ontogenèse, écartant de la sorte toute possibilité de mise en évidence de processus génériques à l'origine de *toute* forme d'acquisition de comportements.

Dans cet exposé, nous présenterons un cadre théorique issu des théories de l'auto-organisation en physique et de modèles mathématiques de systèmes dynamiques qui rend compte de manière cohérente des principes et des processus qui président à l'acquisition de nouveaux comportements. Dans un premier temps, nous verrons comment cette perspective dynamique s'inscrit dans une lignée de modèles qui traitent de la question dans d'autres domaines des sciences de la nature et de la vie (e.g., l'évolution, la morphogenèse ou la différenciation cellulaire). Ensuite, deux fenêtres comportementales seront étudiées tant sur les plans empirique que formel : l'acquisition de la posture graphique chez le gaucher (Athènes & Guiard, 1991) et celle d'une coordination bimanuelle (e.g., Zanone et Kelso, 1997). Bien que ces deux phénomènes d'acquisition évoluent l'un sur quelques années de développement, l'autre sur quelques heures de pratique, ils montrent des similarités quant à leur déroulement qui supposent la mise en jeu de processus dynamiques identiques. Et c'est ainsi que l'exposé s'achèvera sur l'identification de quelques principes et mécanismes génériques qui régissent l'apparition de comportements nouveaux.

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Perception-Action Coupling: Implications for Practice Organisation during Acquisition of Self-Paced Extrinsic Timing Tasks

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Key words : Perception-action coupling ; task constraints ; practice organisation

Introduction

In this communication we review the implications of perception-action coupling for the structure of practice in interceptive actions and the implementation of learning strategies. Central to our analysis are questions about how task constraints should be structured during practice to enhance skill acquisition. In the study of natural interceptive actions such as one-handed catching, the emphasis is on *receptor anticipation* processes to guide ongoing action. Comparing data on timing behaviour in traditional motion prediction tasks and natural interceptive actions suggests that different control mechanisms may be employed by performers under different task constraints. Support for the idea of the specificity of task constraints is evidenced by the typical finding of larger variability in estimation of time-to-contact information reported in motion prediction studies. This level of variability in timing performance is often not present in natural tasks such as fast interceptive movements. The implication for sport psychologists is that perception-action coupling may provide a principle to structure practice of self-paced extrinsic timing tasks.

The Study of Bootsma (1989). Criticisms of the design of experimental paradigms to study perception and movement during interceptive tasks were made by Bootsma (1989). Bootsma's (1989) main target was the 'unprincipled' way in which processes of perception and movement have been studied separately. Bootsma (1989) examined the effects of de-coupling information and movement under three different types of task constraints. Seventeen participants were presented with squash balls dropped through a plastic tube (length = 50 cm, diameter = 4.3cm) from a height of 270 cm above a table surface. They were instructed to try to intercept the ball in one of three different randomised conditions: a) using their own arm and a bat; b) pressing a button to release a 55-cm mechanical arm to hit the ball just before it landed on the table top; and, c) pressing a button when the ball was judged to be level with the table-top surface (equivalent to motion prediction conditions). These conditions were suggested to represent a successive degradation in perception-action coupling. Data comparing percentage of accurate hits under the natural-arm task constraints (82.4%) and artificial-arm constraints (49.5%) were significantly different. Movement times were more variable under the natural-arm task constraints (14.6 ms) than in the artificial-arm task constraints (5.0 ms). These findings supported the notion of information as specificational in regulating behaviour under the natural task constraints of interceptive actions. The variability in timing the initiation of striking movements was lower under natural-arm task constraints (SD = 16.3 ms) compared to artificial arm task contraints (SD = 34.0 ms). When only perceptual judgements of interceptions were required, variability was significantly higher (61.8 ms) than both arm conditions.

Bootsma (1989) Revisited. In interpreting the data, Bootsma (1989) preferred not to consider an alternative explanation for the results: the view that "swinging a bat is more familiar to the subjects than pressing a button" (Bootsma, 1989, p.497). Since only 20 trials were performed in each block within a repeated-measures design, it is unclear whether the data may be attributed to the lack of familiarity of the participants with the specific task constraints of the artificial arm and motion prediction conditions. A stimulus-response compatibility argument, based on more extensive experience with the task constraints in the natural-arm condition, could also be proposed to explain the results. This explanation was scrutinised recently in our laboratory. We replicated the task constraints of Bootsma's (1989) experiment (i.e. the natural-arm and motion prediction conditions). Data indicated that, even after an 80-trial learning period (plus 20 familiarisation trials) movement initiation time (MIT) in the motion prediction conditions was significantly different from the natural-arm conditions ($F_{1,10} = 15.32$, $p < .01$). Results also demonstrated significant differences in the variability (operationalised by the SD) of MIT between the two conditions. Variability of MIT was greater in the motion prediction conditions compared to the natural-arm condition ($F_{1,10} = 11.95$, $p < .01$).

The data of Bootsma (1989) need not be interpreted as a result of greater experience with the task constraints of the natural-arm condition. When the number of trials in the perceptual judgement (i.e. CA) task were increased to 100 (including habituation trials), as evidenced by variability of MIT, performance was still significantly better in the natural-arm striking condition. We find no reason to disagree with the proposal of Bootsma (1989) for a conceptualization of "a movement-dependent use of perceptual information, emphasizing the inseparability [of perception and movement]" (Bootsma, 1989, p.498). It appears that the task constraints of striking a ball sets up the saliency of various sources of perceptual information involved in timing the movement (Stins and Michaels, 1997).

Implications for Practice Organisation in Sport

An interesting issue concerns the implications of these ideas for sport psychologists interested in practice in sport. Does the preservation of the coupling between key informational and task constraints provide a principled basis for task decomposition for the purposes of practice in sport? When sports tasks contain complex information processing demands, there are benefits in initially slowing down task performance or in breaking tasks into smaller parts components. A fundamental objective of traditional task decomposition techniques in sports training and coaching is the reduction of the attentional demands on the learner during skill acquisition, by making informational loads more manageable. The volleyball serve provides an ideal activity for studying this question. In successfully satisfying the task constraints of serving, the performer must integrate information provided by the perceptual system on the trajectory of the ball (vision), and from the motor system components (e.g., haptic and proprioceptive sources from the hand and arms) to facilitate successful striking. Recent work in our laboratory with national-level volleyballers has shown that the timing of the change in direction of the hip joint centre from back-swing to fore-swing occurred at an average of 76% of total movement time and was highly invariant ($\pm$ 0.5 %) (Davids et al., 1999). It seems that national-level players prefer to use a strategy of maintaining a consistent movement time during overarm serving and to initiate the movement of force production at a relative moment. . The previous analysis of the relationship between information from the ball zenith and initiation of forward hip movement showed that the occurrence of these two events was invariant and strongly coupled. In other words, as the ball reached its zenith, performers were able to pick up visual information to support the initiation of the force production phase with forward movement at the hip. This finding implies that individual servers were controlling the height of ball zenith to ensure that the time remaining before contact was equivalent to the time required for the proximo-distal unfolding of the kinematic chain involved in the striking movement.

The implication of these data is that, because visual information from the dropping ball constrains the initiation of the striking movement, ball toss should not be decoupled from the strike. Decoupling the ball placement phase from the reach and contact phase could disrupt co-ordination in self-paced extrinsic timing tasks. In our laboratory, when subjects were required to perform the ball toss with and without striking the ball, there were some noticeable differences in the characteristics in ball flight. A comparison of eight trials selected from each of the two conditions revealed two key differences which were consistent across subjects: i) the variance of ball zenith was less for the serving condition; and ii) the mean ball zenith was greater in the placement-only condition, compared to the condition in which the ball was actually struck. The greater ball zenith in the placement-only practice conditions may increase the likelihood of error at the point of contact. It seems that in the other condition, the performer and the ball form a 'serving system', and that consistent ball placement should be best practised in relation to striking, rather than in isolation. Since, the striking phase seems coupled to the ball-placement phase, it is unsurprising that different ball-placement profiles emerge under the different task constraints imposed on the learner. From a practical standpoint, the empirical data from our work on perception-action coupling are beginning to reveal some relevant information for research on the strategies of coaches and athletes during practice. More work is needed to focus on the implications of manipulating various constraints in the learning environment, and in understanding how to organise practice regimes in sport.

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INTER-JOINT COORDINATION SUBSERVING THE VOLLEY-BALL SERVE: A DYNAMICAL APPROACH TO EXPERTISE

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Mots-clés : Coordination pattern, dynamical approach, volley-ball, expertise.

Introduction

In the last decade, the number of works devoted to motor coordination has considerably increased. This recent concern reflects the desire to understand what mechanisms are needed in order to master the redundant degrees of freedom of the neuro-musculo-skeletal system while assembling stable but flexible coordination (Bernstein, 1967). Following Bernstein (1967), it has been suggested that a possible strategy for studying motor coordination is to 'summarize' the relations between the various components by one or several essential variables. Within the framework of a dynamical approach to motor learning, the acquisition of a new skill is considered as the transition of one stable coordination state to another stable state. This study concerns the development of expertise as reflected in the intra-limb coordination of the serving arm in the volleyball serve. The aim of this study was twofold 1) to identify the essential variable(s) that characterize(s) the coordination, and 2) to determine whether the development of coordination consists of the transition of one stable state to another, or directly from disorder to a unique final ordered coordination state.

Method

Subjects

Twenty male subjects took part in the experiment. An expert group and a novice group

Task

Subjects had to perform volleyball services of the overhand type, which is the common service for experts.

Movement analysis

The subjects were filmed from the side with a video camera (Panasonic AG 455 ME) with a frequency of 50 Hz and an exposure time of 0.001 s.

Movement variables

First, the performances of the two groups were compared to determine their effectiveness at the task. We then analyzed the coordination between shoulder, elbow, and wrist components via the trajectory of each of these joints along the x axis (i.e. in the forward-backward direction).

Results

Task Performance

Analysis of the performances thus confirmed that the two groups differed in their capacities to perform the task. Level of expertise is, therefore, a variable that allows us to distinguish the two groups, at least for task performance.

3.2. Time to maximum amplitude of joint displacement

The trajectories of the shoulder, elbow, and wrist of the serving arm in the front-back dimension, i.e. on the x-axis, were analyzed. Observation of the trajectories of the three components suggested the existence of important differences between the experts and the novices, in particular for the times of the trajectories' turning points at the start of the forward hitting motion. For the experts, peak shoulder amplitude was at 38 % of mean movement time. It preceded peak elbow amplitude (70 %) and peak wrist amplitude (82 %). The tests revealed significant differences between the times of peak amplitude of the shoulder and elbow, elbow and wrist, and shoulder and wrist. For the novice group, peak shoulder amplitude occurred at 42% of mean total movement time. It was followed by elbow and wrist peak amplitude, which both occurred at 69 % of mean total movement duration. Pairwise comparisons showed significant differences between the times of peak amplitude of the shoulder and elbow, the shoulder and wrist, but not the elbow and wrist.

3.3. Type of coordination

The time of the change from backward to forward movement, though a useful measure, is, however, a discrete variable that only gives limited information on the coordination of the different components. To analyze the coordination pattern between the shoulder, elbow, and wrist, we calculated the cross-correlation coefficients (with zero time lag) for the three pairs formed: shoulder/elbow, shoulder/wrist, and elbow/wrist. The type of coordination is reflected in the sign of the correlation coefficient. A correlation close to +1 indicates a strong in-phase coordination; a coefficient close to -1 indicates a strong anti-phase coordination; a coefficient close to 0 indicates that the joints function independently of one another.

We calculated the frequency of trials performed with an in-phase relationship (i.e. a positive correlation) of each joint-pair for each subject. There were significant main effects of expertise, joint-pair, and an interaction between these two variables. The decomposition of the interaction into simple effects showed that expertise was manifested in a modification - from positive to negative - of the sign of the correlation coefficient of the shoulder-wrist coupling. The mean frequency of trials for which the shoulder-wrist coupling was in-phase was 6.7% for the experts and 63.6% for the novices. The proportions of in-phase couplings were similar for the shoulder-elbow (experts: 80%, novices: 93.6%) and elbow-wrist joint-pairs (100% for both groups).

Analysis of different coordination patterns

To determine the extent to which different patterns were used, we took each subject group as a whole and looked at the different overall coordination patterns used. In other words, we considered the novices and the experts as two systems and calculated the frequency of the different patterns observed in each sample. Calculation of the frequency of each coordination pattern relative to the total number of trials performed by each group showed the presence of two dominant profiles. These results show that the coordination pattern representative of the experts (B) existed at a low frequency among the novices, and that the coordination pattern representative of the novices (A) persisted among the experts even after several years of extensive practice.

Discussion

This study had two goals. First, to identify (an) order parameter(s) or essential variable(s) characterizing intra-limb coordination in the volleyball serve. Second, to determine whether the development of expertise in this skill consists of a succession of different states of coordination.

Analysis of the nature of the inter-joint couplings showed that the coordination pattern of the volleyball serve differed qualitatively between the two groups of novices and experts, presumably as a result of the development of expertise. Analysis of the times of direction change (from backward motion to forward motion) of the three components suggested that expertise is manifested in a dissociation of the displacements of the shoulder, elbow, and wrist. Analysis of the signs of the cross-correlations of the joint-pairs showed that, among the novices, the dominant coordination pattern was that of an in-phase relationship of all three joint-pairs. In contrast, among the experts, the dominant coordination pattern was of an in-phase relationship of the shoulder/elbow and elbow/wrist joint-pairs, and an anti-phase relationship between the shoulder and the wrist. Thus, the nature of the coupling between the shoulder and the wrist constitutes a variable that allows summarizing the qualitative difference between the coordination patterns of the experts and the novices. Therefore it seems a good candidate as the essential variable of the intra-limb coordination of the serving arm.

The results of the present study also show that the development of expertise, as reflected in the intra-limb coordination of the serving arm is not an all or none process, but is a succession of at least two qualitatively different but stable states of coordination. This is consistent with a dynamical systems approach conception of learning, which considers the acquisition of new motor skills to result from the transition of one stable state to another (Zanone & Kelso, 1992). Considering each subject group (i.e. each level of expertise) as a system whose behavior can be analyzed with respect to the total number of trials performed, allowed us to examine the distribution of the different coordination patterns and to obtain additional information on the nature of the changes that underlie the development of coordination. The distributions observed among both the experts and the novices were trimodal and composed of the same coordination patterns. In other words, the coordination pattern of the expert existed among the novices, though at a low frequency, and the pattern of coordination of the novices existed among the experts, even after extensive practice. From a dynamical view of learning, one can assimilate the novices' repertoire to an initial 'intrinsic dynamic' from which expertise develops. Viewed in this light, expertise consists of the strengthening of a coordination pattern that exists intrinsically in the repertoire of the novice rather than in the creation of a completely new pattern.

This study confirms the interest of the expert-novice paradigm and the conceptual and methodological framework of the dynamical approach to coordination patterns in the study of the development of complex motor coordination, particularly those found in sporting contexts.

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L'EVOLUTION DES COORDINATIONS MOTRICES AU COURS DE L'APPRENTISSAGE: CONTINUITES ET RUPTURES

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Mots-clés : Apprentissage, modélisation dynamique, bifurcations

Introduction

L'apprentissage moteur a été longtemps conçu comme un processus d'affinement progressif et continu. Cette idée a notamment été portée par les théories cognitivistes, et trouve sa plus claire illustration dans le modèle classique de la loi puissance. Newell (1991) critique sévèrement ces conceptions. Selon lui, l'apprentissage est essentiellement discontinu, non-linéaire. Les descriptions continues ne constituent que des artefacts, liés (1) à la simplicité des tâches expérimentales (limitées le plus souvent à un seul degré de liberté), (2) à la brièveté de l'étude et (3) à la nature strictement chronométrique des variables dépendantes utilisées pour rendre compte de la performance.

On trouve cependant peu d’expérimentations dans la littérature susceptibles de satisfaire simultanément à ces trois objections. Le but de l’expérience présentée ici était d’analyser l’évolution du comportement dans une tâche complexe (le simulateur de ski), sur un terme suffisamment long (13 semaines de pratique). Nos analyses portent sur la modélisation de la dynamique du déplacement de la plate-forme du simulateur.

Dans un travail antérieur (Delignières *et al.* , 1999), nous n’avions pas pu mettre en évidence de modification qualitative majeure au cours de quatre sessions successives de pratique : les sujets impliqués dans l’expérimentation exploitaient une fonction d’amortissement de type *van der Pol*, et ce comportement ne semblait pas altéré par la pratique. La seule évolution notable résidait en une linéarisation progressive de la fonction de raideur, caractérisée lors des premiers essais par une fonction de *Duffing* fortement non-linéaire, perdant progressivement de l’importance au fur et à mesure des sessions. Nous faisons l’hypothèse qu’avec une durée plus longue de pratique, les sujets doivent bifurquer vers un autre type de comportement, exploitant de manière plus efficiente les propriétés de l’appareil.

Méthode

Cinq sujets, quatre hommes et une femme (âge moyen 29.2, écart-type 6.3) ont participé à cette expérimentation. Nous avons utilisé un simulateur Skier Edge®, modifié en mono-ski. Les sujets étaient absolument débutants dans la tâche au début de l’expérimentation. Chaque séance de travail était composée de dix essais d'une minute. Trois séances par semaine ont été réalisées, durant 13 semaines, soit en tout 39 séances de travail. La position du chariot du simulateur a été enregistrée en continu au moyen d'un potentiomètre, à une fréquence d'acquisition de 100 Hz. Les séries recueillies ont été traitées selon une adaptation de la *W-method* de Beek et Beek (1988), destinée à la construction de modèles dynamiques de mouvements rythmiques. Cette méthode se base sur l’analyse d’un cycle moyen normalisé (Mottet & Bootsma, 1999), et combine des procédures qualitatives graphiques et des procédures quantitatives pour déterminer la nature des termes à inclure dans le modèle et l’importance de leurs contributions respectives.

Résultats

La modélisation montre que les 5 sujets, dès le début de l'expérimentation ou après quelques essais "chaotiques", adoptent et exploitent de manière relativement stable un comportement d'amortissement de type *Rayleigh*. Au cours de l'expérimentation, tous les sujets transitent de manière plus ou moins brusque vers un comportement d'amortissement de type *van der Pol* (voir figure 1). Cette transition apparaît dès la septième séance pour le sujet 2, mais pas avant la 21[ème] pour le sujet 3. La phase de transition est parfois assez longue (voir sujets 1, 3 ou 5), et caractérisée par des comportements d'amortissement moins aisés à modéliser. La transition s'accompagne d'un accroissement brusque de la fréquence d'oscillation, passant d'une valeur de 1 Hz lors des essais la précédant, à une valeur moyenne de 1.4 Hz.

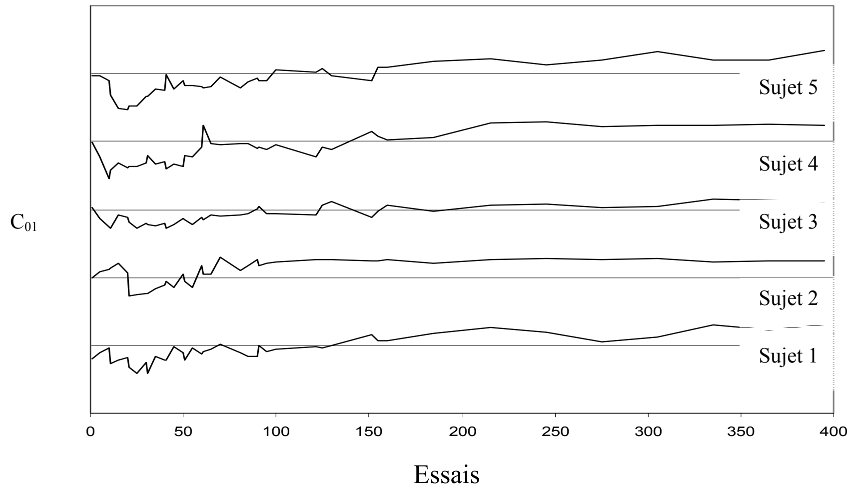

Figure 1 : Séries des coefficients d'amortissement linéaire obtenus lors de l'estimation d'un modèle de type Rayleigh. Lorsque ce coefficient est négatif, le modèle de Rayleigh est stable. Lorsqu'il est positif, les données peuvent généralement être ajustées sur un modèle de type van der Pol. La bifurcation apparaît donc au moment où la courbe passe des valeurs positives aux valeurs négatives.

L'évolution de la fonction de raideur est conforme à nos résultats précédents. Les premières sessions sont caractérisées par une fonction de raideur fortement non-linéaire, comprenant notamment des termes de *Duffing* de puissance 3 (négatif) et 5 (positif). La pratique induit une progressive linéarisation de cette fonction, qui semble précéder la bifurcation vers l'amortissement de type *van der Pol*.

Discussion

Cette expérimentation montre clairement que l'apprentissage moteur est un processus marqué par de profondes réorganisations qualitatives du comportement. Nos résultats permettent de distinguer deux étapes, la première correspondant à un comportement spontané, exploité et progressivement optimisé durant quelques semaines, et la seconde renvoyant à l'adoption d'un comportement expert. Le passage d'une étape à l'autre peut être conçu comme une bifurcation, au sens de la théorie des systèmes dynamique, entre deux attracteurs potentiels du système. Une analyse plus précise des essais encadrant et accompagnant la bifurcation devrait nous permettre de mieux comprendre la nature et la fonction de ce type de réorganisation du comportement au cours de l'apprentissage.

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