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Infant bouncing: Analysis of skilled and less-skilled behaviour

by

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Over the course of this project I have learned a great deal about biomechanics, motor control and the collection, interpretation and dissemination of scientific data. In the process of working with my advisor, colleagues and various other mentors, I have learned a great deal about myself and feel that I have grown academically, professionally and personally.

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ABSTRACT: This study examined joint kinematics and muscle activation patterns produced by infants of different bouncing skill levels as they bounced in a Jolly Jumper harness system. The relationship between three components of bouncing was also determined. The three components were: i) the oscillation pattern of the mass-spring system which can be characterized as a harmonic oscillator; ii) the baby's contribution to the bouncing behaviour which can be characterized in part as a forcing function and in part as a harmonic oscillator; and iii) the combination of these two components which corresponds to the output or the bouncing behaviour. Infants (N = 9) were instrumented with five surface electrodes over the lower leg muscles and dressed in black tights and a black long-sleeved body suit with reflective markers placed on the tights over seven body landmarks. Infants were then supported in a modified Jolly Jumper harness and encouraged to bounce. Loading of the harness and spring was recorded using a loadcell attached to the ceiling. Vertical ground reaction forces were recorded using two force platforms mounted into the floor beneath the infant's feet. Bouncing behaviour was recorded for six 30-second trials. While bouncing, the infants were filmed with a video camera placed at ninety degrees to the sagittal plane. The infants were grouped as less-skilled, moderately-skilled and skilled bouncers. There was a general trend from a chaotic to an organized pattern of interjoint co-ordination as the level of bouncing skill increased. Infants in the moderately-skilled and skilled groups bounced at one of two distinct frequencies, 1.5 or 2 times the resonant frequency of the spring. Similarly, the baby contributions and kinematics of the lower limbs as reflected in qualitative analysis of phase-plane plot patterns were distinctly different for the two frequencies of bouncing. The phase-plane patterns suggested that one group of infants used a spring-like control mechanism for lower limb movement while the second group of infants incorporated a point-specific (focused, position-specific) control of forces into the mechanism for lower limb movement. This distinction was less apparent in the qualitative analysis of angle-angle plots. The qualitative dynamics suggest that there are two predominant attractor states for the production of bouncing behaviour. This research expands the current literature of infant behaviour and furthers our understanding of the qualitative dynamics of skilled and less-skilled bouncing.

CHAPTER ONE

INTRODUCTION

It has been suggested that organized action patterns emerge from spontaneous activity as infants explore and exploit the physical properties of their bodies and environments (Goldfield, Kay and Warren, 1993; Thelen and Fisher, 1983). Assembling an action system that yields a stable movement pattern which corresponds to the intended action requires infants to become involved in a complex decision making process. The intricacies of controlling the movement pattern present complex problems which must be solved by an infant before he/she is able to produce successful movement behaviour. These problems are, in fact, more involved than they seem at first glance. An infant must decide which muscles to activate, in which sequence and to what level. Also, the position of the body and orientation of ground reaction forces will influence the movement outcome.

Goldfield *et al.* (1993) outlined an approach to motor learning and development from a dynamical perspective and reported the results of infant bouncing while using this model. Two processes are involved in the transformation of spontaneous activity into a task-specific action pattern. These processes are: i) assembly of an action system with low dimensional dynamics followed by, ii) tuning of the system to refine and adapt the movement. Assembly is a process of self-organization which establishes a temporary relationship amongst the components of the neuromuscular system, transforming the components into a task specific action system. Once assembled, the components are tuned so that the movements are adapted, or made functional, for specific environmental conditions. In the course of learning a task, an infant experiments with different combinations of musculoskeletal components, adopting different functions over the learning process to experience consequences of different movement patterns.

Most of the everyday actions of adults involve multi-joint movements in which specific patterns of joint movements are required in order to achieve segmental acceleration and to exert forces on the environment in the appropriate direction with the appropriate magnitude (van Ingen Schenau. Pratt and Macpherson. 1994). Formation of these patterns can be quite complex as demonstrated by the following problems: (1) transformation of joint rotations into the desired translation of objects or of one's own body: and (2) controlled application of force against the environment, often called "contact control tasks". The awesome task that faces developing infants is to discover and formulate specific patterns of joint motion that, once assembled must be tuned in order to adapt the movement pattern to changing environmental conditions.

For infants as well as adults. movement is a product not only of the central nervous system. but also of biomechanical and energetic properties of the body. environmental conditions and specific. sometimes changing. demands of the task. Organizing different systems to complete a fluid and flexible motor task is a complex process. and explaining how a motor pattern develops. demands an understanding of processes by which infants learn new skills. Growth or biomechanical factors are important in early infancy for skill acquisition. while practice and environmental conditions appear to be more dominant later in the perfection and advancement of coordination of a movement system. For example. Thelen. Fisher and Ridley-Johnson (1983) conducted a series of three experiments designed to test the behavioural consequences of the rapid growth which occurs during early infancy. In the first study. the relationship between differential growth rates during the early weeks and the disappearance of newborn stepping response was examined. The researchers reasoned that infants who had rapid growth rates would show the greatest decrease in step rate with increased maturation as the increased growth would in turn increase the segment mass. thereby increasing the physical demands placed on the infants while performing the stepping task. In studies two and three. the mass of the infants' legs was experimentally manipulated while the infants performed spontaneous kicking by adding weights to the infants' legs and by submerging the infants' legs under the water. respectively. The researchers hypothesized that adding weights to the legs would decrease the number of steps produced by the infants and would increase the maximum joint angles. indicating a weaker flexion of the lower limb. Furthermore. reducing the mass of the legs via submersion in water was expected to result in an increase in step frequency and a decrease the maximum joint angles of the infants legs. These researchers found that the rate of stepping was indeed limited by muscle strength (due to rapid physical growth) indicating that physical growth and neurological maturation were interdependent. Thelen and colleagues (1983) proposed that muscle strength development may not be synchronous with mass increase but rather that environment and neurological factors may also contribute to the rate of stepping produced by an infant. The disappearance of kicking behaviour and possibly the disappearance of the similar motor task, upright stepping, in maturing infants may be explained by the changes in physical characteristics an infant experiences due to asynchronous growth. Once new patterns of muscle coordination are discovered by the infant, they must be tuned through repeated cycles of action and perception of the consequences of the action in relation to the goal. These researchers proposed that if the parameters of a skill are practiced throughout a period of asynchronous growth, an infant will become proficient at the skill and will be able to complete the motor task accurately and smoothly. If the skill is not practiced the movement patterns may disappear due to the increased physical demand asynchronous growth places on the maturing infant.

Goldfield, Kay and Warren (1993) studied infant bouncing and suggested that organized action patterns emerge from spontaneous activity as infants explore and exploit the physical properties of their bodies and environments. These researchers sketched an approach to motor learning and development from a dynamical perspective and reported the results of infant bouncing while using this model.

From a dynamic perspective, the developmental question is not what motor abilities infants learn and what parts of their behaviour are genetic, but how separate parts cooperate to produce a cohesive motor pattern (Thelen, 1995). A dynamic model of skill acquisition predicts an initial high variability in motor pattern configuration during the exploration stage with a narrowing to a few possible motor patterns and progressive stability as the task becomes more practiced (Saltzman and Kelso, 1987; Kay, Saltzman and Kelso, 1991; Kelso, Holt, Rubin and Kugler, 1981). Similarly, Goldfield *et al.* (1993) defined learning as "the process of change in the intrinsic dynamics to converge on a stable solution or attractor at the required pattern and can involve qualitative changes in coordination" (p.1140). These definitions would suggest that when acquired skills are perfected, the large-scale variability in movement trajectories is reduced as an infant becomes sensitive to the consequences of his/her actions. More specifically, when a biological system and a mechanical system cooperate and arrive at a common solution, movement variability is minimized: when they compete, there is an increase in the variability of the movement pattern. In the bouncing study by Goldfield *et al.* (1993), the biological and mechanical systems correspond to the bouncing infant and the Jolly Jumper apparatus, respectively. Furthermore, initially rigid reflex movements become skilled movements as infants acquire an organized pattern for motor behaviour (Goldfield *et al.*, 1993).

Substantial research in the area of motor control has recently addressed the development of kicking (Geerdink, Hopkins, Wiero and Heriza, 1996; Thelen, 1995; Jensen, Thelen, Ulrich, Schneider and Zernicke, 1995 Schneider, Zernicke, Ulrich, Jensen and Thelen, 1990), walking (Clark and Phillips, 1993; Ulrich, Schneider, Jensen, Zernicke and Thelen 1994; Zelazo,1983) and posture control (Sveistrup and Woollacott, 1996; Sveistrup and Woollacott, 1997; Shumway-Cook and Woollacott, 1983). These analyses provide valuable insights into the development of organized movement patterns that produce coordinated motor task patterns. Limited research has addressed the development of bouncing behaviour (Goldfield *et al.*, 1993) and analysis has focused on the number of bounces, bounce amplitude and mean period within a prespecified trial length. The current study will extend our understanding of infant bouncing and via extensive qualitative analysis of the bouncing behaviour, a qualitative model of the underlying control processes of the behaviour will be proposed. It is the goal of this research to expand the current literature and to further our understanding of the processes by which infants learn the skills necessary to produce bouncing behaviour. This information will contribute to understanding the steps or pattern of human development when learning a complex task, such as bouncing.

Statement of the Problem

Given the limited current research on the topic of infant bouncing, the first objective of this study was to examine the bouncing behaviour of infants from six different perspectives: i) *global behaviour: evaluation of bouncing skill levels*, taking into account the fluidity and consistency of the bouncing behaviour; ii) *resonant frequency*, examining the rate of oscillation of the mass-spring system relative to the baby bouncing frequency; iii) *baby contribution*, examining the contribution of the infant to the bouncing behaviour; iv) *control mechanisms*, examining the causal control processes of the three lower extremity joints involved in bouncing- the ankle, knee and hip; v) *interjoint coordination*, examining the relationship between the three lower extremity joints involved in bouncing; and v) *neural contribution* to the bouncing behaviour, with emphasis on the role of lower extremity muscles producing bouncing behaviour.

Hypotheses

Global behaviour

There will be a distinction between skilled and less-skilled bouncing behaviour across the infant population. Skilled infants will demonstrate global bouncing behaviour, where several bounces will be included in each bout. Less-skilled infants will demonstrate a more disjointed movement pattern with sudden stops and starts throughout the bouncing cycle. The ranking of global bouncing behaviour will allow us to determine i) how joint angular range of motion changes as a function of skill level; ii) the phase-relationships between joints as illustrated qualitatively through the use of angle-angle plot analyses; and iii) causal mechanisms of joint kinematics as illustrated qualitatively through the use of phase-plane plot analyses

Control mechanisms and interjoint co-ordination

When first acquiring the skill of kicking, motion is prevalent about the hip (Jensen, Thelen, Ulrich, Schneider and Zernicke, 1995). As a child becomes more efficient at the task, coordination of the kick includes the hip and knee followed by inclusion of the ankle when the skill is further perfected. I propose that the learning process of acquiring bouncing skills will follow a similar sequence of skill mastery: coordination of the hip followed by knee and finally inclusion of the ankle with perfection of the skill. For this reason, a study of joint range of motion about the three joints involved in bouncing was included.

The joints of skilled bouncers will move into and out of phase with each other, such that the ankle, knee and hip will move easily into flexion and extension simultaneously throughout the bouncing cycle. Less-skilled bouncers will demonstrate an out of phase relationship between the joints responsible for producing the bouncing behaviour. Flexion may occur at one joint with extension occurring simultaneously at another joint.

Resonant frequency

Skilled bouncers will produce a frequency of bouncing which is a multiple of the spring resonant frequency thereby illustrating that these infants are capable of using the spring of the Jolly Jumper harness system to produce effective and consistent bouncing behaviour. Less-skilled bouncers will be unable to hone in on the exact resonant frequency of the system and will produce bouncing behaviour that is a fraction of the resonant frequency rather than a multiple of the spring system resonant frequency. Less-skilled infants, in turn, will produce ineffective bouncing behaviour that lacks in consistency and efficiency.

Neural contribution

Sveistrup and Woollacott (1996) studied the development of automatic postural responses elicited during stance following perturbation of a support surface and determined that a reproducible and consistent pattern of phasic muscle activation emerged out of a high level of tonic activity as infants' behavioural level progressed from one level to the next. It is expected that the changes in muscle activation patterns recorded across the level of bouncing skills will follow a similar sequence for infants. Electromyography patterns for skilled bouncers will demonstrate alternating bursts of activity between muscle antagonists like the gastrocnemius and tibialis anterior. Less-skilled bouncers will demonstrate predominately co-activation of muscle antagonists with high levels of tonic activity across all muscle groups.

Definition of terms

The following are definitions of basic concepts and terms which will be used repeatedly throughout this document.

Bounce

A bounce is defined as one complete cycle of vertical displacement in which the knees flex so that the body moves towards the floor, and then extend so that the body moves away from (and sometimes off) the floor (Goldfield *et al.*, 1993).

Bout

A bout is a continuous series of bounces with no pauses between bounces.

Bout length

A bout length is the number of bounces in a bout.

Baby contribution

The combination of the infant's behaviour on the ground and in the air produce the baby's contribution to the mechanical system. I will collectively term this contribution the infant's forcing function.

Muscle burst

A muscle burst is a level of muscle activity that is a minimum of two standard deviations above the baseline activity of that muscle for a specific individual.

Muscle co-contraction

A muscle co-contraction is the simultaneous activation of two or more muscles.

Point attractor

A central time keeper which drives the periodicity of a biological system: a stable state of motion to which a system returns to following perturbation (Thelen, 1995).

Resonance

If a system possess no damping, and is excited by a harmonic force with a frequency very close to the natural frequency, the amplitude of the system becomes very large. This condition is known as resonance (Riley and Sturges, 1993).

Skill levels of bouncing behaviour

Skill levels of bouncing behaviour were evaluated according to i) consistency and vertical height of the bounces (assessed qualitatively); ii) number of bouts of bouncing performed during the testing session; and iii) total body control during the task. Infants were placed in groups (skilled, moderately-skilled and less-skilled bouncers) and ranked in order within the groups (the less-skilled infants of the less-skilled infants, to the most-skilled infant of the less-skilled infants, and so on).

Limitations and delimitations

The subject population for this study consisted of nine infants with no known pathologies aged 6- to 12-months. The results of this study are therefore limited to that population. Generalizations made to alternate population groups would be inappropriate and could prove to be misleading. It was beyond the focus of this study to conduct a longitudinal analysis of infant bouncing behaviour. Rather, it was the scope of this study to explore and better understand the intricacies and cumulation of the neural and joint contributions in the production of infant bouncing behaviour.

The nature of the Jolly Jumper harness system allowed infants the latitude and flexibility to explore the limits of the apparatus while discovering the consequences of their actions. To control for some of the openness of the system, the infants were secured while bouncing so that they remained sagittal to the video camera. The infants' behaviour was not limited in such a way where posterior or anterior sway was impossible while bouncing. Thus, some amount of out of plane motion resulted due to the nature of the harness system.

CHAPTER TWO

REVIEW OF LITERATURE

Theories of motor development

The task that faces all newborns is almost overwhelming. How do these small infants learn to control their limbs to the extent that they are able to produce organized and functional movement behaviour? Three different theories attempt to explain this question. The first is the neural-maturational theory of motor development. This theory takes the approach that organisms have a set of predetermined motor patterns that are inherent by nature. Physical maturation unfolds motor patterns as they are required by the infant to successfully function in their changing environment. Forssberg (1992) stated that development of a motor behaviour emerges as a result of the determined development of the various subsystems in the brain stem, which modulate things like muscle tone and speed of activity, and are controlled by messages from the motor cortex and basal ganglia. Voluntary goal directed locomotion, according to this theory of motor development, reflects maturation of the locomotor networks in the brainstem and their increasing control of the spinal locomotor networks. Forssberg (1992) concluded that the environment does not alter or develop the motor patterns, but rather presents an infant with a reason for eliciting the patterns inherent in its nature.

The cognitive theory of motor development is the second theory of motor development. It emphasizes the formation of progressively higher levels of motor plans as the infant develops. This theory postulates that motor development may be dictated by an underlying change in information processing ability. As an individual's capacity to generate ideas or access different associations from memory improves, the integration capacity for balance and co-ordination occurs thereby permitting advanced motor control to develop. Zelazo (1983) stated that the stable appearance of appropriate use of an object by a developing infant implies a capacity on behalf of the infant to make specific associations for specific situations. He viewed this as a fundamental cognitive change that may free an infant from the stereotypical repertoire of characteristics often displayed at a younger developmental age. Zelazo (1983) stipulated that the new and appropriate use of an object allows an infant to develop a whole new set of behaviours appropriate to different situations, implying that it is not the infant's motor dexterity that changes with maturation, but the cognitive program that guides the infant's manipulative skills.

Essential to both neural-maturational and cognitive theories is the fact that predetermined plans exist prior to onset of motor behaviour and that these motor programs are more important than the resulting motor performance. Limitations exist in both the cognitive and neural-maturational theories, but the most obvious limitation is that they do not address the variability of context of the movement behaviour. Natural movements are rarely performed in under exactly the same context, with the same level of arousal or level of focus. A complex relationship exists between the active (muscle-produced) and passive forces of an individual interacting with the environmental forces (gravity). Yet despite the restrictions placed on the human system, mastery of the relationship between these forces enables us to produce what appears as simple, synchronous fluid motion (Schneider, Zernicke, Ulrich, Jensen and Thelen, 1990).

Schneider *et al.* (1990) postulated that the central nervous system is quite capable of dealing with the multitude of interacting forces which humans experience as they move through their surrounding environment. Environmental factors such as physical location, social setting and the emotional state of an individual, actually change the dynamics of the motor behaviour. The individual must react to their environment and adapt his/her actions to the changing environment in order to produce functional movements. It is through the adaptation of motion to environmental conditions that individuals begin to integrate control of basic preferable behavioural motor patterns with the self-organizing properties, like muscle stiffness and neuromotor control which allows an individual to produce, over time, optimal skill function (Thelen, Kelso, and Fogel, 1987). Dynamical systems theory offers a third theory of motor control which explains an individual's adaptation of their movement patterns in order to produce functional motion in a changing environment.

Dynamical systems

The ability of dynamic models to trace and analyze change as it occurs over time proves them to be a valuable tool to help explain developmental maturation as it evolves (Howe and Rabinowitz, 1994). The main advantage of dynamic modeling is that it focuses attention on the developmental change itself, yet it is still able to account for development of orderly as well as disorderly actions. For the researcher interested in the coordination and mastery of physical skills, dynamic models are ideal because they can expand on properties of individual action units, muscles and joints, which make-up the whole dynamic task. These models can thus aid in understanding how coordination and control of the musculoskeletal system develops and ultimately produces skilled actions.

A dynamic system can be modeled many ways, one of which is as an undamped mass spring system or a harmonic oscillator. Harmonic oscillators occur naturally in nature: any motion about a stable equilibrium is harmonic as long as the motion is small. Simple harmonic oscillators obey the equation of motion in a "frictionless" environment. They move back and forth, oscillating sinusoidally at the natural resonant frequency of the spring used (Davis, 1986). Harmonic oscillators have a mass, m, attached to one end of a spring having a spring constant ("stiffness"), k. The other end of the spring is attached to a rigid support. When the mass is moved some distance, x, away from equilibrium, the spring exerts a force to restore, push or pull the mass, back to equilibrium. This force is found to be proportional to the distance the mass is from equilibrium (the constant of proportionality being the spring constant, k).

In real life, however, the relationship is not as simple as that expressed by a simple harmonic oscillator due to the presence of forces which affect the velocity of the oscillator. These forces can either increase or decrease the velocity which will, in turn, directly affect the acceleration of the oscillator. The oscillating human body is never exactly periodic as it is made of materials which change from day to day and it is exposed to forces which are constantly acting upon it, like air resistance and gravity, which affect its velocity and acceleration.

Due to the nature of biological systems, the forces these systems produce as well as the forces which act upon these systems, it would be inappropriate and inaccurate to model the movement behaviour of biological systems as harmonic oscillators, as these biological systems are non-linear and produce limit cycles. Rather the oscillation of biological systems is linear in nature to the extent that a forced harmonic oscillator is linear. A forced harmonic oscillator is an oscillator which has an external force that is impressed upon it. When considering a human system, such as an infant hanging from a spring and pushing off the floor, it is assumed that this external force continues with time. Factoring the amplitude and period of the consistent motion produced by a biological system into the harmonic oscillation equations of a mechanical system actually defines the resonant frequency of the external forcing function produced by the biological system. The external forcing function of a forced harmonic oscillator is influenced by many factors including initial displacement of the biological system, damping ratio and spring stiffness coefficient. Moreover, in the case of the previous example of an infant hanging from a spring, the body mass of the infants suspended from the spring will also influence the external forcing function produced by the biological system. Careful control and management of these factors by the biological system will yield consistent, reproducible external forcing functions which, in turn, produce consistent dynamic behaviour.

Motor behaviour from a dynamical, functional perspective

Motor behaviour arises from the merging of the components which cause a movement to occur. These components include the central nervous system, the musculoskeletal system as well as external constraints, such as the environment and the task to be performed. Each component is vital and necessary for the development of motor behaviour. The dynamical systems approach allows for the description of a highly complex multi-dimensional system composed of many elements by just a few variables which characterize the essence of the system.

According to the dynamical systems movement theory, muscles and joints do not work in isolation. Rather the incorporation of several body units, such as muscles and joints, produces a functional, organized movement outcome. Neural-maturationists and cognitive theorists would propose that these units act together due to a strict predetermined motor plan. From a dynamical systems approach however, units are synchronized, acting together to achieve a common goal, thus meeting task demands and adapting to often dynamic environments. All final movements are the result of a combination of patterned electromyographic (EMG) output, passive forces generated by the length and resting conditions of the muscles and ligaments of the body, the pull of one body segment in relation to another, the effects of gravity as well as the effects of other external environmental forces present (in the case of an infant hanging in a Jolly Jumper harness, the extension and compression of spring). A simple harmonic oscillating spring system illustrates the complexity of motor behaviour from a dynamic perspective. The final position of the spring is not a function of the initial position, but rather the attributes of the system, the spring constant and mass attached. As these attributes do not change, the system will reach the same final position each time it is stretched. The stable cycle of the spring is maintained even if the system is disturbed in mid-cycle.

Being able to achieve the understanding of a complex system from a low dimensional perspective (joint angular displacement and velocity) enables researchers to make behavioural predictions about a movement pattern. This can be determined by analyzing the various units which contribute to the motor behaviour, for example, muscular forces, joint displacements and environmental factors. An unstable dynamical system demonstrates a high degree of variability during motion, whereas a stable dynamical system demonstrates a low degree of variability.

A force driven harmonic oscillator is an appropriate model of human walking as this type of oscillator requires periodic forcing to maintain its oscillations as a result of the gravitational, damping and stiffness forces that tend to decrease the oscillations over time (Holt, Hamill and Andres, 1990). The relatively constant period and amplitude of walking is also found in forced harmonic oscillators. The importance of frequency in walking is relevant when referring to resonant frequency. Resonant frequency of a forced harmonic oscillator is the frequency for which a minimum force is needed to maintain the oscillation of the system's spring. In walking, applying force at the "right point" in the walking cycle will produce a walking frequency equivalent to the resonant frequency of the biological system. Organisms capable of walking at this resonant frequency will yield efficient walking behaviour from both mechanical and physiological perspectives.

Qualitative dynamics is an outgrowth of dynamical systems theory (Kay, Saltzman and Kelso, 1991). In this approach, the evolution of a system's observable characteristics and motion are described in terms of equations of motion. This branch of dynamics describes the movement of a single limb to a target or a point attractor. A point attractor is the stable equilibrium point that attracts all trajectories from arbitrary initial conditions. Point attractor dynamical movements are unique in that when a transient perturbation is applied during the movement, the achievement of the original goal is not forsaken. In the case of a bouncing infant, one could determine if an infant has in place a stable equilibrium point (point attractor) by perturbing the system (adding weight to the ankles, for example) and studying the infant's response. If an infant has established a point attractor for the behaviour, he/she will be capable of bouncing at approximately the resonant frequency of the Jolly Jumper spring following the perturbation. If, however, a point attractor is not established, the resonant frequency of the bouncing behaviour produced by the infant will not approximate the resonant frequency following a perturbation.

Stable states are called "attractors" in dynamic terminology. As a system settles into a pattern, it tends to return to that pattern after being perturbed (Thelen, 1995). Kay, Saltzman and Kelso (1991) conducted a study on rhythmic movements using four subjects, two trained musicians and two untrained volunteers. Subjects were required to rhythmically cycle the index finger of the dominant hand for several cycles. Following this, the experimenter delivered a single perturbation after which the subject was required to continue the cycling for several cycles. The same subjects were later required to perform steady-state uninterrupted finger cycling. The researchers found that their model of the central oscillator was not independent of the limb's dynamics. They proposed that if there is, in fact, a central timekeeper which drives the periodicity of a biological system, it is affected by perturbations or unexpected disturbances which are delivered to the limb being controlled. The central timer and the peripheral musculoskeletal oscillator are bi-directional, thus future models must include feedback from the peripheral, controlled system. These results were obtained for only single simple joint systems thus the question remains, would this model be relevant for multi-joint and multi-limb tasks? Saltzman and Kelso (1987) found that the speed of task-specific responses to perturbations of the biological system indicates that adjustments in the organism occur according to an automatic or reflexive organization of the biological system's musculoskeletal parts. Skilled movements, such as multi-joint activities, show some degree of task-specific flexibility or "immediate compensation" indicative of an innate motor response which stabilizes the biological system following a perturbation. This immediate compensation actually corresponds to an innate motor response. This means that when perturbations occur that may affect the coordination of the movement, the system is able to automatically adjust the activities of the system to replan a new movement, execute the new movement pattern and attain the original goal.

Like a point attractor, a limit-cycle attractor attracts trajectories for initial conditions, but only when a stable oscillation of fixed amplitude and frequency is attained. Position and velocity are coordinates that define phase space. The presence of a limit-cycle attractor can be determined by comparing frequency and amplitude before and after a mechanical perturbation is experienced by the system. The strength of the attraction can play a very important role in the limit cycles rapid return to the strong attractor or no return to the weak attractor. The strength of the attractor can be determined by measuring the time taken for the system to return to the limit cycle following a perturbation. The shorter the time the stronger the attractor. For example, changing the spring stiffness of a Jolly Jumper harness from which an infant is suspended will result in a perturbation of the biological system, by changing the resonant frequency of the mechanical system. If the limit-cycle attractor is strong, a bouncing infant will quickly adapt to the changes in the task conditions, adjusting their bouncing behaviour in response to the perturbation. If the limit cycle attractor is weak, however, the infant will be unable to adapt to the changes in the task conditions quickly and will either produce inefficient bouncing behaviour or will cease production of the bouncing behaviour all together. The amount of shift which the new control rhythm must deviate from in order to produce efficient movement behaviour is normalized to the period of the oscillation and is termed accordingly, phase shift (Thelen, 1995).

Schneider, Zernicke, Ulrich, Jensen and Thelen (1990) suggested that the analysis of intersegmental dynamics is an effective method of gaining greater insight into the control of natural movements. Dynamical analysis of a movement behaviour can provide a model which identifies the characteristics of the behaviour and also demonstrates how a biological system is capable of compensating spontaneously for unpredicted disturbances or perturbations. "Learning" a new task involves the design of an action unit or co-ordinative structure that has dynamics appropriate to the skill being learned and adapting these action units in response to unpredicted disturbances or perturbations (Saltzman and Kelso, 1987). Developmental changes can be seen in dynamic terms as a series of states of stability, instability and phase shifts. A developmental pattern will emerge under particular environmental constraints. Changing components of the system will disrupt stable patterns freeing the system to explore and select new coordinate patterns (Thelen, 1995).

Weinstein and Garfinkel (1989) introduced a qualitative dynamic approach to evaluate disordered locomotion. Phase-plane and angle-angle plots were used to study the topological forms of movement that are seen in movement systems. The authors attempted to relate these forms to characteristic types of causal control processes in known dynamical systems such as an oscillating spring or pendulum. The shapes of the curves obtained in the phase-plane plots were more important than exact numerical predictions since the shapes can be related to known casual control processes (spring, pendula) that are not revealed by traditional time series plots. As such, the phase-plane plots provide a picture of the resultant action of the control mechanisms. The angle-angle plots also illustrate intersegmental patterns of organization with joints moving into and out of phase during the movement as well as illustrating the variability between and within episodes of movement behaviour.

Infant studies

Thelen and Fisher (1993) have argued that the prolonged motor immaturity of human infants makes them ideal subjects for the study of the emergence of skilled movement. As infants develop, they learn to control their limbs and body so that they become proficient at moving in their environment and are able to manipulate the components of movement thus producing efficient and smooth continuous movements. In general, these infant studies examined complex movement behaviours with a limited number of these studies following skill development with maturation. Characteristics that were examined included the phase-relationships between the joints of the lower extremities, the relationship between active and passive forces as the infants interact with their environment, and the variability of the behaviour with development.

One of the complex motor tasks that has been studied in infants is kicking from two weeks to seven months of age. Two-week-old infants (Thelen and Fisher, 1983; Jensen *et al.*, 1995) demonstrated an in-phase relationship between the knee and ankle joints, with the hip excluded from the coordination of these two joints. After just two weeks, four-week-old infants were able to produce a highly structured and synchronized tight interjoint coordination between all three joints throughout the kicking cycle (Thelen and Fisher, 1983). Phasic movements of the legs showed temporal organization in cyclical repetitions throughout the duration of the kicking cycles. Strong phasic co-activation of tibialis anterior and rectus femoris was evident during flexion, with co-activation of gastrocnemius often, but not always present. Extension phases of the kicking cycle lacked clear evidence of active muscle participation. Onset latencies of muscles during kicking did not present a clear indication that reciprocal activity was present in antagonist pairs as represented by the lag times of the muscles. Jensen *et al.* (1995) also reported that over a period of 6 months there was a progression from synchronous to asymmetrical kicking behaviour and suggested that this reflected an exploration of movement consequences and an adaptation of the movement to meet changing task demands. It was proposed that the asynchronous relationship between the joints provided the flexibility the infants needed as they underwent the process of exploring movement outcomes and consequences, perhaps to accommodate for changing task demands as a result of a perturbation (disturbance) experienced by the infant.

Similarly, Geerdink *et al.* (1996) reported that full-term infants tested at 6-, 12- and 18-weeks of age had tight interjoint coupling that, with maturation, progressed to a low level of interjoint coupling. However, the movement organization in pre-term infants was different from their full-term peers. Although phase-plane plots containing nearly vertical sides with sharp corners indicating ballistic control of the movement pattern were hypothesized for the pre-term infants, the phase-plane plots obtained for these infants contained primarily convex segments which indicated smooth increases and decreases in velocity throughout the movement pattern. These patterns were similar to the phase-plane plots of the full-term infant data. Despite the similarities between the within-joint organization patterns, differences were noted in the interjoint organization. Full term infants initially showed a tight interjoint coupling between all three joints followed by a decrease in the interjoint coupling with maturation. Pre-term infants, however demonstrated a low correlation between ankle-hip and ankle-knee joint angles throughout the testing period. Thus, pre-term infants did not follow the sequence of tight interjoint coupling that decreased with maturation as seen in full-term infants.

It was suggested that the kicking behaviour of three-month old infants could be achieved in a variety of ways depending upon the characteristics of the leg and its orientation in space (Schneider *et al.*, 1990). A linked, synchronous motion in the hip, knee and ankle joint during flexion and extension produced a fluid, cyclical kicking motion and provided insight into the control processes of the developing infant. The cyclical kicking motion observed was organized at a peripheral level as the behaviour was not limited by accuracy or speed constraints. Intersegmental analysis was used to explain the ability of an infant to adapt a motor task under dynamic circumstances. The developmental progression from production of low-skilled motion to production of highly-skilled movement patterns required an infant to integrate kinematic, EMG and environmental information with the task specific goals. The integration of biomechanical and neural control processes enables a developing infant to produce a repeatable, interactive and predictable motor pattern.

When the body position of three-month old infants was manipulated from supine, a 45 degree angle and vertical, certain kicking patterns specifically those using the spring-like properties of the lower extremity muscles emerged as being more stable than others (Jensen *et al.*, 1994). This suggested that even when there were no task demands, infants at this age possessed their own intrinsic dynamics that produced organized kicking behaviour. Furthermore, analyses of angular impulse and muscle torque indicated that the kicking leg was under proximal control at the level of the hip. Thus movements of the ankle and knee were actually dependent upon the behaviour at the level of the hip. It was proposed that the leg has properties of a mass-spring system with the active (muscle-produced) and passive forces of the infant in combination with environmental forces (gravity) playing a role and that the proximal to distal control was due to anatomical and energetic constraints rather than neurological constraints. Despite the absence of corroborating EMG data, these results were consistent with the concept of a mechanical system that is sensitive to a changing environment, but whose behaviour is grossly restricted by its physical design.

Thus, in kicking extensive antagonist co-activation is characteristic of immature and unskilled movement. Infants as young as two weeks of age were capable of producing movement behaviour indicative of a periodic or rhythmic organization of joint angles during the kicking cycle. Kicking progresses from synchronous to asyschronous behaviour and follows a proximal to distal order of development.

Walking, like kicking, is another complex motor task that requires infants to control various action units in order to produce behaviour that is both organized and effective. In contrast to kicking however, infants initially produce high levels of variability in walking patterns. With maturation, the walking patterns become stabilized and a low level of variability in interlimb coordination emerges (Clark and Phillips, 1993; Ulrich *et al.*, 1994).

In over ground walking, the double-peak walking force curves observed in adult walking force curves are observed at approximately three months after walking onset. Although high amounts of variability in treadmill stepping behaviour were observed, by seven months of age infants were able to produce a predominately alternating stepping pattern. While EMG activity has not been reported, it has been proposed that infants have some level of structured neuromuscular control which makes alternating stepping the preferred motor pattern. Ulrich *et al.* (1994) postulated that at this low level of skill, infants lack control details of the movement and have yet to master the functional control of the innate action pattern. Muscle stiffness, the infant's level of focus on the task, as well as the infant's level of arousal, have an effect and contribute to the variability present in the infant's movement outcome. The cause of high variability in the movement pattern could be due to several factors. In contrast with young adults, infants were not aware of any task specific goals. As well, while treadmill stepping the infants are supported and thus did not have the constraint of having to control their own posture. Therefore, the infants were free to explore their environment, moving their body and legs without experiencing falls as a consequence of their movement. Ulrich *et al.* (1994) also suggested that while the basic neural network may be established in infants, the sequence and level of muscular activity could still be affected by changes in multiple sources including joint structure, goals of the infant, posture, muscle strength and properties of connective tissue.

Although a vastly different task from infant kicking and walking, development of the automatic postural response follows a proximal to distal order as well as a shift from highly variable to less variable muscle activity (Sveistrup and Woollacott, 1996). This is similar to development of kicking behaviour. The presence of coordinated, albeit simple actions in young infants shows that infants are capable of controlling the firing pattern of their muscles and ultimately mapping the movement of their joints, producing movement patterns that can repeatedly achieve a functional purpose.

Jumping studies

The vertical jump relies on the ability of the muscle groups involved to raise the body's center of gravity (Shetty and Etnyre, 1989). Producing a vertical jump is really quite complicated. It requires the integration of a number of factors: the angle of take-off, the position of the body, the mono- and biarticular nature of the muscles involved and the eccentric and concentric contractions of the antagonist muscle patterns. Add to this the use of arm, trunk and head movements and the analysis of the vertical jump becomes even more complicated. All the above factors actually affect the vertical ground reaction forces produced while jumping. The ground reaction force produced is, in essence, the intrinsically produced forcing function that an individual contributes to the system of external forces acting on the body to produce the jumping behaviour.

In general, studies have found that during the complex task of jumping, a definite flow of power across joints occurs (Gregoire, Veeger, Huijing and van Ingen Schenau,1984; Jacobs, Bobbert and van Ingen Schenau, 1992; van Ingen Schenau, Boots, Groot, Snakers, and van Woensel, 1992; van Soest, Schwab, Bobbert and van Ingen Schenau, 1993; van Ingen Schenau, Pratt and Macpherson, 1994; Voight, Simonsen, Dyre-Pulson and Klausen, 1995). Moreover, jumping is a motor task which requires all muscles of the lower extremity to participate in the activity at a specific point in the jumping sequence, although some controversy still exists about the exact point where specific muscle activation occurs during the jumping cycle.

Specifically, Gregoire *et al.* (1984) found that movements of the hip, knee and ankle joints in rapid sequence during jumping allowed an energy flow from a proximodistal direction. Specifically, optimal vertical jumps could be produced if extension of the hip and knee occurred almost simultaneously with plantarflexion in the ankle joints. In order to produce optimal vertical jumping, rotational movements of the body have to be minimized by the leg muscles throughout the jumping cycle (van Ingen Schenau *et al.*,1992; Jacobs *et al.*,1992). These researchers have proposed that the central nervous system controls the contraction patterns of the numerous muscle groups involved in producing the jump, while simultaneously providing feedback about the joint displacements and external forces influencing the behaviour to the muscles and joints which produce the behaviour. Moreover, van Ingen Schenau *et al.* (1994) stressed the importance of the role that muscles play in controlling the direction of the vertical ground reaction forces on the body's center of gravity during vertical jumping behaviour. After examining the relationship between antagonist pairs of muscles in the shank during vertical drop jumping, Voight *et al.* (1995) determined that the tibialis anterior (TA) muscle was active primarily at the toe down phase of vertical jumping while the antagonist gastrocnemius (GA) and soleus (SO) muscles were active primarily just prior to toe down. During reversal, where the body center of mass is at its lowest point, the SO muscle was active while the G muscle was active during toe off.

Thus, the key to vertical jumping is the activation of the gastrocnemious muscle, which provides the force and power that is necessary in order to achieve vertical take-off.

Previous research on infant jumping/bouncing

It is crucial to deal with growth or biomechanical factors in early infancy in order to ensure skill acquisition, however, practice and environmental conditions appear to be more dominant later in life for advancing the coordination of a movement system (Thelen, 1995). Once new patterns of muscle coordination are discovered by the infant, the patterns must be practiced in order for the infant to become efficient, accurate and smooth at completing a task. The dynamic model predicts an initial high variability in configurations during the exploration stage with a narrowing of possible states to a few patterns and progressive stability as patterns become practiced and reliable (*Ibid*, 1995). Exploring the parameters of a movement can help an infant develop the structural stability and organization of the components of the movement pattern which may be critical in the learning process when controlling transitions from one action mode to another, as when walking progresses to running. When an infant becomes more proficient at performing a task, the large-scale variability in movement trajectories is reduced as the infant becomes sensitive to environmental information. This increased sensitivity helps them to specify the task's dynamics as well as stabilize and fine tune the parameters of the movement. Initially rigid reflex movements become more flexible and adaptive under varying conditions as sensitivity to the particulars of the environment develop.

Goldfield, Kay and Warren (1993) studied longitudinally the development of bouncing in eight healthy infants (N=8) aged seven to nine months. The infants were secured in a Jolly Jumper infant harness system, suspended from a door frame in their own home with their knees slightly flexed and the soles of their feet just touching the floor. Infants were given time to become comfortable in the harness system. The infants were filmed once a week over a period of six weeks for a minimum of four minutes per week. A time signal was recorded simultaneously to facilitate post-hoc scoring for the bouncing behaviour. Goldfield *et al.* (1993) counted the number of bounces and bout length performed by each infant. In early test sessions, infants demonstrated sporadic, irregular bouncing patterns with a limited number of bounces per bout. As testing sessions progressed, the onset of a sustained bouncing pattern was demonstrated by the infants. The peak number of bounces performed and the peak bounce amplitude for most infants occurred when they were approximately 8.25 months of age. Bout length increased gradually over the bouncing sessions up to a mean of 4.2 bounces, until it suddenly doubled in the peak session to 8.7 bounces. After reaching a peak, the bout length began to decline in subsequent sessions. The bouncing behaviour recorded during the peak session illustrated a large increase in mean bounce amplitude when compared to previous bouncing sessions, but a decrease in the amplitude variability was also illustrated in this session.

To determine if the infants' legs acted like springs, Goldfield *et al.* (1993) i) determined the resonance period of the external spring, the spring stiffness and damping ratio of the Jolly Jumper system via the dynamic method and compared the infants' bouncing oscillation period to the resonance period calculated mathematically; and ii) modeled the infants' legs as a hypothetical second spring and recompared the infants' bouncing oscillation period to the recalculated period. If the infants' legs acted like springs the infants could locate and mimic the resonant frequency of the Jolly Jumper system indicating that the infants had learned the low dimensional dynamics of the bouncing task. The mean period of baby bouncing, did not vary significantly over the sessions, the bouncing behaviour recorded in the last several testing sessions illustrated a significant decline in the variability of the period length for all eight subjects. The infants' preferred bouncing frequency decreased in variability over the last several testing sessions so dramatically that the infants' bouncing behaviour could be predicted by the resonant frequency of the model that incorporated the two springs. The results of the two spring model indicated that the predicted period of oscillation for this model was in close agreement with the observed bouncing behaviour produced by each of the infants (mean error = 0.016, statistically no significant difference was apparent, $p > 0.1$). The preferred bouncing frequency of the infants could, therefore, be predicted by the resonant frequency of the two-spring system. The spring stiffness was found to be 523 N/m, with damping ratios of 0.0014 on small amplitude oscillations and 0.005 on large amplitude oscillations.

Due to the minimal value of the damping ratio, the researchers determined that it did not contribute appreciably to the observed oscillation behaviour.

Goldfield *et al.* (1993) claimed that their results provided evidence that infants assemble and tune a periodic bouncing system similar to a forced mass-spring system, homing in on the spring resonant frequency by exploring the dynamics of the system via spontaneous activity and maximizing energy transfer to the system. In the assembly phase during the initial bouncing session, the behaviour of the infants was both sporadic and irregular, indicating that the infants were attempting to explore the system while observing results of their interaction with the environment. The dynamics of the system were thus explored through spontaneous activity. As the sessions progressed, a steady decline in the variability of the period was noted as the infants began the process of adjusting their leg stiffness to match the spring stiffness. The onset of sustained bouncing occurred in the peak testing session. This indicates that the system was optimized when the infants matched the impedance of the spring to maximize energy transfer. The infants actually homed in on a stable attractor and drove the system at its resonant frequency. The average period length over the sessions did not change, however the within-bout variability in period length decreased significantly. The researchers found that the preferred period of forced harmonic oscillation for the infants closely approximated the harmonic resonant period of the two spring mechanical system. This suggests that an appropriate periodic attractor was assembled as the bouncing test sessions progressed. The infants' behaviour was refined, but not qualitatively altered, by parameter tuning.

The decrease in period variability observed as the testing sessions progressed indicated that the infants learned that bouncing at the resonant frequency of the spring both conserved energy and provided a stable frequency for them to produce bouncing behaviour. Goldfield *et al.* (1993) point out that it is this proprioceptive feedback characteristic of biological systems which renders a linear mass-spring system into a nonlinear autonomous system. The close prediction of the preferred bouncing period length by the resonance of the two spring system, the increase in the bouncing amplitude at the resonant peak, and the reduction in the period variability across time support the researchers' statement that the behaviour of the biological system moved to a more optimized attractor state which corresponded to the resonant frequency of the mechanical system.

Infants. over time. learned to optimize the system by matching the impedance of the spring to maximize energy transfer. thus driving the system at its resonance frequency. Goldfield *et al.* (1993) suggested that future studies on infant bouncing be conducted to determine the infant's adaptability to the system by adding mass or changing spring stiffness between trials. This intervention would shift the system's resonant frequency. If the infant had learned only a fixed driving frequency and leg stiffness. he/she would require a period of adaptation to optimize movement to the new frequency. If the infant had learned the low-dimensional dynamics of the task. angular position and velocity dynamics. he/she would be able to adapt quickly to scale changes in the task conditions. This would provide direct evidence that infants were able to locate the resonant frequency of a spring. ruling out a coincidental correspondence between the observed and resonant periods. These researchers also point out that learning to bounce required considerable experience on the part of infants. It could be hypothesized then. that the process of adapting to a new resonance frequency would take a considerable amount of time for an infant.

Studies have shown that by young adulthood. individuals are able to organize their muscles. forces. and powers during jumping in such a manner that they are able to create an external forcing function and return this energy to the system (van Ingen Schenau *et al.* 1994; van Leeuwen *et al.*. 1992; Voight *et al.*. 1995). We can assume that infants do not have this ability at their developmental age. however. **the problem that exists is that little research has been performed on infants' ability to co-ordinate their motor activities while <u>bouncing</u>.**

In this study. we will examine how infants use information from their environment to control their neuromuscular system and the phasic relationships between the joints to maximize their contribution to the Jolly Jumper harness system while maintaining upright posture. This study will also examine the relationship between the resonant frequency of the mass-spring system. the baby's contribution to the system which can be characterized as a forcing function. and the combination of these two components which produces the output- baby bouncing. We will also examine correspondence between the observed infant bouncing frequencies and the resonant frequency of the spring calculated mathematically and via a direct measurement of the oscillation frequency of the Jolly Jumper harness system.

CHAPTER THREE

METHODS

The following sections detail the subject sample and explain the anthropometric parameters which were measured. Subsequent sections describe data acquisition and data processing as well as statistical treatment of the experimental results.

Subjects

Fifteen infants were recruited to participate in this study however, six infants were not included in the data acquisition as they were distressed in the jumping harness or they did not produce bouncing behaviour during the test session. The subject mortality for this study was similar to that reported by Goldfield *et al.* (1993) who began their study on infant bouncing with fifteen participating infants however. Seven infants were not included in the results as they were distressed in the jumping harness or they did not produce bouncing behaviour during any of the six testing sessions. Thus, Goldfield *et al.* (1993) included the analysis of the bouncing behaviour for eight infants (two females, six males) in their study on infant bouncing.

The subject sample for this study included a final total of nine infants (N=9) between 6- and 12-months of age with no known pathologies as determined from parental reports. No infants involved in this study were seen by medical specialists prior to their testing session. Two infants were born seven weeks premature (I5 and I3), however they were within the normal range for motor development for their peers at the time of the testing session and at 18-months chronological (16-months corrected) age, they were both walking and developing normally. Contact with parents of the infant participants six months following the testing session found that all infants were continuing to develop normally.

The age range of 6- to 12-months was chosen for three reasons. First, the recommended age for using a commercial Jolly Jumper is three months to walking age thus limiting the youngest age. Second, Goldfield *et al.* (1993) studied the bouncing behaviour of infants as young as 6-months and as old as 9-months of age and reported that uniform bouncing behaviour was produced in infants of 8 months of age. Our study on infant bouncing selected a population which spanned this period of development. These infants also had to demonstrate the ability to control their head and neck while supporting themselves in a suspended harness system. Third, a pilot study indicated that infants who had mastered the skill of independent walking were not content when secured in the Jolly Jumper. Once independent walking was achieved, the infants wished to explore their new environment walking rather than remain within the confines of the harness system. As most infants master the skill of walking at or around 12 months of age (Piper and Darrah, 1994) we determined this to be the upper limit for our subject population group.

In summary, the inclusion criteria for infants participating in this study were i) aged from 6-to 12-months of age; ii) an ability or willingness to bounce; iii) being comfortable in the jumping harness; iv) an ability demonstrated by the infant to control head and neck while supporting themselves in a suspended harness system; v) being a non-walker; vi) having no known pathologies; and vii) normal development for chronological age as determined by a gross motor development test.

Subject preparation

When subjects first entered the laboratory, infants were secured in a modified Jolly Jumper harness (Figure 1) and encouraged to bounce. If, after encouragement, infants did not produce bouncing behaviour, they were removed from the apparatus and scheduled for a later testing date. The purpose of the study was to examine aspects of bouncing behaviour, thus, infants who never exhibited bouncing behaviour as defined prior to the testing session, were excluded from the study.

Once the infant produced several repeatable bouncing bouts, they were removed from the Jolly Jumper and instrumented with surface electrodes that measured muscle activity. The infant was then dressed in black tights and a black long-sleeved body suit. Reflective markers were placed on the tights over seven body landmarks. Once the

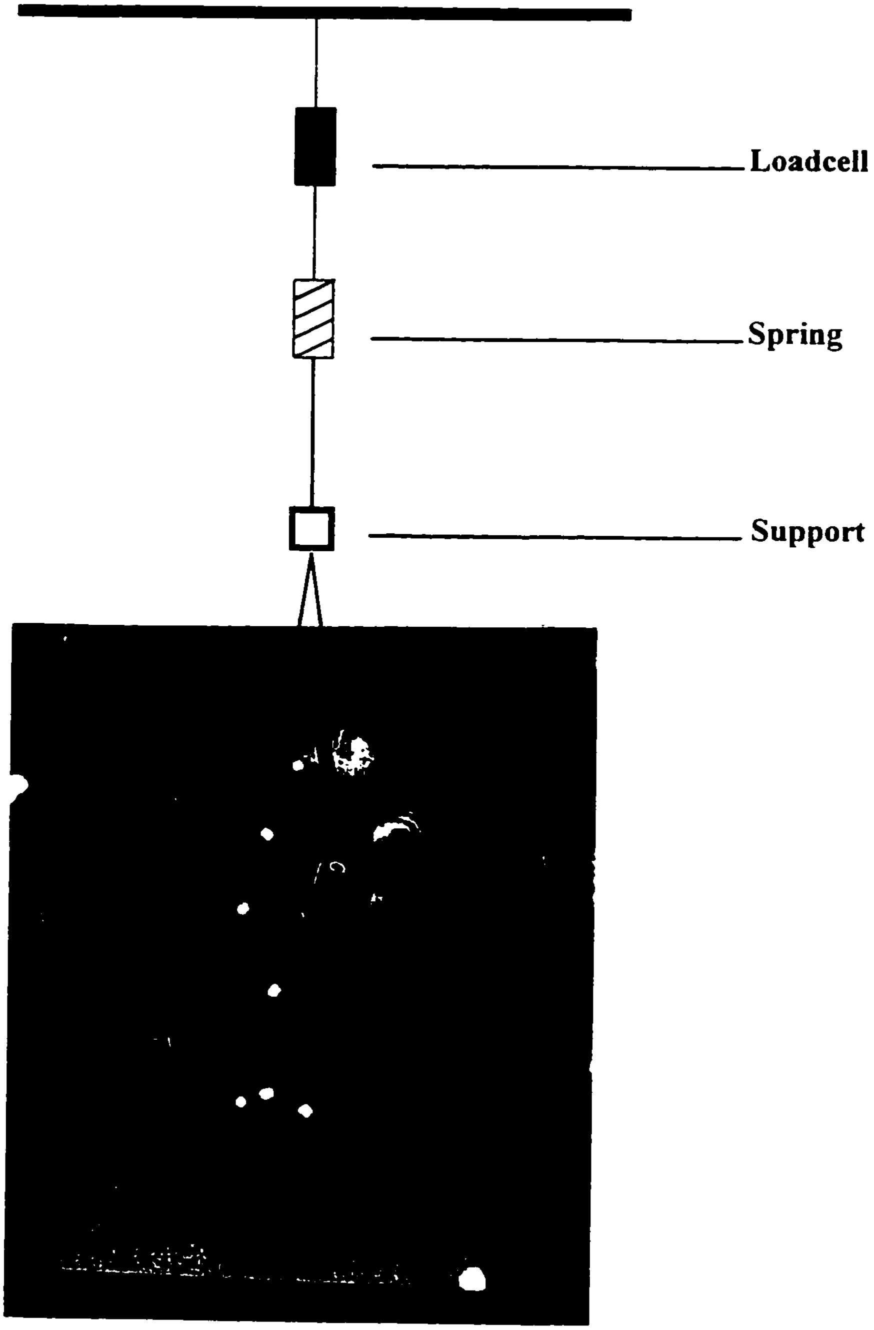


Figure 1. Jolly Jumper harness system

markers and electrodes were applied, the parent assisted the researchers in resecuring the infant in the Jolly Jumper harness and were asked to encourage their child to bounce up and down throughout the testing session.

Electrodes

Five pre-amplified surface electrodes (Neuromuscular Research Center, Boston) designed and built for human use were attached to skin using 3M Transpore Skin Tape™. Electrodes were placed over the belly of the gastrocnemius (G), tibialis anterior (TA), vastus medialis (VM) and semi-tendonosis (ST) muscles and close to the ischial tuberosity on the gluteus maximus (GM) muscle (Goodgold, 1984, p.147) on the right side of the body. The muscles selected for monitoring are a subgroup of muscles identified as primary muscles recruited during vertical jumping in young adult subjects (van Soest, Schwab, Bobbert and van Ingen Schenau, 1993).

Reflective markers

To aid in the digitizing process, seven reflective markers were placed over selected landmarks on the right side of the body prior to the start of the testing session. The markers, plastic beads covered with reflective tape, were applied to the tights and bodysuit using velcro strips. Markers were placed over the fifth metatarsal-phalangeal joint, posterior aspect of the calcaneus, lateral malleolus, head of the fibula, greater trochanter of the femur, waistband of the Jolly Jumper harness and greater tubercle of the humerus. Black drapes and floor coverings were used as a non-reflective background during videotaping to reduce the amount of glare from the surrounding environment. While bouncing, the infants were filmed with a video camera (Panasonic Camcorder AG-188U) set at 90 degrees to the sagittal plane.

Tasks

Infant bouncing

Infants were secured in a modified Jolly Jumper harness during the testing session (Figure 1). The harness was modified by placing a load cell (Revere Transducers, Inc., Model 263D S-type Load Cell) between the ceiling and spring that recorded load for the duration of the experiment. The gain of the loadcell was constant for all infants and for all bouts of bouncing. Further modifications of the harness included replacing the string reinforcements at the sides with covered wire to minimize the loss of signal between the infant and the loadcell during infant bouncing.

The infant was suspended over two force platforms with the knees slightly bent and feet touching the platform. Vertical ground reaction forces were recorded using two Advanced Mechanical Technology. Inc. (AMTI. Model OR6-5) force platforms mounted into the floor beneath the infant's feet. All analog data (EMG. force. loadcell. synchronization channel) were recorded at 600 Hz. Video data were collected at 60 Hz. A light synchronizing unit (Ian Myers. Faculty of Science. University of Ottawa) was used to synchronize the analog and video data. Each infant performed up to six trials. each trial lasting 30 seconds in duration. Regular rest breaks were scheduled as a part of the experimental protocol.

Following the testing session. the researcher viewed the video tapes of the infants' bouncing behaviour prior to extensive analyses of their bouncing skills. Infants were ranked according to the criteria outlined in the skill levels of bouncing behaviour definition and grouped as skilled. moderately-skilled and less-skilled bouncers and ranked in order within the groups - the less-skilled infants of the less-skilled infants. to the most-skilled infant of the less-skilled infants. and so on. A second investigator also viewed the tapes and evaluated the infants' bouncing behaviour. The ranking order of this second investigator was compared to that of the first investigator.

Motor development test

The Alberta Infant Motor Scale (AIMS. Piper and Darrah. 1994) was used to determine the infants' level of gross motor ability. These data were used to confirm that infants were within the normal developmental range for their chronological age. Following the bouncing session. infants were changed out of the body suit and surface electrodes and tape were removed. Infants were changed into a T-shirt and placed in a play pen area with age appropriate toys. The infants were observed by one investigator for 20 to 30 minutes in the four positions outlined by the test protocol: supine, prone, sitting and standing. At least two persons in addition to the investigator were present during the test and verified that the skill was performed by the infant. Items for each of the four subscales were examined as the infant moved naturally in and out of the four positions. Prompting was required for some of the items within the subscale. To determine the infant's total AIMS score, the four positional scores were calculated. The least mature and most mature "observed" item in each position was identified. The AIMS test protocol refers to this as an infant's motor window. Within the motor window, listed items were identified as either "observed" or "not observed". One point was awarded for each item below the least mature "observed" item. Additionally, one point was scored for each item "observed" within the infant's window. For each infant, summation of the points provided a positional score, while a summation of the four positional scores provided the total AIMS score (see Table 1). For one infant, I2, the motor development test data is not available since this component was added to the experimental protocol after testing of this infant.

Anthropometric measurements

Anthropometric measurements and descriptive data were recorded for each subject at the end of the test session. These measurements included body mass, standing height and segment lengths of the foot, shank, thigh and trunk., age and sex (Tables 2 and 3). Subject characteristics are not available for one infant (I2) since these measurements were added to the experimental protocol after testing of this infant.

Mathematical and direct calculation of mass-spring system characteristics

The natural circulating frequency (ω_n) and resonant frequency (f_n) for each infant was calculated using two different methods, mathematical formulas and a direct measurement of the system dynamics. The purpose of these measurements was twofold. The first method established the true natural circulating frequency and resonant frequency for each infant using the spring characteristics of the Jolly Jumper harness apparatus. The

Table 1.

Alberta Infant Motor Scale scores

Infant	**Items Credited**				**Total Score**	**Percentile**
	Prone (@/#)	**Supine (@/#)**	**Sit (@/#)**	**Stand (@/#)**		
I1	13/3	7/2	7/4	4/7	**47**	**50th**
I2	*	*	*	*	*	*
I3	3/5	3/2	3/5	0/1	**22**	**10th**
I4	5/5	3/4	3/6	1/2	**29**	**50th**
I5	3/5	3/2	4/3	0/1	**21**	**10th**
I6	11/8	7/2	6/6	3/6	**49**	**25th**
I7	12/7	5/4	7/5	3/8	**51**	**90th**
I8	11/6	5/3	5/6	3/4	**43**	**10th**
I9	12/7	5/4	7/5	2/6	**48**	**25th**

Note: * indicates data not available. Please see text for details.

@ indicates items credited prior to movement window.

# indicates items credited within movement window.

Table 2.

Infant characteristics

Infant	**Sex**	**Chronological age on day of experiment**	**Corrected age on day of experiment**	**Body mass (kg)**	**Standing height (cm)**
I1	Male	9mons 23days		8.26	71.0
I2	Male	11mons 27days		12.00	72.5
I3	Female	8mons 17days	6mons 22days	9.55	68.0
I4	Female	7mons 03days		7.82	65.5
I5	Female	8mons 17days	6mons 22days	10.00	69.0
I6	Male	11mons 19days		9.89	70.0
I7	Female	9mons 04days		11.36	76.0
I8	Male	11mons 21days		11.36	74.0
I9	Female	11mons 25days		8.15	69.0

Table 3.

Body segment lengths (cm)

Infant	M-C	C-LM	LM-F	F-Fem	Fem-JJ	JJ-H
I1	3.5	3.5	15	14	16	14
I2	*	*	*	*	*	*
I3	4	3.5	15	14	10.5	14
I4	3	3.5	16	13	13	10
I5	4.5	4	13.5	14	10	15.5
I6	2	3	16	16.5	10	16
I7	2.5	5	16	15	9.5	13
I8	4	4	15.5	17	12	16
I9	2	2.5	13.3	15.5	12	14

Note: * indicates data not available.

Abbreviations are as follows: **M-C**, metatarsal-phalangeal joint to posterior aspect of the calcaneus; **C-LM**, posterior aspect of the calcaneus to lateral malleolus; **LM-F**, lateral malleolus to head of the fibula; **F-Fem**, head of the fibula to greater trochanter of the femur; **Fem-JJ**, greater trochanter of the femur to waistband of the Jolly Jumper harness; **JJ-H**, waistband of the Jolly Jumper harness to greater tubercle of the humerus. Please see text for details.

second method enabled us to make a direct comparison between the dynamically calculated resonant frequency for each infant and the frequency at which each infant produced bouncing behaviour. A comparison between the mathematical and direct calculation was made to verify that the methods did not calculate significantly different values for the period length or resonant frequency of an oscillation.

In the mathematical method, the distance (m) from the end of the Jolly Jumper spring to the floor was measured and recorded. Following this measurement an arbitrary mass of 12.08 kg was suspended from the Jolly Jumper spring and the distance (m) from the end of the extended spring to the floor was recorded. The difference between the two distances was calculated and used to determine the spring constant (*k*) of the Jolly Jumper spring. Once this was calculated the natural circulating frequency (ω_n), resonant frequency (f_n), damped period (τ_d) and damping ratio (ξ) for the Jolly Jumper system were calculated using the dynamic method (Riley and Sturges, 1993 p. 437-57; see Appendix E). The natural circulating frequency (ω_n) and resonant frequency (f_n) for each infant's body mass was then calculated using the spring constant (*k*) calculated.

In the direct calculation method, a load cell (Revere Transducers Inc., Model 263D, S-type Load Cell) was attached to the Jolly Jumper spring via chain link and hooked into the ceiling. The loadcell recorded the change in load placed on the spring while an attached mass was oscillated. A mass approximately equal to each of the infants' individual body mass was suspended in the Jolly Jumper harness system, released from an arbitrary extended position and allowed to oscillate naturally. The load cell data were analyzed (Bioproc: M. Lamontagne, D.C. Bradley and E. Lemaire, University of Ottawa, 1989) and used to determine the time for the completion of several complete cycles of oscillation. Dividing this time period by the number of complete cycles of oscillation yielded the damped period (τ_d) of oscillation for the mass equal to the infant's body mass. From this information, the damped resonant frequency (f_n) for each infant suspended in the Jolly Jumper harness system was determined.

Data processing

Video data

Data were processed using the Ariel Performance Analysis System (APAS, Ariel Corporation, Cranbury NJ). Video images were scanned preanalysis to identify periods of bouncing within the 30 second trial. Three bouts of bouncing, generally lasting between two and five seconds and containing bouts of no less than three bounces were carefully selected to represent the infants' bouncing behaviour. Selection criteria required that: i) the fixed point and the majority of the reflective markers were clearly visible throughout the bouts, to facilitate landmark identification during the digitization process; and ii) clear audio cues identifying the start and end of the trial were present. Qualitative analysis of the bouncing behaviour was then performed and infants were ranked according to skill level.

Once bouts of bouncing were selected, the images were grabbed and stored for later processing using the frame Grabbing module. These images were then digitized using the Digitize module. For several infants, the hip and heel reflective markers were not visible for every frame in the sagittal video recording. This was due to either the infant swinging their arms posteriorly and anteriorly or the infants inverting their foot in mid-air. In these cases, the marker locations were approximated with reference to the other visible markers as well as the location of the infant in space. The number of video frames which had to be approximated varied from trial to trial and infant to infant. The infants' swinging arms obscured primarily the hip marker during the bouncing sequence. The analysis of subjects I6 and I5's bouncing sequences (recorded on video), required the hip marker location to be estimated for approximately 3 to 4 frames in a row for a maximum number of 10 to 12 frames per bout of bouncing. Analysis of I8's and I4's bouncing sequence required the hip marker location to be estimated for approximately 2 to 5 frames per bout of bouncing.

Digitized data were processed through the Transformation module of APAS. During this process, a series of two-dimensional, digitized views were converted into a two-dimensional image sequence. The process involved transforming the relative digitized coordinates of each point in each frame to absolute image space coordinates.

Data were digitally filtered via the Smoothing module of the APAS system. Marker positions were smoothed using a Butterworth Low-Pass digital filter at frequencies between 6 Hz at the more distal end and 4 Hz at the more proximal end of the lower extremity. Power spectrum analysis was used to determine if the smoothing procedure was successful in reducing high frequency noise present in the data while maintaining the integrity of the low frequency movement content with the signal. The View module was then used to provide a stick-figure representation of the 2-D image. This stick figure image was examined to ensure that it resembled the original video image of the infant bouncing. Angular displacement and velocities of the ankle, knee and hip joints were plotted using the Graphing module and the data exported and stored for later analysis.

Analog data

Analog data were exported from APAS format to an ASCII file type. The data were further converted to be read by Bioproc (Lamontagne, Bradley and Lemaire, 1989).

The full thirty second bout of bouncing was exported and the exact period of time corresponding to the video data was extracted for analyses. This ensured that the analog data analyzed corresponded to the same time period of video data analyzed. Bioproc was first used to sum the vertical ground reaction force data recorded via the two force platforms. Muscle onset latencies, patterns of muscle activation and the baby's contribution to the mechanical system were then determined. The vertical force data collected by the two force plates were used to determine the point in the bouncing cycle where the infant made contact with the ground. This point in the bouncing cycle was used as time zero in order to determine muscle onset latencies and loadcell analyses or the baby's contribution to the spring-mass system .

Baby contribution data

A preliminary qualitative model of the contribution of the infant to the bouncing behaviour is proposed. This was the first step of modeling baby bouncing behaviour and demonstrates the relationship between: i) the output, baby bouncing; ii) the spring-mass system which acts as a harmonic oscillator; and iii) the baby's contribution to the system which serves in part as a forcing function. This relationship is illustrated in Figure 2.

A mass equal to the infant's body mass was suspended from the loadcell (LC) and oscillated. One complete cycle of oscillation of this mass-spring system was randomly chosen for comparison with the LC curves produced by the infant during bouncing bouts. The cycling action of the spring-mass system can be modeled as a harmonic oscillator.

The LC curve produced by the infant was sliced into complete cycles of motion with each cycle corresponding to a bounce or bounce-like movement. The number of cycles varied from twelve to fifteen per infant.

The infant LC curves were normalized to the time and amplitude of the spring-mass LC trace. The LC curves of the mass-spring system was then subtracted from each of the normalized infant LC curves. The resulting curves represent the baby contribution to the LC trace recorded during bouncing behaviour. This is the *unknown* component of the baby contribution model.

Control mechanisms of the ankle, knee and hip joints

Phase-plane plots are displays of the angular velocity of a joint against the angular position of the same joint. By displaying the relationship between joint angular velocity and joint angular position the phase-plane plot provides a picture of the resultant action of the control mechanism. This removes the need for consulting an angular velocity versus time plot and an angular position versus time plot and then having to extrapolate an association for the separate trajectories. Phase-plane plots are used as windows into particular types of causal control processes that are not revealed by traditional time series plots. Individual plots are presented to illustrate the relationship between angular position and angular velocity for the ankle, knee and hip joints.

Data analyses

Qualitative and quantitative analyses were performed on three bouts of bouncing for each infant.

Loadcell oscillation patterns

Qualitative analyses of these data focuses on changes in general patterns of loadcell oscillations observed from the loadcell traces produced by the infants. Variation and consistency of the organization of loadcell oscillation patterns within and between the infants will be discussed qualitatively in relation to bouncing phases with respect to the initiation of a new bounce.

Mass-spring and baby bouncing oscillation frequencies

The loadcell data recorded during the bouncing sessions characterized the baby bouncing behaviour of each infant. The period (τ), the minimum amount of time before a motion repeats itself, for the oscillating mass-spring system and the oscillating, or bouncing baby was determined. The reciprocal of the period was then calculated to determine the frequency, f, of the oscillation.

The frequency obtained for the baby bouncing was the frequency at which the infants were producing bouncing behaviour. The period, τ, and frequency, f, of oscillation or baby bouncing was then calculated for each of the three bouts of bouncing for each infant. A mean frequency value for each infant was calculated across all trials and normalized to the directly calculated resonant frequency of the spring-mass system.

Patterns of force traces

Qualitative analyses of these data focuses on changes in general patterns of force trace patterns observed between the infants. Variation and consistency of the organization of force trace patterns within and between the infants will be discussed qualitatively in relation to bouncing phases by comparing the force trace patterns present with respect to the initiation of a new bounce.

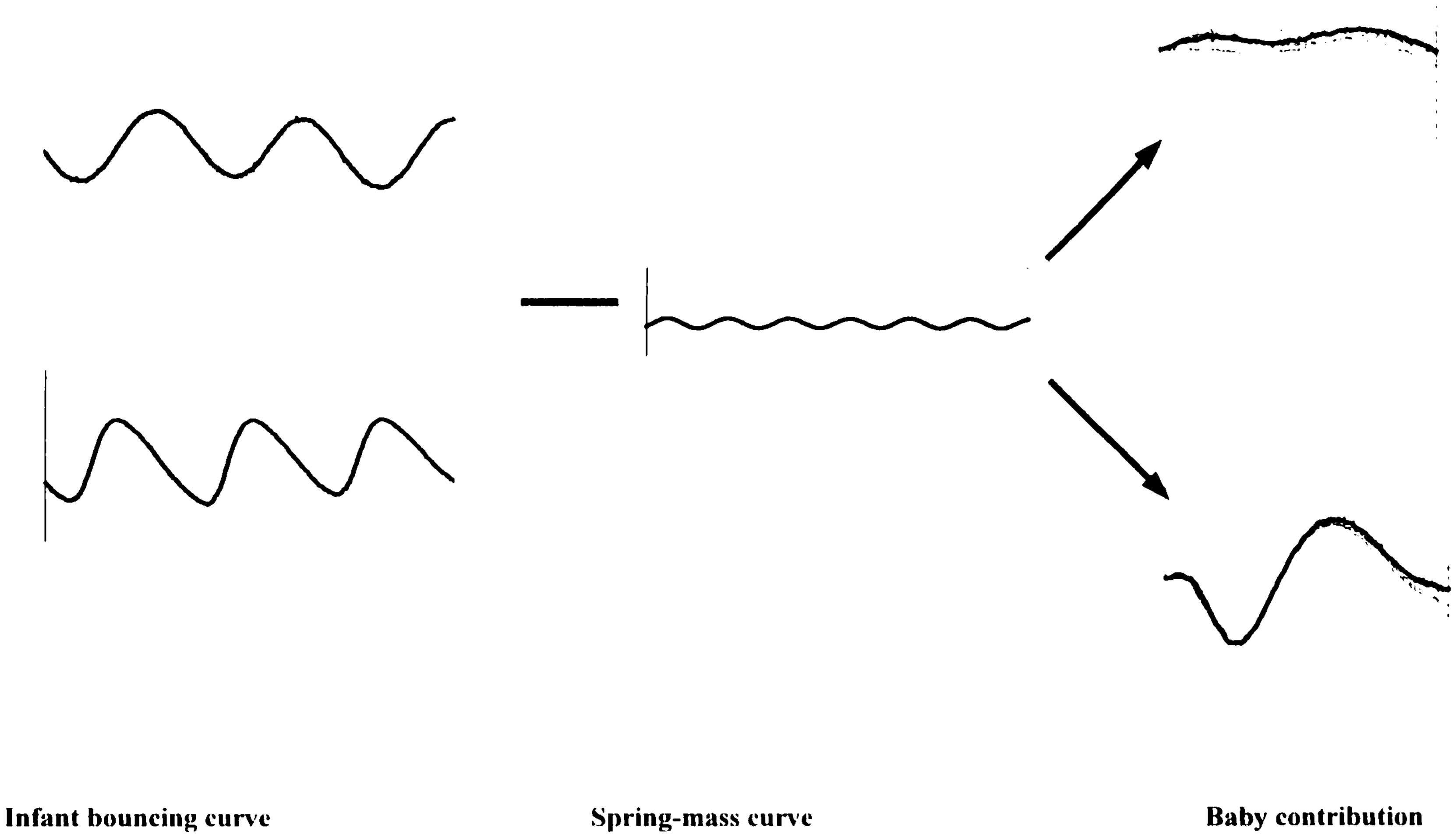


Figure 2. Comparison of the bouncing behaviour of two infants using the baby contribution model. The upper and lower plots to the right illustrate two infants' bouncing curves, 15 and 18, respectively, as recorded via a loadcell apparatus. The middle plot illustrates a loadcell trace for an oscillating inert mass equal to the infants' body mass hanging from the spring and Jolly Jumper apparatus. The infant bouncing curves were normalized to the time of the spring-mass curve. The mass-spring curve was then subtracted from each of the normalized infant bouncing curves. The resulting curves represent the baby contribution to the bouncing behaviour (upper and lower plots to the right for 15 and 18, respectively).

Interjoint co-ordination

Angle-angle plots provide insight to the intersegmental coordination or phase relationship of a movement task that is difficult to see in other representations (Weinstein and Garfinkel, 1989). Angle-angle plots are plots of the angular position of one joint against the simultaneous angular position of another joint for the entire bout period. Individual plots are presented to illustrate the joint angular position relationships of the: i) ankle and knee joints; ii) knee and hip joints; and iii) ankle and hip joints.

Joint angular range of motion

The ranges of motion of the ankle, knee and hip joints were determined. The sum of vertical forces was used to determine when the infants were on or off the ground. The landing or "toe down" point in the bouncing cycle was determined from the force trace and indicated the initiation of a new cycle of bouncing within the bout. The range of motion for each joint was recorded from toe down to the next toe down for each bounce. For each infant, the means and standard deviations of the joint range of motion means were calculated for the ankle, knee and hip joints. The relationship between the means of the joint range of motion for the ankle, knee and hip joints were illustrated. A Spearman rank-order correlation was performed to determine if joint angular range of motion was a function of skill level

Number of bounces

The number of bounces each infant produced during each bout of bouncing was calculated by examining the force trace curves. Each loading and unloading of the force platform was considered one full bounce cycle. If only one portion of this cycle was present on the force trace due to the bout of bouncing being sliced off (for video synchronization), the portion was accorded 0.5 of a total bounce. The number of bounces performed per bout were summed to obtain a total number of bounces performed by each infant. The total time of each bounce was also summed to obtain a total bouncing time. The total number of bounces performed by each infant was then divided by their total bouncing time, for all three bouts of bouncing behaviour, to obtain a ratio of number of bounces per second. The ratio of number of bounces per second was illustrated.

Time off ground versus time on ground

The amount of time each infant spent off ground versus the amount of time they spent on the ground was calculated using the force traces. Each full cycle of bouncing was identified (toe-down to toe-down) and the amount of time spent off ground and on the ground was calculated for each bounce cycle within each bout of bouncing behaviour. The mean amount of time spent off the ground and in contact with the ground was calculated and reported as a percentage of the total bouncing time over all three bouts of bouncing. The relationship between the percentage of total bouncing time spent off the ground and on the ground was illustrated.

Patterns of muscle activation

Qualitative analyses of these data focuses on changes in general patterns of muscle activation observed between the infants. Variation and consistency of the organization of muscle activation patterns within and between the infants will be discussed qualitatively in relation to bouncing phases by comparing the muscle firing patterns present with respect to the initiation of a new bounce. The patterns of muscle activation produced by the bouncing infants was illustrated.

Muscle onset latencies and specific relationship between gastrocnemius and tibialis anterior muscle activation

Muscle activation onset latencies were determined for the G, TA, VM, ST and GM muscles for 9 to 20 bounces per infant. "Toe-down" was used to identify the onset of each cycle of bouncing as this event provided a clear indication of the period where bouncing infants attempted or achieved the airborne stage of the bouncing cycle.

The baseline level of activation was determined for each muscle for each infant. Coding of muscle activation onset latencies was then performed for each muscle using the "toe-down" event of the force trace as time zero. Muscle activation greater than one standard deviation above baseline was identified as a muscle burst. A mean value of muscle onset latencies for each muscle for each subject was calculated for all bounces.

The relationships between the onset latencies of the gastrocnemius and tibialis anterior muscles were further studied. The firing pattern of these muscles was examined with respect to the toe down point in the bouncing cycle. This examination revealed some insight into neuromuscular control of the lower limb during bouncing behaviour.

Proportion of bounces with muscle activity

The proportion of bounces in which activity was recorded was determined for the five muscles for each infant. The number of bounces in which muscle activity was recorded was divided by the total number of bounces to reveal the proportion of bouts of bouncing in which muscles were activated. The data for the individual subjects were then combined to provide group means and standard deviations.

CHAPTER FOUR

RESULTS and DISCUSSION

In the current series of experiments, different skill levels of bouncing behaviour were studied in infants aged 6- to 12-months. In general, analysis of the global behaviour illustrated two distinct patterns of baby bouncing in the baby contribution plots, double-bump and negative-and-positive. Low dimensional kinematic analyses indicated two distinct patterns of joint angular displacement and velocity relationships, cusping and smooth, rounded trajectories. The loadcell curves illustrated in the same plots as the muscle activity, indicated two distinct loadcell patterns which correspond to the two patterns illustrated in both the baby contribution and phase-plane plots. Finally, the underlying control mechanisms represented at the level of surface EMG, showed that although highly-skilled infants produced periods of muscle co-activation, the less-skilled infants had a higher level of tonic activity in their muscles and produced periods of muscle co-activation more frequently. Highly-skilled infants generally produced periods of alternating bursts of activity in the gastrocnemius and tibialis anterior muscles. It is important to note that while a difference in the underlying control mechanisms was apparent between bouncing skill levels, the EMG patterns did not have a relationship to the two patterns of baby contributions, phase-plane plots, loadcell traces or bouncing oscillation frequencies produced by the infants.

The following sections primarily present the experimental results and discussion of the study on baby bouncing for one less-skilled (I1) and two skilled (I7 and I8) infants. Comparisons between the less-skilled infant and the skilled infants will illustrate the differences in behaviour resulting from skill level. Comparisons between the two skilled infants will illustrate the differences resulting from the two patterns of bouncing behaviour observed. The data for the remaining infants, although not presented in the body of the thesis are presented in the Appendices.

Global behaviour: Evaluation of bouncing skill levels

Criteria for skill evaluation was established prior to a researcher viewing the video tapes of the infants' bouncing behaviour and prior to extensive analyses of their jumping skills. Infants were ranked according to the criteria outlined in the skill levels of bouncing behaviour definition.

The nine infants were ranked in the following order as skilled (I9, I8, I7 and I6), moderately-skilled (I5, I4 and I3) and less-skilled (I2 and I1) bouncers. A second investigator ranked the infants in a similar order with the only difference being that I5 and I4 were switched in the continuum.

I8, I6, I4 and I2 had previous exposure to a Jolly Jumper either in their own home or in a day care setting. Parental reports of time spent in the Jolly Jumper either at home or at a caregiver's was an approximation. It did not appear that the time spent in the Jolly Jumper was qualitatively related to the skill level of the infant. I9 had no previous exposure to bouncing in a Jolly Jumper while I2 had previous exposure to the Jolly Jumper prior to involvement in the test. Parental report of exposure time included: i) playing in the apparatus each day for several weeks prior to involvement in this study for maximum of one half hour, I8 and I6; ii) playing in the apparatus once prior to the experimental session, I4; and iii) several 30 minute exposures in the laboratory environment, I2. As the commercial Jolly Jumper was modified for this experiment, infants who had previous exposure to the apparatus still required a few bounces to understand the system, possibly to determine the spring characteristics of the different system. I9, I7, I5, I3, and I1 had exposure to another bouncing toy, the Exersaucer, either at home or in a day care setting. Infants are supported in this toy in a harness similar to the Jolly Jumper harness that, in turn, is suspended in a hard plastic ring that restricts infant movement in the anterior, posterior and lateral directions. By flexing and extending their legs the infants can produce bouncing motion. This toy is quite different than the Jolly Jumper, where the infants were suspended with a spring above them and movement in the anterior, posterior and lateral directions is not restricted. It was felt that the Jolly Jumper system was less restrictive as infants were able to move freely in the frontal plane. Due to the Exersaucer design, the infants who had played in this toy were, at first, unfamiliar with such freedom of motion and may have required some adaptation to the different system.

The skilled infants, like I8 and I7, were able to consistently produce bouts of bounces where they bounced vertically between 15 to 25 centimeters off the floor. These infants used their arms as well as their legs to produce bouncing behaviour, often crouching down at the end of the reversal phase. The skilled infants were, for the most part quite happy in the harness system. They showed excellent full body control during the task, laughing and clapping their hands during all stages in the bouncing cycle. The skilled infants usually bounced continuously, with bouts of bouncing usually lasting the entire 30 second trial duration. Often these infants expressed the desire to remain in the Jolly Jumper harness when it was time to conduct the AIMS motor development test.

In contrast, the less-skilled bouncers, like I1, produced what appeared to be very confused bouncing behaviour during the test session. They would attempt to produce continuous bouts of bouncing, but would bounce for three to five bounces before they suddenly stopped. The cause of the sudden cessation of the behaviour was that these infants often attempted to leave the ground just prior to the spring reaching full extension. These infants thus actively pushed into the extended or extending spring rather than allowing the spring to naturally pull them into the air a few moments later as it compressed. This caused the infants to stop moving and required them to restart the bouncing once the system damped out. The sudden stops and starts in the less-skilled bouncing behaviour resulted in shorter bouts of bouncing which contained less bounces. Moreover the less-skilled infants rarely went into a crouched position at the end of the reversal phase. These infants often bounced on their toes and prevented their heels from making contact with the ground. These infants rarely used their arms to contribute to the bouncing behaviour and often used either their ankles and knees (the hip swayed, but no apparent contribution was evident) or hips and knees (bounced on their toes) to produce the motion needed to bounce.

Infants who exhibited inconsistent behaviour, I5, I4, and I3, that ranged from skilled to less-skilled bouncing from bout to bout fell in the middle of the bouncing skill spectrum. These infants were difficult to place on the skill level continuum as they exhibited behaviours that were common to both the skilled and less-skilled bouncers. The infant who mainly exhibited skilled bouncing with occasional bouts of less-skilled bouncing was placed closer to the skilled extreme, I5, while the infant who mainly exhibited less-skilled bouncing with occasional bouts of skilled bouncing was placed closer to the less-skilled extreme, I3.

Resonant frequency

Mathematical and direct calculation of the mass-spring system characteristics

The spring stiffness was mathematically calculated to be 565.39 N/m, with a damping ratio of 0.468 (see Appendix A for calculations that outline the Jolly Jumper spring characteristics). Over thirty oscillations, the frequency of oscillation decreased by 0.9 percent. Goldfield *et al.* (1993) also reported a small damping ratio for the spring of 0.0014 from small amplitudes and 0.005 for large amplitudes and determined that the effect on the infants' bouncing behaviour was negligible. Due to the minimal decrease in the frequency over repeated oscillations, it was assumed that damping did not appreciably contribute to the observed oscillatory behaviour produced by the infants and thus the damping ratio was not factored into the baby contribution model.

The two methods to characterize the spring, mathematical and direct measurement of the system dynamics, resulted in slightly different period lengths and resonant frequencies for each infant (see Tables 4 and 5, respectively). The ratios of the directly calculated and mathematically calculated oscillation resonant frequencies for the infants had a mean and standard deviation of 1.181 +/- 0.0117 (Table 6). A two-tailed t-test between the mathematical and directly calculated oscillation frequencies found that the frequencies were statistically significant ($p < 0.0001$). While the results of the two methods were statistically different, a ratio of the mathematically calculated divided by the directly calculated frequency of oscillation was approximately 1.18 for all nine infants (see Table 6). The curves were, in effect phase shifted with respect to each other. Due to this constant ratio, normalizing bouncing frequencies to either the mathematically or the directly calculated resonant frequencies of the mass-spring system would yield results different only with respect to the constant multiplier. It was decided to normalize the

Table 4.

Mathematically calculated period and resonant frequencies (using *k* = 565.39 N/m) of the mass-spring system compared to baby bouncing frequencies

Infant	**Natural circulating frequency (ω_n)**	**Period (τ)**	**Resonant frequency (*f*)**	**Baby bouncing frequency**
I1	8.273	0.759	1.317	0.336
I2	6.864	0.915	1.092	2.303
I3	7.694	0.816	1.225	1.430
I4	8.503	0.739	1.353	1.999
I5	7.519	0.835	1.197	1.483
I6	7.561	0.831	1.203	1.958
I7	7.055	0.890	1.123	1.446
I8	7.055	0.890	1.123	2.028
I9	8.329	0.754	1.326	1.560

Table 5.

Directly calculated damped period and oscillation frequencies of the mass-spring system compared to baby bouncing frequencies

Infant	**Mass oscillated (kg)**	**Number oscillations**	**Length of oscillation (time, s)**	**Damped period (τ_d)**	**Mass oscillation frequency**	**Baby bouncing frequency**
I1	8.12	11	9.936	0.903	1.107	0.336
I2	12.09	8	8.680	1.085	0.922	2.303
I3	9.50	10	9.744	0.974	1.026	1.430
I4	7.87	11	9.600	0.873	1.146	1.999
I5	10.11	9	8.844	0.983	1.018	1.483
I6	9.72	9	8.664	0.963	1.039	1.958
I7	11.21	10	10.488	1.049	0.954	1.446
I8	11.21	10	10.488	1.049	0.954	2.028
I9	8.12	11	9.936	0.903	1.107	1.560

Table 6.

Ratio of directly calculated and mathematically calculated oscillation resonant frequencies

Infant	**Directly calculated resonant oscillation frequency (*f*)**	**Mathematically calculated resonant oscillation frequency (*f*)**	**Ratio of directly and mathematically calculated resonant frequencies (*f*)**
I1	1.107	1.317	1.190
I2	0.922	1.092	1.185
I3	1.026	1.225	1.194
I4	1.146	1.353	1.181
I5	1.018	1.197	1.176
I6	1.039	1.203	1.158
I7	0.954	1.123	1.178
I8	0.954	1.123	1.178
I9	1.107	1.326	1.198

baby bouncing frequencies to the directly calculated resonant frequencies obtained from the loadcell data since the directly measured resonant frequency was determined in a similar way as the baby bouncing frequency.

Resonant frequencies of the mass-spring system and bouncing frequencies of the infants

A mass equal to the body mass of each infant was suspended in the Jolly Jumper apparatus and oscillated. The directly calculated frequency of the mass-spring system ranged from 0.922 to 1.146 oscillations per second. The frequency of the baby bouncing oscillation ranged from 2.303 to 0.336 with a group mean and standard deviation of 1.557 oscillations per second +/- 0.0572 (Table 5). Figure 3 illustrates the baby bouncing oscillation frequency normalized to the directly calculated mass-spring oscillation frequencies recorded for each infant.

The mean frequency calculated for the infants in the current study (1.557 Hz) was very close to the mean frequency reported by Goldfield *et al.* (1993, 1.61 Hz). However, analysis of the behaviour of the individual infants suggest that there were, in fact, two primary clusterings of babies who bounced at either just below 1.5 Hz (Infants 3,5,7 and 9) or close to 2 Hz (Infants 4, 6 and 8). Infants 1 and 2, the less-skilled infants, did not fit either pattern. This suggests two important aspects in the development of bouncing. First, as suggested by Goldfield *et al.* (1993), the initial phase of bouncing skill development is one of assembly. As results reported later in the thesis demonstrate, the two less-skilled infants had behaviour that was highly variable and distinct from the remaining infants.

A similar assembly phase has been suggested in the development of speech (Fry, 1966) and of posture (Sveistrup and Woollacott, 1997). The seven moderately skilled and skilled infants bounced consistently suggesting that they were in a period of tuning or establishing the parameters of the pattern of bouncing. Second, in contrast to the Goldfield *et al.* (1993) report of a single frequency of bouncing, there were two distinct frequencies of bouncing recorded. Moreover, the likelihood of an infant producing one specific frequency was skill-independent although any one infant bounced at only one of the two frequencies. This suggests that there are at least two attractor states or possible

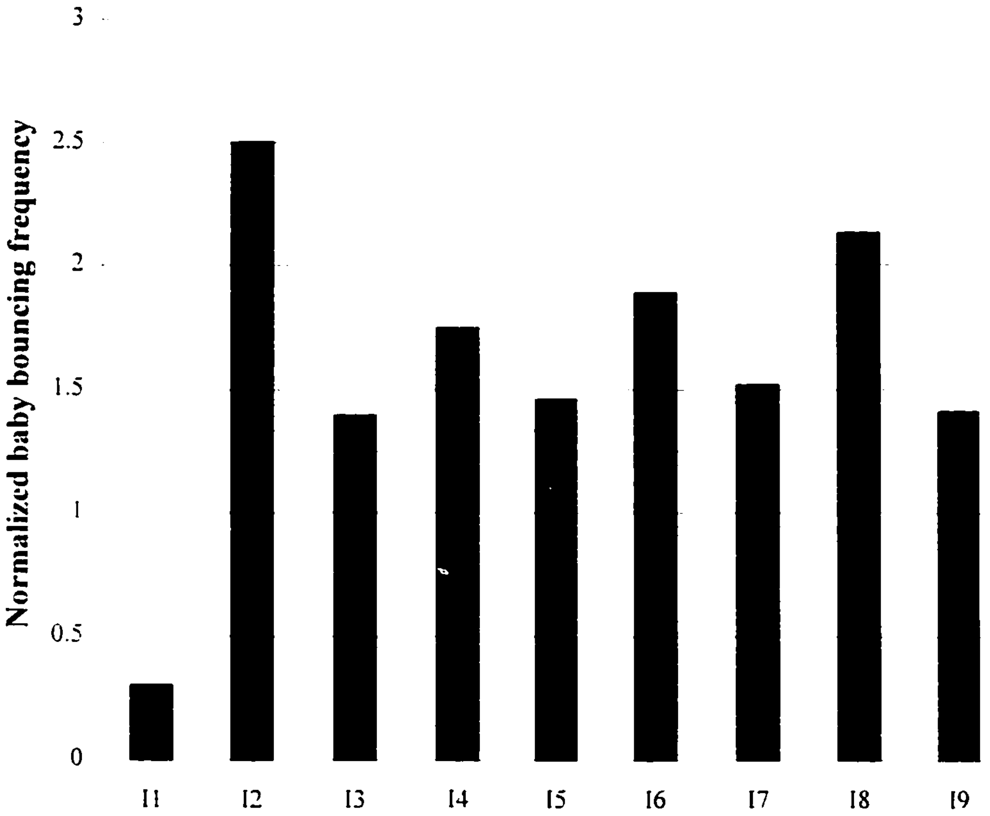


Figure 3. Normalized baby bouncing frequencies. The baby bouncing frequencies were normalized to the directly calculated mass-spring oscillation frequencies for each infant's body mass. Note that infants whose bouncing behaviour produced an up-and-down pattern in the loadcell traces (I3, I5, I7 and I9) and infants whose bouncing behaviour produced a slanted pattern in the loadcell curve (I4, I6 and I8) produced frequencies of oscillation close to 1.5 and 2.0 times the oscillation frequency of the inert mass, respectively. The less-skilled infants, I1 and I2, whose bouncing behaviour produced highly variable loadcell patterns had oscillation frequencies that were less than half or greater than double the oscillation frequency of the inert mass.

patterns of behaviour that will result in moderately-skilled or skilled bouncing. The distinct frequencies of bouncing also corresponded to distinctions in the analyses of other global variables such as the baby contribution to bouncing as well as the underlying mechanisms of control as reflected in phase-plane plots.

Specifically, infants whose bouncing behaviour produced a primarily cusping pattern in the phase-plane plots and a double-bump pattern in the baby contribution curves (I7) oscillated at frequencies close to 1.5 times the oscillation frequency of the mass-spring system. Infants whose bouncing behaviour produced a primarily a smooth, rounded pattern in the phase-plane plots and a negative-and-positive pattern in the baby contribution curves (I8) oscillated at a frequency approximately double that of the mass-spring system. Less-skilled infants, like I1 whose bouncing behaviour produced highly variable phase-plane plots containing both cusped and smooth, rounded trajectories as well as highly variable baby contribution plots, oscillated at frequencies that were less than half or greater than double the oscillation frequency of mass-spring system. Qualitatively there was no relationship between frequency of bouncing and bouncing skill.

Number of bounces

A ratio of the number of bounces per second performed by each infant was obtained by dividing the total number of bounces performed by each infant by the infant's total bouncing time for all bouts of bouncing behaviour (Table 7). The maximum and minimum number of bounces per second were calculated to be 2.53 and 1.40, respectively. The ratio of number of bounces per second is illustrated in Figure 4.

Infant 7 produced just under 1.5 bounces per second, while I8 produced approximately 2.0 bounces per second during their bouncing behaviour and I1 produced 1.92 bounces per second, respectively. Interestingly, the infants who produced approximately 1.5 bounces per second were also the infants who produced the double-bump pattern of the baby contribution plots, the cusping pattern of the phase-plane plots and the up-and-down pattern of the loadcell curves at an oscillation frequency of close to 1.5. The infants who produced approximately 2.0 bounces per second produced the

Table 7.

Number of bounces per second as calculated by force plate data

Infant	Bout 1	Bout 2	Bout 3	Total number of bounces	Total time (s)	No. of bounces / Total time (bounces/s)
I1	8	4	4	16.0	8.32	1.92
I2	11	6	2	19.0	7.50	2.53
I3	4	4	3.5	11.5	8.11	1.42
I4	5.5	4.5	5.5	15.5	7.164	2.16
I5	5	4.5	5	14.5	9.37	1.55
I6	5.5	5	6	16.5	7.94	2.08
I7	4.5	4	4	12.5	8.434	1.48
I8	5	5	6.5	16.5	8.33	1.98
I9	5	4.5	4.5	14	10.06	1.40

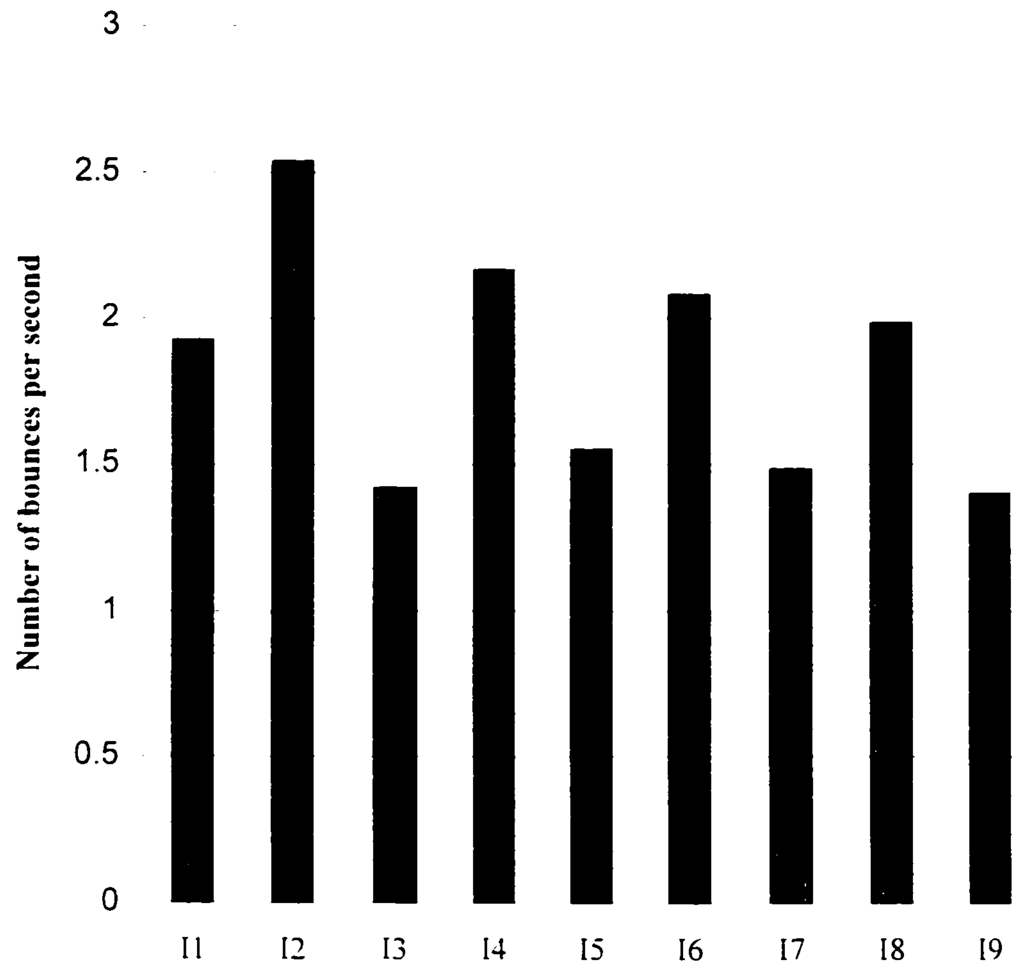


Figure 4. Number of bounces per second. A ratio of the number of bounces per second performed by each infant was obtained by dividing the total number of bounces performed by each infant (as indicated by the force trace curves) by the infant's total bouncing time for all bouts of bouncing behaviour. Note that a the infants who produced just under 1.5 bounces per second produced the up-and-down pattern in the loadcell curves. The infants who produced approximately 2.0 bounces per second produced the slanted pattern of the loadcell curves. Note that the relationship between the loadcell curve pattern and the number of bounces was not apparent in the bouncing behaviour produced I1 and I2. See the results section for more details about this relationship.

negative-and-positive pattern in their baby contribution plots, the smooth, rounded trajectory pattern of the phase-plane plots and an oscillation frequency in the loadcell curves of close to 2.0.

Two distinct patterns of loading the Jolly Jumper

There were two distinct orientations for the loadcell data curves. The first orientation for the loadcell data curves is an up-and-down pattern which resembles a sine wave (I7). This loadcell orientation suggests that the bouncing infant was spending approximately the same amount of time loading the loadcell, illustrated from peak to valley in the loadcell curve, as unloading the loadcell, illustrated from valley to peak in the loadcell curve. The second orientation for the loadcell data curves is a slanted, to the right, pattern which resembles a sine wave that has been elongated to the right (I8). This loadcell orientation indicates that the bouncing infant was spending a longer amount of time unloading relative to the amount of time spent loading the loadcell.

Infant 7 produced primarily an up-and-down patterns in the loadcell curves (Figure 5b). Infant 8 produced primarily a slanted patterns in the loadcell curves (Figure 5c). Note the variability, both within and between bouts of bouncing behaviour, of the loadcell traces of the less-skilled infants (I1, Figure 5a). The loadcell curves produced by these infants have a small amplitude and in fact these traces appear at times to be flat, indicating that the loadcell did not record a change in the loading or unloading of the Jolly Jumper harness apparatus during the bouncing cycle. The force trace, however, indicates that this was not the case as infants achieved the airborne stage of bouncing although the airborne phase may not have been consistently produced throughout the bouncing cycle. The loadcell curves produced by I1 were extremely variable (Figure 5a). Bouts 1 and 2 contained bouncing behaviour which produced loadcell curves that illustrated a slight increase and decrease in the load placed on the loadcell over the bouncing cycle, while bout 3 contained bouncing behaviour which produced loadcell curves that resembled an up-and-down loadcell pattern with a very small amplitude.

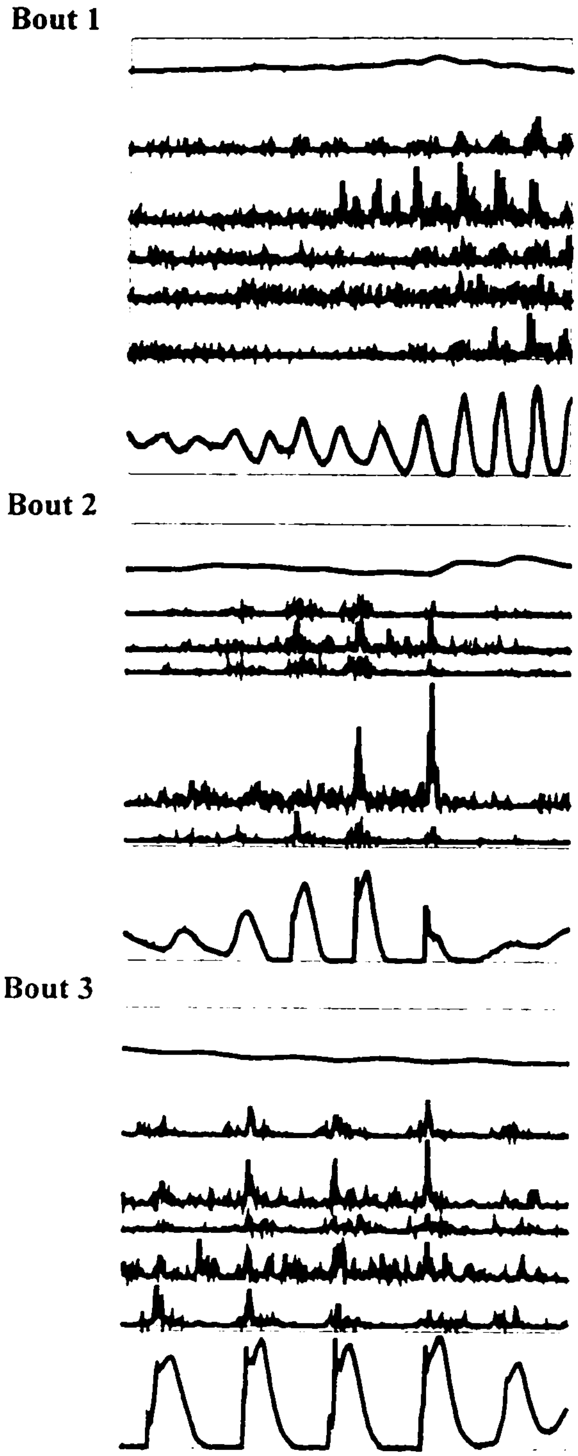


Figure 5a. Loadcell, EMG and force plots for I1. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 3.97, 2.55 and 1.80 seconds, respectively. The y-axis is arbitrary units. Note the predominant pattern of co-activation of all five muscles that was recorded for I1's EMG traces as well as the variability across and within bouts for the loadcell and force traces.

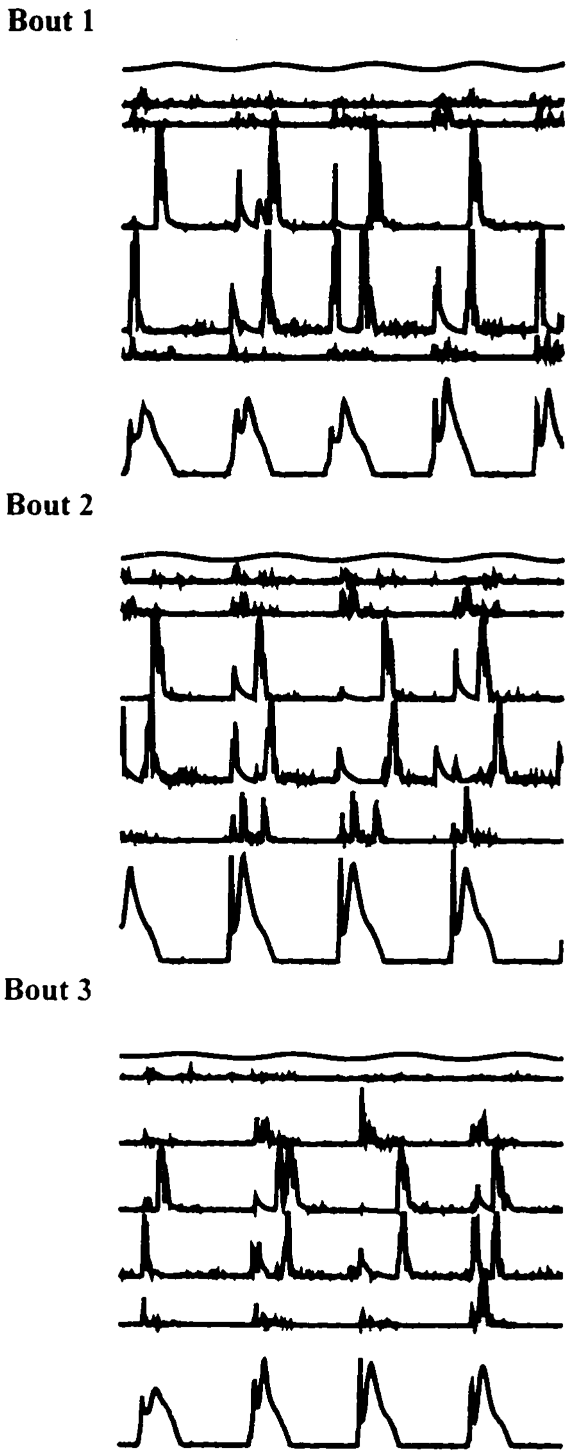


Figure 5b. Loadcell, EMG and force plots for I7. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 2.99, 2.71 and 2.73 seconds, respectively. The y-axis is arbitrary units. Note periods of muscle co-activation present in gastrocnemius and tibialis anterior muscles in I7's EMG traces. Also note the consistency, within and across bouts, for loadcell and force traces.

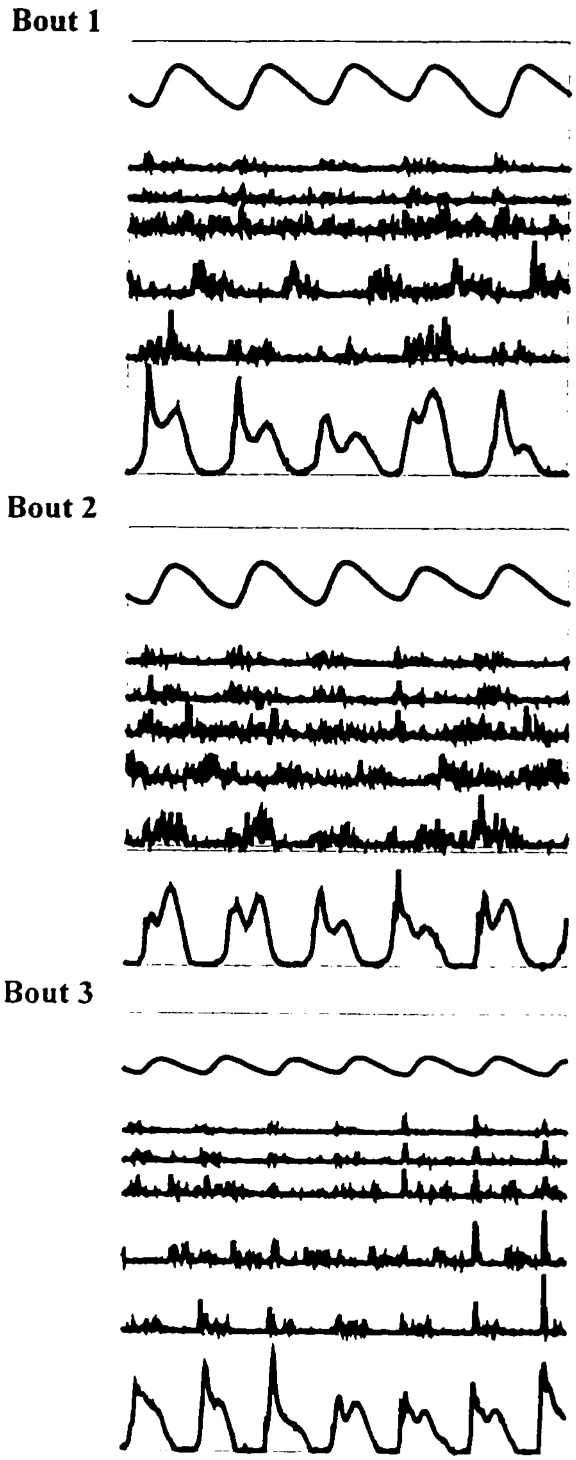


Figure 5c. Loadcell, EMG and force plots for I8. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 2.48, 2.65 and 3.20 seconds, respectively. The y-axis is arbitrary units. Note predominant alternating muscle bursts in I8's EMG traces of gastrocnemius and tibialis anterior muscles. Also note the consistency, within and across bouts, for the loadcell traces.

Patterns of loading the force platform

The force trace patterns of less-skilled infants have a high degree of variability between and amongst bouts of bouncing (Figure 5a and Figure 5d from Appendix D). The force traces of skilled bouncers contain a more consistent pattern, with a double-hump, occurring in the middle of the trace (indicating the reversal phase of the behaviour). These consistent patterns are evident in the force patterns of I7 and I8 (Figures 5b and 5c). Moderately-skilled infants produced force traces that either contained primarily a single-hump pattern or primarily a double-hump pattern similar to that produced by skilled infants.

Time off ground versus on ground

The two different loading patterns of the loadcell curve are indicative of the amount of time each infant spent loading the loadcell, illustrated from peak to valley in the loadcell curve, and unloading the loadcell, illustrated from valley to peak in the loadcell curve. The up-and-down pattern indicates that the infant is spending approximately the same amount of time is spent loading as unloading the loadcell, while the slanted pattern indicates that the infant is spending more time unloading the loadcell relative to the time spent on loading the loadcell. This relationship illustrates the impact that time has on the two patterns and indicates that each pattern can be related to the amount of time an infant spends on the ground and off the ground during bouncing behaviour.

The mean amount of time spent off the ground and in contact with the ground was calculated and reported as a percentage of the total bouncing time of all three bouts of bouncing for each infant (Table 8). There was a general trend from more to less time in contact with the ground from less-skilled to skilled bouncers, however the two loadcell patterns, up-and-down and slanted also influenced the amount of time spent on the ground and off the ground (Figures 5b and 5c). Note that I8, the infant who produced a slanted loadcell pattern, was off the ground for approximately 30 percent of all bouts of bouncing, with the remaining time of the bouts spent on the ground. In contrast I7, the infant who produced an up-and-down loadcell pattern was off the ground for

Table 8.

Percentage of time off ground and on ground

Infant	**% of time off ground**	**% of time on ground**	**% time off ground / % time on ground**
I1	29	71	0.41
I2	13	87	0.15
I3	20	80	0.25
I4	27	73	0.37
I5	39	61	0.63
I6	31	69	0.45
I7	56	44	1.27
I8	27	73	0.36
I9	48	52	0.92

approximately 56 percent of bouncing time. Infant 1, who produced highly variable loadcell patterns, was off the ground for under 30 percent of bouncing time.

The relationship between the percentage of time off and on the ground was illustrated in Figure 6. Infant 9 spent approximately 50 percent of the total bouncing time on the ground and 50 percent of the total bouncing time off the ground. Infant 2 spent the highest percentage of time in contact with the ground with less than 15 percent of the total bouncing time off the ground. Infant 7 spent the highest percentage of time off the ground with less than 45 percent of the total time in contact with the ground.

Baby contribution to bouncing behaviour

Preliminary modeling was performed of the relationship between: i) the bouncing behaviour produced by the infants; ii) the mechanical system which included the Jolly-Jumper, the spring, and an inert mass equal to each infants' body mass (kg); and iii) the baby's contribution to the system, the unknown component of the output signal that is composed of a forcing component and a non-forcing component (Figure 2).

Two patterns in the baby bouncing loadcell curves were apparent, up-and-down and slanted. The spring-mass system was characterized by a sinusoidally oscillating damped curve that qualitatively did not alter in shape regardless of the mass suspended. To determine the baby contribution to the bouncing behaviour, the infant loadcell bouncing curves were normalized to the time of the spring-mass loadcell trace. The mass-spring loadcell curve was then subtracted from each of the normalized infant bouncing loadcell curves to obtain each infant's contribution to the bouncing behaviour.

Two distinct patterns of baby contribution were identified in these experiments (illustrated in Figures 7b and c). The two patterns illustrated as the baby contribution were not associated with a particular skill level. We have termed the first pattern "double-bump" (Figure 7b) and the second pattern "negative-and-positive" (Figure 7c). Less-skilled infants (I1) produced baby contribution plots which did not distinctly illustrate either a double-bump or a negative-and-positive pattern (Figure 7a). Skilled infants, like I8 and I7, produced baby contribution curves that reflected a more consistent

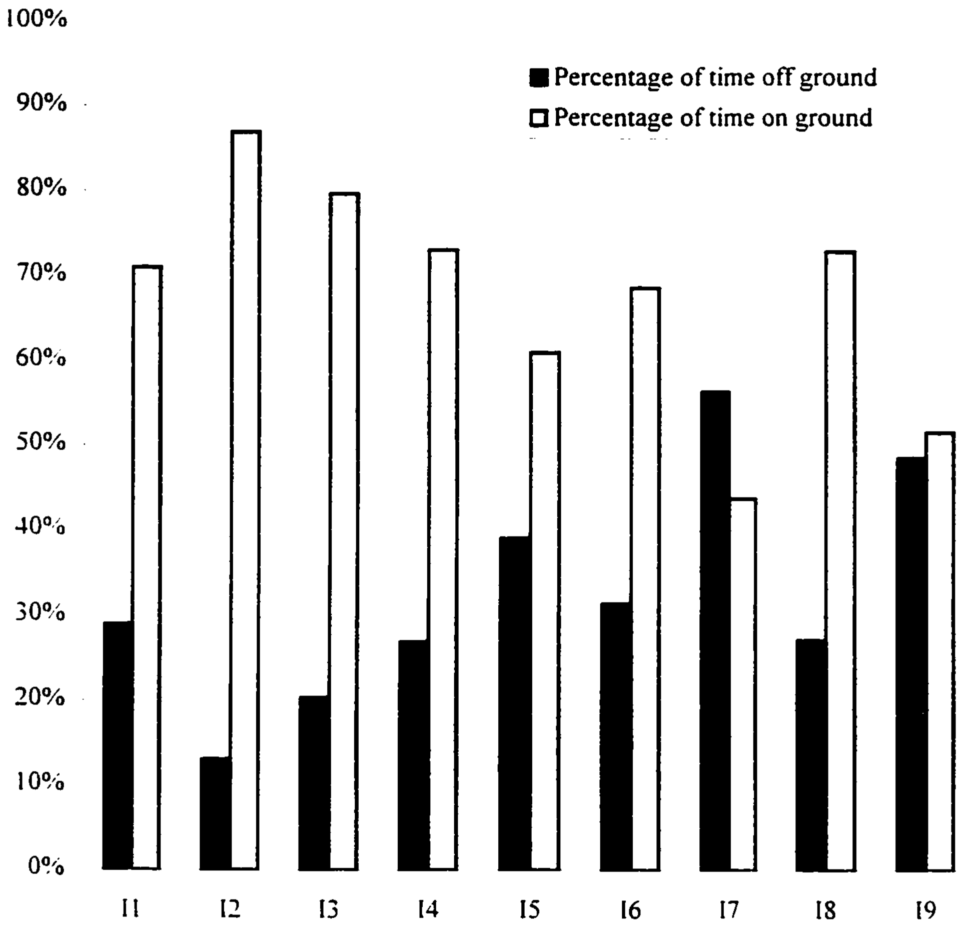


Figure 6. Percentage of time off and on ground. The mean amount of time spent off and on the ground was calculated and reported as a percentage of the total bouncing time over three bouts of bouncing for each infant. There was a general trend from less to more time in contact with the ground from less-skilled to skilled bouncers. Please see the results section for more details about this relationship.

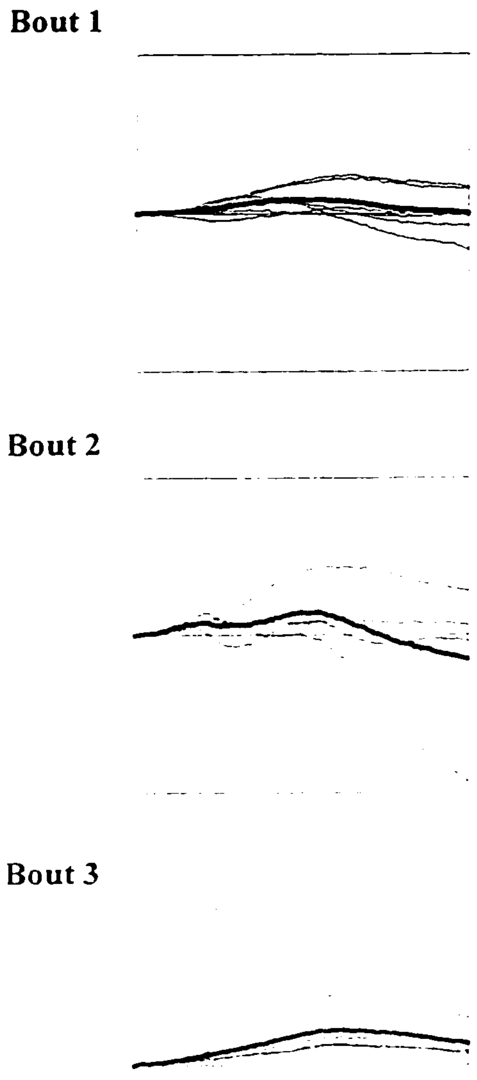
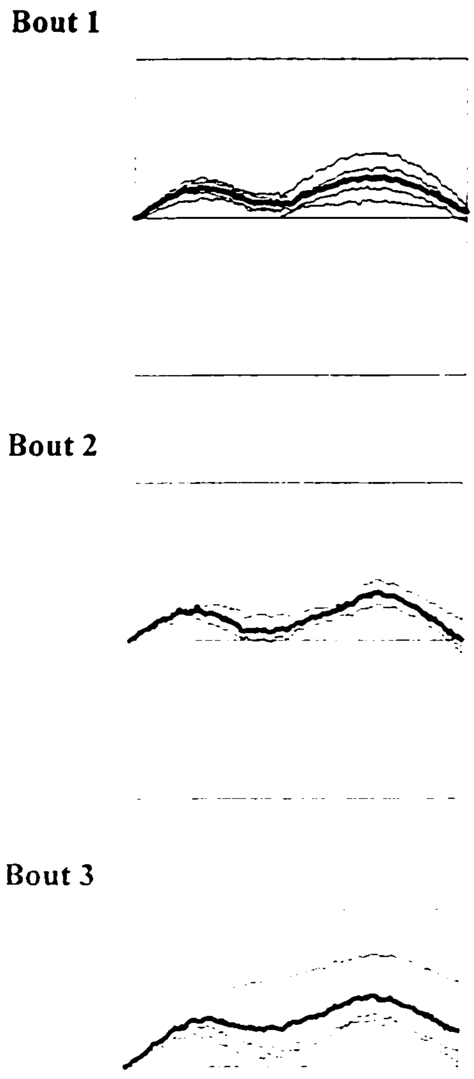


Figure 7a: Model of baby contributions to the bouncing task for I1. The graphs represent I1's contribution to the bouncing behaviour. For each graph, the thin curves represent I1's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note I1's variability of baby contribution between and within bouts which suggests that he was still exploring possible organization patterns of variables which would produce bouncing behaviour that is both organized and efficient.



Bout 1

Bout 2

Bout 3

Figure 7b: Model of baby contributions to the bouncing task for I7. The graphs represent I7's contribution to the bouncing behaviour. For each graph, the thin curves represent I7's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note that while a double bump line pattern is predominant (bouts 1 and 2), intrabout variability is still illustrated in I7's baby contribution curves (bout 3). This suggests that I7 was still exploring possible organization patterns of the variables which produced bouncing behaviour.

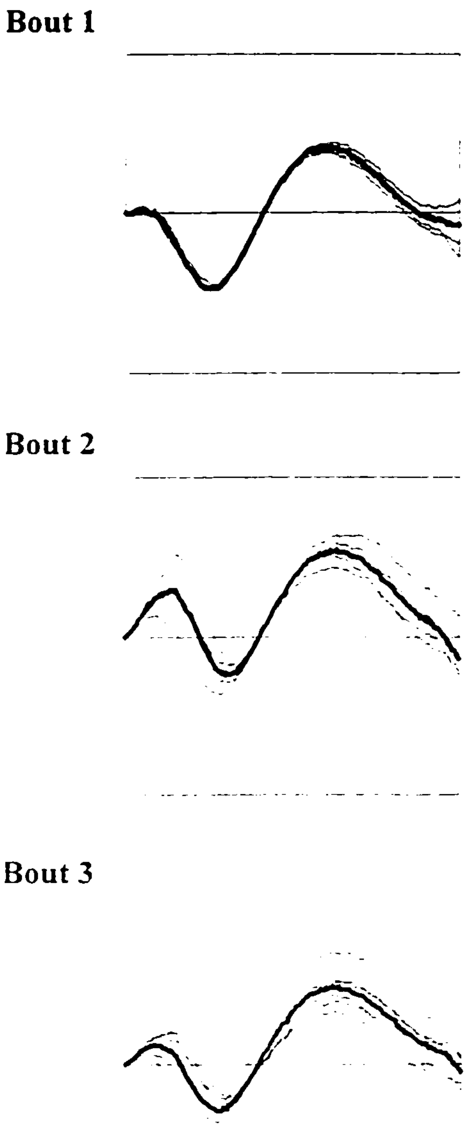


Figure 7c: Model of baby contributions to the bouncing task for I8. The graphs represent I8's contribution to the bouncing behaviour. For each graph, the thin curves represent I8's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note I8's consistent negative to positive line patterns, both within and between bouts, for baby contribution.

output both within and across bouts. Specifically, the curves maintained the same shape and were less variable, indicating that these infants had mastered the skill of bouncing.

The double-bump pattern remained positive on the y-axis throughout the bouncing cycle. The double-bump pattern begins at zero on the x-axis, increases along the y-axis and then decreases to zero, or near zero, at approximately halfway through the bout of bouncing. This pattern is repeated once more prior to completion of the bout of bouncing. This double-bump pattern corresponds to an "up-and-down" pattern in the baby bouncing loadcell curve (Figure 7b).

The negative-and-positive pattern also begins at zero on the x-axis and either quickly increases along the y-axis then suddenly decreases along this axis or immediately decreases. Both curves then reach a peak negative value before increasing, crossing zero and reaching a peak positive value before descending again to zero just prior to completion of the bout of bouncing. This negative-and-positive pattern corresponds to a "slanted" baby bouncing LC curve (Figure 7c).

Two attractor states

Goldfield *et al.* (1993) compared the observed period of resonant frequency in the peak period of bouncing for each of the infants they studied with the resonant frequency their system. From graphical data illustrating the infant bouncing, the mean resonant period was determined to be 0.62 seconds. In all cases, the infants bounced with a shorter period than predicted by the resonant frequency of the mass-spring system. A second spring modeled the infants' legs and was used to determine if the infants' legs acted like a spring. These researchers recompared the infants' bouncing oscillation period to the recalculated resonant period of the two-spring model. The results of the observed and predicted periods of oscillation of the two-spring model were found to be closely related for all subjects. Goldfield *et al.* (1993) concluded that the preferred bouncing frequency of the infants could be predicted by the resonant frequency of the two-spring model of infant bouncing.

In the current study, a qualitative forced harmonic oscillation model of the baby contribution to harmonic Jolly Jumper oscillation system was proposed. The resonant frequency of the Jolly Jumper harness apparatus was calculated mathematically and directly for each infant through the use of a loadcell output. The direct method of calculating resonant frequency was chosen as it was determined that the directly measured resonant frequency was determined in a similar way as the frequency of baby bouncing was determined. This analysis revealed that infants who produced a double-bump pattern in their baby contribution curves (I7) also produced a frequency of oscillation rate close to 1.5 times (period $\cong$ 0.66) the oscillation frequency of an oscillating mass equal to their body mass (mean and standard deviation of 1.026 +/- 0.063) when suspended in the Jolly Jumper apparatus. Infants who produced a negative-and-positive pattern in their baby contribution curves (I8) produced a frequency of oscillation rate double (period = 0.5) the frequency of an oscillating mass equal to their body mass (mean and standard deviation of 1.046 +/-0.096). Less-skilled infants, like I1 and I2 who produced baby contribution plots that contained both cusped and smooth, rounded trajectories had frequencies that were less than half or greater than double the oscillation frequency of the inert mass. As well, no significant relationship could be established between skilled and less-skilled bouncers from loadcell frequency of oscillation data.

It is important to note that the relationship between the oscillation frequency calculated separately from the loadcell curves or the number of bounces was not apparent in the bouncing behaviour produced by I1 and I2. Thus, the bouncing behaviour that was illustrated at the level of the force traces was not the same behaviour as that illustrated at the level of the loadcell traces. It is proposed that this was due to these less-skilled infants actively pushing into the extended or extending spring rather than allowing the spring to naturally pull them into the air a few moments later as it compressed. This bouncing behaviour would therefore be illustrated quite differently when frequency of bouncing was determined from force plate or loadcell data.

Goldfield *et al.* (1993) calculated the period of oscillation in both spring models as well as the oscillation period of the infants mathematically. They claimed that an infant's preferred bouncing frequency could be predicted by the resonant frequency of the system that modeled the infants' legs as a spring that contributes to the Jolly Jumper spring during bouncing behaviour. The resonant frequency of the system is a stable attractor which infants with increased skill level, can tune into and mimic, thereby producing energetically efficient and stable bouncing behaviour. This study used a loadcell hooked into the ceiling and attached to the Jolly Jumper harness system to determine the oscillation frequency of an inert mass-spring system, acting as a harmonic oscillator, as well as the infant bouncing, acting as a forced harmonic oscillator. From a direct measurement of the oscillation frequency of the mass-spring system, the infant's preferred bouncing frequency could be determined and compared to the resonant frequency of the Jolly Jumper harness system. No significant differences were found between the different skill levels of the infants and the infants' preferred oscillation frequency. Also, at least two preferred bouncing frequencies were identified, one double the resonant frequency; the second a preferred frequency of 1.5 times the resonant frequency of the spring-mass system. The addition of a second spring to our bouncing task skill analysis was outside of the parameters of this study, however it would be interesting to examine the effect that changing the spring constant during the task of bouncing would have on the bouncing behaviour on infants. The second spring coefficient could also provide *direct* evidence to determine if the infants had learned only the fixed resonant frequency of a specific system and therefore required a period of time to adapt to the new system's resonant frequency. Alternatively, if an infant had learned the dynamics of the task of bouncing, they would quickly adapt to the dynamics of the new system.

Understanding the underlying control mechanisms that would result in this behaviour seemed to be the next step to take in order to determine possible causes of differences between skill levels and to explore the emergence of two distinct patterns of bouncing present in the bouncing data of moderately-skilled and skilled infant bouncers.

Control mechanisms

In order to determine whether the two patterns of baby contributions were produced by distinct underlying control mechanisms, phase-plane analyses were performed. The following section presents the general characteristics of phase-plane plots as well as outlines the phase-plane plots for the skilled and less-skilled bouncers.

General overview

Two observations can be made about the data obtained via this analysis of bouncing behaviour (Figures 8a, b, and c). The first observation is the differences that are apparent across the bouncing skill levels. Notice in the less-skilled infant's (I1) phase-plane plots, the highly variable pattern displayed throughout his bouncing behaviour. These phase-plane plots were characterized by their extreme variability, both within and between bouts. The phase-plane plots produced by I1 primarily show periods where line patterns are disorganized and do not overlay from bounce to bounce. Most of the phase plane-plots of the moderately-skilled and skilled infants however, were very consistent, both within and between bouts of bouncing represented here by I7 and I8's bouncing behaviour. These plots showed periods of very organized line patterns overlying on top of each other from bounce to bounce.

The second observation about the data shown involves the two patterns which emerged in the moderately and skilled infant bouncers phase-plane plots, represented here by the skilled bouncing behaviour produced by I7 and I8. The first pattern, produced by I7, repeated a distinct overlying pattern from one bounce cycle to the next and included a cusp line pattern near the toe-down event of the bouncing cycle (asterix). This cusp represents sudden cessation of forces opposing motion and sudden resumption of motion during toe down. The second phase-plane plot pattern contained primarily smooth, rounded trajectories throughout, and was produced by infants like I8. This pattern is indicative of the presence of position-dependent forces opposing motion such as in springs or pendulum motion.

The two patterns of phase-plane plots corresponded to the two patterns observed in the baby contribution plots. Specifically, the primarily cusping phase-plane pattern was produced by infants who also produced the double-bump pattern in the baby contribution plots. The smooth, rounded phase-plane plot was produced by the infants who produced the negative-and-positive pattern of the baby contribution plots. Again, these phase-plane patterns did not correspond to skill level, but rather were present across the skill levels of the nine infants. I7 (Figure 8b) demonstrated primarily the cusping pattern in her phase-plane plots and a double bump pattern in her baby contribution plots. I8 (Figure 8c) demonstrated primarily the smooth, rounded trajectory pattern in their phase-plane plots and a negative-and-positive pattern in their baby contribution plots. I1 (Figure 8a) demonstrated a combination of the two patterns with high variability both between and within bouts of bouncing behaviour.

Phase-plane plots of less-skilled, moderately-skilled and skilled infants

The phase-plane plots for all infants are presented identically (Figures 8a - c for I1, 7, 8 in body of thesis, remaining data presented in Appendix D). Specific details including the ranges of angular position and angular velocity for each infant are given in the figure captions. For each infant the three columns, from left to right, contain the phase-plane plots of the ankle, knee and hip, respectively. The data for three bouts of bouncing are represented for each infant.

In the less skilled infants, I2 and I1, the phase-plane plots are characterized by their extreme variability, both within and between bouts. For example, in Figure 8a bouts 1, 2 and 3 the ankle, knee and hip phase-plane plots are highly variable. The phase-plane plots produced by I1 show primarily periods where line patterns are disorganized and do not overlay from bounce to bounce. Note for both the less-skilled infants, the small angular position and angular velocity of the hip joint throughout the bouncing cycles relative to the ankle and knee joints.

The phase-plane plots of the moderately-skilled infants, I3, I4 and I5 ranged from variable to organized plots. The bouncing behaviour produced by these moderately-skilled infants resulted in phase-plane plots which had periods with very organized line patterns overlying on top of each other from bounce to bounce as well as line patterns that appear to be disorganized and did not overlay from bounce to bounce. Note that the angular range of motion and the range of angular velocity of the hip joint was smaller relative to that recorded for the ankle and knee joints for some moderately-skilled infants

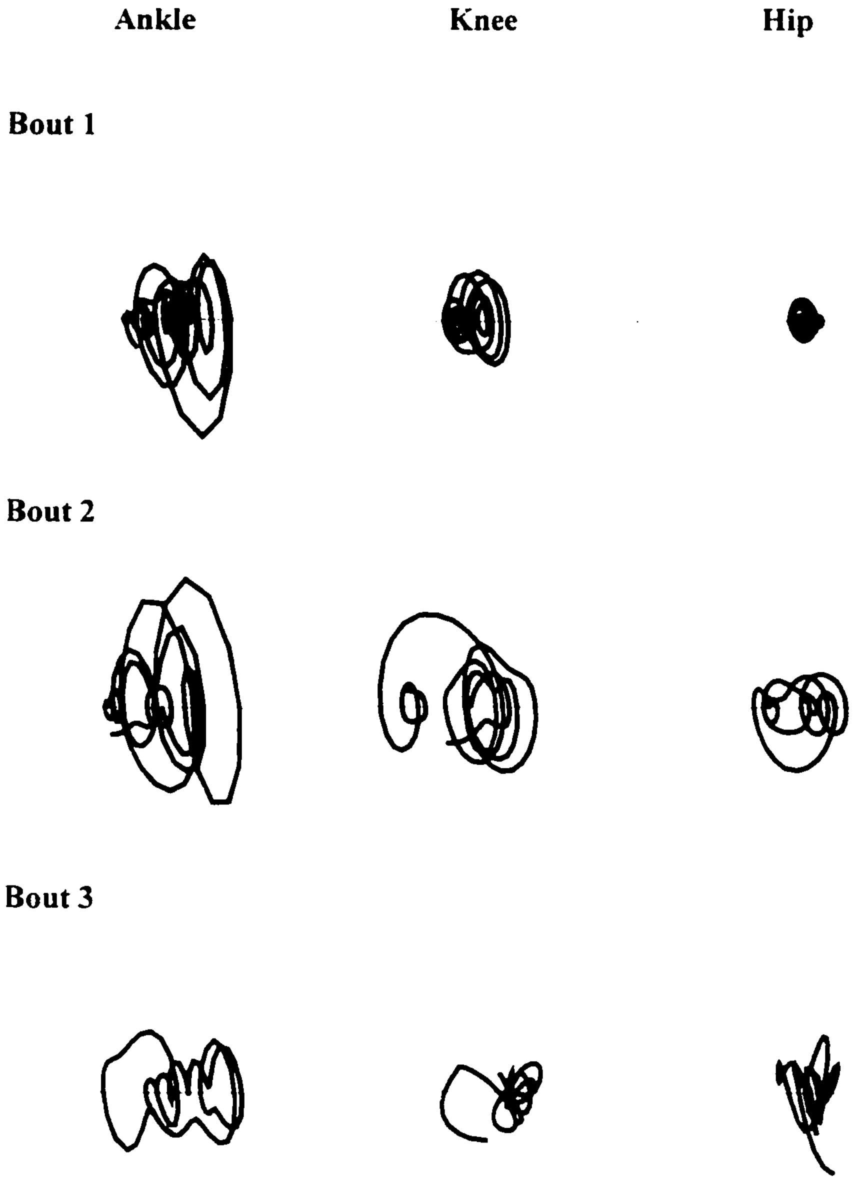


Figure 8a: Phase-plane plots for I1. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (500 to -500) with the horizontal line on the y-axis indicating zero velocity. The joints moved from flexion to extension on the x- and y-axis from left to right and bottom to top, respectively. Columns one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the high variability in line patterns which illustrate I1's phase-plane plots across all three joints.

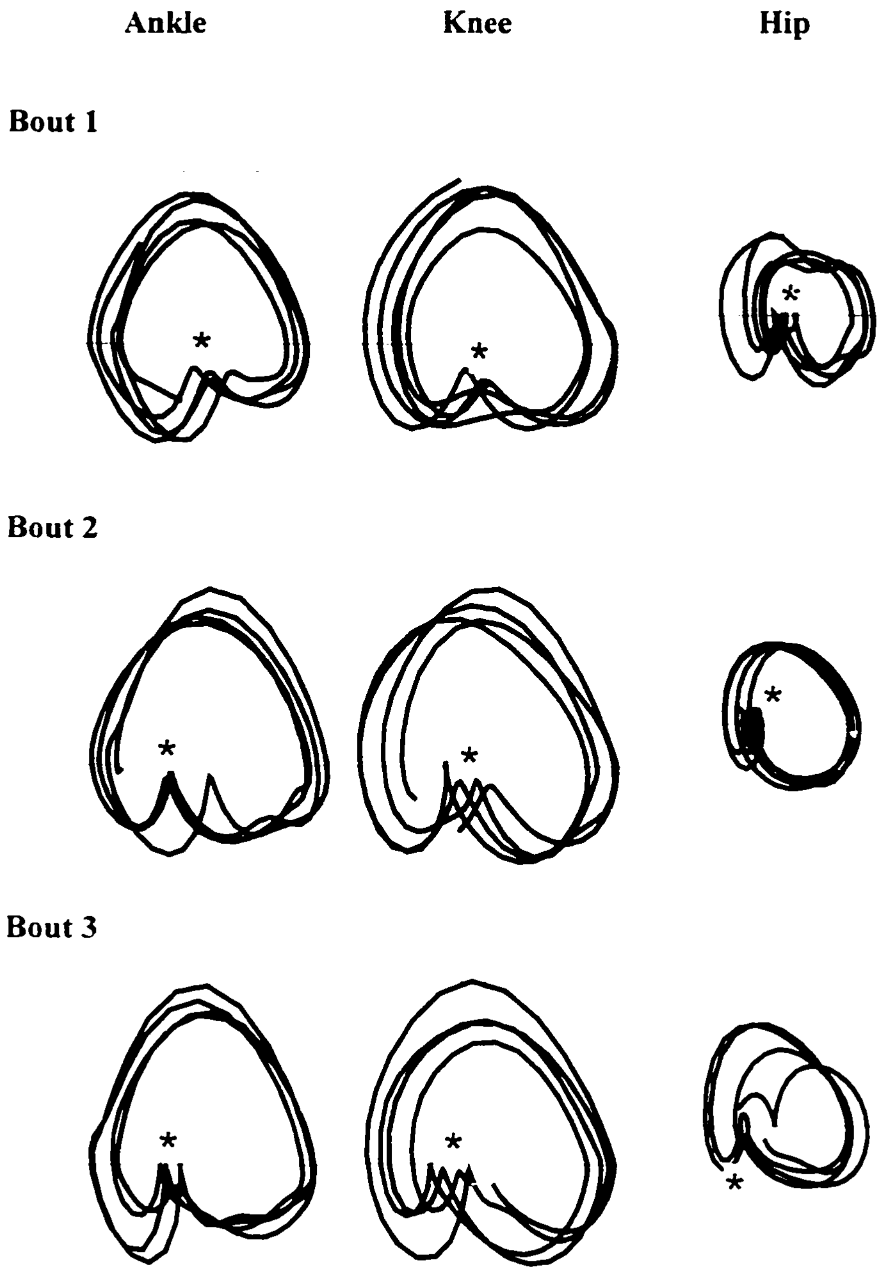


Figure 8b: Phase-plane plots for I7. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. Toe-down is represented by an asterix. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (B1: 600 to -400; B2: 650 to -350; and B3: 650 to -350). Column one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the organized line patterns which overlap repeatedly across each of I7's three phase-plane plots.

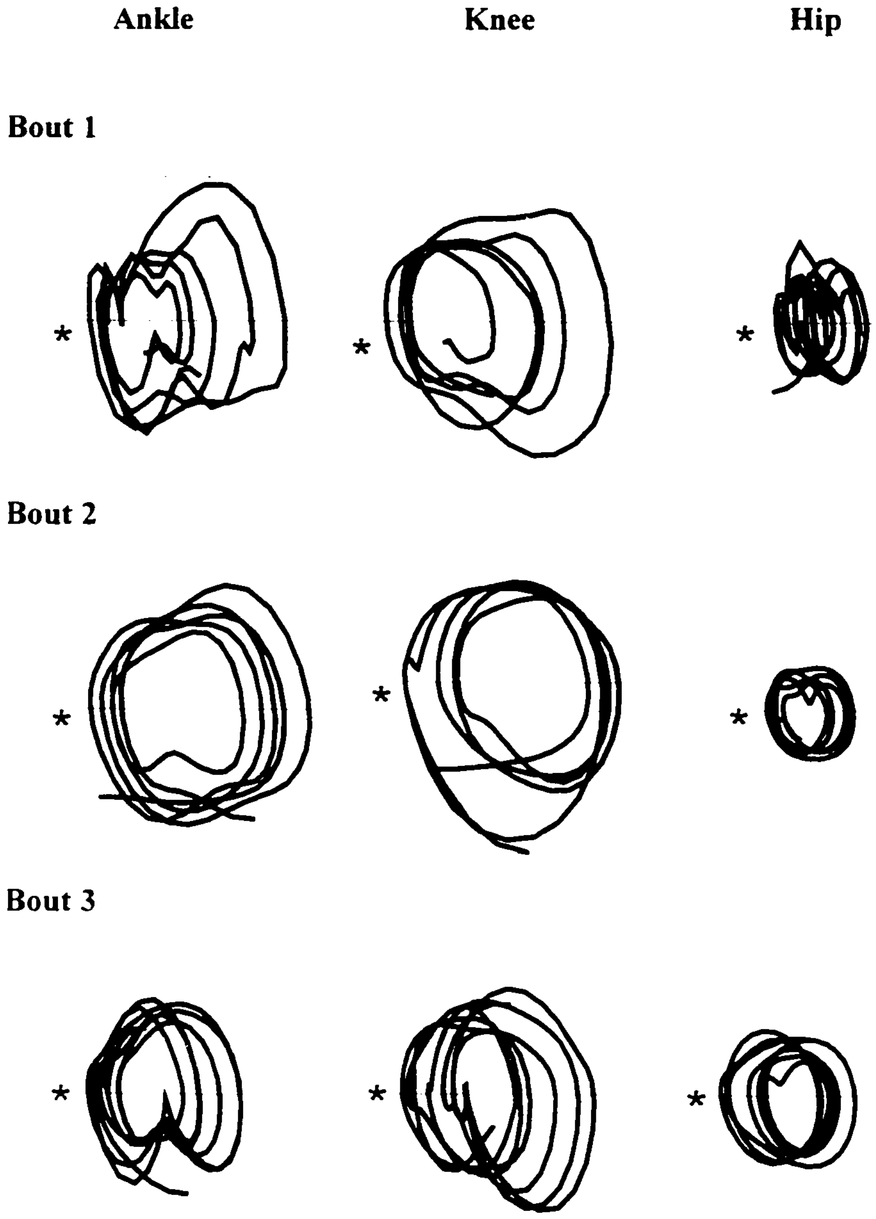


Figure 8c: Phase-plane plots for I8. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. Toe-down is represented by an asterix. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (500 to -500). Column one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the organized line patterns which overlap repeatedly across each of I8's three phase-planes, and especially in bout 3.

Most of the phase plane-plots of the skilled infants. I7 and I8. are very consistent. both within and between bouts (Figures 8b and c) with the phase-plane plots showing periods of very organized line patterns overlying on top of each other from bounce to bounce. Note that the ranges of angular motion and the angular velocity of the hip joint. while still smaller compared to that recorded for the ankle and knee phase-plane plots. they are still higher than those recorded for the hip joints of the moderately- and less-skilled infants.

Ankle phase-plane plots

Skilled bouncers primarily produced bouncing behaviour that yielded ankle phase-plane plots with either a cusping pattern that occurred during the loading phase of the bouncing cycle or a smooth. rounded pattern. For example. I7 demonstrated excellent examples of cusping patterns during the loading phase of the bouncing cycle in the ankle joint phase-plane plots (Figure 8b). Infant 8 demonstrated excellent examples of smooth. rounded patterns throughout their bouncing behaviour (Figure 8c). Patterns were relatively consistent for skilled bouncers both within and across bouncing trials. Less-skilled bouncers produced ankle phase-plane plots that contained smoothly rounded or cusping patterns that did not overly each other. rather they occurred randomly during the bouncing cycle (Figure 8a bout 3 ankle). Recall that these line patterns are indicative of the presence of position-dependent forces opposing motion such as in spring or pendular motion and sudden cessation and resumption of movement. respectively. These two types of movement patterns occurred randomly throughout the bouncing cycle. Both of the less-skilled infants also demonstrated highly variable phase-plane patterns within and across bouts of bouncing (Figure 8a. bouts 1 through 3).

Knee phase-plane plots

In general. skilled bouncers produced knee phase-plane plots with overlying patterns similar to the patterns illustrated in their ankle plots (Figure 8b and 8c. bouts 1 through 3). The line patterns for these bouncers were consistent and overlapped both within and across trials. Less-skilled bouncers. however. demonstrated greater variability within and between trials for knee phase-plane plots (Figure 8. bouts 1 through 3). It is important to note that the less-skilled infants had plots where the line patterns did not overly between bouts of bouncing behaviour.

Hip phase-plane plots

Skilled bouncers. I7 and I8. had larger angular ranges of motion and greater angular velocities at the hip joint (Figures 8b to c) when compared to the angular ranges of motion and angular velocities about the hip in less-skilled infants (Figure 8a). Hip phase-plane plots for less-skilled bouncers showed virtually no range of motion or angular velocity changes when compared to the plots for the knee and ankle joints. Hip phase-plane plots for less-skilled infants were concentrated in a small area and consisted of cusped patterns that contained small loops indicative of movement reversals. Some infants. I1. produced phase-plane plots with vertical segments indicating ballistic control (Figure 8a). Cusp patterns were also evident in some moderately-skilled infants. as well as for the skilled bouncers. I7.

Two patterns that produce bouncing behaviour

Moderately-skilled and skilled bouncing infants produced one of two distinct phase-plane plot patterns. The first was a cusping pattern which was repeated from bounce to bounce and occurred at approximately toe-down in the bounce cycle. The second phase-plane plot pattern contained primarily smooth. rounded trajectories which repeated a distinct overlying pattern from one bounce cycle to the next. These two patterns of phase-plane plots were closely linked to the plots obtained for the baby contribution data. Infants who primarily produced a cusping pattern in their phase-plane plots also primarily produced a double bump pattern in their baby contribution (I7). Infants who primarily produced smooth. rounded trajectory pattern in their phase-plane plots also primarily produced a negative-and-positive pattern in their baby contribution plots (I8). Infant 1 and I2 were the only infants who did not produce one pattern or the other. Rather. these lesser-skilled infants produced baby contribution plots which contained characteristics of both patterns and that were highly variable between and within the bouts of bouncing.

This observation is quite interesting and important as the baby contribution and/or the phase-plane patterns produced by the infants did not directly correspond to their subjective placing on the skill level spectrum. In fact the two most skilled infants, I8 and I9, produced quite different baby contribution and phase-plane plots.

Less-skilled infants produced baby contribution values that were quite low as reflected in the low amplitude of the curves indicating that the baby's contribution to the behaviour was minimal. The amplitudes of baby contribution plots produced by moderately-skilled and skilled infants, like I8 and I7, were consistent and higher relative to the amplitudes produced by infants like I1. It can be suggested that the baby contribution plots with lower amplitudes indicate that an infant is contributing less to the bouncing behaviour compared to an infant who produced baby contribution plots of higher amplitudes.

From a qualitative dynamics approach (Kay, Saltzman and Kelso, 1991), the evolution of a system's observable characteristics and motion are described in terms of equations of motion. This branch of dynamics describes the movement of an organism to a point attractor which is a stable equilibrium point that attracts all trajectories from arbitrary initial conditions. If a point attractor has been established in a dynamical movement pattern the achievement of the original goal is not forsaken when a perturbation is applied during the movement. In the case of a bouncing infant, one could determine if an infant has in place a stable equilibrium point (point attractor) by perturbing the system (adding weight to the ankles, for example) and studying the infant's response. If an infant has established a point attractor for the behaviour, he/she will be capable of bouncing at approximately the resonant frequency of the Jolly Jumper spring following the perturbation. If, however, a point attractor is not established, the resonant frequency of the bouncing behaviour produced by the infant will not approximate the resonant frequency following a perturbation.

It is proposed that the moderately skilled and skilled infants had established a point attractor, or stable equilibrium point that attracts all trajectories from arbitrary initial conditions for their bouncing behaviour. This point attractor was actually the frequency of oscillation, either 1.5 or two times the resonant frequency of the mass-spring system. The moderately-skilled and skilled infants who produced bouncing frequency of either 1.5 times or approximately two times the resonant frequency of the mass-spring system actually had in place a stable point attractor. One additional observation about the two frequencies of bouncing is that it appears that bouncing at two times the resonant frequency was a weaker attractor (more variable) than bouncing at 1.5 times (less variable) the resonant frequency of the mass-spring system. This observation could be confirmed by further studies involving moderately-skilled and skilled infants. If these infants did have in place a stable point attractor they would be able to revert back to the initial bouncing behaviour following perturbation to their bouncing behaviour. While infants in this study were not exposed to a perturbation, like adding weights to their ankles or changing the spring constant, the skilled and moderately-skilled infants produced highly consistent bouncing behaviour as illustrated by loadcell curves which recorded the loading and unloading of forces on the Jolly Jumper spring over time, as well as the consistent baby contribution and phase-plane plots.

Alternatively, less-skilled infants, like I1, produced bouncing behaviour that appeared to be outlyers in relation to frequencies of bouncing behaviour produced by the moderately-skilled and skilled infant bouncers. The less-skilled infants produced bouncing frequencies that were less than half or greater than double the oscillation frequency of the inert mass. Their bouncing frequency was highly variable between bouncing bouts. Therefore, it is proposed that the less-skilled infants had not yet established a point attractor, illustrated by the highly variable bouncing behaviour, their frequency of oscillation as well as their highly variable baby contribution and phase-plane plots. That is, if these infants were perturbed while bouncing they would not be able to revert back to the arbitrary initial bouncing behaviour due to the lack of a point attractor being in place for the task of bouncing.

A movement outcome can be achieved in a number of ways depending upon the characteristics of the limbs, their orientation in space and the constraints of the environment itself (Schneider *et al.*, 1990). The task of bouncing while secured in a hanging Jolly Jumper harness is in fact an open task. Infants were free to move vertically, posteriorly, anteriorly and laterally. The only restriction placed on the bouncing behaviour was that the Jolly Jumper support bar was guided so that the infant's remained sagittal to the video camera. Thus, infants were given the opportunity to freely explore their environment, the Jolly Jumper harness and the bouncing task itself. Infants were encouraged by their parents and by the researchers to bounce, but they were not presented with any specific goals regarding the bouncing behaviour. Jensen *et al.* (1994) examined infant kicking behaviour and found that infants displayed a wide variety of movement patterns when no specific task demands were placed upon them. Despite the variety in the movement patterns that the infants produced, these researchers found that in kicking, similar to what we found in bouncing behaviour, certain patterns of movement seemed to be more stable than others. Another interesting relationship apparent in our data was that moderately-skilled and skilled bouncers consistently produced only one of the two types of movement patterns, illustrated in the baby contribution plots, frequency of bouncing and phase-plane plots, while less-skilled infants attempted different movement patterns throughout most of their bouts of bouncing behaviour.

The differences between less-skilled infants and the moderately and skilled infants as well as the presence of two distinct patterns of bouncing, prompted further questioning about whether this relationship continued at the level of interjoint co-ordination of the lower limb.

Consistency of interjoint movement

The moderately-skilled and skilled infants can be divided into two groups based on the previously discussed data. The first group, I3, I5, I7 and I9, produced double-bump baby contribution plots, cusping patterns in their phase-plane plots, an up-and down pattern of loading the Jolly Jumper as reflected in the loadcell curves and an oscillation frequency of approximately 1.5 oscillations per second. The second group, I4, I6 and I8, produced negative-and-positive baby contribution plots, smooth, rounded patterns in their phase-plane plots, a slanted pattern of loading the Jolly Jumper as reflected in the loadcell curves and an oscillation frequency approximately 2.0

oscillations per second. Figure 9 illustrates the relationship between the two patterns of loadcell traces, baby contribution and phase-plane plots. These variables are either measures of total body movement or single joint movement. In order to determine whether the distinction of two forms of bouncing behaviour continued at an interjoint coordination level, the consistency of interjoint movement was determined.

The joint angular position, in degrees, was determined for the ankle, knee and hip joints for each infant and plotted against the duration of the bout of bouncing behaviour. Figures 10a through i (Figures 10a-c in body of thesis; Figures 10d-i in Appendix E) illustrate the changes in joint angular position during the bouncing bout. Bout length for each bout of bouncing for each infant is given in the figure caption of these figures. The top, middle and bottom curves in each plot represent the position of the hip, knee and ankle joints, respectively. For trials where lines representing joint positions are close and difficult to distinguish from each other, the joint position of the ankle, knee, and hip joints will be indicated by the letters A, K and H, respectively.

Less-skilled infants produced bouncing behaviour that illustrated an out-of-phase relationship between the joints of the lower extremity (I1 Figure 10a) and a high degree of variability of joint angular position, both within and between bouts of bouncing. Moderately-skilled bouncers produced bouncing behaviour that generally illustrated an in-phase relationship between the ankle, knee and hip joints, with the hip joint producing a significantly lower range of motion over the duration of the bouts of bouncing. Skilled bouncers, I7 and I8 (Figures 10b and c, respectively), generally produced bouncing behaviour which reflected an in-phase relationship between the ankle, knee and hip joints. The skilled infants produced bouncing behaviour which reflected a larger hip angular joint position range relative to that produced by the less-skilled and moderately-skilled infants.

Interjoint co-ordination

Angle-angle plots provide insight into the interjoint organization or phase relationship of the joints that are plotted. These plots depict the joint angular position measured in degrees for one joint on the x-axis, versus the simultaneous joint angular

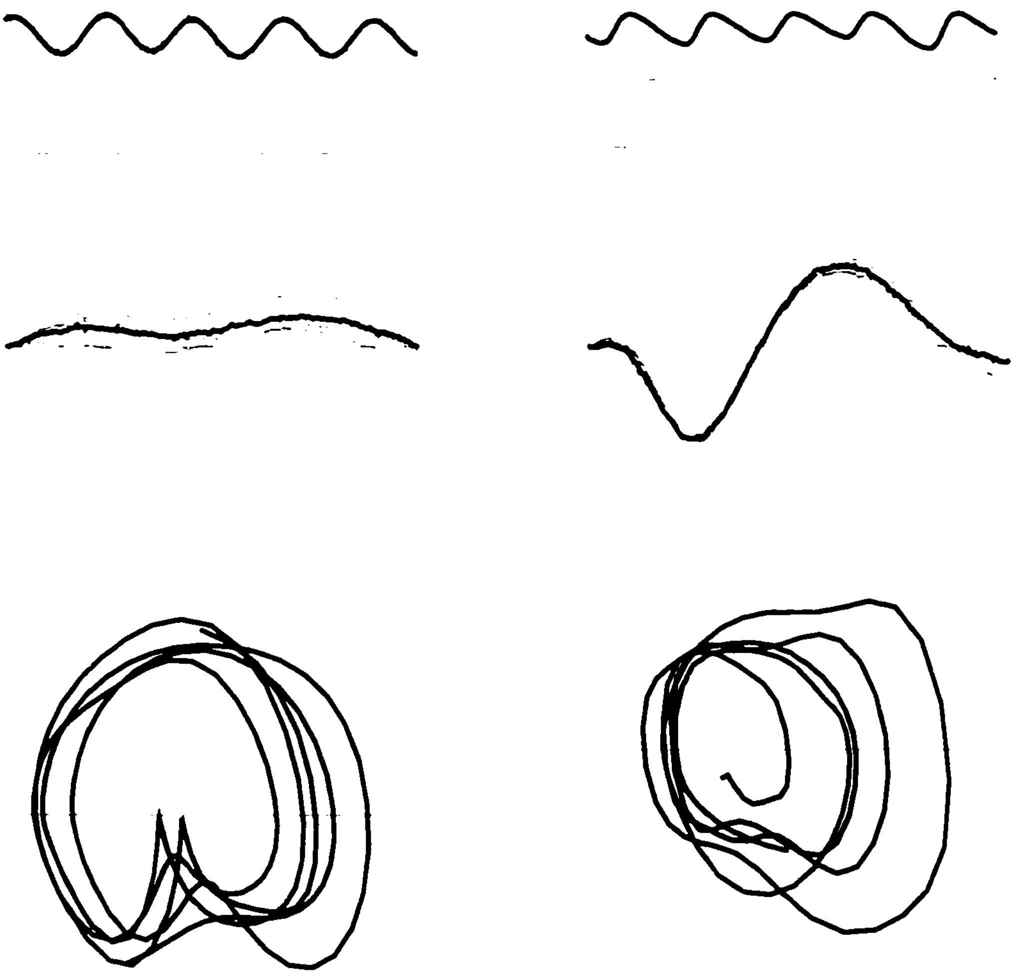


Figure 9: Relationship between loadcell traces, baby contribution and phase-plane plots. The left and right columns of data illustrate the bouncing behaviour of I5 (bout 2) and I8 (bout 1), respectively. The top left and right plots illustrate the two loadcell trace patterns, up-and-down and slanted, respectively. The middle left and right plots illustrate the two baby contribution patterns, double-bump and negative-and-positive, respectively. The bottom left and right plots illustrate the two phase-plane plot patterns, cusping and smooth, rounded trajectory, respectively.

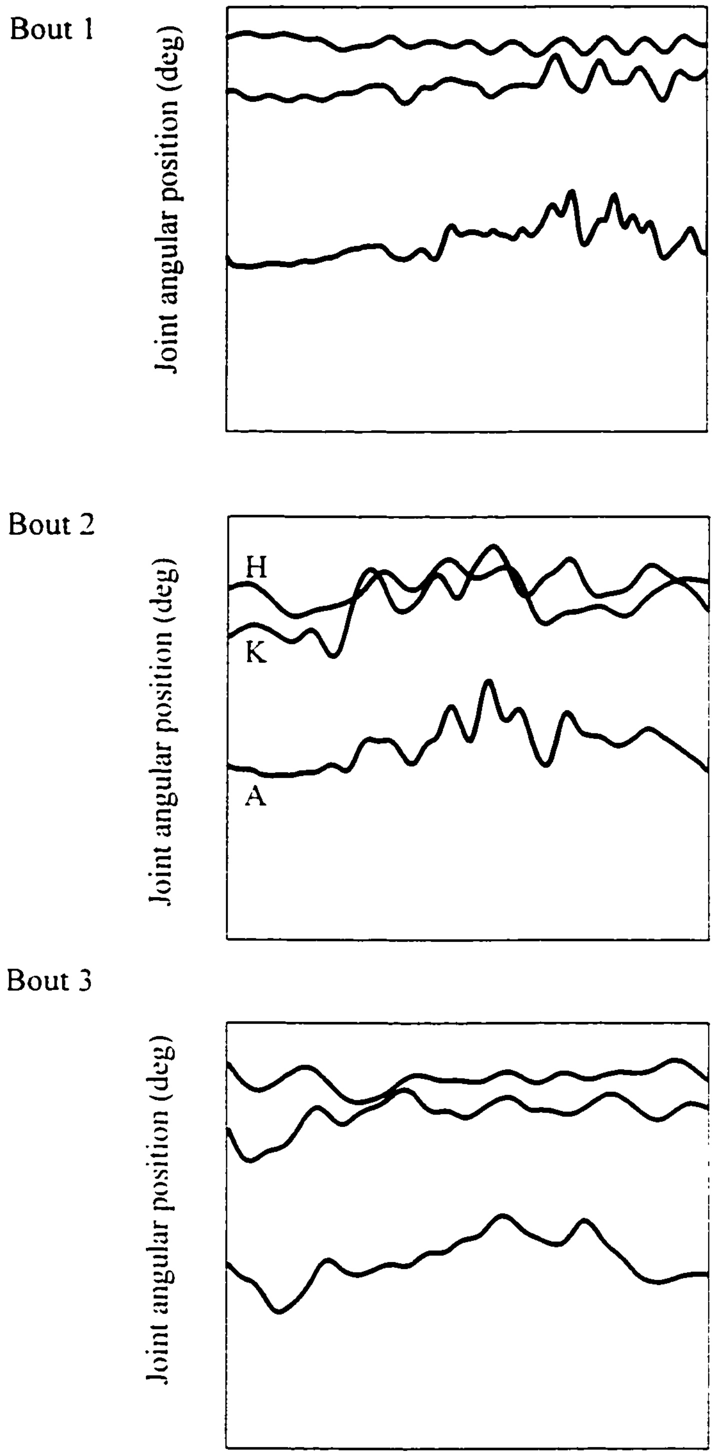
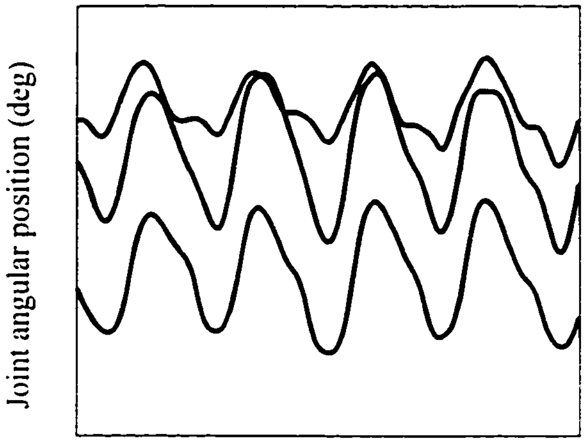
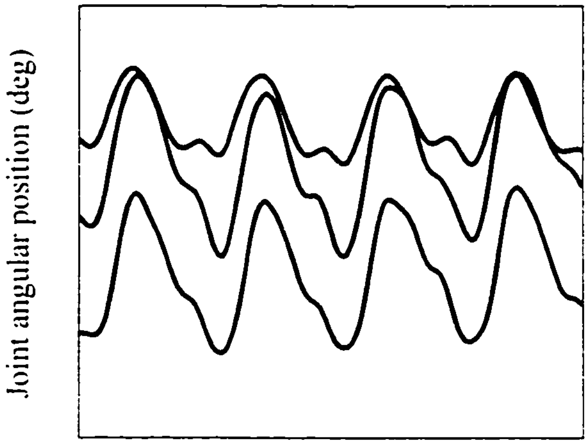


Figure 10a. Joint angular position for I1. The top, middle and bottom curves in each plot represent the angular position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. In bout 2, the letters A, K and H indicate ankle, knee and hip joint position traces, respectively. Bout length for bouts 1, 2 and 3 are 3.97, 2.55, and 1.80 seconds, respectively. Note the out-of-phase relationship between Marc's joints and inconsistency between and within bouts of bouncing.

Bout 1



Bout 2



Bout 3

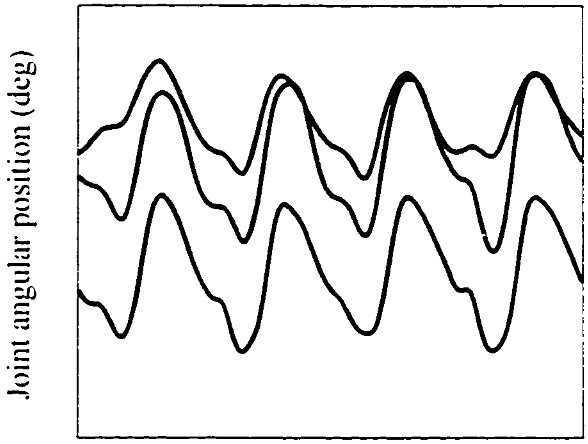


Figure 10b. Joint angular position for I7. The top, middle and bottom curves in each plot represent angular position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. Bout length for bouts 1, 2 and 3 are 2.99, 2.71 and 2.73 seconds, respectively. Note the in-phase relationship between the three joints and the consistency between and within bouts of bouncing.

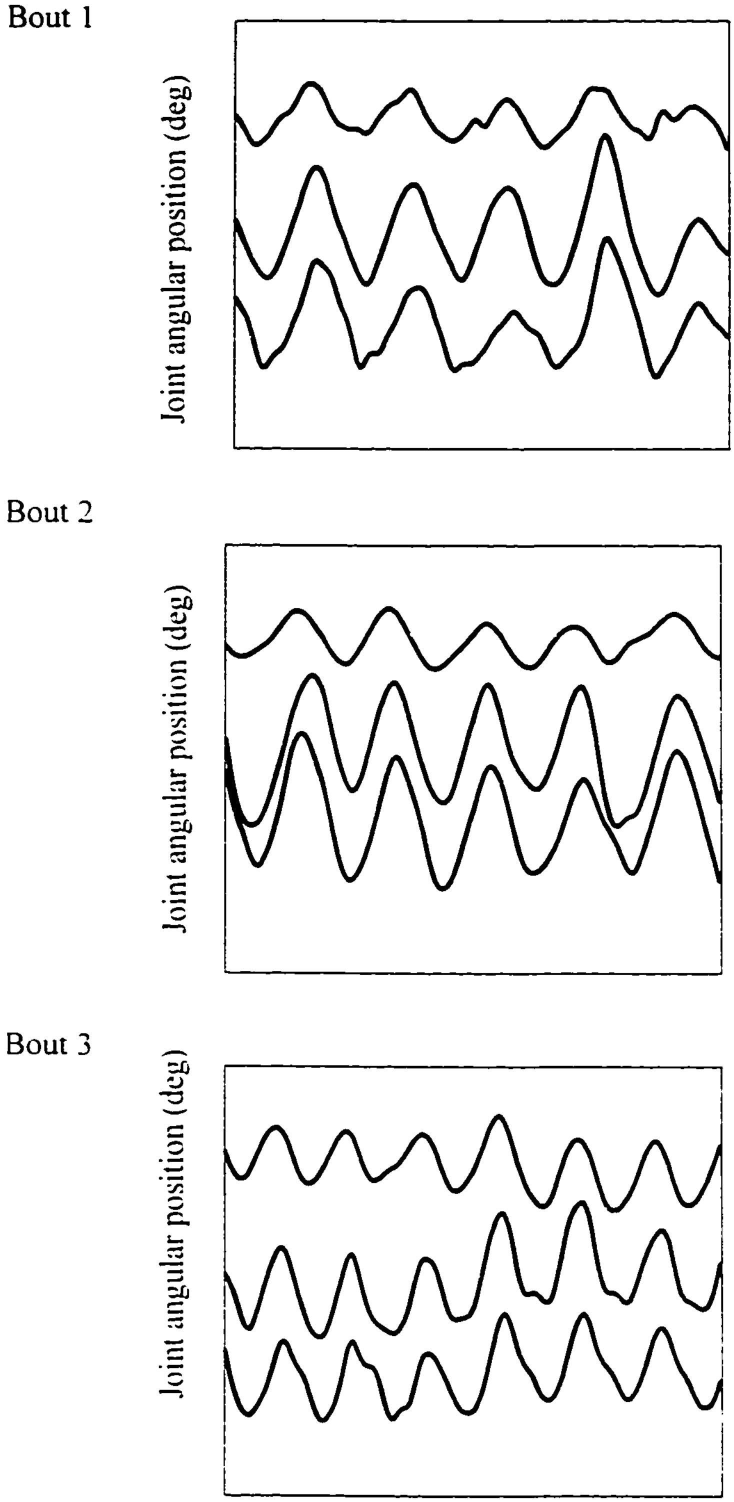


Figure 10c. Joint angular position for I8. The top, middle and bottom curves in each plot represent the angular position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. Bout length for trial 1, 2 and 3 are 2.48, 2.65 and 3.20 seconds, respectively. Note the in-phase relationship between Sam's joints and the consistency, between and within trials.

position for another joint on the y-axis. This analysis will address general characteristics of angle-angle plots as well as present the plots which illustrate the relationships between the ankle, knee and hip joints for less-skilled, moderately-skilled and skilled bouncers.

General overview

There was a general trend in the data from a chaotic to an organized interjoint co-ordination from less-skilled to skilled infant bouncers.

A relationship similar to that found between baby contribution, phase-plane plots, loadcell patterns and oscillation frequencies was not apparent in the bouncing behaviour when illustrated by angle-angle plots for any of the nine infants.

Interjoint co-ordination for less-skilled, moderately-skilled and skilled infants

The less-skilled bouncers, I1 and I2, produced behaviour that reflected inconsistent angle-angle relationships, indicative of chaotic interjoint organization. I1 has angle-angle plots (Figure 11a) which are a combination of vertical and horizontal segments, indicative of one joint angle changing while another is held constant. The angle-angle plots which illustrate I1's bouncing behaviour in bout two clearly showed that the ankle, knee and hip joints moved into and out of phase with each other throughout the bouncing cycle (Figure 11a). During portions of the bouncing cycle, less-skilled infants were actually flexing their ankle while simultaneously extending their knee, or visa versa (Figure 11a bout 2, ankle-knee angle-angle plot).

Moderately-skilled bouncers demonstrated bouncing behaviour that produced consistent to highly variable angle-angle plots with a combination of vertical and diagonally oriented positively sloped straight lines. The angle-angle plots of these infants indicate that there was both a low level and a higher level of interjoint coupling between bouts of bouncing behaviour. Periods of vertically oriented segments indicate that one joint angle changed while another was held constant. Diagonally oriented segments indicate that both joints of the plot reached their maxima and switched direction of motion simultaneously. Vertically oriented segments characterize an out-of-phase relationship between the two joints while diagonally oriented segments characterize an

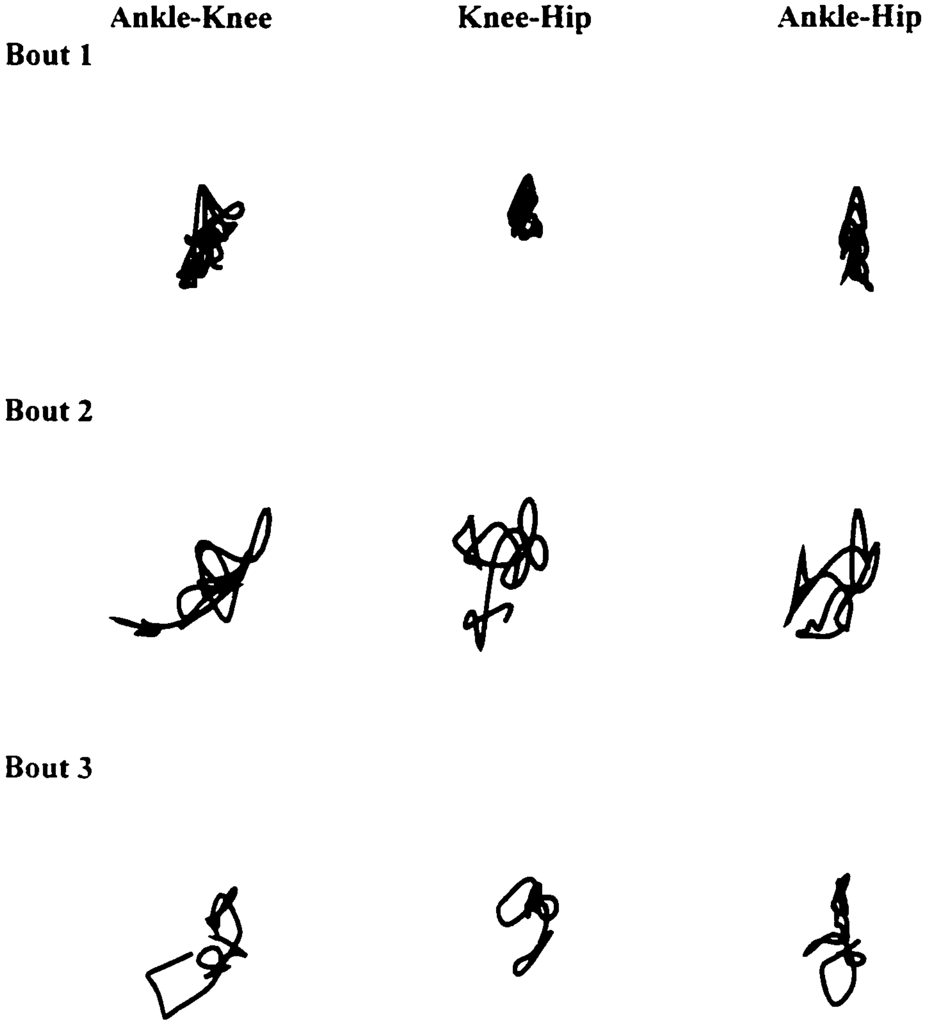


Figure 11a: Angle-angle plots for I1. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the high variability present in the line patterns of I1's angle-angle plots for all three joint angular position relationships.

in-phase relationship between the two joints. Therefore, these moderately skilled infants produced periods of bouncing behaviour with characteristics of both relationships. illustrate that at certain points in their bouncing behaviour some joints extended and flexed together, while other joints of the lower limb flexed while another joint extended.

Skilled bouncers, I7 and I8, demonstrated bouncing behaviour that yielded more consistent angle-angle plots with diagonally oriented positively sloped straight lines (Figure 11b and c, respectively). This indicates that both joints of the plot reached their maxima and switched direction of motion simultaneously. This turning point synchronization suggests an organized intersegmental relationship between joints that changed at a constant ratio during the bouncing cycle. The ankle, knee and hip joints were in-phase with each other, thus when the ankle was extended, the knee and hip also extended.

Ankle-knee angle-angle plots

Less-skilled bouncers, demonstrated a high degree of variability within and between trials (Figure 11a and Figure 11d). A combination of patterns is evident in these angle-angle plots with the primary shapes of the curves being a combination of looping segments that did not repeat an overlying pattern. These curve shapes indicate that the ankle angle was changing while the knee angle was held constant or that a decoupled coordination between the two joints was occurring throughout the bouncing cycle. Moderately-skilled infants produced bouncing behaviour which contained vertical and diagonal line patterns both within and between bouts of bouncing behaviour. Skilled bouncers produced behaviour that was consistent both within and between bouts of bouncing. These infants had angle-angle plots which primarily demonstrated diagonally oriented straight lines with positive slopes, indicating an in-phase relationship between the joints of the lower limb (Figure 11b and c ankle-knee angle-angle plots). Thus, when one joint was flexing the other joint was also flexing, and visa versa.

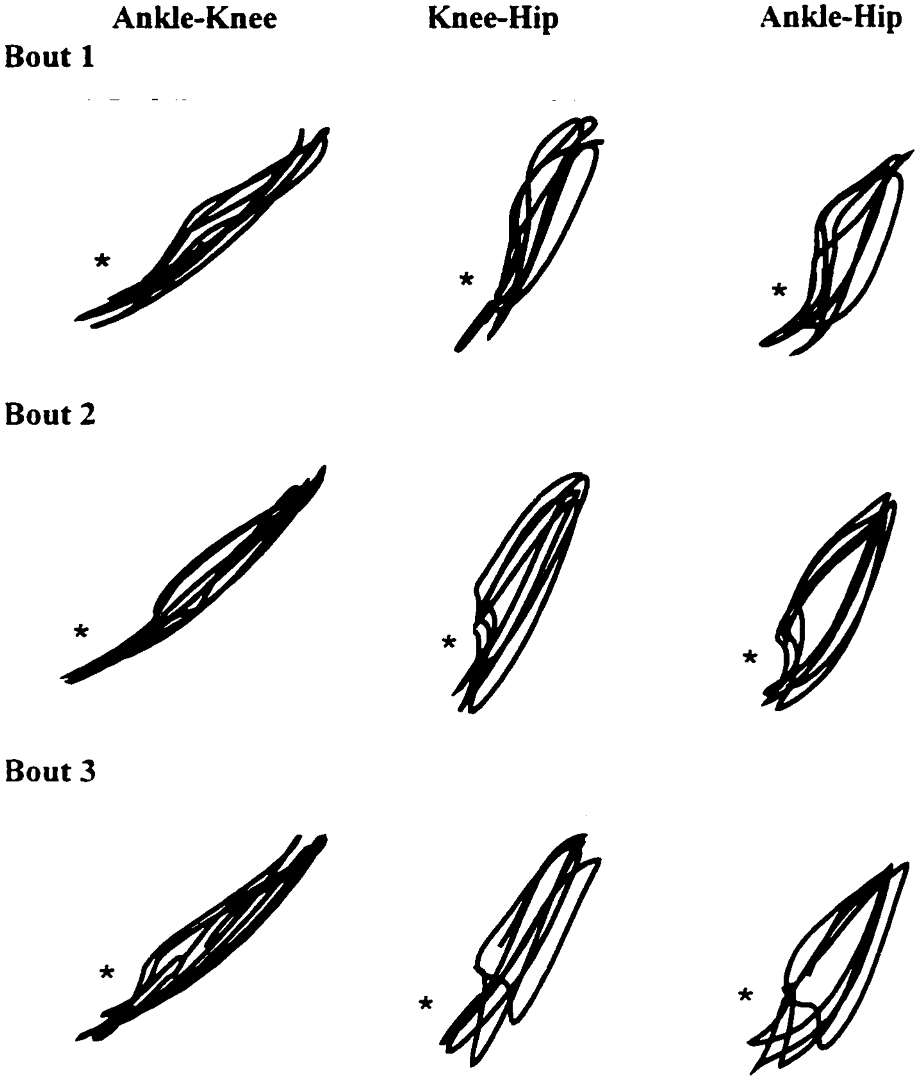


Figure 11b: <u>Angle-angle plots for I7</u>. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Toe-down is represented by an asterix. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the consistent overlying pattern of I7's joint angular position relationships across all three angle-angle plots.

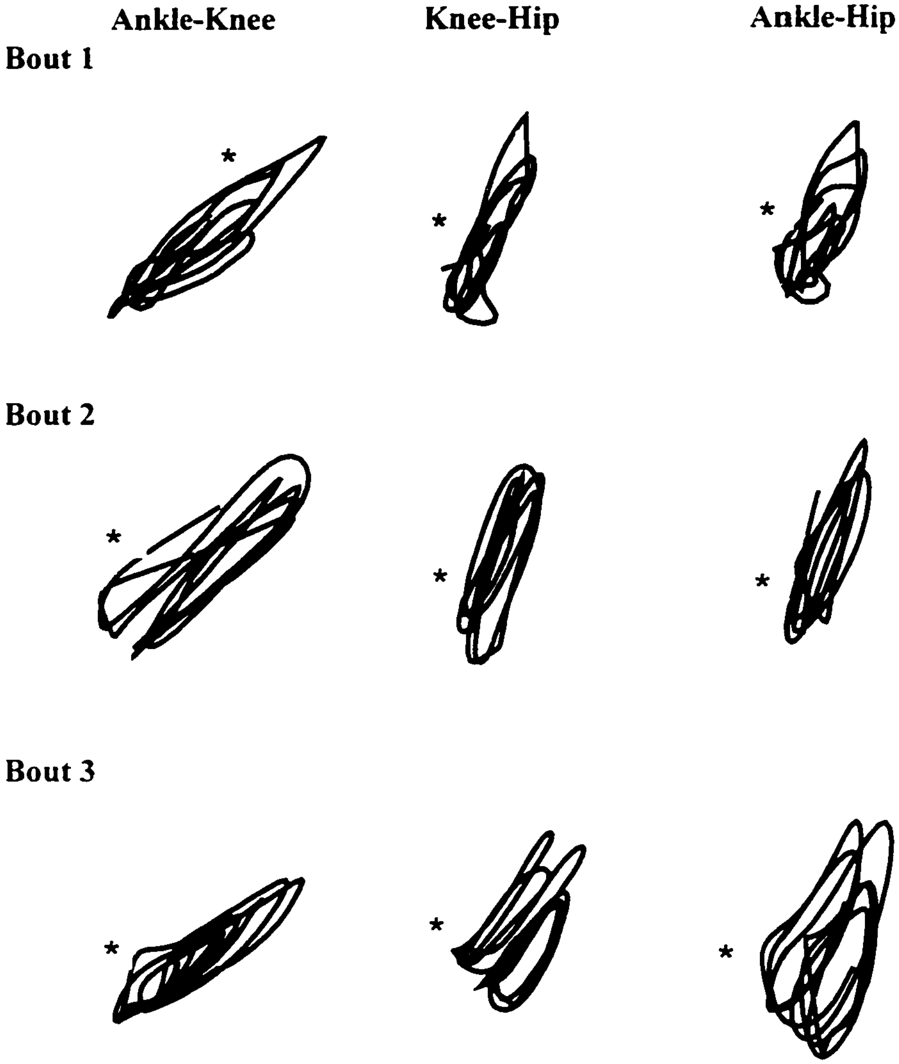


Figure 11c: Angle-angle plots for subject I8. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Toe-down is represented by an asterix. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the organized patterns which repeat throughout I8's angle-angle plots for all three joint angular position relationships.

Knee-hip angle-angle plots

Less-skilled bouncers primarily had angle-angle plots which contained some horizontal or vertical segments with small looping segments that indicated a sudden cessation of movement at one joint followed by a quick segmental reversal, cessation of movement and another segmental reversal. These changes occurred often throughout the angle-angle plots (Figure 11a, bouts 2 and 3 knee-hip angle-angle plots). Moderately skilled infants produced bouncing behaviour which contained a combination of vertical and diagonal line patterns both within and between bouts of bouncing behaviour. Skilled bouncers primarily demonstrated nearly diagonal, positively oriented straight lines, indicating an in-phase relationship between the knee and the hip (Figure 11b and c knee-hip angle-angle plots). Thus, while the knee was extending to its maximum, the hip was simultaneously extending to its maximum. A consistent overlying pattern was present both within and between bouncing trials. Skilled bouncers primarily demonstrated nearly diagonal, positively oriented straight lines, indicating an in-phase relationship between the knee and the hip (Figure 11c bout 2 knee-hip angle-angle plots). Thus, while the knee was extending to its maximum, the hip was simultaneously extending to its maximum. A consistent overlying pattern was present both within and between bouncing trials.

Ankle-hip angle-angle plots

Again, less-skilled bouncers demonstrated a mixture of horizontal and vertical segments. In general, the ankle angle seemed to change throughout the bouncing cycle while the hip angle remained almost constant (Figure 11a bouts 1 and 3). Moderately skilled infants generally produced an ankle-hip relationship which closely resembled an in-phase relationship during most of their bouts of bouncing, although they also produced ankle-hip plots where the ankle changed while the hip joint was held in a constant position. Skilled bouncers primarily produced a consistent large looped pattern that was overlying between bouts of bouncing. This pattern was present both within and between bouncing trials (Figure 11c bout 2 ankle-hip). This indicates not only that the relationship between the ankle and the hip joints were in-phase, so that the ankle joint was extending as the hip joint was extending and visa-versa, but also that the movement was controlled at the extremes of full extension and flexion.

Joint angular range of motion

Joint positions and ranges of motion were determined from the video data. Figure 12 represents the ankle, knee and hip joints range of motion during bouncing.

The range of joint angular position for the ankle, knee and hip joints ranged from 21.29 to 65.38 degrees, 16.93 to 81.56 degrees and 8.46 to 39.82 degrees, respectively (see Tables 9a, b and c for exact values). The ankle and knee joints produced a larger range of motion than the hip joint during bouncing behaviour for all infants.

A Spearman rank-order statistical test was performed to determine if there was a significant relationship between skill level and joint angular position range of motion in the ankle, knee and hip joints. Infants were ranked, from one to nine, in order of less-skilled bouncers to skilled bouncers. The infants were again ranked from one to nine, in order from largest range of motion to smallest range of motion for each of the three joints. Ankle, knee and hip correlation coefficients obtained from this analysis were 0.667 ($\underline{P}=0.05$), 0.7333 ($\underline{P}=0.025$) and 0.9667 ($\underline{P}=0.00$), respectively. Thus, indicating that joint angular range of motion tended to increase from less-skilled to skilled bouncers.

Motor learning

Two observations can be made about the angle-angle data of the bouncing behaviour. The first observation is the general trend from a chaotic to an organized interjoint co-ordination from less-skilled to skilled infant bouncers. Less-skilled bouncers (I1), reflected inconsistent joint relationships, indicative of chaotic interjoint organization. Less-skilled infants' angle-angle plots showed the ankle, knee and hip joints moving into and out of phase with each other throughout the bouncing cycle. During portions of the bouncing cycle, less-skilled infants actually flexed their ankle while they simultaneously extended their hip, or visa versa.. A combination of patterns is evident in these angle-angle plots with the primary shapes of the curves being a

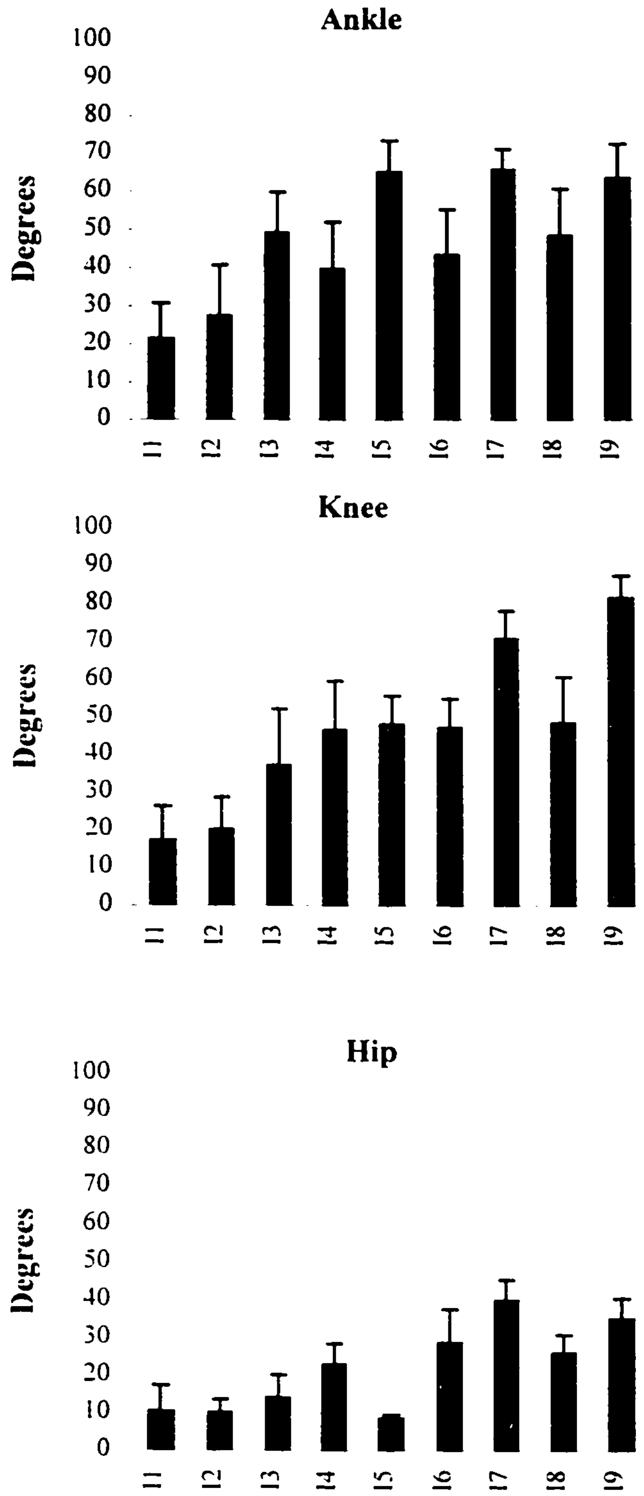


Figure 12. Joint angular range of motion values for ankle, knee and hip joints. The graphs, from top to bottom, represent the range of motion about the ankle, knee and hip joints, respectively. The time period is the same as that illustrated in the EMG onset latency graphs for each infant. Infants were arranged from left to right as skilled and less-skilled bouncers. Note that the angular range of motion for all three joints generally decreases from the skilled to less-skilled infants.

Table 9a.

Ankle joint range of motion (degrees)

Infant	Minimum	Maximum	Range for all bouts	
			Mean	StDev
I1	63.38	121.93	21.29	9.42
I2	79.4	132.87	27.26	13.35
I3	50.09	120.94	48.85	10.74
I4	50.16	107.08	39.45	12.34
I5	18.05	99.47	64.81	8.45
I6	56.36	116.92	43.05	11.98
I7	39.0	116.02	65.38	5.61
I8	34.25	146.79	48.13	12.29
I9	20.63	100.32	63.24	9.14

Table 9b.

Knee joint range of motion (degrees)

Infant	Minimum	Maximum	Range for all bouts	
			Mean	StDev
I1	133.52	186.15	16.93	9.27
I2	121.06	162.86	19.87	8.65
I3	92.17	174.54	37.02	15.08
I4	81.27	156.92	46.46	13.22
I5	84.64	150.45	47.98	7.75
I6	86.23	153.55	47.08	7.83
I7	83.72	168.66	70.79	7.50
I8	36.97	139.3	48.44	12.34
I9	49.74	148.95	81.56	5.97

Table 9c.

Hip joint range of motion (degrees)

Infant	Minimum	Maximum	Range for all bouts	
			Mean	StDev
I1	149.15	185.37	10.27	7.04
I2	148.6	168.73	9.98	3.46
I3	162.16	193.07	13.92	6.16
I4	134.54	171.55	22.85	5.56
I5	169.23	186.37	8.46	0.97
I6	115.41	162.55	28.57	9.05
I7	120.09	173.72	39.82	5.61
I8	132.99	176.81	25.89	4.85
I9	106.39	159.84	34.98	5.45

combination of looping segments that did not repeat an overlying pattern (Figure 11a). These curve shapes indicate that the ankle angle was changing while the knee angle was held constant or that a decoupled coordination between the two joints was occurring throughout the bouncing cycle. Skilled bouncers like I7 and I8, however produced bouncing behaviour which yielded more consistent angle-angle plots with diagonally oriented and positively sloped straight lines. This indicated that both joints of the plot were reaching their maxima and switching simultaneously (Aragon-Vargas and Gross, 1997). This turning point synchronization suggested an organized intersegmental relationship between joints that changed at a constant ratio during the bouncing cycle. The ankle, knee and hip joints were in-phase with each other, thus when the ankle was extended, the knee and hip also extended. Angle-angle plots illustrate the intersegmental organization or phase relationship of two joints thus, these plots are not time dependent.

A second observation that can be made about the angle-angle data is that a relationship similar to that found between baby contribution, phase-plane plots, loadcell patterns and bouncing frequencies of the moderately- and skilled infants was not as apparent in the bouncing behaviour when illustrated by angle-angle plots for I7 and I8, as well as for the other infant participants in this study.

Clark and Phillips (1993) studied the development of infant walking and compared infant walking with adult walking. These researchers found that new walkers produce different phase relationships between the shank and thigh than the adult walkers. These researchers also stated that due to the complex nature of the motor task of walking, the intralimb coordination between the thigh and shank is not fixed but rather changes across the walking cycle. These researchers did however, identify four segment reversals, which indicate a change in direction for the segment, during walking behaviour which require a fixed phase relationship between the shank and thigh. These four segmental reversals were: first thigh reversal, first shank reversal, thigh-shank reversal and shank reversal near to heel strike. Phase-locking of these segment reversals would indicate that the shank and thigh were flexing and extending together throughout the walking cycle. The only segmental reversal that was phase locked for the infants at the onset of walking was the first thigh reversal. Similarly to the phase-relationships we found between the ankle, knee and hip joints during infant bouncing, the remaining segmental reversals became phase-locked with maturation in the infant walking so that at the end of three months of walking behaviour, the infants were producing phase-relationships between the shank and thigh that were similar to those found in walking adults.

Thelen (1995) discussed the development of complex motor behaviours in infants from a dynamical systems perspective. For the development of any particular motor task, the dynamic view predicts an initially high variability in configurations representing an exploration stage, a narrowing of possible states to a few patterns and progressive stability as these patterns become practiced and reliable. These stable states are referred to as attractors because a movement system will settle into that pattern from a wide variety of initial positions and will tend to return to that pattern if perturbed. As infants mature, the attractors become stronger, as the stable state becomes more stable. This increased stability in turn results in a decrease in the variability in the movement pattern, thus decreasing the variability in the phase-relationship between the body segments which produce the movement pattern. Although our study on infant bouncing was not longitudinal we found that the phase relationships of the joints of the less-skilled and skilled bouncers appeared to have similarities to the phase relationships of the immature infants, who were in the process of learning a motor task and mature infants who had mastered the motor task, respectively. In our study on infant bouncing, less-skilled infants demonstrated a high degree of variability and skilled infants demonstrated a lower degree of variability in the phase-relationships between the ankle, knee and hip joints while producing bouncing behaviour. In keeping with Thelen's dynamical systems theory interpretation, it is postulated that a high degree of variability in angle-angle phase relationships between the joints of the less-skilled bouncers would indicate that these infants possess an unstable motor pattern- a point attractor was not yet established for these infants. A lower degree of variability in angle-angle phase relationships between the joints of the skilled infants indicates that a stable motor pattern or point attractor was established for the infants producing this bouncing behaviour.

Thus, the motor skill of infant bouncing was found to progress from an asymmetrical relationship between the ankle, knee and hip joints in less-skilled behaviour to a synchronous relationship between these joints in skilled bouncing behaviour. This progression is quite different than that found in the research of Jensen *et al.* (1995) in infant kicking behaviour. These researchers found that in contrast to adult kicking behaviour which showed a tight coupling between the knee-hip joints (synchronized flexion and extension), but a low level of joint coupling present between the ankle-knee and ankle-hip joints, infant kicking behaviour initially produced synchronous flexion and extension between all three joints. With changing task demands however, an asymmetrical relationship emerged between the three joints. Jensen *et al.* (1995) proposed that the asynchronous relationship between the joints of mature kickers provided the flexibility the infants need as they underwent the process of exploring movement outcomes and consequences, perhaps to accommodate for changing task demands as a result of a perturbation (disturbance) experienced by the infant.

Clark and Phillips (1993) examined the development of intralimb coordination over the first year of independent walking in three infants and compared their walking patterns to those produced by three adult subjects. These researchers found that at the onset of the new motor behaviour, walking, a period of instability was evident. However, over time, the system appeared to stabilize with a decrease in variability of interlimb coordination. It was not until approximately three months after walking onset when infants primarily produce the double-peak walking force curves observed in adult walking force curves. Clark and Phillips (1993) explain this difference between infant and adult patterns of walking behaviour by pointing out that growing infants are still in the process of mastering the complex task of walking. The absence of an in-phase relationship between the limbs (joints) involved in walking, provides infants a certain amount of flexibility which they require in order to adjust their walking behaviour as they react to a dynamic environment where their walking path could be cluttered with toys and other objects.

In contrast to the findings of Jensen *et al.* (1995) in infant kicking but in agreement with the findings of Clark and Phillips (1993) in infant walking, I propose that for the task of bouncing, less-skilled infants require an asynchronous relationship between the joints involved in bouncing as it provides the infants a higher level of flexibility which they require to explore the open task of bouncing in a Jolly Jumper harness. The asynchronous relationship between the joints provides a learning environment that allows the less-skilled infants to play in the apparatus and discover the consequences of contributing a forcing function while secured in the Jolly Jumper. The less-skilled infants often did not get off the ground, however they were still in the process of organizing their muscles and joints and attempted to produce bouncing behaviour. Moderately-skilled infants produced bouncing behaviour which permitted them to experience successful bouncing (getting off the ground), but they were still in the process of exploring their muscles, joints and the Jolly Jumper itself so their behaviour was sporadic and unpredictable between bouts of bouncing. Skilled bouncers were generally in control of their joints and were able to reproduce bouncing behaviour consistently with very little variability in their bouncing from bout to bout. Ulrich *et al.* (1994) proposed in their study on treadmill stepping, that the variability present in the stepping patterns of infants relative to the adult stepping patterns was actually an attempt by the infants to integrate the complex neuromuscular, joint kinematics and environmental conditions during the dynamic task. I propose that the high degree of variability in the bouncing behaviour of less-skilled infants is similar to the treadmill stepping in infants in that the motor behaviour is an attempt by these infants to control and integrate the components of the bouncing behaviour, neuromuscular, joint kinematics and environmental factors which are necessary to produce successful bouncing behaviour. Alternatively, a lower degree of variability in an infant's bouncing behaviour, both between and within bouts of bouncing, would indicate that an infant possesses a higher level of control over the various components which, when integrated result in skilled bouncing behaviour.

Neuromuscular contribution to infant bouncing

Patterns of muscle activation

Two patterns of muscle activation were apparent in the less-skilled infants (I1) i) co-activation of all five muscles; and ii) tonic activity (Figure 5a). Moderately-skilled infants produced EMG traces that demonstrated characteristics of both skilled and less-skilled behaviour. These infants lack consistency between trials and often had periods of both co-activation and alternating muscle activity. Although skilled bouncers also produced period of co-activation (Figure 5c, bout 3 in the G and TA muscles), they were less consistent than with the less-skilled infants. Skilled bouncers also demonstrated periods of alternating bursts of activity in the gastrocnemius and tibialis anterior muscles (Figure 5c).

Muscle onset latencies

Muscle onset latencies were determined for the activation of G, TA, H, Q and GM muscles. Onset latencies were positive as they were recorded in relation to toe down. The mean muscle onset latencies are represented for each muscle in Table 10. With the exceptions of I7 and I2, all subjects fired their gastrocnemius muscle prior to activating the tibialis anterior muscle (Figure 13). Onset latencies for the gastrocnemius muscle ranged from 0.027 to 0.114 seconds with a group mean and standard deviation of 0.050 +/- 0.026 seconds. Onset latencies for the tibialis anterior muscle ranged from 0.025 to 0.221 seconds with a group mean and standard deviation of 0.108 +/- 0.064 seconds. This indicates that for the majority of the subjects, the gastrocnemius muscle was fired almost immediately following toe down suggesting that it served to absorb some of the landing forces. Activation of the tibialis anterior muscle followed the activation of the gastrocnemius muscle. It is proposed that the TA muscle activity occurred in order to bring the toes from a plantarflexed to a dorsiflexed position in preparation for the next landing.

Table 10.

Mean values of muscle activation onset latencies

Infant	G		TA		H		Q		GM	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
I1	0.039	0.029	0.065	0.049	0.059	0.043	0.033	0.024	0.038	0.025
I2	0.083	0.060	0.059	0.074	0.112	0.083	0.055	0.044	0.000	0.000
I3	0.029	0.008	0.117	0.231	0.083	0.049	0.061	0.027	0.000	0.00
I4	0.033	0.021	0.063	0.083	0.067	0.071	0.056	0.053	0.045	0.022
I5	0.037	0.031	0.157	0.193	0.090	0.039	0.080	0.017	0.000	0.000
I6	0.054	0.086	0.109	0.123	0.032	0.025	0.051	0.029	0.036	0.015
I7	0.027	0.006	0.025	0.009	0.117	0.104	0.038	0.012	0.056	0.033
I8	0.114	0.204	0.221	0.144	0.086	0.089	0.112	0.203	0.052	0.021
I9	0.034	0.040	0.097	0.122	0.048	0.020	0.030	0.026	0.105	0.056

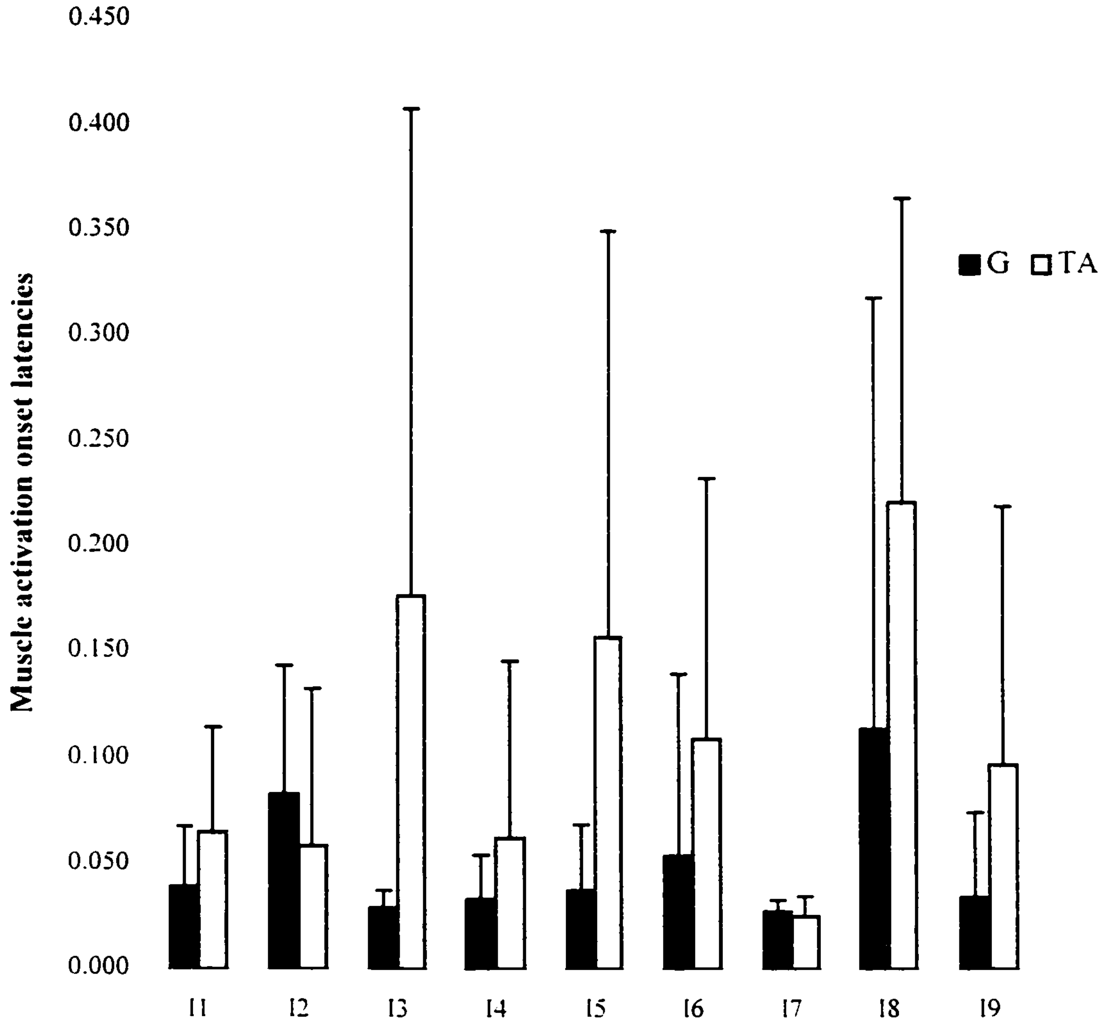


Figure 13. The muscle activation onset latencies of the gastrocnemius and tibialis anterior muscles. The black and gray bars illustrate the muscle onset latencies recorded in milliseconds of the gastrocnemius and tibialis anterior muscles, respectively. Infants were arranged from left to right as skilled and less-skilled bouncers. Muscle onset latencies were recorded using toe down as time zero for each bounce cycle. For most infants, activation of the gastrocnemius muscle was followed by activation of the tibialis anterior muscle. I7 was the sole exception and demonstrated almost co-activation of the gastrocnemius and tibialis anterior muscles.

Proportion of bounces

The proportion of bouts of bouncing in which lower limb muscles were activated is represented in Table 11. As outlined in the methods section, toe down was the point in the bouncing cycle that was used as time zero.

Neural contribution to bouncing

EMG recordings of the muscle activity of all the infants involved in this study varied both within and between bouts of bouncing behaviour. In contrast, studies on adult jumping behaviour by Voight *et al.* (1995) and Gregoire *et al.* (1984) reported that the muscles of the lower limb play an integral part in the production of the force and thus the power that results in the sequential movements of the hip, knee and ankle joints. This allows an energy flow in a proximodistal direction that is necessary in order to produce a vertical jump and in turn, vertical take-off. The task of bouncing while secured in a Jolly Jumper infant harness system is quite different from the task of vertical jumping in adults. Most adults master the task of jumping as they mature. Infants are still in the process of maturing. Bouncing in the harness system is also an open motor task relative to other motor tasks, like posture, and infants were freely permitted to explore the harness system, their surrounding environment and the bouncing task itself. This would suggest that perhaps the consistency seen in the muscle activation patterns of adult jumping is necessary for posture control. If adults changed the muscle activation pattern they may get off the ground but they would also be more susceptible to falling.

Kinematic behaviour represented in phase-plane and angle-angle plots, especially in skilled infants had a low degree of variability and consistency both within and between bouts of bouncing. Therefore, it is postulated that the variable muscle activity of the infants involved in this study allowed the infants a large degree of flexibility which they needed in order for them to produce kinematic behaviour that was both consistent and reproducible both within and between bouts of bouncing. These infants seemed to possess a level of self-organized neuromuscular patterns of activation, which allowed them to produce organized, consistent patterns of bouncing behaviour at a joint kinematic

Table 11.

Proportion of bouts of bouncing in which muscles were activated

Infant	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I9**
G	0.55	0.91	1.00	0.83	0.90	1.00	1.00	1.00	0.87
TA	0.90	0.55	1.00	0.67	0.70	0.83	1.00	1.00	0.93
H	0.90	0.91	1.00	0.83	0.90	1.00	1.00	1.00	1.00
Q	0.75	1000	1.00	0.92	0.80	1.00	1.00	1.00	1.00
GM	1.00	0.00	0.00	0.67	0.00	0.92	0.80	1.00	0.40

level. The adaptability of the neuromuscular system to the changing task dynamics during the open bouncing task enabled skilled infants to produce consistent joint kinematic patterns, where joints were in phase throughout the bouncing cycle. This high level of organization at the joint level, in turn, produced consistent, bouncing behaviour with a low degree of variability within and between bouts of bouncing.

The infants involved in this study were provided with postural support in the Jolly Jumper harness. In their study on infant treadmill stepping, Ulrich *et al.* (1994) supported the infants by holding them under the armpits while they were performing the motor task of treadmill stepping. Ulrich *et al.* (1994) determined that not having the constraint of controlling their own posture allowed infants freedom to explore the motor task and as well as their environment without experiencing consequences of not controlling their posture- namely falling. Bouncing infants involved in this study were not faced with the additional neuromotor task requirement of controlling their posture - the harness system provided this support. This granted infants the freedom to explore their environment and experiment with the bouncing task itself.

The hip's role in tasks like kicking and treadmill stepping tends to be one of stabilization and postural control (Jensen *et al.*, 1995). Infants more inclined to rely solely upon posture support provided by the harness system were the less-skilled bouncing infants. These infants would relax their legs and let the Jolly Jumper maintain their upright posture when they were not producing bouncing behaviour. Note the small role that the hip plays in bouncing behaviour for these infants in the EMG muscle activation recordings, baby contribution plots, phase-plane plots, joint angular position and angle-angle plots (Figures 5, 7, 8, 10 and 11, respectively). Less-skilled infants produced bouncing behaviour extremely variable within and between bouts of bouncing thereby producing inconsistent neuromuscular patterns with high levels of tonic muscle activity and highly variable phase relationships between the three joints of the lower leg.

Sveistrup and Woollacott (1996) reported a lack of phasic response to platform perturbation in their youngest infant group studied. These infants produced high levels of background muscle activity in the leg and trunk muscles in a significant proportion of trials. These researchers propose that this high level of tonic muscle activity was actually a strategy of postural control and an attempt by the infant to decrease movement across multiple joints. The neuromuscular activity of less-skilled bouncers demonstrate high levels of tonic activity as reflected in EMG recordings (Figure 7a bout 1 and Figure 7b bout 2). Similarly to the strategy of postural control following a platform perturbation, the high levels of background muscular activity during bouncing behaviour in the less-skilled infants may have served to increase stability and support across joints. This would allow less-skilled infants to produce bouncing behaviour which, although not highly skilled, resembled bouncing behaviour at a kinematic and global level.

Infants who were more skilled at the task of bouncing had phase-plane plots, angle-angle plots, joint angular displacement and EMG muscle activation patterns which indicated the increased role the hip played in the production of organized bouncing behaviour. The neuromuscular activity patterns of these infants were closely linked with the phases of the joints and rather than producing tonic or co-activation of antagonist muscle groups, skilled infants produced muscle activation patterns with alternating patterns of muscle activation in antagonist muscle groups such as the gastrocnemius and tibialis anterior muscles. These skilled bouncers were concerned not only with the task of producing bouncing behaviour, but were also beginning to play a more active role in postural support during the bouncing task.

CHAPTER FIVE

CONCLUSIONS and FUTURE RECOMMENDATIONS

The following section will address the conclusions that can be made from this study.

Skilled and less-skilled bouncing

The motor task of bouncing is in fact quite a complex task. When learning how to bounce, an infant must undergo a complex decision making process. "How hard should I push" and "when should I push" are just some of the problems that an infant must solve before they are able to produce successful bouncing behaviour. These problems are in fact more involved than they seem at first glance. For example, the problem of "how hard should I push" requires the infant to decide which muscles to activate, in which sequence and to what level. Also, the position of the body and orientation of ground reaction forces will influence the movement outcome. This study characterized the underlying causal control processes of bouncing and examined the differences between skilled and less-skilled bouncing behaviour. Although this study did not examine the development of bouncing behaviour, we would suggest that our data potentially reflects the development or learning a complex motor skill, like bouncing for infants with no known pathologies aged 6- to 12-months. The subject population for this study consisted of a small sample size nine infants with no known pathologies aged 6- to 12-months, therefore the results of this study are limited to that population. Generalizations made to alternate population groups would be inappropriate and could prove to be misleading. It was beyond the focus of this study to conduct a longitudinal analysis of infant bouncing behaviour. Rather, it was the scope of this study to explore and better understand the intricacies and cumulation of the neural and joint contributions in the production of infant bouncing behaviour.

Four infants in this study demonstrated "skilled bouncing behaviour" (I9, I8, I7 and I6) and two infants demonstrated "less-skilled bouncing behaviour" (I1 and I2). The remaining three infants fell in between the two classifications of skill level and were characterized as "moderately-skilled bouncing behaviour". The moderately-skilled infants demonstrated characteristics of both skilled and less-skilled bouncing behaviour-their bouncing performance varied between and within trials. Due to the inconsistent bouncing behaviour of the less- and moderately-skilled infants, I would hypothesize that infants progress from a less-skilled to a skilled bouncing behaviour. I do propose however, that the examination of development of skilled bouncing behaviour be studied in future longitudinal studies on bouncing where the same infants are followed as they progress from less-skilled to skilled bouncing behaviour.

Similarities between kicking, walking and posture development

Previous research on infant motor development examined complex motor tasks including kicking (Jensen *et al.*, 1995; Thelen and Fisher, 1983; Geerdink *et al.*, 1996), walking (Clark and Phillips, 1993), and posture (Sveistrup and Woollacott, 1996). This study on infant bouncing sought to further examine the development of infant bouncing since limited work has been done in this area. The current work used a more extensive research paradigm than the sole previously reported experiments of bouncing (Goldfield *et al.*, 1993) and analyses were performed to determine the underlying control processes of the behaviour. Although this research paradigm did not include a longitudinal analysis of the development of the behaviour, it is reasonable to make the assumption that the complex skill of bouncing will follow the developmental progression of similar skills like kicking, walking and posture. Through analysis of our data on infant bouncing, we outlined certain characteristics of less-skilled and skilled bouncing behaviour.

Jensen *et al.* (1995) found that with development of kicking in infants, there was a progression from infants producing spontaneous synchronized flexion or extension of the leg to complete asymmetrical kicking behaviour. These researchers stated that as infants develop they learn to adapt the movement to specific task demands. While the development of kicking behaviour progresses from synchronous leg movements to independent joint movements our data suggest that the development of efficient bouncing follows the opposite progression. Skilled infants demonstrated synchronous leg movements (simultaneous flexion and extension at the joints) during bouncing behaviour and produced phase-plane plots with spring-like characteristics. These infants were able to adjust their leg stiffness, via their neuromuscular system, to match a multiple of the spring stiffness of the Jolly Jumper harness system. Less-skilled infants demonstrated asynchronous leg movements (flexion at one joint, extension at another joint) during bouncing behaviour and produced phase-plane plots with characteristics of ballistic control of the movement pattern.

Thelen and Fisher (1983) examined infant kicking patterns and found that similar to infant bouncing, periods of co-activation in antagonist muscles existed in immature and unskilled movement, while alternating periods of activation in antagonist muscles indicated a higher degree of skill at performing the movement. These researchers found that the ankle, knee and hip joint organization went through a period of development between two- and four-weeks of age. At 4-weeks of age, the joint organization was highly structured and movements of different joints were synchronized with each other when compared to the same infants joint coupling just two weeks prior. Geerdink *et al.* (1996) reported that intralimb coordination between ankle, knee and hip joints followed a sequence of an initial phase of tight interjoint coupling followed by a decrease in cross correlation in full term infants, while preterm infants demonstrated a lower correlation between the angles of the hip-ankle and knee-ankle. This "proximal-to-distal" development of the skill of kicking was also found in our results. Angle-angle and phase-plane plots display this developmental progression quite well. Less-skilled infants had hip phase-plane and angle-angle plots with small changes in joint angular positions and low angular velocities during bouts of bouncing. Skilled infants, however, had phase-plane and angle-angle plots with larger changes in joint angular positions as well as higher angular velocities during bouts of bouncing. Some infants demonstrated characteristics of both skilled and less-skilled behaviour. These infants had a high degree of variability across the three joints, as well as within and between bouts of bouncing. Due to the inconsistent bouncing behaviour of the infants demonstrating highly variable behaviour, it could be hypothesized that the behaviour of these infants progressed in a "proximal-to-distal" pattern.

Clark and Phillips (1993) reported that infants learning to walk, similar to infants learning to bounce, experience a period of instability at the onset of the new movement behaviour. Over time, this movement behaviour develops into a stable and controlled motion. Sveistrup and Woollacott (1996) examined the development of posture in infants and found that with development, infants had a higher degree of phasic response to perturbations, over time learning to incorporate their ankle (gastrocnemius, tibialis) muscles followed by their thigh (quadriceps, hamstring) muscles and finally trunk (abdominal, trunk extensor) muscles into the movement pattern. This motor pattern follows a progression of "distal-to-proximal" with development, which is opposite of the pattern of "proximal-to-distal" muscle recruitment which was present between less-skilled and skilled infant bouncing.

Posture and bouncing behaviour

This study found similarities between the task of infant bouncing and other complex motor tasks such as walking and kicking, however similarities were not found between the development of posture in infants and the different skill levels of infant bouncing. This may have been due to the nature of the movement task of bouncing. In our study, infants were supported so that they were not required to sustain their own upright posture during production of bouncing behaviour. Rather, these infants were given the opportunity to freely explore the open task of bouncing without having to experience the consequences of not controlling their posture during the task- falling. Posture is not an open task like walking, kicking or bouncing. Rather specific reactions to perturbations of a stable system are expected. The "distal-to-proximal" motor control pattern is actually an early strategy of postural control: an attempt by the infants to decrease the movement about multiple joints when their stable stance is perturbed. Infants who are learning to kick, walk and/or bounce are not attempting to decrease movement about multiple joints, rather they are attempting to control the multiple joints in such a manner so as to produce efficient, consistent movement patterns with a low level of variability across the joints as well as between and within episodes of the movement behaviour.

Future recommendations

The results obtained from this study on infant bouncing, have raised additional research questions about the different skill levels of infant bouncing behaviour that should be further examined. The first question is- could the different bouncing skill levels be a result of normal infant maturation? To answer this question a longitudinal study that follows the development of infants of age as they mature and master the skill of bouncing.

The second research question is- what effect does experience or supervised playing in the jolly jumper have on the skill of bouncing? A training study would determine if a chronologically young infant could produce the same level of bouncing behaviour as a chronologically older infant. If this conclusion could be made it would indicate that experience and practice of the task had a stronger influence than maturation on the bouncing skill level of an infant.

A third question raised from my research involves the two attractor states that appear to be present in the data recorded for the bouncing behaviour of the moderately-skilled and skilled infants. The application of a perturbation- the addition of weight or a change in spring stiffness, during a bout of bouncing in a moderately-skilled and/or skilled infants. If these infants had in place the point attractor, that was proposed, a bouncing frequency of either 1.5 or two times the resonant frequency of a mass-spring system, the behaviour of these infants would be altered for a few moments but would quickly revert back to the original stable point attractor. This would indicate that infants had learned a stable frequency of the spring -mass system at which to produce bouncing behaviour and were using this frequency as a point attractor. If infants did not have in place a point attractor, they would not quickly adjust their behaviour to compensate for the perturbation and would either cease to bounce or would resume bouncing at new and unstable frequency. If a point attractor did not exist, further studies into the two patterns of bouncing behaviour would be required.

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APPENDIX A

THE EQUATIONS OF MOTION FOR A DAMPED HARMONIC SYSTEM AS DETERMINED USING THE METHOD OF RILEY AND STURGES (1993 p. 437-57)

(1) The spring constant (k)was obtained by suspending a mass (m) from the Jolly Jumper spring and measuring the elongation (Δx) of the spring. Given an elongation of 0.2096 m with a mass of 12.08 kg, the following was used to determine the spring constant:

$$F = k * \Delta x$$

where,

$$F = m * g$$

$$m * g = k * \Delta x$$

so,

$$k = \frac{m * g}{\Delta x}$$

$$k = \frac{12.08 * 9.81}{0.2096}$$

$$k = 565.39 \text{ N/m}$$

(2) The coefficient (ω_n) is related to the frequency of the oscillation of the harness system and is called the natural circular frequency of the harness system:

$$\omega_n = \frac{k}{m}$$

$$\omega_n = \frac{\sqrt{565.39}}{\sqrt{12.08}}$$

$$\omega_n = 6.841 \text{ rad/s}$$

(3) The damped period (τ) of the system was determined by hanging and oscillating an arbitrary mass (m) of 5.5 kg from the Jolly Jumper harness system. The loadcell trace was used to measure the length of time for the completion of one oscillation. Using this technique, the damped period of the system was determined to be:

$$\tau = 1.037 \text{ s}$$

(4) To calculate the damping ratio (ζ) using the following equation:

$$\tau_d = \frac{2 * \pi}{\omega_n \sqrt{1 - \zeta^2}}$$

$$\sqrt{1 - \zeta^2} = \frac{2 * \pi}{\tau_d * \omega_n}$$

So,

$$\zeta = \sqrt{1 - \left(\frac{2 * \pi}{\tau_d * \omega_n} \right)^2}$$

$$\zeta = \sqrt{1 - \left(\frac{2 * \pi}{(1.037) * (6.841)} \right)^2}$$

$$\zeta = 0.464$$

APPENDIX B

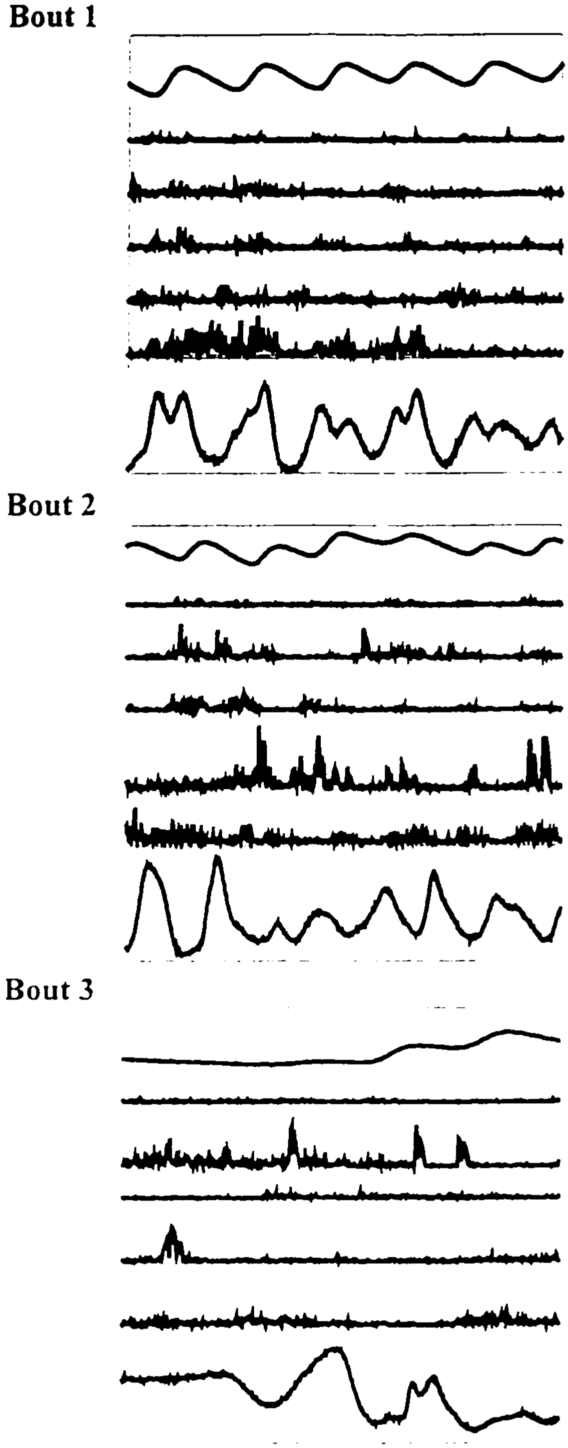


Figure 5d. Loadcell, EMG and force plots for I2. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 2.48, 2.32 and 2.70 seconds, respectively. The y-axis is arbitrary units. Note the lack of consistency in I2's EMG traces, as well as the variability, across and within bouts, in both loadcell and force traces.

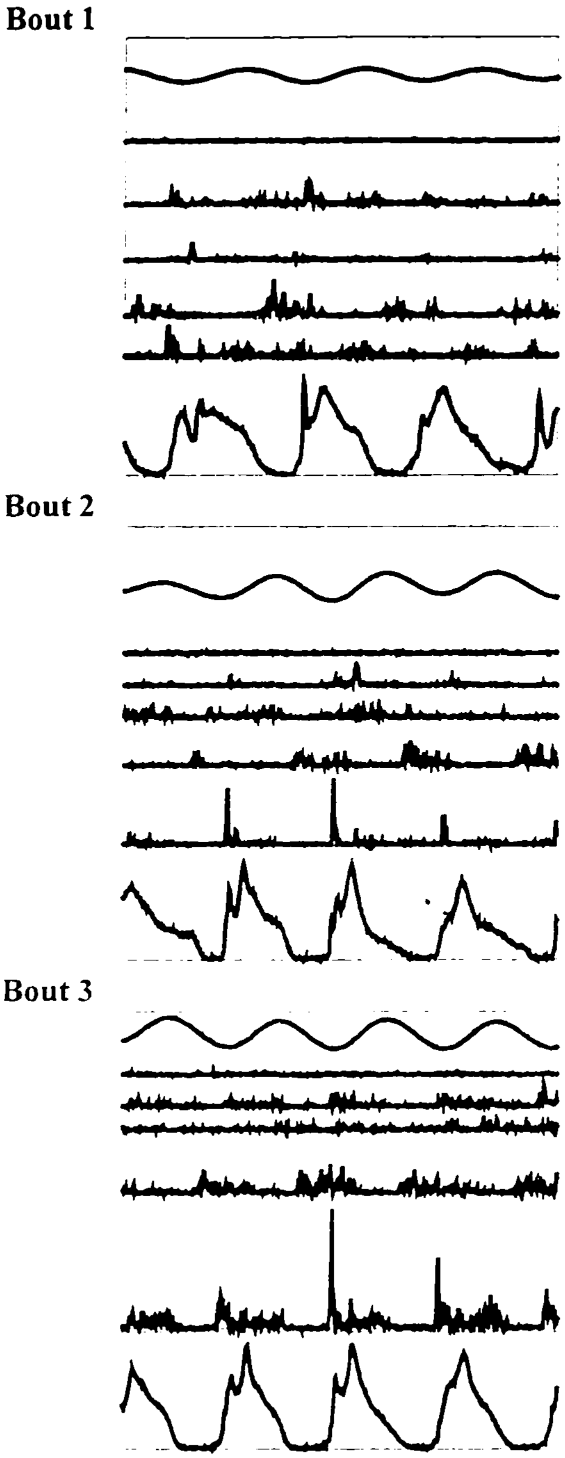


Figure 5e. Loadcell, EMG and force plots for I3. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 2.48, 2.95 and 2.65 seconds, respectively. The y-axis is arbitrary units. Although I3 had a highly variable loadcell trace across bouts, periods alternating bursts of activity in gastrocnemius and tibialis anterior muscles were evident across and within bouts.

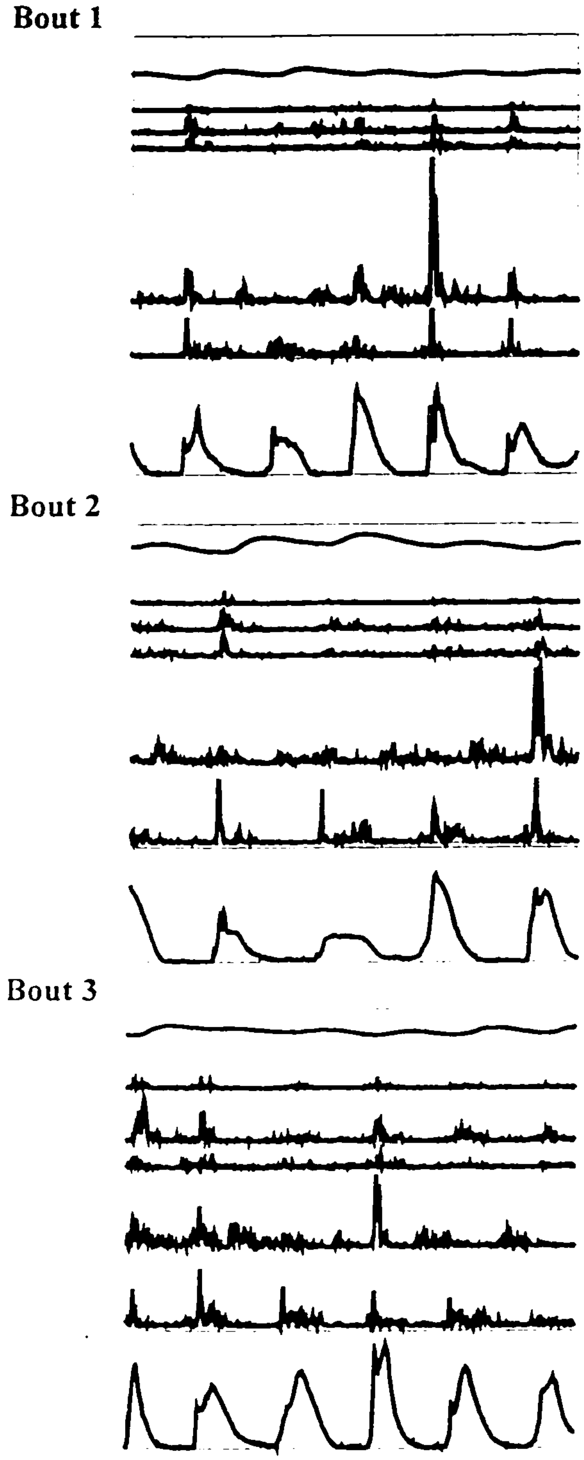


Figure 5f. Loadcell, EMG and force plots for I4. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 2.60, 2.08 and 2.48 seconds, respectively. The y-axis is arbitrary units. Note that I4 primarily produced periods of muscle co-activation within and across bouts. Also note the high variability across load cell (three bouts) and force (bout 1 -> 2 and 3) traces.

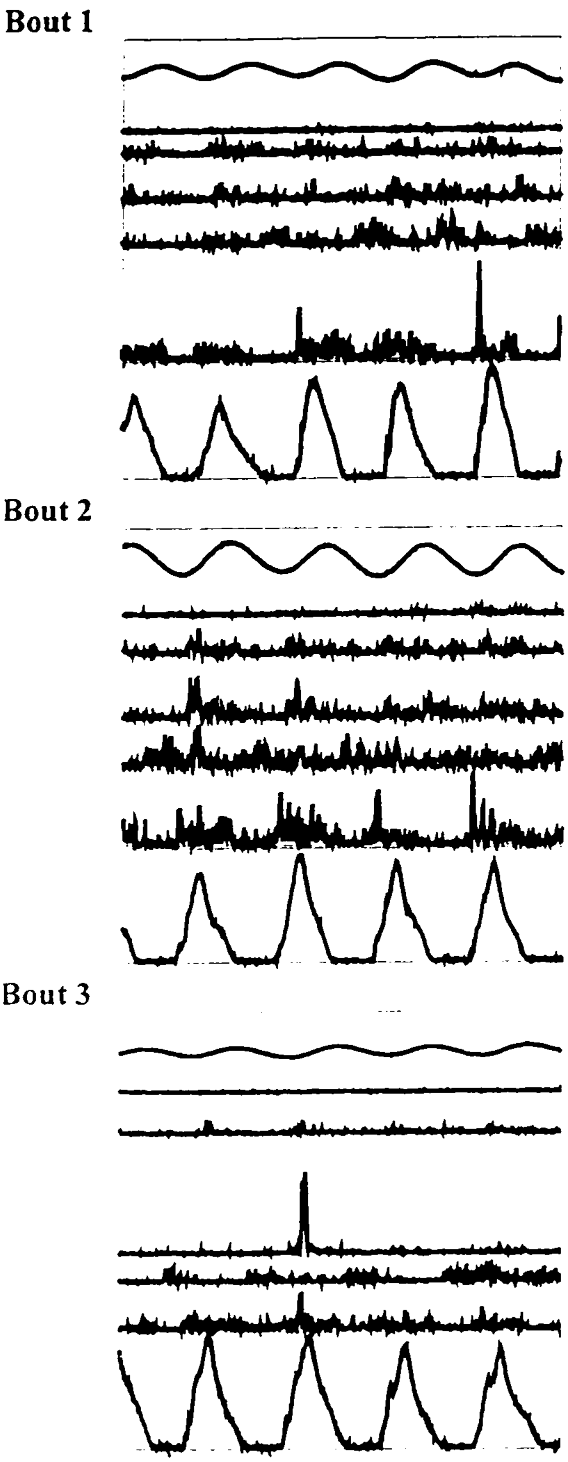


Figure 5g. Loadcell, EMG and force plots for I5. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 3.20, 3.10 and 3.08 seconds, respectively. The y-axis is arbitrary units. Alternating bursts of activity were evident in I5's gastrocnemius and tibialis anterior muscles EMG (bout 1). Note I5's consistent force traces, across and within bouts.

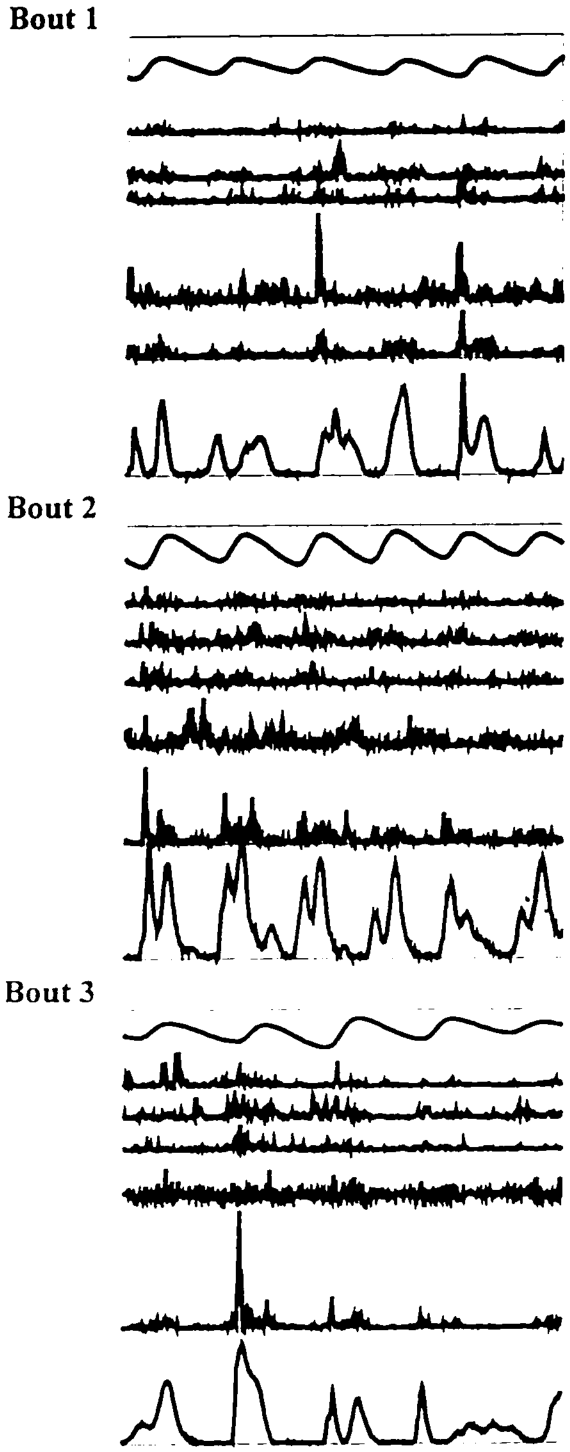


Figure 5h. Loadcell, EMG and force plots for I6. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 2.83, 2.80 and 2.30 seconds, respectively. The y-axis is arbitrary units. I6's EMG illustrates discrete bursts of muscle activation (bout 3, gastrocnemius) and periods of alternating muscle activation (bout 2). Note increasing consistency in loadcell patterns.

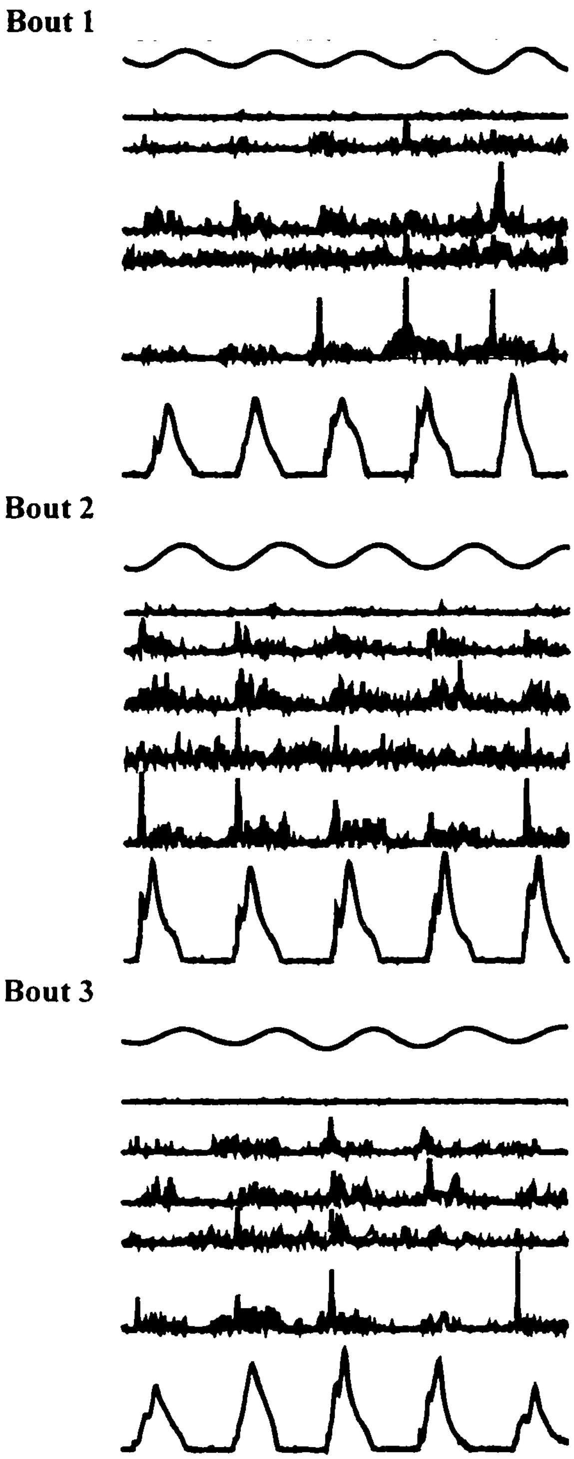


Figure 5i. Loadcell, EMG and force plots for I9. The data plotted from top to bottom in each of the above graphs correspond to loadcell output, gluteus maximus, quadriceps, hamstrings, tibialis anterior, and gastrocnemius muscles activity and vertical ground reaction force trace, respectively. The duration of the three bouts of bouncing are 3.27, 3.69 and 3.01 seconds, respectively. The y-axis is arbitrary units. I9's EMG illustrates discrete bursting patterns in gastrocnemius across all bouts. Consistency, within and between bouts is evident for loadcell and force traces.

APPENDIX C

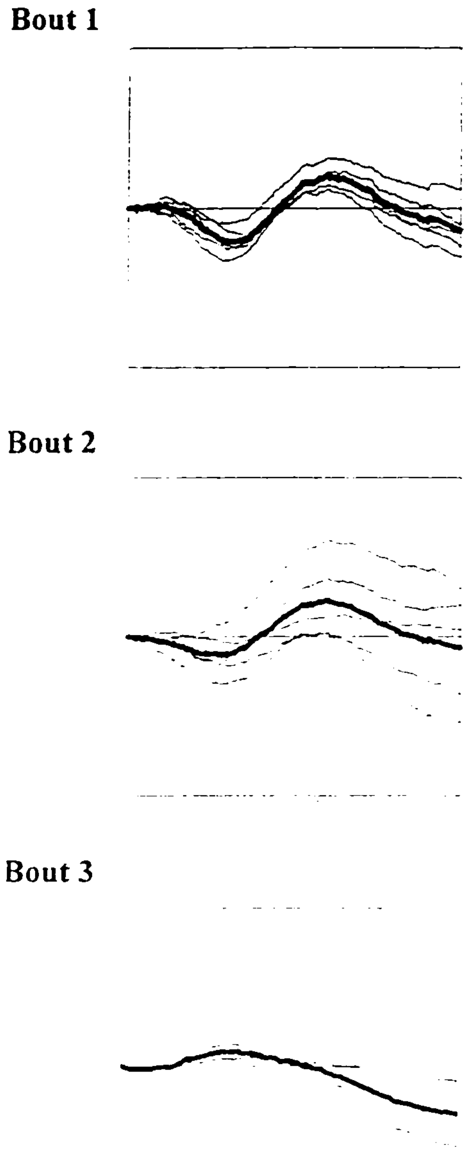
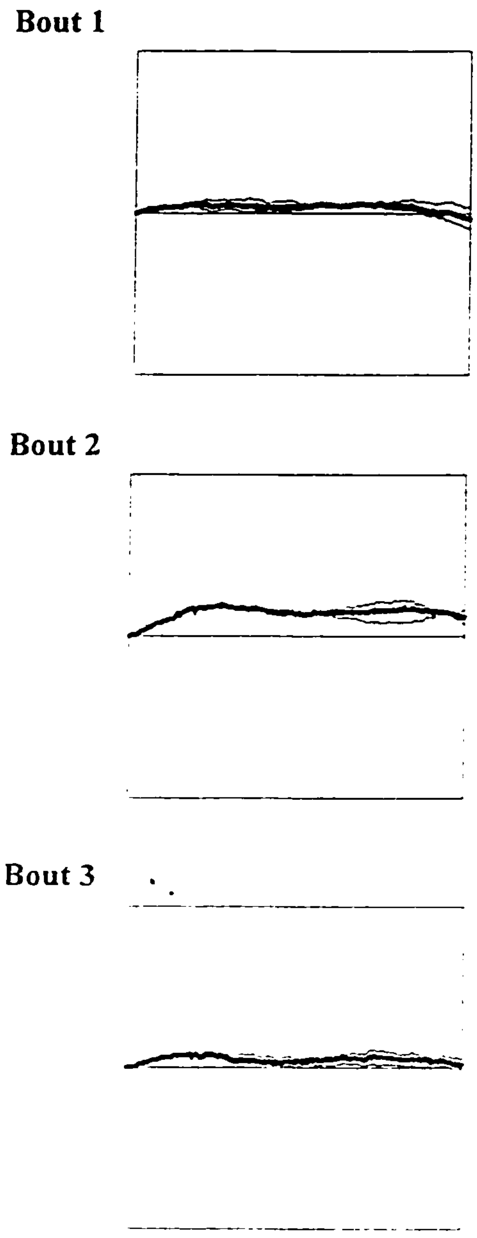


Figure 7d: Model of baby contributions to the bouncing task for I2. The graphs represent I2's contribution to the bouncing behaviour. For each graph, the thin curves represent I2's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note the interbout variability of the baby contribution (though a negative-to-positive line pattern is predominant), suggesting that I2 was still exploring possible organization patterns of the variables which would produce bouncing behaviour.



Bout 1

Bout 2

Bout 3

Figure 7e: Model of baby contributions to the bouncing task for I3. The graphs represent I3' contribution to the bouncing behaviour. For each graph, the thin curves represent I3' contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note that although the amplitude of the curve, represented by the heavy line, is small, a consistent double bump pattern is present in I3' baby contribution curves.

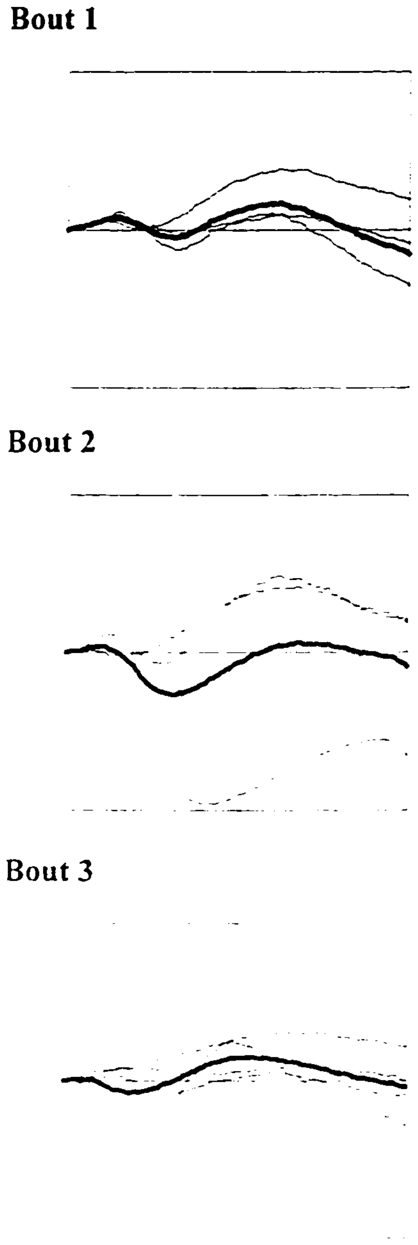


Figure 7f: Model of baby contributions to the bouncing task for I4. The graphs represent I4's contribution to the bouncing behaviour. For each graph, the thin curves represent I4's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert. The y-axis is arbitrary units. Note that while a negative-to-positive line pattern is predominant, intrabout variability is still illustrated in I4's baby contribution curves. This suggests that I4 was still exploring possible organization patterns of the variables which produced bouncing behaviour.

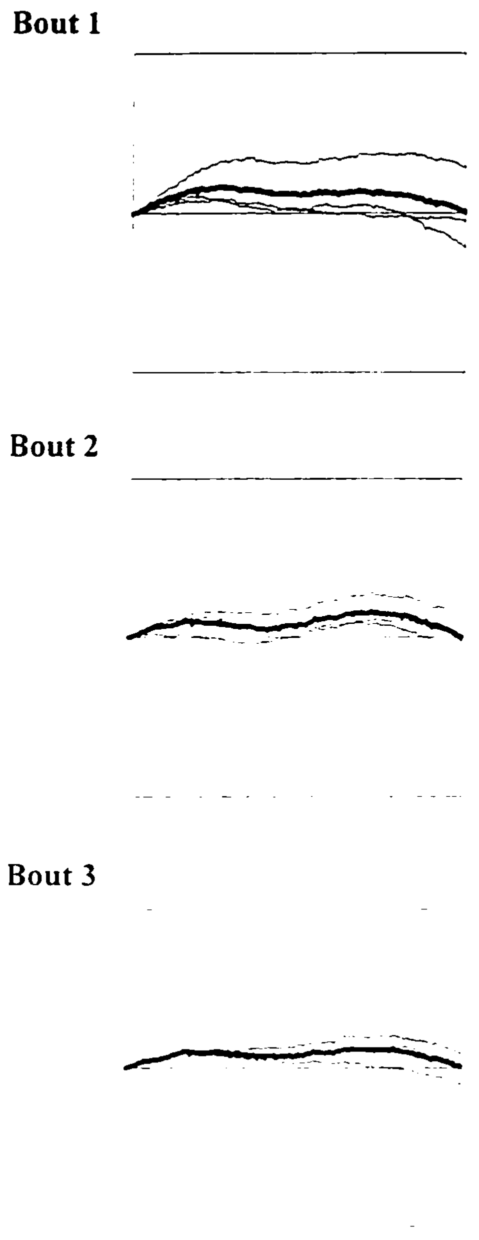


Figure 7g: Model of baby contributions to the bouncing task for I5. The graphs represent I5's contribution to the bouncing behaviour. For each graph, the thin curves represent I5's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note that although the amplitude of the line curve is small, a consistent double bump pattern is present in I5's baby contribution curves, especially in bouts 2 and 3.

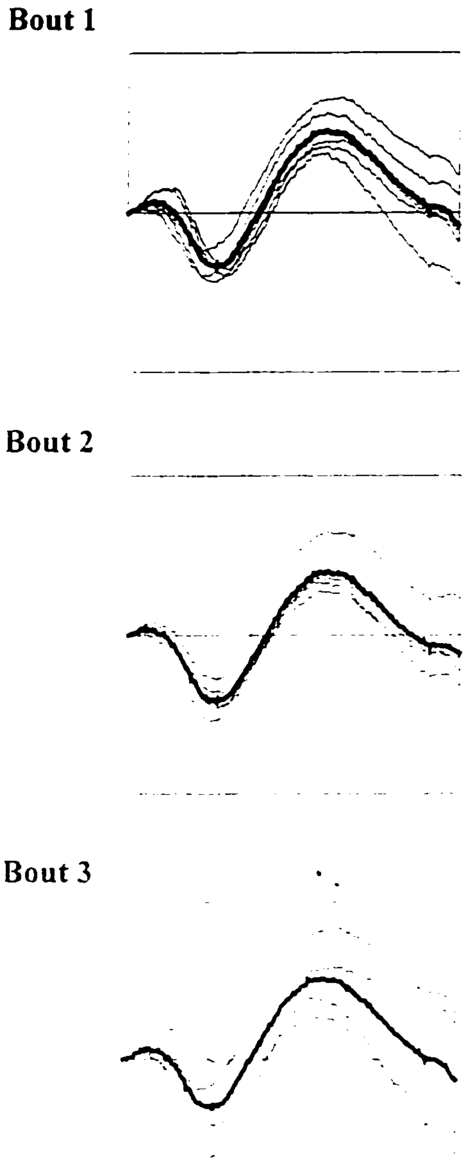


Figure 7h: Model of baby contributions to the bouncing task for I6. The graphs represent I6's contribution to the bouncing behaviour. For each graph, the thin curves represent I6's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note the consistent negative-to-positive line pattern, within and between bouts, for the curves representing I6's contribution to the bouncing task..

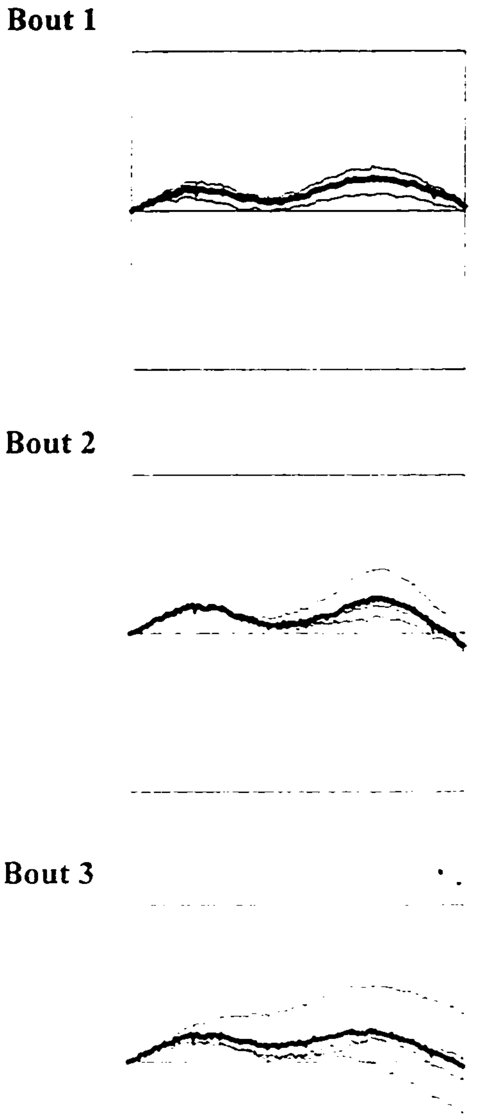


Figure 7i: <u>Model of baby contributions to the bouncing task for I9</u>. The graphs represent I9's contribution to the bouncing behaviour. For each graph, the thin curves represent I9's contribution to individual bounces within a bout while the thickened line indicates the average of the individual bounces for the bout. The x-axis is normalized time. The loadcell traces from individual bounces were normalized to the length of one complete cycle of the spring system when it was loaded with an inert mass. The y-axis is arbitrary units. Note that while a double bump line pattern is predominant (bouts 1 and 2), intrabout variability is still illustrated in I9's baby contribution curves (bout 3).

APPENDIX D

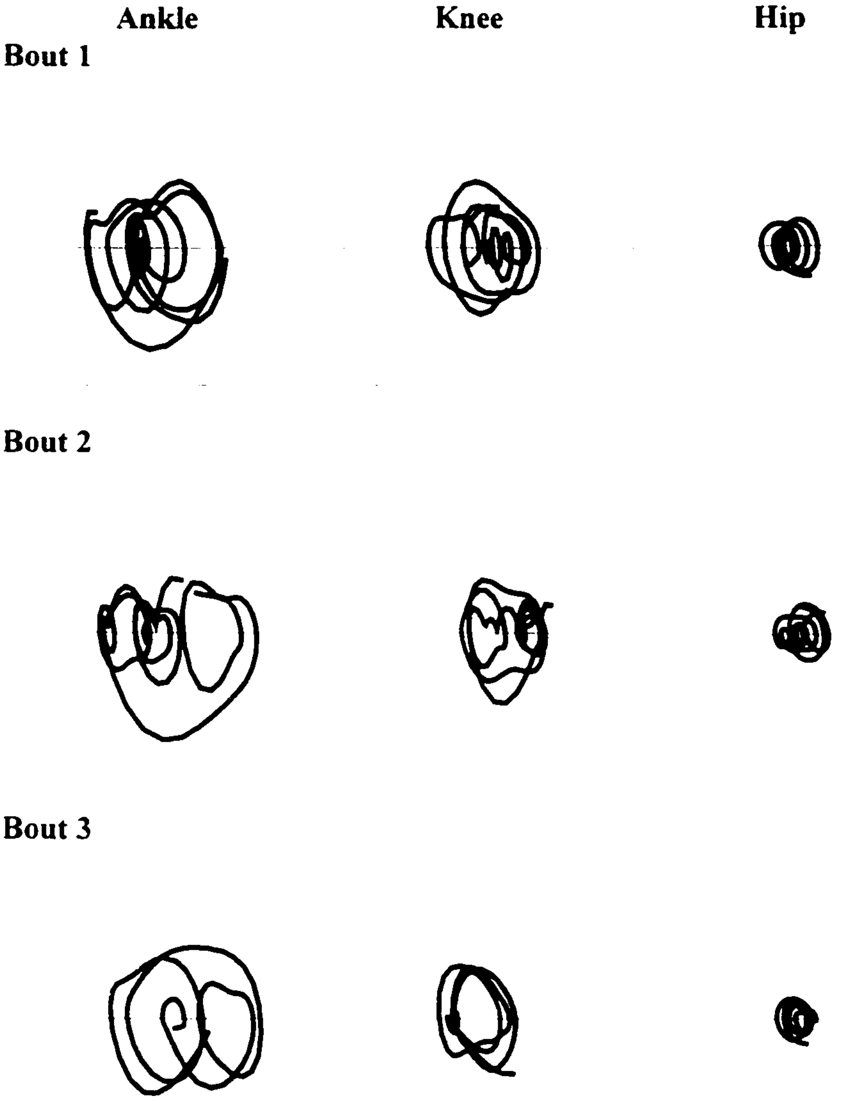


Figure 8d: Phase-plane plots for I2. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (500 to -500) with the horizontal line on the y-axis indicating zero velocity. The joints moved from flexion to extension on the x- and y-axis from left to right and bottom to top, respectively. Columns one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the disorganized line pattern across the ankle and knee joints; also note the decrease in velocity and joint position of hip when compared to the ankle and knee.

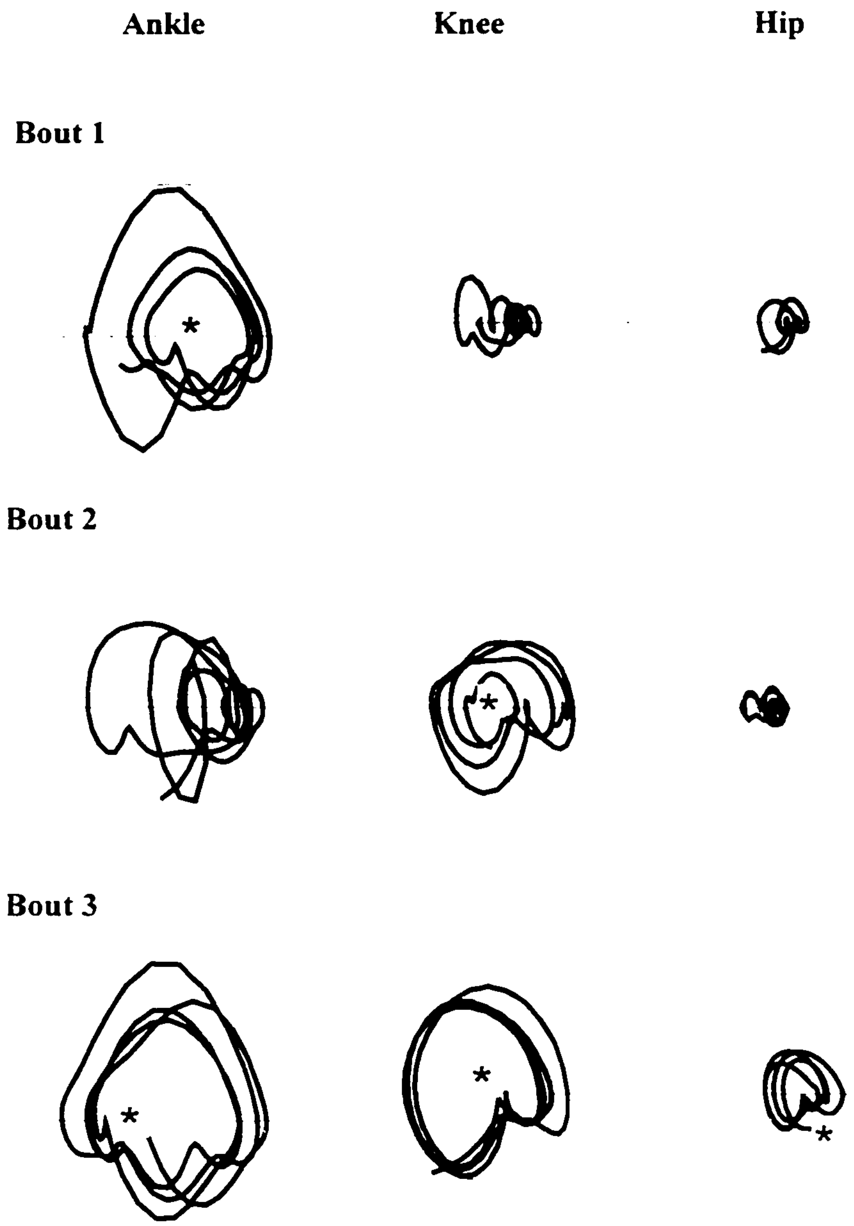


Figure 8e: Phase-plane plots for I3. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. Toe-down is represented by an asterix. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (B1: 550 to -450; B2: 500 to -500; and B3: 600 to -400), with the horizontal line on the y-axis indicating zero velocity. The joints moved from flexion to extension on the x- and y-axis from left to right and bottom to top, respectively. Columns one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the disorganized and inconsistent pattern for all three joints within and between trials; also note differences in velocity and joint position for the three joints.

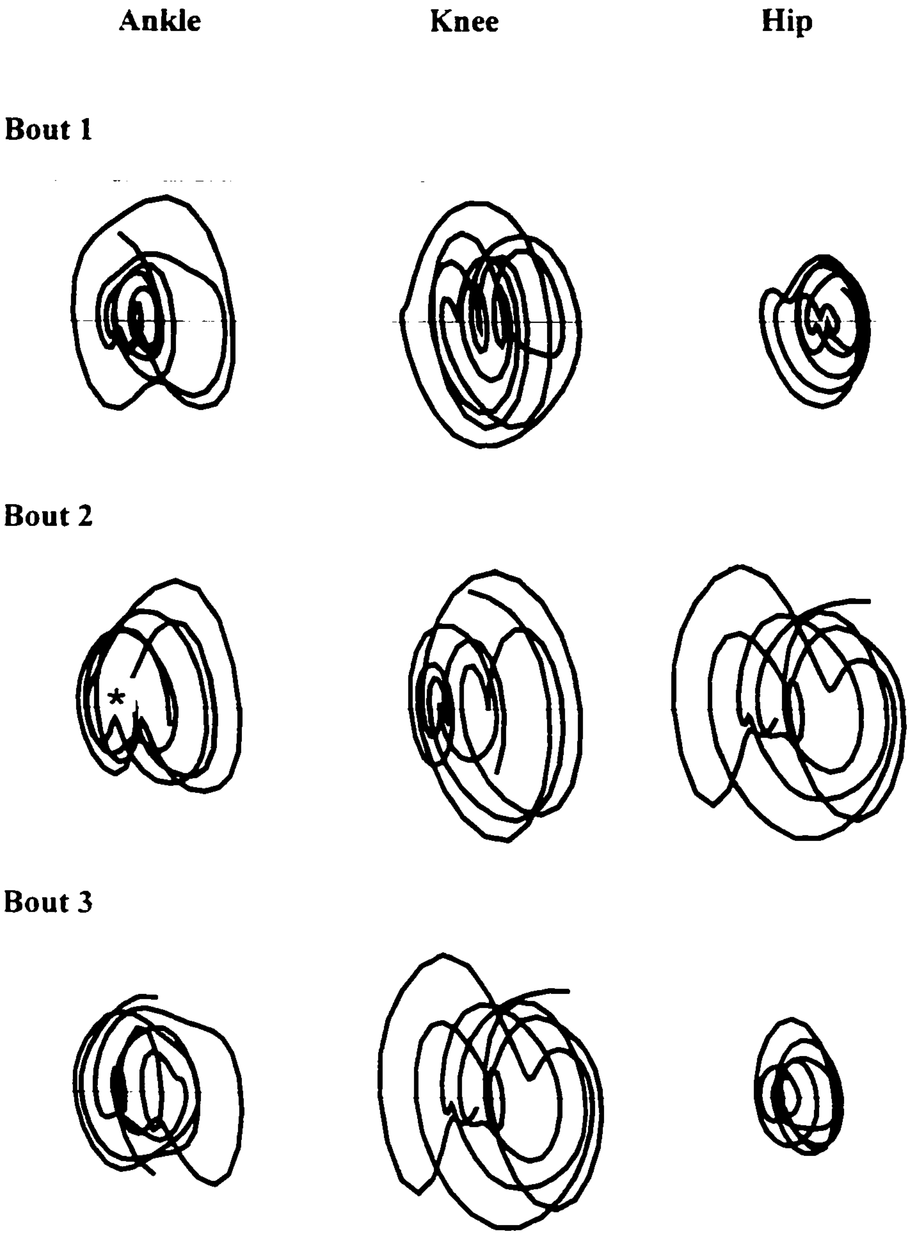


Figure 8f: Phase-plane plots for I4. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. Toe-down is represented by an asterix. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (500 to -500). Column one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the disorganized line pattern which denotes inconsistent bouncing behaviour, both within and between trials for each of I4's three joints phase-plane plots.

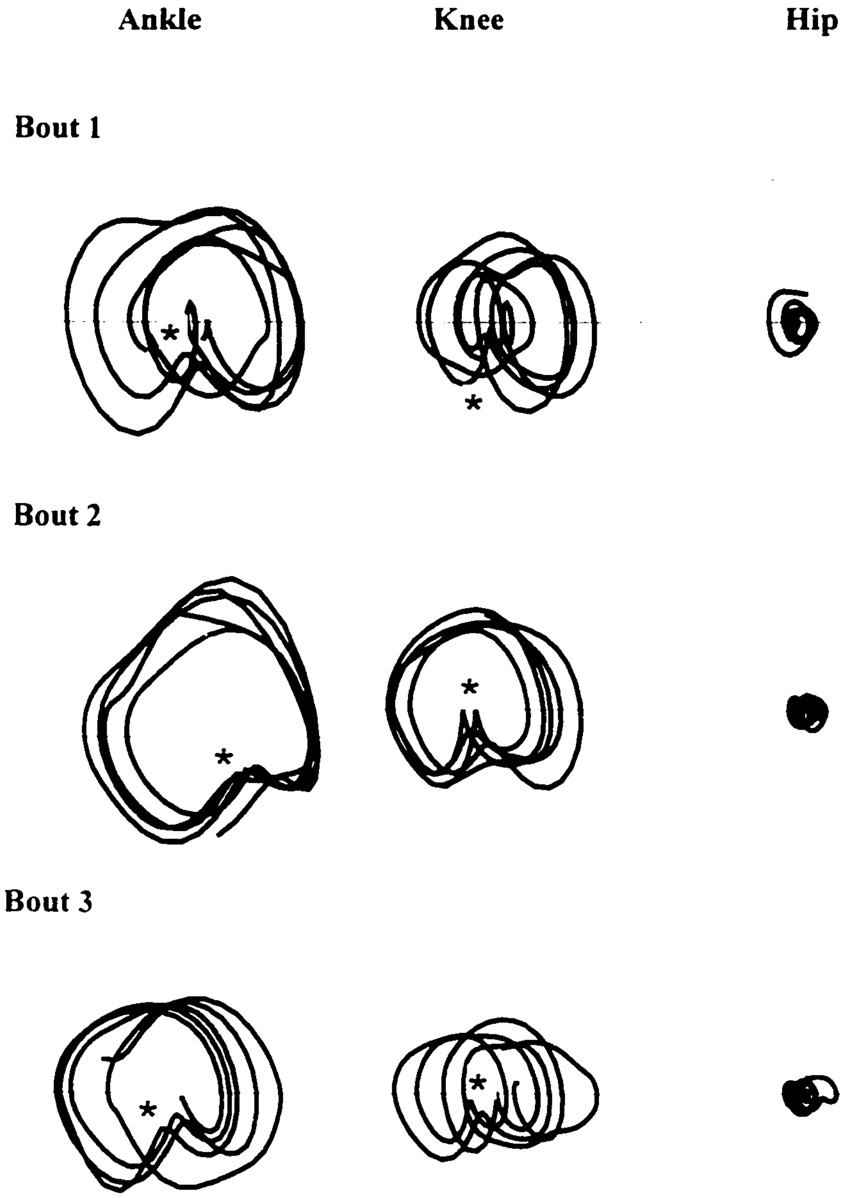


Figure 8g: Phase-plane plots for I5. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. Toe-down is represented by an asterix. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (B1: 500 to -500; B2: 600 to -400; and B3: 500 to -500). Column one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the line pattern for I5's hip plots, which denote a reduced velocity and range of movement for the hip when compared to the knee and hip.

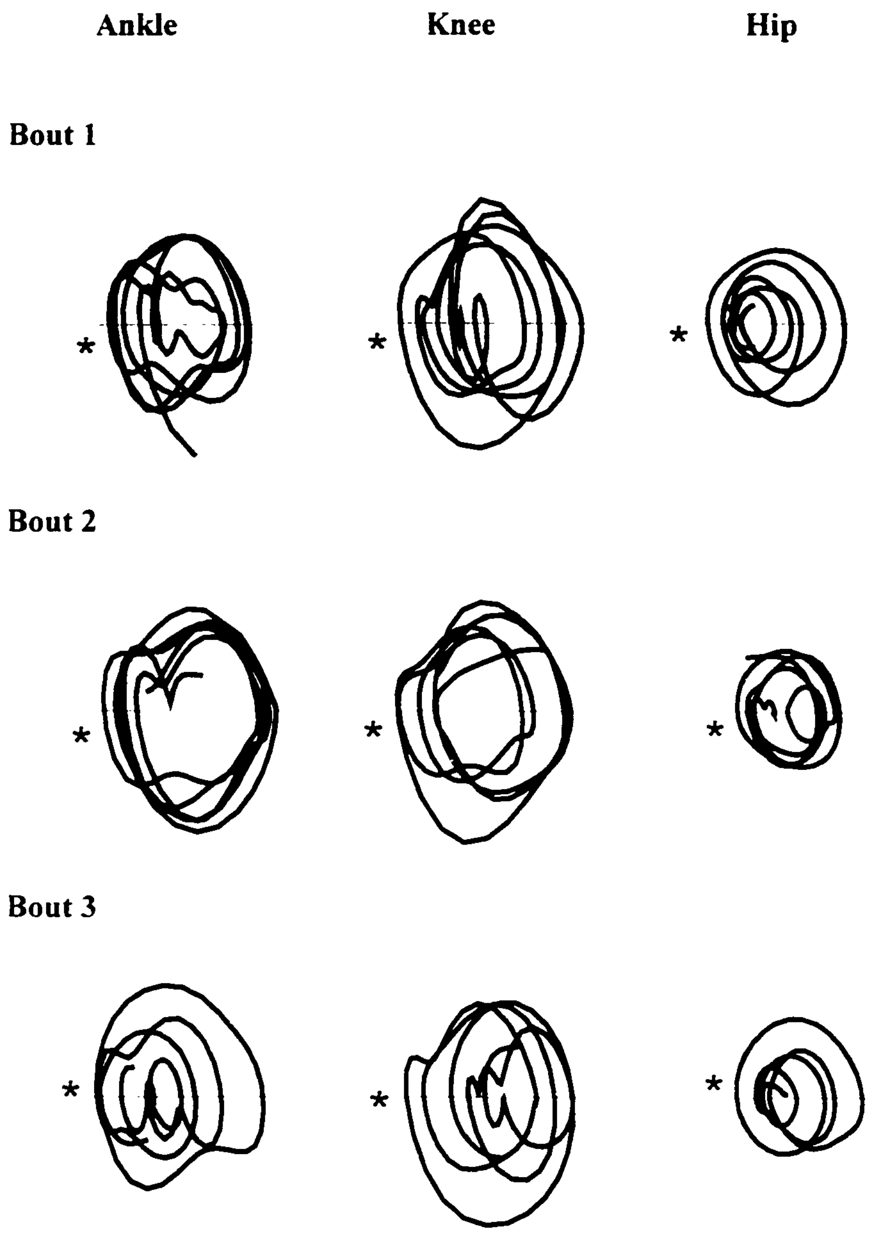


Figure 8h: Phase-plane plots for I6. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. Toe-down is represented by an asterix. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (500 to -500). Column one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively. Note the hip phase-plane plots which demonstrate consistent, overlapping lines between and within trials; compare this to ankle and knee plots.

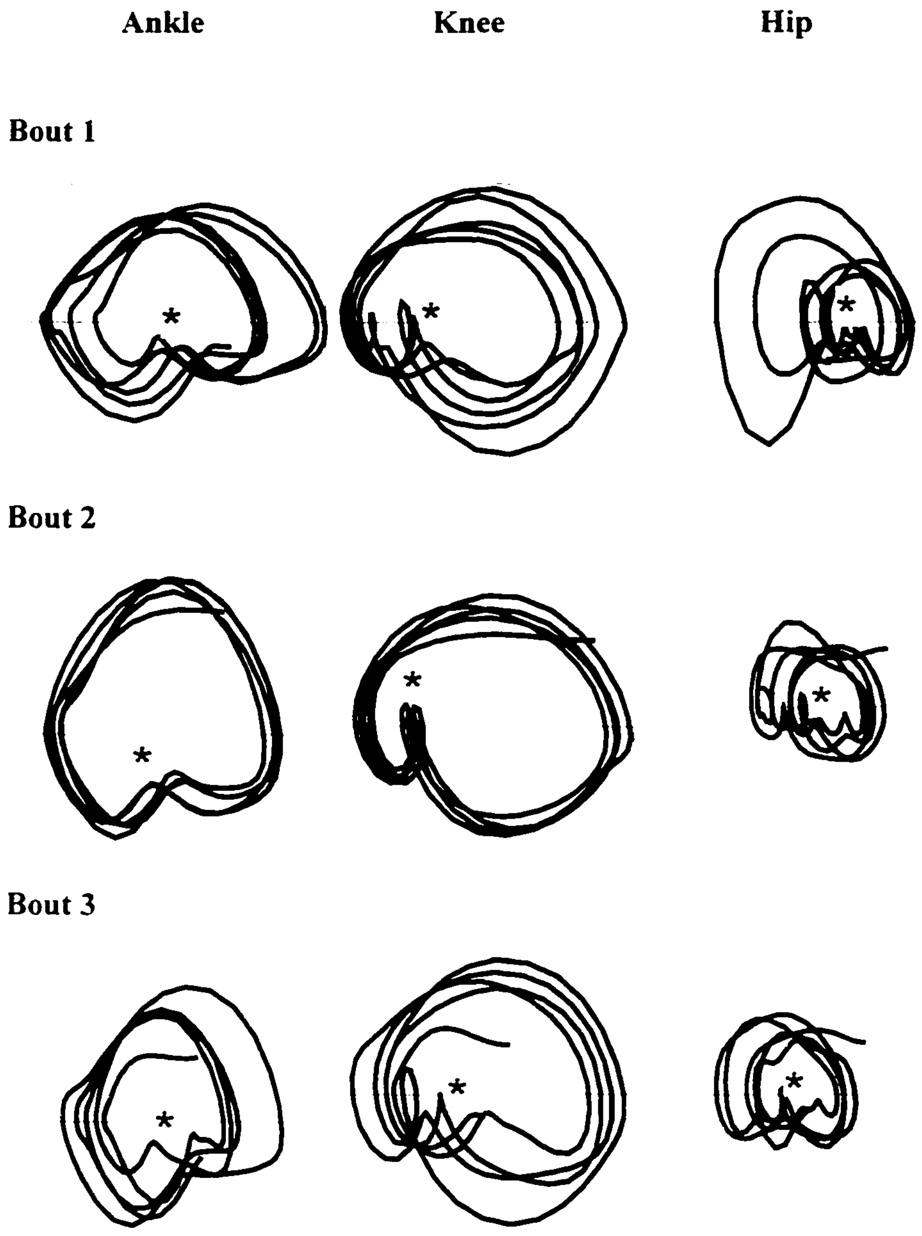


Figure 8i: Phase-plane plots for I9. The curves illustrate the change in joint angular velocity with respect to change in joint angular position in bouts of bouncing behaviour in a clockwise direction. Toe-down is represented by an asterix. The x-axis represents joint angular position over a range of 100 degrees. The y-axis represents joint angular velocity in degrees per second, over a range of 1000 degrees (B1: 600 to -400; B2: 605 to -395; and B3: 600 to -400). Column one, two and three contain phase-plane plots where the relationship between angular velocity and angular position are portrayed for the ankle, knee and hip joints, respectively Note the organized overlying line pattern of the ankle and knee joints across trials; compare these to the disorganized line patterns of the hip joint across trials.

APPENDIX E

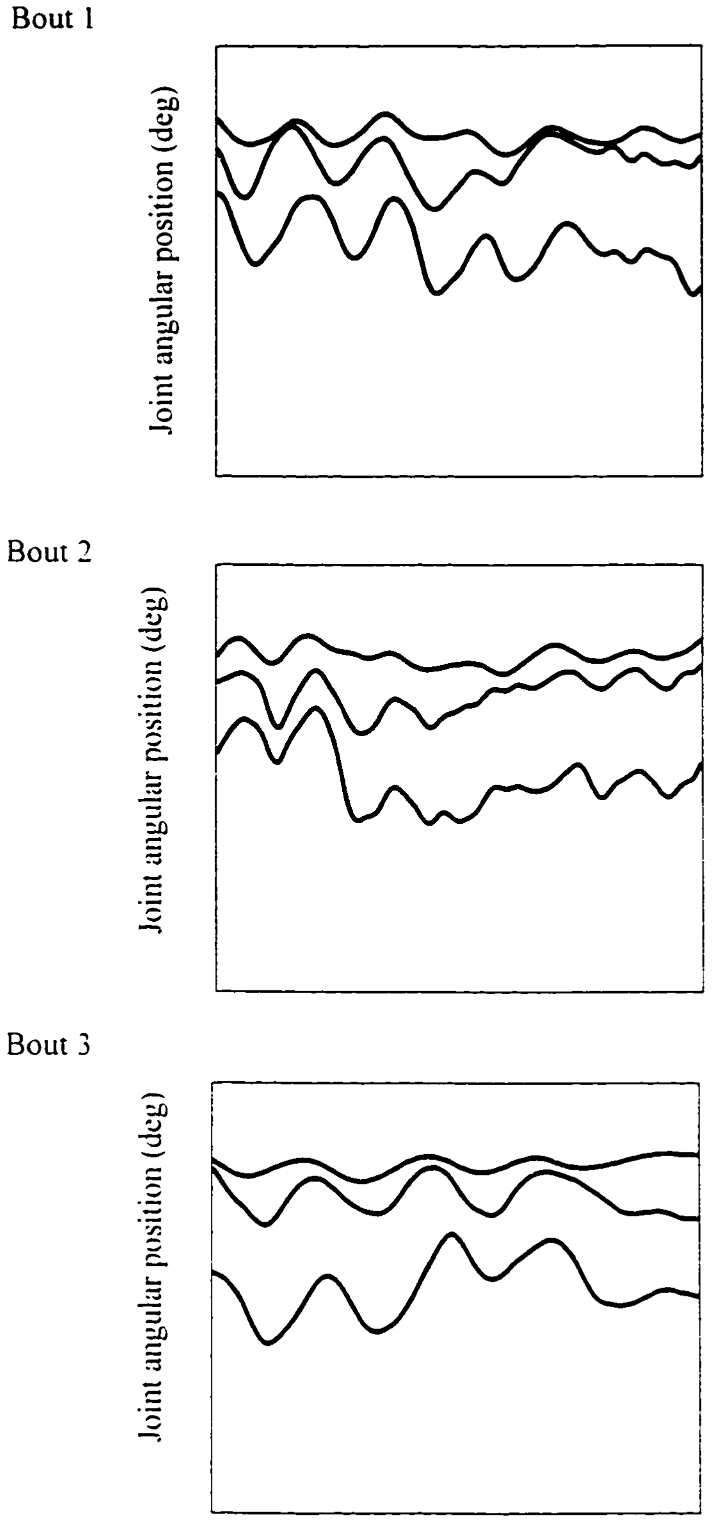


Figure 10d. Joint angular position for I2. The top, middle and bottom curves in each plot represent the angular position of the hip, knee and ankle joints, respectively. Bout length for bouts 1, 2 and 3 are 2.48, 2.32 and 2.70 seconds, respectively. Note that the three joint are in-phase with each other, however, there is a high degree of variability with respect to joint angular position, both within and between bouts of bouncing.

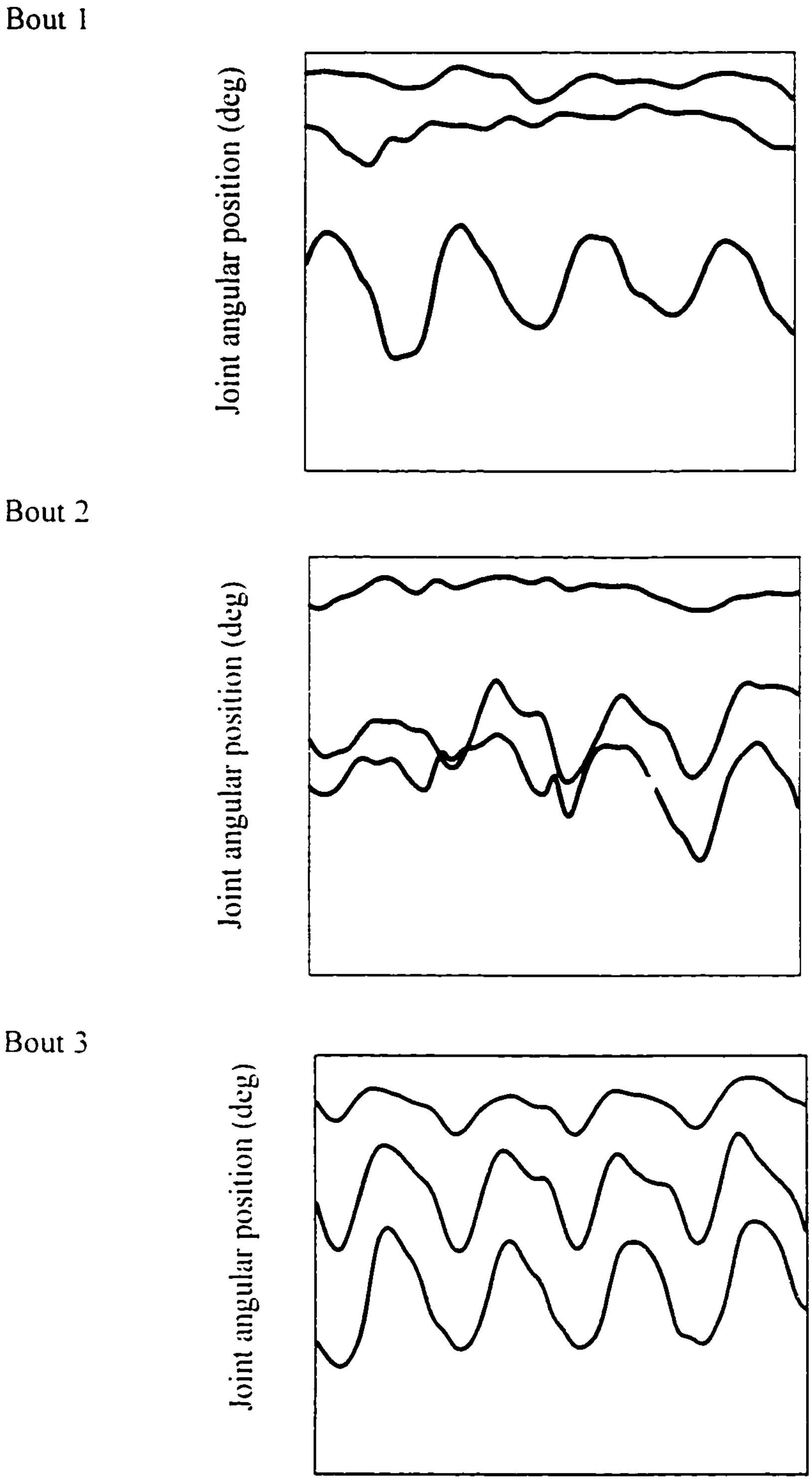


Figure 10e. Joint angular position for I3. The top, middle and bottom curves in each plot represent the angular position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. Bout length for bouts 1, 2 and 3 are 2.48, 2.95 and 2.65 seconds, respectively. Note the inconsistent phase relationship between the joints both within and between bouncing trials.

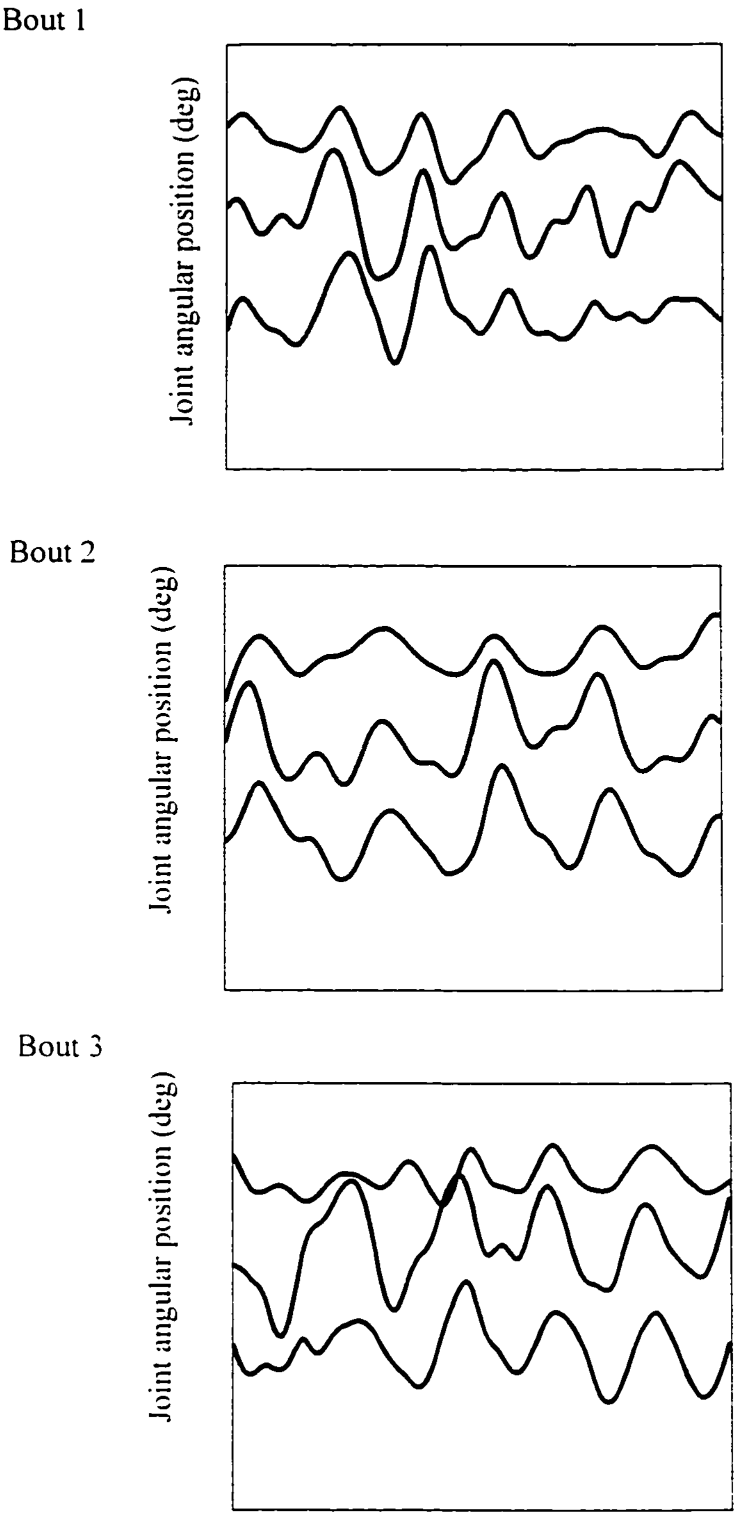


Figure 10f. Joint angular position for I4. The top, middle and bottom curves in each plot represent the angular position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. Bout length for bouts 1, 2 and 3 are 2.60, 2.08 and 2.48 seconds, respectively. Note the in-phase relationship between all three joints and inconsistent angular position between bouts.

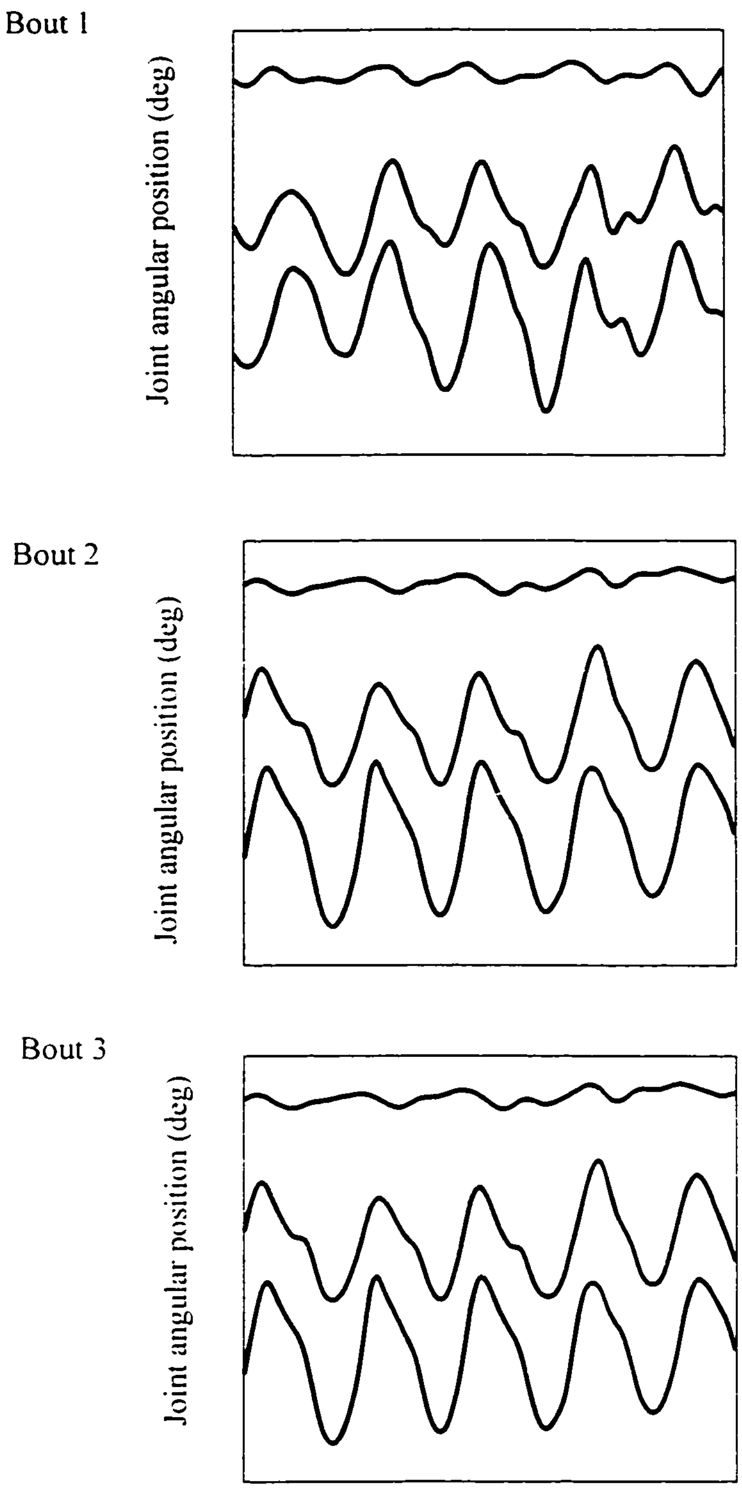
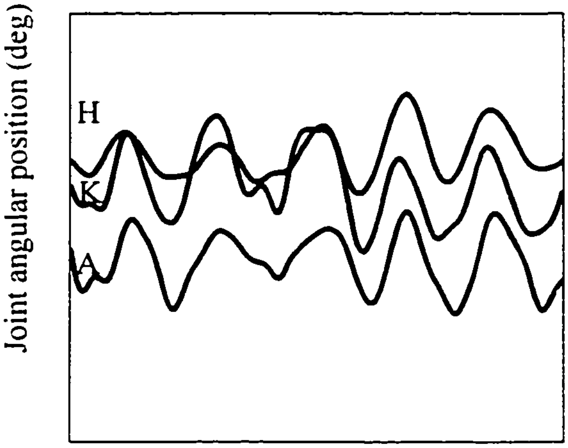
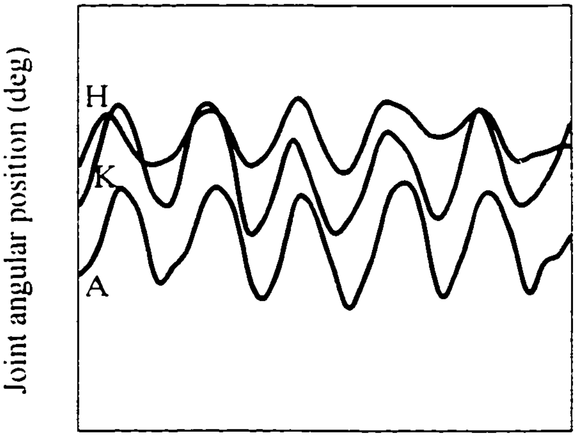


Figure 10g. Joint angular position for I5. The top, middle and bottom curves in each plot represent the angular position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. Bout length for bouts 1, 2 and 3 are 3.20, 3.10 and 3.08 seconds, respectively. Note the different phase relationships between the joints: ankle and knee in-phase, hip out-of phase.

Bout 1



Bout 2



Bout 3

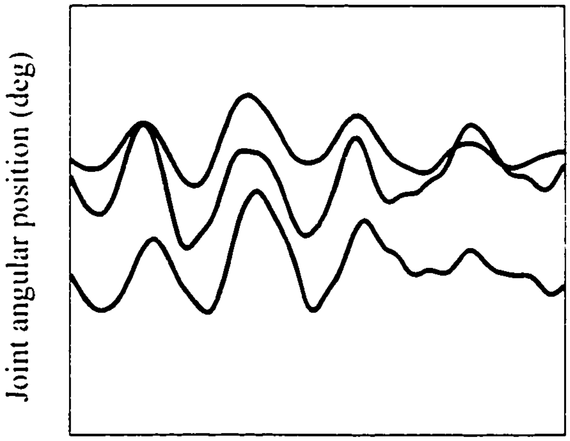
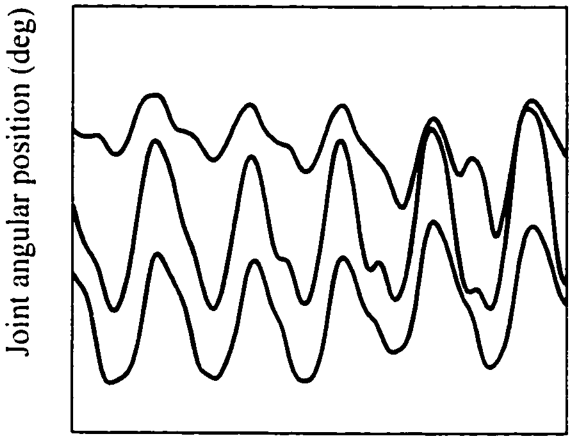
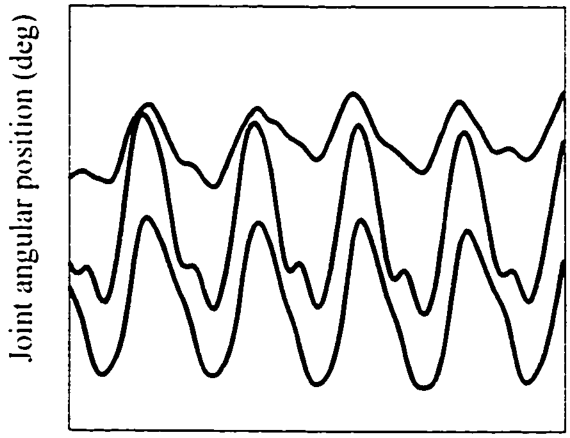


Figure 10h. Joint angular position for I6. The top, middle and bottom curves in each plot represent the angular position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. In bouts 1 and 2 the letters A, K and H point to the ankle, knee and hip joint position traces, respectively. Bout length for bouts 1, 2 and 3 are 2.83, 2.80 and 2.30 seconds, respectively. Note the in-phase relationship between Jac's joints and overlap of hip and knee angular position.

Bout 1



Bout 2



Bout 3

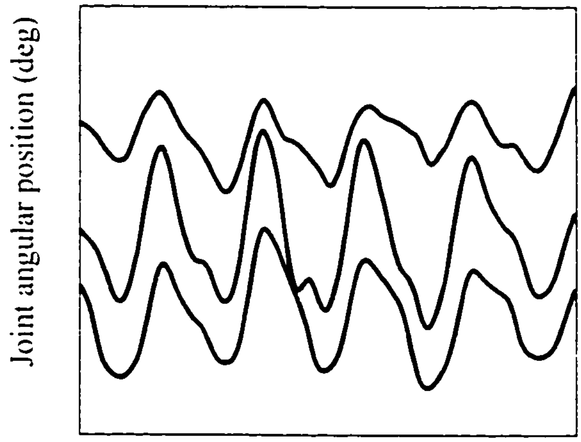


Figure 10i. Joint angular position for I9. The top, middle and bottom curves in each plot represent the joint position of the hip, knee and ankle joints, respectively. The y-axis ranges from 0 to 200 degrees. Bout length for bouts 1, 2 and 3 are 3.27, 3.69 and 3.01 seconds, respectively. Note the in-phase relationship between the joints and consistency of angular position between and within bouts of bouncing.

APPENDIX F

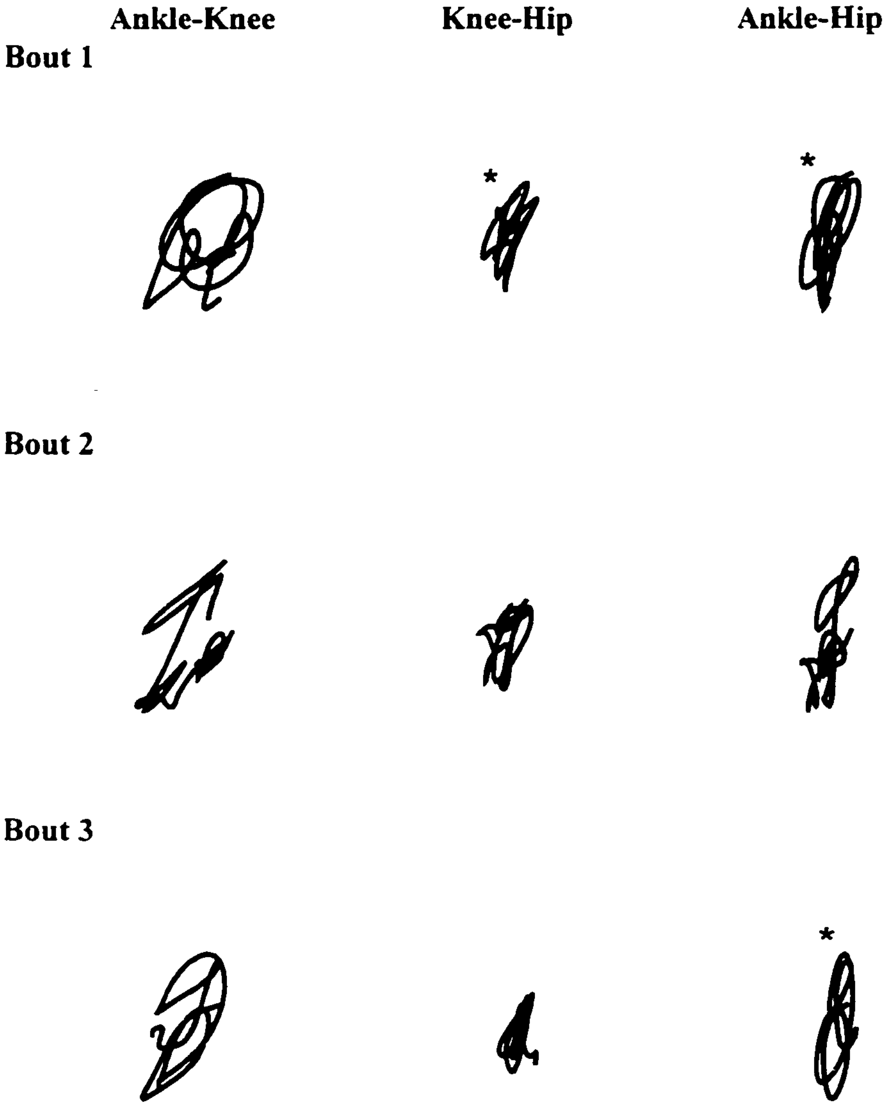


Figure 11d: Angle-angle plots for I2. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Toe-down is represented by an asterix. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the disorganized pattern for each of the three joint angular position relationships illustrating I2's bouncing behaviour. As well, note the intertrial variety present in the ankle-knee plots for each of the three bouts.

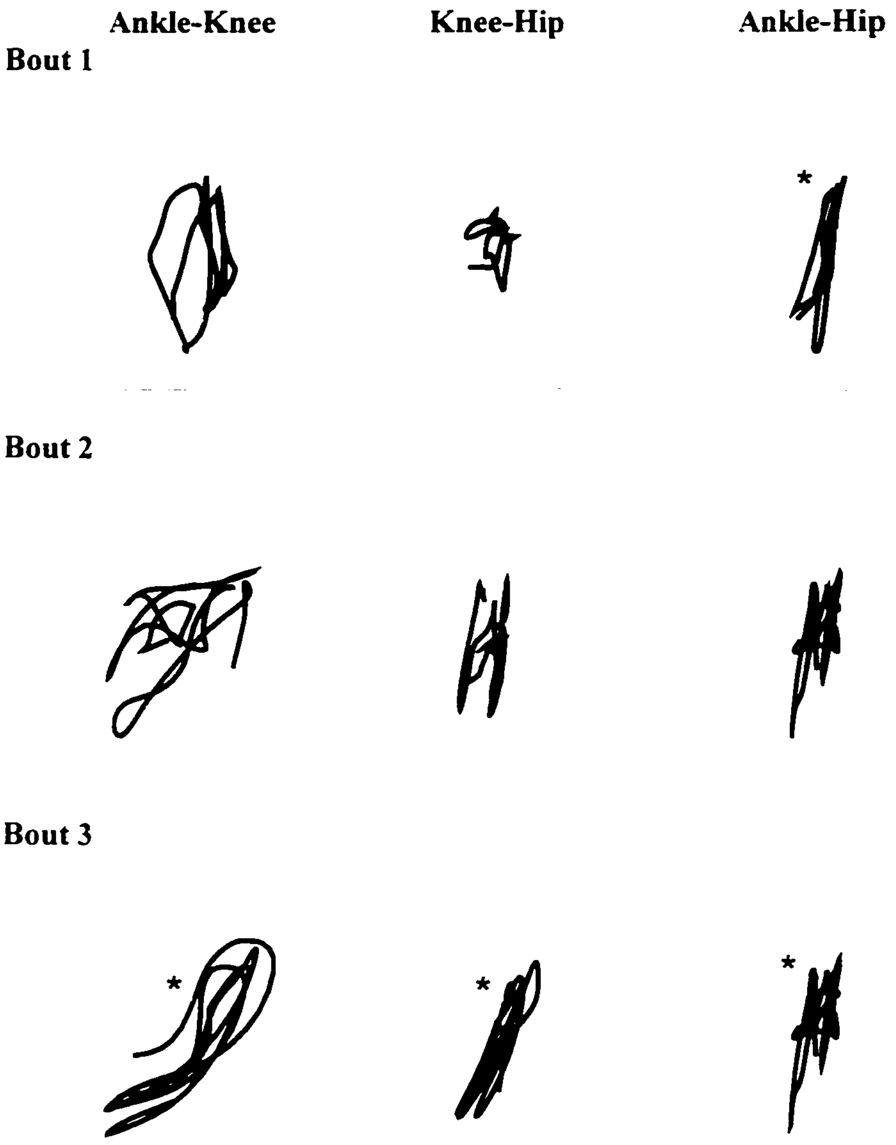


Figure 11e: Angle-angle plots for I3. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Toe-down is represented by an asterix. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the intertrial variability and lack of overlying pattern for each of I3' three joint angular position relationships.

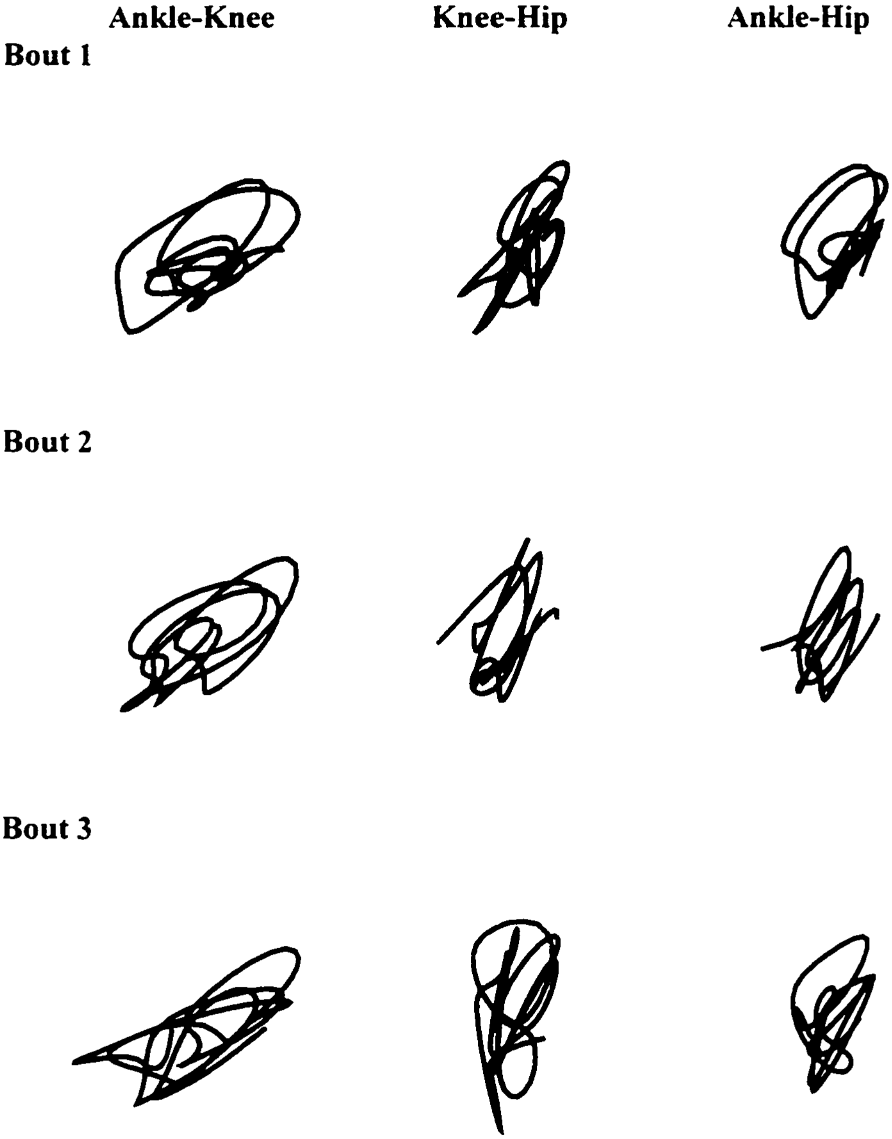


Figure 11f: Angle-angle plots for I4. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the variability present in the line patterns which represent I4's all three joint angular position relationships.

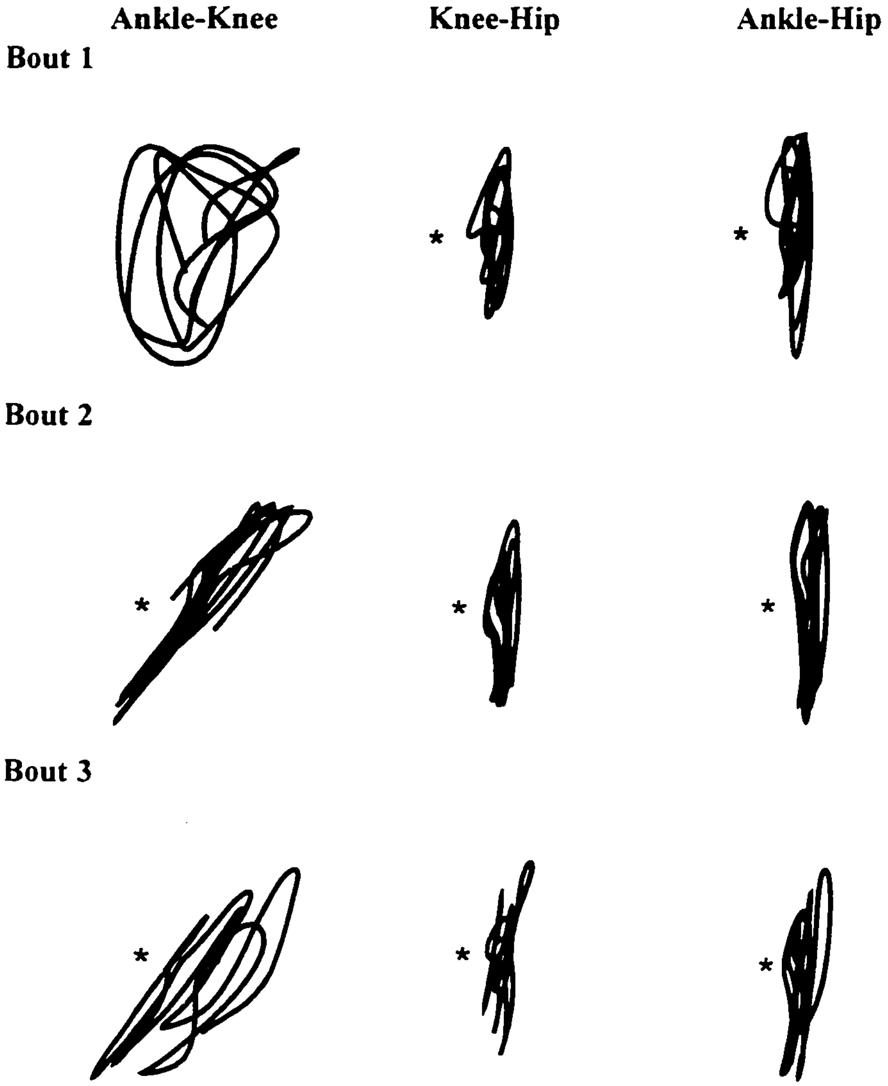


Figure 11g: Angle-angle plots for I5. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Toe-down is represented by an asterix. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note I5's overlying line patterns representing joint angular position relationships for each of I5's angle-angle plots. As well, note the nearly vertical lines for the knee-hip and ankle-hip plots.

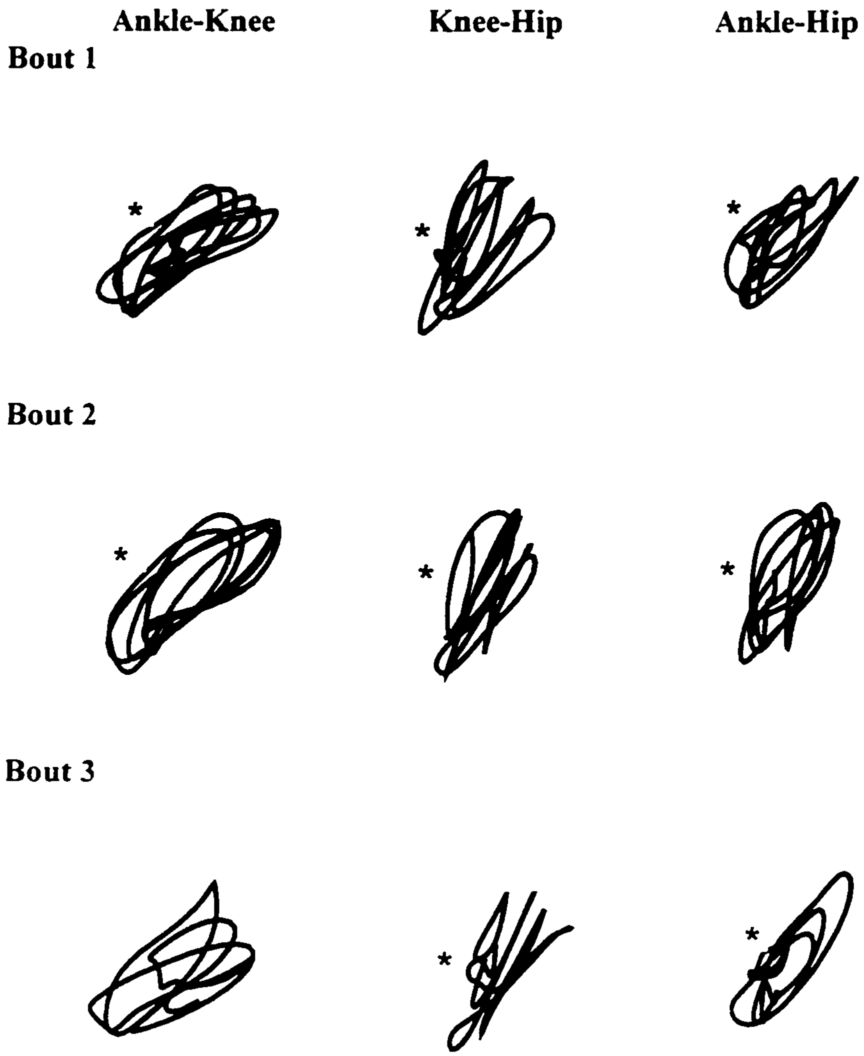


Figure 11h: Angle-angle plots for I6. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Toe-down is represented by an asterix. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the overlying traces for I6's ankle-knee and ankle-hip joint angular position relationships.

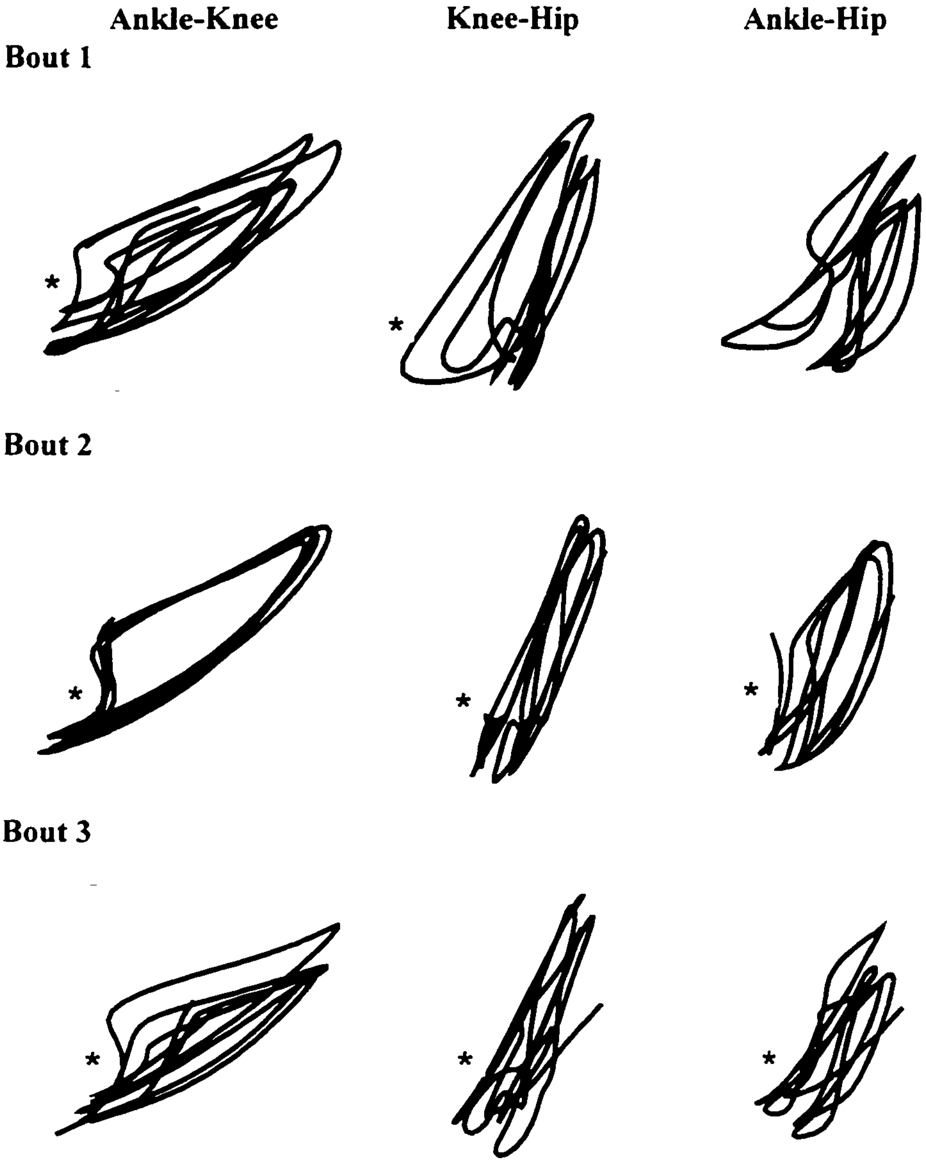


Figure 11i: Angle-angle plots for I9. Each axis represents change in joint angular position in a counter-clockwise direction with a range of 100 degrees. Toe-down is represented by an asterix. Column one, ankle-knee, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in knee position. Column two, knee-hip, contains angle-angle plots where the y-axis represents the change in knee position and the x-axis represents the change in hip position. Column three, ankle-hip, contains angle-angle plots where the y-axis represents the change in ankle position and the x-axis represents the change in hip position. Note the overlying pattern of I9's joint positions, especially in the bout 2 ankle-knee plot.

APPENDIX G

LETTER OF INFORMATION AND CONSENT (PARENT)

This letter of information and consent, which you are being asked to read and sign, indicates that you agree to allow your child to participate in the study. The letter is designed to outline the research project and to explain what your and your child's involvement in the project will entail.

PURPOSE: The aim of this research is to better understand the emergence or acquisition of an organized pattern for jumping behaviour. This study will provide information about the age when infants can jump using a Jolly Jumper attached to a spring. This information will also contribute to understanding the steps or pattern of human development when learning new tasks. like jumping. This project is being conducted for the fulfillment of the thesis requirement for Lori Vallis' Master's degree.

PROCEDURE : At the start of the testing session. we will ask you to assist us in placing five surface electrodes that will measure muscle activity over the muscles of the calf. shin. front and back of thigh and buttocks of your child. Following this we will ask you to change your child into black tights and a black long-sleeved body suit which we will provide. We will then record your child's weight, height, foot length age and sex. We will ask you to hold your child while styrofoam markers are placed on his or her toe, ankle, knee, hip waist and shoulder. Once the markers and electrodes have been applied, we will ask you to encouraged your child to jump up and down while they are secured in a modified Jolly Jumper. Your child will perform five trials each and each trial will last 30 seconds in duration. Your child will be filmed while performing the jumps. In addition to video information, and information about muscle activity, the forces that your child produced while jumping will be recorded using a weight scale mounted into the floor and a loadcell mounted into the ceiling.

Following the testing session, we will determine your child's general level of motor development by observing him/her for approximately 20 minutes.

The entire session is expected to last approximately two hours.

RISKS AND BENEFITS OF THESE TESTS

Your child may find it uncomfortable when we apply and remove the tape holding the Styrofoam markers and electrodes on the skin. We will minimize this discomfort by using a glue dissolvent, formulated specifically for use on skin, to remove the tape. The skin will then be washed and a moisturizing cream will be applied to the area. Your child may find that he/she get tired. We will schedule regular rest breaks and will stop the test at any time if you see signs of fatigue or if your child indicates that he/she is tired.

We require that infants included in the study be able to control their head and neck while jumping. The recommended age for using a commercial Jolly Jumper is 3 months to walking age. Previous research using Jolly Jumpers has included infants as young as six months of age (Goldfield, Kay and Warren; Child Development, 1993, 64: 1128-1142). Thus, we have minimized the risks to your infant by limiting participation to those infant having sufficient head and neck control to regulate head position during jumping.

YOU MAY STOP THE TEST AT ANY TIME. You may stop the test at any time simply by telling the person controlling the test that you do not wish your child to continue. You may also withdraw your child from the experiment, at any time, without fear of reprisal simply by informing the person controlling the test. During all test sessions, you will be present in the room.

You will be reimbursed for the cost of your parking at the University and an honorarium of $20 will be issued upon completion of the study. You will receive no other direct benefit from this research. The information which results from your test will be used to further understand the steps or pattern of human development when learning a task, such as jumping.

All records from this research, including video cassette, will be kept confidential and will not be given or shown to anyone other than the researchers involved in the project unless you give us written permission to do so. No name will be attached to the data and anonymity will be assured by coding procedures. Only researchers involved in the project will view the original data collected (force, video cassette and muscle activity). Your child's results may appear in publication, but he/she will not be identified by name.

CONSENT

In signing this informed consent form, I acknowledge that I have read and understood all of the information of this document. Before signing, I have been allowed to observe the procedures that will be used in the research project. I acknowledge that my child will be videotaped. I have been instructed that I am free to withdraw my consent to participate in the project at any time. I also acknowledge that I will be compensated for the cost of my parking at the University and that I will receive a $20 honorarium upon completion of my child's participation in this study. I understand that I can contact the project directors, Dr. Heidi Sveistrup (562-5800 ext. 8016), Lori Vallis (562- 5800 ext. 8085) with questions about experimental procedures and that I can contact Dr. Proulx, Chair of the Human Research Ethics Committee (562-5800 ext. 4251) regarding any ethical concerns that I might have.

DATE : ______________________________

PARENT'S NAME (please print) ______________________________

PARENT'S SIGNATURE ______________________________

INFORMED CONSENT FOR THE USE OF VIDEOTAPES FOR TEACHING, RESEARCH OR MEDICAL PRESENTATION
(PARENT)

I understand that video cassettes will be made of my child while he/she is participating in this study. I understand that data will be extracted from the video cassette for research purposes.

By signing this document I hereby consent to and authorize the use and reproduction of the videotapes taken of my child during his/her participation in this research project for the purpose of teaching, research presentation, or medical presentation with the understanding that the identity of my child will remain confidential. I understand that videotapes taken of my child will remain in a locked filing cabinet the Motor Development Lab at the University of Ottawa.

I understand that the individuals who see the videotape of my child will not be told my child's name.

I understand that I can ask to view the video and decide, without fear of reprisal, not to let people other than the researchers directly involved in the research project, see the videotape made of my child jumping. If I do not want other people to see the video, I will tell one of the researchers.

DATE ________________________________

PARENT'S NAME ________________________________

PARENT'S SIGNATURE ________________________________

Research Announcement

We are looking for parents of infants between 6- and 12-months of age who are interested in participating in a research project with their children at the University of Ottawa, School of Rehabilitation Sciences. The aim of the research is to learn more about the way infants learn to coordinate their bodies when bouncing in a Jolly Jumper. Your infant will be placed in a Jolly jumper harness suspended from the ceiling and encouraged to bounce. A weight scale mounted into the floor will measure the amount of push they place on the floor, while a video camera filming while they are bouncing will determine the number of bounces they perform. Their muscle activity will be recorded as well.

You will be asked to come to our laboratory at the University of Ottawa, 451 Smyth Road (between the Ottawa General Hospital and the Children's Hospital of Eastern Ontario). The research session will take about two hours.

If you think you may be interested in hearing more about this research project, please contact Lori Vallis at 562- 5800 ext. 8085 or Dr. Heidi Sveistrup at 562- 5800 ext. 8016.

Infant data sheet

Subject name:____________________ Date of assessment (yy/mm/dd):__________

Height (m): ____________________ Date of birth (yy/mm/dd):_______________

Weight (kg):____________________ Age at assessment:____________________

AIMS score: ____________________ Percentile: __________________________

No. Hours in JJ at home: ___________ Sex: _______________________________

Anthropometric measurements (cm):

5th M-C, metatarsal-phalangeal joint to posterior aspect of the calcaneus:_____________

C-LM, posterior aspect of the calcaneus to lateral malleolus:____________________

LM-F, lateral malleolus to head of the fibula: ________________________________

F-Fem, head of the fibula to greater trochanter of the femur: ____________________

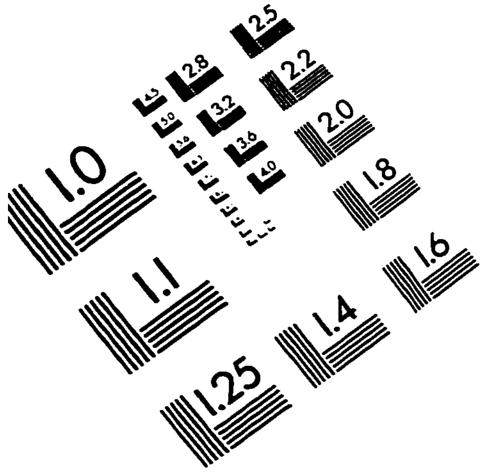
Fem-JJ, greater trochanter of the femur to waistband of the Jolly Jumper harness:

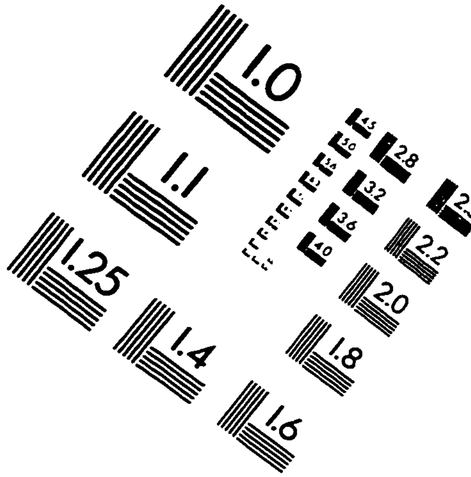
____

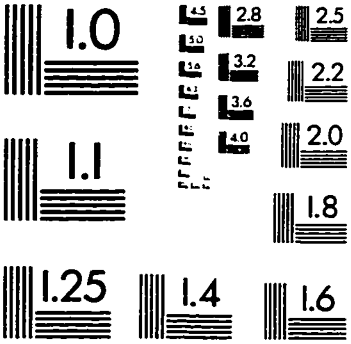
JJ-H, waistband of the Jolly Jumper harness to greater tubercle of the humerus:

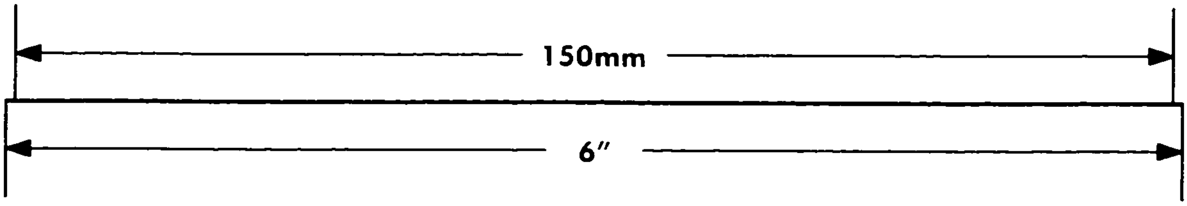
____

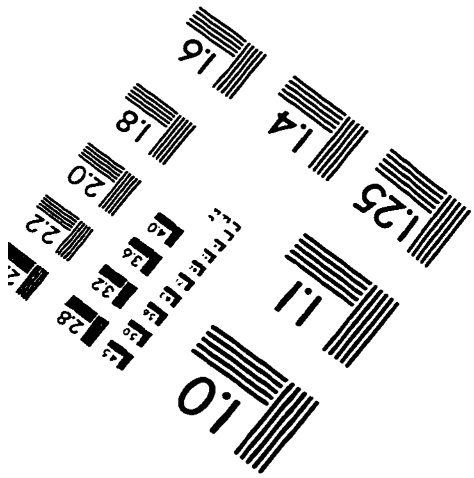
IMAGE EVALUATION
TEST TARGET (QA-3)

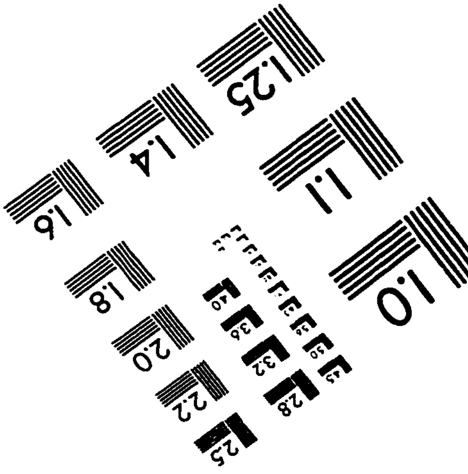












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