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Emergence and transition in locomotion of typical infants from 5 to 18 months old: developmental pathways and elements of the epigenetic landscape.

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Sao Paulo
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UNIVERSIDADE DE SÃO PAULO
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Emergência e transição na locomoção de lactentes típicos entre 5 e 18 meses de idade: caminhos de desenvolvimento e elementos da paisagem epigenética.
(VERSÃO CORRIGIDA)

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I personally believe that knowledge is more powerful when it is driven by love. This thesis is full of love. First, my love was present in every tiny step of this graduate process. Second, the love of families that kindly gave their time and effort to allow me to materialize this work. Last, the infant´s love in its magical presence "here and now" in each meeting and video record. I dedicate this work to any person that acts motivated by love to help our children to grow and develop successfully.

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“You haven't yet opened your heart fully, to life, to each moment. The peaceful warrior's way is not about invulnerability, but absolute vulnerability--to the world, to life, and to the Presence you felt. All along I've shown you by example that a warrior's life is not about imagined perfection or victory; it is about love. Love is a warrior's sword; wherever it cuts, it gives life.”

Dan Millman, Way of the Peaceful Warrior.

ABSTRACT

GRACIOSA, MD. **Emergence and transition in locomotion of typical infants from 5 to 18 months old: developmental pathways and elements of the epigenetic landscape.** 2023. 132f. Thesis (Doctorate in Science) – School of Physical Education and Sports, University of Sao Paulo, Sao Paulo. 2023.

Locomotion is one hallmark of autonomy in infancy. From a dynamical perspective, different elements compose a developmental system, and behavioral patterns are characterized as states reached by this system over a time scale. While the onset of a new state is called emergence, a transition is the phase shift from one state to another. This study aimed to characterize the emergence and transition of locomotor behaviors of typical Brazilian infants from 5 to 18 months old and to verify associations of these events with the infant´s characteristics (sex, anthropometric data, and developmental status by Alberta Infant Motor Scale), parental belief, body positioning, and home experiences. This longitudinal research assessed remotely 45 full-term infants divided into age groups from 5 to 18 months old (G1: 5 to 11 mo, n=19; G2 9 to 15 mo n=18; G3: 13 to 18 mo, n=8). Parents recorded infants during 7.73±1.21 minutes of free play at home every 15 days over the follow-up. Locomotion bouts were identified and coded according to the behavioral state: crawling on the belly; hands-and-knees; hands-and-feet; asymmetrical, walking on knees or feet. An emergence was registered when a new behavior appeared in the locomotor repertoire and a transition when there was a change in the predominance of behaviors observed between videos. Results showed that the age at locomotion onset and not the behavioral form was associated with subsequent events of emergence and transition. There were 15 different pathways of emergence of locomotor behaviors for G1 and 8 for G2, whereas transition was characterized by 12 different pathways for G1, 13 for G2, and 3 for G3. Most emergence and transition events were related to hands-and-knees crawling and walking on feet. Motor developmental status was the only characteristic of the infant associated with the emergence and transition of behaviors. The emergence of independent walking took longer for those infants whose parents agreed that development is a natural process that does not depend on stimulation. Parental expectations and beliefs were only related to independent walking which may suggest that their infant handling practices focused only on this behavior. The frequency of playing on the floor was positively associated with age at locomotion onset and the emergence of hands-and-knees crawling whereas staying in the cradle, or the supine position was negatively associated with age at the emergence and transition of upright locomotor behaviors. This thesis showed that in the diversity of pathways, the most stable states in locomotion development were crawling on hands-and-knees and walking on feet with or without support. The elements of the epigenetic landscape associated with emergence and transition in locomotion development were the developmental status, some parental beliefs, and the frequency of infants playing on the floor, staying in the cradle, or in the supine posture. Finally, the fact that parental beliefs were only related to unsupported walking on feet shows that in addition to biomechanical aspects, there is a social reason for this behavior to be the most attractive state in the epigenetic landscape of locomotion.

Keywords: Environment; human development; infant behavior; locomotion; motor skills; parent.

RESUMO

GRACIOSA, MD. **Emergência e transição na locomoção de lactentes típicos entre 5 e 18 meses de idade: caminhos de desenvolvimento e elementos da paisagem epigenética.** 2023. 132f. Tese (Doutorado em Ciências) – Escola de Educação Física e Esporte, Universidade de São Paulo, São Paulo. 2023.

A locomoção é um marco de autonomia para o lactente. A partir de uma perspectiva dinâmica, diferentes elementos compõem um sistema desenvolvimentista e padrões de comportamento são caracterizados como estados apresentados por este sistema. O surgimento de um novo estado é chamado de emergência e a transição é a mudança de fase entre um estado e outro. Este estudo teve como objetivo caracterizar a emergência e transição de comportamentos locomotores em lactentes brasileiros típicos entre 5 e 18 meses de idade e verificar associações destes eventos com as características individuais (sexo, medidas antropométricas e status de desenvolvimento pela Escala Motora Infantil de Alberta), crenças parentais, posicionamento corporal e experiências domiciliares. Esta pesquisa longitudinal acompanhou remotamente 45 lactentes a termo divididos em grupos (G1: 5 a 11 meses, n=19; G2: 9 a 15 meses, n=18 e G3: 13 a 18 meses, n=8). Os lactentes foram filmados pelos pais durante 7.73±1.21 minutos de brincadeira livre em casa a cada 15 dias durante o acompanhamento. Turnos de locomoção foram codificados em: arrastar em prono, engatinhar sobre mãos e joelhos, mãos e pés ou de forma assimétrica, e andar sobre os joelhos ou pés. Uma emergência foi registrada quando um novo comportamento apareceu no repertório do lactente, e uma transição quando houve uma mudança na predominância dos comportamentos observados entre vídeos. Os resultados mostraram que no início da locomoção a idade estava associada a eventos subsequentes de emergência e transição. Foram observados 15 diferentes caminhos de emergência de comportamentos para o G1, e 8 para o G2, enquanto a transição foi caracterizada por 12 diferentes caminhos para G1, 13 para G2 e 3 para G3. A maioria dos eventos de emergência e transição foram relacionados ao engatinhar sobre mãos e joelhos e andar sobre os pés. O status de desenvolvimento motor foi a única característica individual associada com eventos de emergência e transição. Lactentes cujos pais concordavam que o desenvolvimento é um processo natural que não depende de estimulação demoraram mais para andar independentemente. Expectativas e crenças dos pais foram associadas apenas ao andar independente o que sugere que as práticas manuais parentais podem estar focadas neste comportamento. A frequência de permanência no chão foi associada positivamente com o início da locomoção e emergência do engatinhar sobre mãos e joelhos, enquanto houve associação negativa entre a frequência de permanecer no berço ou na posição em supino e a idade de emergência e transição da locomoção na postura em pé. A tese mostrou que estados mais estáveis na paisagem epigenética da locomoção são o engatinhar sobre mãos e joelhos e andar. Os elementos da paisagem epigenética associados a emergência e transição no desenvolvimento da locomoção foram o status de desenvolvimento, algumas crenças parentais e a frequência que o lactente brinca no chão, permanece no berço ou na posição de supino. O fato de que as crenças parentais se relacionaram apenas ao andar independente mostra que existe um fator social para este comportamento ser o maior atrator da paisagem epigenética da locomoção.

Keywords: Ambiente; desenvolvimento humano; comportamento do lactente; locomoção; habilidade motora; pais.

SUMMARY

1 INTRODUCTION

1.1 CONTEXT, RESEARCH PROBLEM, RELEVANCE, AND THESIS

The ability to move from one place to another depicts a remarkable step for the infant toward autonomy where each new locomotor skill acquired dramatically changes his or her relationship with the environment both physically(MULDER *et al.*, 2022; SCHWARZER *et al.*, 2022; THURMAN; CORBETTA, 2017, 2019) and socially (CAMPOS et al., 2000; SCHNEIDER; IVERSON, 2022; SCHWARZER et al., 2022; THURMAN; CORBETTA, 2017). This implies that looking into locomotion development as a research subject must consider the individual in the environmental context. In this sense, the developmental system notion (OYAMA, 1985) composes an appropriate theoretical perspective for this purpose, understanding that the developmental process is the result of the coaction of the organism and the environment as a unified unit (VALSINER; CONNOLLY, 2003). From this view, developmental changes depend on complex, multidirectional, and multilevel relationships among individual (genetic, physiologic, behavioral…) and environmental (physical, social, cultural) elements (GRIFFITHS; TABERY, 2013).

Concerning the physical characteristics of these relationships there must be a fit between the environment (medium, layout, surface…) and the organism (height, weight…), known as affordances(GIBSON, 1979). In other words, affordances refer to the possibilities of motor actions within a context (CHEMERO, 2003). When the infant is moving around the place, he or she is learning how to explore its surroundings to perceive affordances (ADOLPH; EPPLER; GIBSON, 1993). This exploration demand self-initiated movements involving attention and the produced knowledge is used for future planned actions (ADOLPH; AVOLIO, 2000). In locomotion, the higher the experience, the most efficient exploratory behaviors are, and consequently, the better infants can use perceptual information to move around safely (KRETCH; ADOLPH, 2016). Moreover, there is an integration of brain-behavior in the perception-action cycle. Once crawling starts the brain processing of visual motion undergoes a change which implies more competent action with prospective control, namely, the ability to predict events and to act accordingly (VAN DER MEER; VAN DER WEEL, 2022).

Sociocultural factors also underlie behavior and change, as caregivers' beliefs and practices about the infant and motor development influence the opportunities offered for movement and how the environment is prepared for them (VAN SCHAIK; OUDGENOEG-PAZ; ATUN-EINY, 2018). While parental beliefs are the ideas, values, and goals caregivers have about the child, the practices involve the performed tasks in the infant´s daily care (DARLING; STEINBERG, 1992). Literature shows that cultural differences result in variations in age estimates for motor skill acquisition (HOPKINS; WESTRA, 1990), as well as differences in parental practice regarding body positioning opportunities (KARASIK *et al.*, 2015) and the physical surfaces where the infant stays (OUDGENOEG-PAZ; ATUN-EINY; VAN SCHAIK, 2020). Moreover, gender influences parents' expectations of the infant´s age for skill acquisition (MONDSCHEIN; ADOLPH; TAMIS-LEMONDA, 2000) and specific caregiving practices employed (ISHAK; TAMIS-LEMONDA; ADOLPH, 2007) in locomotion development. Lastly, when it comes to locomotion onset as an emotional milestone for the family, there is a bidirectional influence, where parents can either create environmental conditions to anticipate or promote its acquisition or respond differently after the infant starts to move around (HENDRIX; THOMPSON, 2011).

To summarize, the context as an individual-environment relationship not only influences but also responds to changes in development, indicating that dynamic properties must be considered in motor development research. However, until the present moment, little is understood about the context of locomotion development, and there are two main reasons for that. First, up until 1970, most studies were mainly focused on what and when changes happen in motor development (a product-oriented vision), and few were guided by the process-oriented vision that investigates "why" and "how" these changes occur (CONNOLLY, 1970). Whereas descriptive studies(GESELL; AMES, 1940; MCGRAW; BREEZE, 1941) with a product-oriented approach provided important information on the chronology of locomotor behaviors acquisition, the process-oriented approach enables the identification of underlying mechanisms of developmental changes, such as experience.

Second, a lot of research that has investigated locomotion development adopted standardized tests that are too far removed from representing the richness and complexity of motor behaviors in infancy (ADOLPH; HOCH; COLE, 2018). Variable routes duration, shape, and omnidirectional steps mark the infant´s actual locomotion activity during free play (LEE *et al.*, 2017). In this sense, capturing the real locomotor experience demand an observation of the infant in an experimental situation that allows this complexity to be depicted. One solution is to analyze infants moving around during free play. For this type of research, the method of segmentation into locomotion bouts (periods of action where behavior is observed, separated by periods of rest where behavior is not expressed) is a good strategy that allows the measurement of the number of steps, distances, paths covered, the number of falls, support surfaces, or other characteristics of the environment explored by the infant during free locomotion (ADOLPH *et al.*, 2012). From this method, process-oriented studies have investigated infant´s interactions with objects and people (HOCH *et al.*, 2021; KARASIK; TAMIS-LEMONDA; ADOLPH, 2011), as well as goals and destinations (HOCH; O'GRADY; ADOLPH, 2019; HOCH; RACHWANI; ADOLPH, 2020) in locomotion development.

Another way of studying motor development with the process-oriented view is from dynamic systems theory (DST) which conceives a formal model for investigating changes at different time scales (ZANONE; KELSO; JEKA, 1993). DST treats development as a process of changes in the way a system is organized (CONNOLLY, 1986). When applied to motor development study, behaviors are products of the system´s elements interaction such as environment (physical, social, context), task, and organism (genetics, neural maturation, growth, specific characteristics, etc.) (THELEN; KELSO; FOGEL, 1987). Thus, by this theoretical perspective behavior is dynamic (changes over time); it is relational (depends on the interaction between elements); and it is multilevel (interpretation is level-dependent) (THELEN, 1986).

The dynamic view proposes that development claims something qualitatively new in the system (SPENCER; PERONE; BUSS, 2011). Further, DST characterizes patterns as stable states reached by a system that reflects its organization at a given point in time (SCHÖNER; KELSO, 1988). In development, a state can be represented by a categorization of a defined behavior pattern based on a qualitative analysis of the movement(PRECHTL, 1974). When a pattern is easily expressed by the system from a variety of previous states, or after some perturbation, it has some degree of stability (THELEN, 1995). Therefore, the observation frequency is directly proportional to the stability of the analyzed behavior pattern (ZANONE; KELSO; JEKA, 1993).

Developmental changes in a dynamical system can be treated as three different events: emergence, transition, and adaptation. When there is the onset of a new spatial or temporal pattern in the dynamic system, that is, the observation of a new behavioral state, an emergence is considered (SCHÖNER; KELSO, 1988). Yet, a discontinuous change in the stability regime of the system is a transition, characterized by a phase shift from one state (that lost stability) to a new more stable state (that gained stability) (ZANONE; KELSO; JEKA, 1993). At last, adaptation is the ability of the system to solve a new motor problem demanding flexibility enough to explore old strategies or create solutions (THELEN, 1995). Therefore, by these events, DST sees development as changes toward adaptation where there is a differentiation from simpler and more homogeneous states to more adaptive, complex, and heterogeneous states (CONNOLLY, 1986).

In the present research, the dynamical systems view provided the formal framework for looking into locomotion development. A longitudinal design was adopted to identify and characterize the emergence and transition in the motor development of typical infants from five to 18 months old. **The thesis is that the emergence and transition of locomotor behaviors compose different developmental pathways toward upright locomotion that result from the elements of the epigenetic landscape in coaction (infant´s characteristics, parental beliefs, body positioning, and home experiences).**

This proposition is based on Waddington´s metaphor where the developmental paths are represented by a ball rolling over a landscape that is shaped by the interaction among many elements (genes, environment…) (WADDINGTON, 1941). Furthermore, Driesch’s axiom of Equifinality supports that the same final state can be achieved from different developmental paths or distinct initial conditions (GOTTLIEB, 2003). Yet, it considers that development has a component of uncertainty meaning that some events may have more chance to occur than others and the onset and occurrence of behaviors happen in a probabilistic way (CONNOLLY, 1986).

Waddington’s metaphor of the epigenetic landscape is in line with a dynamic systems perspective. In fact, Muchisky et al., (1996) have shown just that. The landscape is conceived as regions of changing stability, the valleys and plain refer to attractor states. The epigenetic dynamic landscape of locomotion is of particular interest to the present thesis. The investigation of motor development can be seen as the exploration of how epigenetic landscapes are set to generate different behavioral patterns that allow the individual to act upon the context and make the context as he or she goes along. It is in this sense that this thesis focused on the investigation of how emergences and transitions of locomotor behaviors compose developmental pathways in the dynamic landscape.

This was done on the assumption that gathering knowledge on how multiple elements will configure the epigenetic landscape of locomotion development can support intervention in the home environment and parental education, and hence, collaborate with the promotion of infants´ autonomy. Moreover, this thesis assumes that its outcomes can bring insights into locomotion development in children with motor impairment and their environment. Finally, the results from the present investigation can provide some hints into methodological approaches adopted from dynamical theoretical perspectives for motor development research, particularly if we consider that the whole research method had to be thought over as the investigation was carried out during the COVID-19 Pandemic. This meant that parents were active not only as caregivers, hence giving support for the infant's explorations but also as co-researchers who minded the research settings together with the present author of this thesis.

1.2 RESEARCH QUESTION

How do infants' characteristics, parental beliefs, body positioning, and home experiences are associated with variations in the emergence and transition of locomotion behaviors in typical motor development from five to 18 months old?

1.3 OBJECTIVES

1.3.1 Primary objective

To characterize the emergence and transition of locomotion behaviors in infants with typical motor development from five to 18 months old.

1.3.2 Secondary objective

To investigate how elements of the epigenetic landscape (infants' characteristics, parental beliefs, body positioning, and home experiences) are associated with variations in the emergence and transition of locomotor behaviors in typical motor development from five to 18 months old.

1.4 HYPOTHESIS

1.4.1 Null hypothesis

Elements of the epigenetic landscape in coaction (infants' characteristics, parental beliefs, body positioning, and home experiences) are not associated with variations in the emergence and transition of locomotor behaviors in typical motor development from five to 18 months old.

1.4.2 Alternative hypothesis

Variations in the emergence and transition of locomotor behaviors in typical motor development from five to 18 months old are associated with elements of the epigenetic landscape (infants' characteristics, parental beliefs, body positioning, and home experiences).

1.4.2.1 Parental beliefs

It was assumed that the importance attributed by caregivers to their role in promoting motor development would be associated with the emergence and transition of locomotion behaviors.

1.4.2.2 Body positioning and places for play

The frequency the infant was placed in each position and each place was expected to be associated with the emergence and transition of specific locomotion behaviors. For instance, it was expected that the higher frequency the infant with 5-month-old stays in the prone position while awake, the sooner a crawling behavior would emerge during the follow-up. Further, it was assumed that a higher frequency of playing on the floor would anticipate the emergence and transition of locomotion behaviors.

1.4.2.3 Locomotion experience

It was assumed that the higher frequency of experiencing certain locomotion behavior in the home environment would be associated with the anticipation of the emergence and transition of locomotor behaviors in the same posture.

The next chapter intended to support these hypotheses by showing factual evidence from locomotion development investigation and linking to conceptual and theoretical perspectives adopted to investigate motor development as a research phenomenon.

2 LITERATURE REVIEW

This chapter is divided into two sections. The first section presents conceptual and theoretical aspects of motor development as a phenomenon under investigation focusing on approaches adopted for the present thesis. The second section reviews studies on locomotion development and environmental aspects associated with this process.

2.1 MOTOR DEVELOPMENT: A PHENOMENON UNDER INVESTIGATION

Human development is a process of continuous changes that goes in a direction and occurs from conception up to the death of an individual (VALSINER; CONNOLLY, 2003) in different domains such as physical, cognitive, and psychosocial (PAPALIA, DIANE E.; OLDS, SALLY WENDKOS; FELDMAN, 2013). When this process involves changes in movements, the phenomenon is recognized as motor development (HAYWOOD; GETCHELL, 2016). However, it is worthwhile to mention that not all changes that happen to movements are considered development and hence, this section brings important concepts that characterize motor development as an object of scientific research.

At the start, it is fundamental to appoint important processes such as motor learning and development. Traditionally, these processes are treated as parallel concepts. The conventional view defines developmental changes as those related to the experiences in an individual´s lifetime (CLARK; WHITALL, 1989), that is, on a long-time scale, while learning is the relatively permanent acquisition of skills that depends on specific practice, on a shorter time scale (SCHMIDT *et al.*, 2018). Recently, Adolph (2019) proposed that instead of being reduced to an accelerated version of development, learning refers to a complex way for the individual to manage actions toward developmental changes in the behavior, body, skills, and environment. That is, learning occurs in a developmental context. In short, while development brings new opportunities for action by changing the individual-environment relationship, learning entails the behavioral flexibility necessary to deal with these developmental outcomes (ADOLPH, 2019).

The history of the study of motor development goes back a long time according to Clark (2017). She proposed that the motor development studies went through four periods: precursor (1787-1928), maturational (1928-1946), normative/descriptive (1946-1970), and process-oriented (1970 to date)(CLARK, 2017). According to the author the publication of the book “Mechanisms of Motor Skill Development” introduced the oriented process period of motor development studies. In this book, Connolly (1970) emphasizes that most studies were focused on what changes and when it changes in motor development (a product-oriented vision) thus indicating the necessity of new research guided by the process-oriented vision that could answer “why” and “how” these changes occur (CONNOLLY, 1970). Whereas research based only on a product-oriented vision provides information about “what” are these changes and “when” they appear, the implementation of a process-oriented approach enables the identification of subjacent mechanisms of these changes. The oriented process approach led to a distinct way to characterize development giving the first steps to overcome the maturation-experience dichotomy.

Connolly (1986) indicates changes over time between conceptions about mechanisms responsible for development: preformationist and epigenetic. According to the preformationist conception, it was thought that the organism was already formed in conception and that development had only a quantitative nature, that is growth(VALSINER; CONNOLLY, 2003). In other words, the preformationist view which has been abandoned for quite some time, considered that development entails an organism's growth from a miniature of itself. The epigenetic view brought the actual notion that the features that the organism presents during life are not pre-existent but rather are gradually expressed throughout time (CONNOLLY, 1986). This latter conception brings the implication that developmental changes are also qualitative and are based on interactions between levels of the organism and its surroundings (VALSINER; CONNOLLY, 2003). Hence, the epigenetic view understands development as a process of changes not only in the structure, but also in the function of an organism (morphology, physiology, and behavior) (CONNOLLY, 1986).

The present thesis adopts the epigenetic conception as a theoretical perspective for locomotion development investigation. The next topic aims to elucidate conceptual and theoretical aspects relevant to the study of motor development through this approach.

2.1.1 Epigenetic approach for motor development study

The application of the epigenetic perspective for investigation in development is reasoned in the important work of the biologist Conrad Waddington. Waddington supported epigenesis theory by adding the idea that characteristics of a developing organism appear gradually because of multiple interactions between simple components in a fertilized egg (WADDINGTON, 1942). Based on this notion, the biologist coined the epigenetic concept by connecting epigenesis and genetic terms referring to a process in which interactions between various genes originate the epigenotype that relates to its microenvironment to produce certain phenotypes (WADDINGTON, 1942). Furthermore, Waddington was the first to adopt the developmental system's expression in advancing the epigenesis definition.

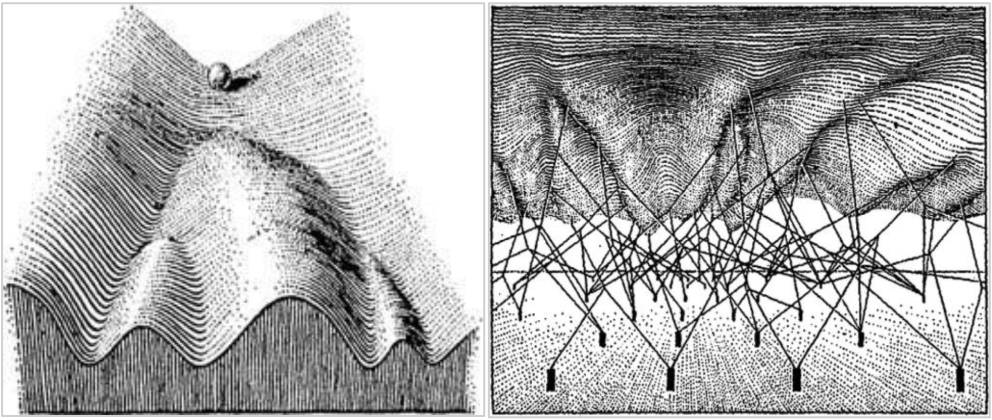
According to Griffiths e Tabery (2013), although Waddington´s epigenesis was centered on genetics, it has a view of the developmental system(GRIFFITHS; TABERY, 2013). This is because, he considered, the dynamic and complex interactions between the genome, its product (e.g., a protein that performs a function in the body), and its environment(TRONICK; HUNTER, 2016). In his publication ´Evolution of developmental systems´ (1941), Waddington argues that any characteristic of an animal is both, a product of its development, and a substrate of this process (WADDINGTON, 1941), and in 1952 he declares: "An animal is, in fact, a developmental system" (GRIFFITHS; TABERY, 2013). One implication of Waddington´s notion of a system is that alterations in a single gene, for instance, are not sufficient to determine the phenotype, but instead, the effects of the genotype depend on its interaction with the rest of the system to modify the characteristics of the organism (GRIFFITHS; TABERY, 2013). Finally, Waddington's (1952) illustrative representation of the developmental system was a precursor to what he later called the epigenetic landscape (GRIFFITHS; TABERY, 2013).

The epigenetic landscape metaphor developed by Waddington (1957) was designed to illustrate conceptual aspects of the development process. According to this idea, the developmental phenotype is represented by a ball rolling over a landscape (PERROTTI; MANOEL, 2001). As can be seen in Figure 2.1, the landscape shape is determined by specific genes in their different environments which are represented by pegs, and their biochemical products by tension in the cords (CONNOLLY, 1986). In this way, the formation of the valleys, as well as their depth and location in the landscape, depends on the interaction between many genes, and between the tensions of the cords.

One important feature of the epigenetic landscape is that it is not static, since changes in the gene's environment influence its action, and therefore, alter the tensions of the cords over the valleys, which can lead to a reformulation of its shape (PERROTTI; MANOEL, 2001). Further, these environmental changes can cause the ball to drift from one developmental track to another (SANTOS, 2015). In this sense, Connolly (1986) highlights two important implications resulting from Waddington's metaphor(CONNOLLY, 1986). One is the notion that, like the landscape, development is a dynamic process. Another has to do with the possibility of diverse paths of change, which are formed by the morphology of the landscape (CONNOLLY, 1986).

The concept of equifinality serves as a complement to understanding development from this perspective. Developed by Driesch, the Equifinality axiom states that organisms of the same species can achieve the same final state through different developmental pathways(GOTTLIEB, 2003). It is this principle that supports the fact that infants can present different sequences for the acquisition of motor skills (NEWELL; LIU; MAYER-KRESS, 2003). Therefore, it implies that from different initial conditions, infants can reach the same final motor skill, such as walking independently; but also starting from similar initial conditions, they can achieve the same final state through different paths.

Figure 2.1 – A part of the epigenetic landscape and interactions (genes are represented by pegs, their biochemicals products by tension in cords)

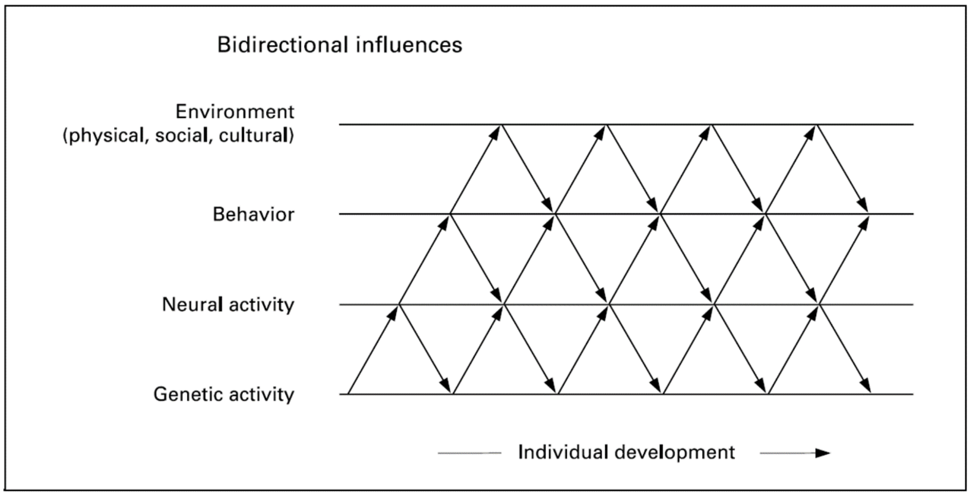


Source: WADDINGTON, 1957

According to this view, development can be treated as a probabilistic process in which there is a component of uncertainty meaning that some events may have more chance to occur than others(CONNOLLY, 1986). In a developmental context, it means that the onset and occurrence of behaviors happen in a probabilistic way and that the environment is a critical factor in this process (GRIFFITHS; TABERY, 2013). Thus, probabilistic epigenesis coined by Gottlieb (1970) considers that behavior or developmental process must be described at four levels of analysis (genetic, neural, behavioral, and environmental) and assumes a bidirectional relationship between these levels (GOTTLIEB, 2003).

These bidirectional influences distinguish probabilistic epigenesis from predetermined epigenesis (Figure 2.2) (GOTTLIEB, 2003). In the unidirectional relationship presented by predetermined epigenesis, structure determines function, so that behavioral development can be explained by the maturation of the central nervous system (VALSINER; CONNOLLY, 2003). Probabilistic epigenesis understands that not only structure determines function, but function can also modify the structure, and thus, the relationship occurs in both directions (GOTTLIEB, 2003). Based on this, Gottlieb's epigenesis recognizes experience as a facilitator of behavioral and neural development(CONNOLLY, 1986).

Figure 2.2 – Gottlieb's probabilistic epigenesis model



Source: GOTTLIEB, 2003

Another relevant concept directly related to Gottlieb's view of causality in development is coaction(GOTTLIEB, 2003). For the author, the behaviors produced in development are consequences of at least two components in coaction implying that the cause is always a relationship between the two and is never due to one element or another. From this perspective, development is characterized by the emergence of novelties in function and structure that result from coaction between different components of the individual and the environment (GOTTLIEB, 2003). Gottlieb (2003) defines experience as a relational term adopted to designate these coactions. Connolly (1986) explains from Gottlieb's notion of coaction that instead of interacting with each other, organism and environment form a unit that results in behavior as an emergent property. Thus, changes only in the genotype or in the environment produce units that will not necessarily change the phenotype(CONNOLLY, 1986).

The Waddington and Gottlieb concepts introduced so far supported the developmental system perspective, which was later referred to as a theory. Developmental system theory is recognized as an epigenetic approach to the study of development, heredity, and evolution(GRIFFITHS; HOCHMAN, 2015). Although Waddington was the first to adopt the term developmental system as mentioned earlier, Susan Oyama was the one who systematically contributed to the current concept of this theory with the work "The Ontogeny of Information" of 1985.

In this book, Oyama (1985) argues that the information that guides development has an ontogeny, which means that it is constructed throughout this process. In this way, the author rejects the view that development is guided by a genetic program that contains the information (GRIFFITHS; HOCHMAN, 2015). Oyama adopted this line of thought to highlight the role of non-genetic factors as causal in development (GRIFFITHS; TABERY, 2013). Moreover, the author used the principle of "causal symmetry" to show that an effect depends on many different causal factors and that an investigation must comprise the impact of each of these causes (OYAMA, 2000a). Finally, this principle also rejects the proposition that one cause can be more explanatory than another (GRIFFITHS; HOCHMAN, 2015).

Oyama argued that the developmental phenotype is always contextual, and that the context depends on the system as a whole (GRIFFITHS; TABERY, 2013). In this sense, Oyama's view of the developmental system proposes one solution to the maturation/nature versus experience/culture dichotomy (OYAMA, 2002). The author states that the organisms and the environment are inseparable. First, it means that an organism exists in a time and space and cannot be characterized independently from its surroundings. Second, that causality cannot be attributed to any parts of the system. Thus, Oyama considers nature as the changing unity formed by the organism-environment complex and nurture as the developmental process that results in changes in this unity (OYAMA, 2002).

Another relevant contribution from developmental system theory was the characterization of development as a process of dynamic interaction (GRIFFITHS; HOCHMAN, 2015). Through this dynamic vision, it is understood that the development of an organism in a moment is built by its product in a previous stage (GRIFFITHS; TABERY, 2013). According to Lehrman (1953), the components that interact to result in the development process change over time and form new components that will interact to yield development in the future. Thus, not only do the components of the organism change during this process but also the environment changes because of development (LEHRMAN, 1953). These were the principles that supported the "dynamic interactionism" of Ford and Lerner (1992), who conceived the organism-environment interaction as the "heart" of development(FORD; LERNER, 1992).

Ford and Lerner (1992) were the first to call the developmental system perspective a theory, and together with the idea of the dynamic interaction mentioned above, they introduced the notion of "developmental contextualism". Related to Gottlieb's concept of probabilistic epigenesis, contextualism conceives development as a process that occurs at multiple levels of the organism and environment, and that dynamic interactions take place between components, and these levels (GRIFFITHS; TABERY, 2013). Finally, the approach of Ford and Lerner (1992) defines development as a series of functional transformations produced by interactions between the momentary state of an organism and its context(FORD; LERNER, 1992).

So far, the content of this chapter has presented the main foundations that constituted the developmental system approach to the study of human development. Griffiths and Hochman

(2015) emphasize that this is not a theory in the strict sense, but rather a perspective that serves as a framework for the study of biological phenomena(GRIFFITHS; HOCHMAN, 2015). Oyama, Griffiths, and Gray (2001) define it as a theoretical structure free from the nature and culture dichotomy, useful for conducting and interpreting research in biology, composed of some essential issues:

Multiple causes: every feature in a developing organism is produced by the interaction of many resources (OYAMA; GRIFFITHS; GRAY, 2001).

Context sensitivity and contingency: the effect of changes in a single causative factor depends on the rest of the system (the other components of the interaction) (OYAMA; GRIFFITHS; GRAY, 2001)

Extended inheritance: diverse resources (not only genetic) passed on participate in interactions for the construction of the development. These resources include epigenetic inheritance, nutrients, environment, temperature, cultures, traditions, habits, etc. (OYAMA; GRIFFITHS; GRAY, 2001).

Development is a process of construction and reconstruction: characteristics are not inherited, pre-formed, or programmed, but rather constructed and reconstructed through interactions between countless factors. The products of development are co-determined and co-constructed by organisms and the environment (OYAMA; GRIFFITHS; GRAY, 2001).

The organism is a resource for its development and determines which other resources will contribute to this process and impact(OYAMA; GRIFFITHS; GRAY, 2001).

The developmental system approach defines development as a dynamic process of construction and reconstruction in which heterogeneous resources are contingent and reassembled during each organism's life cycle (OYAMA; GRIFFITHS; GRAY, 2001). Based on this approach, this thesis intends to adopt the metaphor of epigenetic landscapes as a theoretical model for the study of motor development. Dynamic systems theory (DST) is recognized for providing a formal conceptual framework for the study of probabilistic pathways of developmental change supported by the epigenetic view (MUCHISKY *et al.*, 1996). Thus, the following topic aimed to highlight the aspects of DST that are relevant to the present research.

2.1.2 DST as a formal conceptual framework for motor development study

The theory of nonlinear dynamic systems uses concepts from the physical and mathematical sciences and conceives a formal model proper for investigating a phenomenon at different time scales (ZANONE; KELSO; JEKA, 1993). This perspective has been adopted in the study of motor development in the first year of life, as it offers useful principles for describing and predicting the dramatic changes that comprise this process (NEWELL; LIU; MAYER-KRESS, 2003). Through this approach, development is seen as a process of changes in the way a system is organized (CONNOLLY, 1986).

The notion that underlies the application of DST in biology is that an organism is always connected to the environment. This implies recognizing it as an open system that presents continuous exchange relations with its environment (VON BERTALANFFY, 1977). In this way, living organisms behave as an open dynamic system that must constantly receive energy and information from their surroundings to maintain an organization, develop and avoid possible dissipation (TRONICK; HUNTER, 2016).

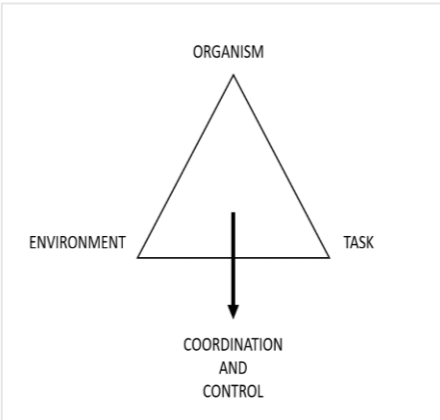
A dynamic system consists of an ensemble of interacting elements that generate changes in its product at different time scales (NEWELL; LIU; MAYER-KRESS, 2003). When it comes to behavior, it is considered the product of a dynamic system, that results from the interactions between environment (physical, social, context), task, and organism (genetics, maturation, growth, specific characteristics, etc.) (THELEN; KELSO; FOGEL, 1987). Also, studying human development from this point of view requires an understanding that behavior is dynamic, relational, and multilevel (THELEN, 1986). It is dynamic because it changes over time; it is relational because depends on the interaction between elements; and it is multilevel because its interpretation is level-dependent (THELEN, 1986).

By this view, Newell's model (1986) illustrates the possible elements that interact to result in a particular emergent behavior (Figure 2.3). These elements are called constraints and consist in characteristics present in the organism or in its interaction with the environment that limit or eliminate certain configurations or patterns of response of the system(NEWELL, 1986). There are three categories of constraints that interact to determine an optimal movement pattern: individual, environment, and task.

The individual's constraints are characteristics of a person at different levels of analysis (structural, functional, macroscopic, and microscopic) (NEWELL, 1986). Whereas the structural ones are relatively time-independent, the functional ones are relatively time-dependent. As an example of structural constraint, Newell (1986) presents the child's physical growth characterized by an increase in body mass and height. In contrast, the individual's functional constraint can be exemplified by the development of synaptic connections since it characterizes rapid changes during development (NEWELL, 1986).

Environmental constraints are those external to the organism, which can be general or specific to the task (NEWELL, 1986). Those defined as general are the characteristics of the environment that are relatively time-independent, such as the force of gravity, the presence of natural light, and ambient temperature, among others (NEWELL, 1986). At first, these constraints cannot be controlled by the researcher, unless the location is changed (such as a change of geographic location) (NEWELL, 1986). There are also specific constraints, which are those features of the environment that reflect the conditions for the execution of the task and can be controlled by an experiment (NEWELL, 1986). For instance, the type of surface on which individual moves can be considered an environmental constraint associated with the task. Finally, task constraints are defined as specific to the execution of an activity and can be relative to the goal (final product of the movement); to the rule (norms that specify or constrain a motor response); or to implements (objects capable of constraining the dynamic response) (NEWELL, 1986).

Figure 2.3 – Newell´s model of constraints for coordination and control



Source: Adapted from NEWELL, 1986

From the model presented above, one implication is that the omnipresence in order and regularity of behaviors acquisition during motor development is a consequence of the similarity between the constraints imposed on infants and children, rather than the result of common genetic prescriptions for the human species(NEWELL, 1986). In a dynamic system, the idea of constraints is associated with the concept of control parameters, which are the variables that lead the system to produce a specific pattern, and sometimes to change (ZANONE; KELSO; JEKA, 1993). According to the epigenetic theoretical background presented in this review, this thesis does not intend to consider the isolated effects of variables on locomotion development. However, Newell´s model can be useful as a tool for the identification of the possible elements that co-act to result in behavior. Hence, the idea that the present research considers is that the elements of the individual and his environment that change in different time scales act together as control parameters in motor development (NEWELL; LIU; MAYER-KRESS, 2003).

The order parameter also called a collective variable, is the product of the interactions between the components and characterizes the organization pattern of the system (that is, it provides information about its state and if there has been a change in this state) (ZANONE; KELSO; JEKA, 1993). In addition, the collective variable of the system is described by the stable states that correspond to the behavior patterns produced by the system. It should be noted that under non-specific sets in control parameters, behavior patterns emerge spontaneously from the intrinsic dynamics of the system (ZANONE; KELSO; JEKA, 1993). Therefore, intrinsic dynamics reflects the tendency of the system to present stable states under non-specific constraints of its subcomponents (ZANONE; KELSO; JEKA, 1993).

Zanone, Kelso, and Jeka (1993) affirm that studying the temporal evolution of the collective variable of the system entails mapping the stable states observed over time. So, the goal of the dynamic perspective is to characterize patterns as stable states reached by a system. Furthermore, changes are characterized by transitions between these states over time (ZANONE; KELSO; JEKA, 1993). A state reflects the organization of the system at a given point in time and can provide relevant information about the individual's biological functions (SCHÖNER; KELSO, 1988). In motor development, a state can be represented by a categorization of a defined behavior pattern based on a qualitative analysis of the movement (PRECHTL, 1974). Yet, in infant motor behavior, for instance, states can be characterized by motor and sensory patterns that may correspond to developmental particularities (THELEN; KELSO; FOGEL, 1987).

The dynamic view proposes that development implies something qualitatively new in the system, something that was previously unobserved (SPENCER; PERONE; BUSS, 2011). Hereupon, the observation of a new behavioral state, called emergence, corresponds to the onset of a new spatial or temporal pattern in the dynamic system (SCHÖNER; KELSO, 1988). Assuming the emergence of a new state requires some degree of behavioral stability. So, to consider the emergence of a state, which may be represented by the acquisition of a motor skill, for example, is necessary the observation of a new motor behavior for a minimum period, which indicates stability (PRECHTL, 1974; THELEN; KELSO; FOGEL, 1987)

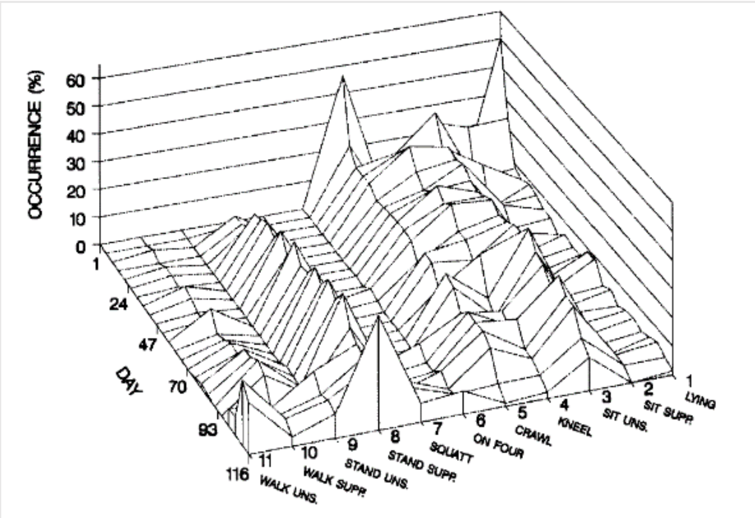
A stable state also called an attractor, corresponds to patterns easily expressed by the system from a variety of previous states, or after some perturbation (THELEN, 1995). In dynamical systems, attractors are a mathematical construct characterized as stable solutions of the dynamics of the collective variable, where the system tends to converge regardless of its initial conditions (ZANONE; KELSO; JEKA, 1993). One way to verify the stability of a state in the system is to detect the reproduction of a pattern qualitatively (SCHÖNER; KELSO, 1988). Therefore, in the study of motor development, the assessment of the stability of a state can be performed by recording the frequency in which the behavior is observed.

The observation frequency is directly proportional to the stability of the analyzed behavior pattern (ZANONE; KELSO; JEKA, 1993). For instance, alternating kicks presented by infants in the first months of age are stable states, since they are frequently observed movements (KAMM; THELEN; JENSEN, 1990). Also, the system may have a multi-stability property, which is when more than one stable state is observed for a given configuration of the control parameters (NEWELL; LIU; MAYER-KRESS, 2003). Still, stability is relative because it can vary according to circumstances (MUCHISKY *et al.*, 1996). Living organisms generally exhibit multi-stable regimes, in which the probability distribution for observation of various stable states reflects the intrinsic dynamics of the system (figure 2.4) (ZANONE; KELSO; JEKA, 1993). In this regime, if there is no manipulation of the control parameters, all the stable states of the intrinsic dynamics of the system are eventually visited; so that the occurrence of the infant´s behaviors reflects the extension and stability of its motor repertoire (ZANONE; KELSO; JEKA, 1993).

In analogy with epigenetic landscapes, an attractor is represented as a valley (NEWELL; LIU; MAYER-KRESS, 2003). The stability of the states observed in the system at a given moment is inferred by the depth of the valleys in the landscape, and the probabilistic component is the estimate of stability and instability related to each behavior (NEWELL; LIU; MAYER-KRESS, 2003). Thus, the various stable states can have different levels of stability, which coincide with the chances (probability) of the system falling into each state(NEWELL; LIU; MAYER-KRESS, 2003). This set of probabilities is illustrated by the epigenetic landscape adapted from a dynamic perspective (Figure 2.5) (MUCHISKY et al., 1996). Differently from Waddington´s view, the phenotype (collective variable) of development is not represented by a ball rolling over the landscape, but rather by a cross-section (represented by a line in a certain time point) indicating the likelihood of each behavioral state emerging in the dynamics of the system (MUCHISKY *et al.*, 1996). Further, in the dynamic view, the landscape is shaped by the underscape design that consists of the dimension in which control parameters constrain this probability of behaviors emergence (MUCHISKY *et al*., 1996).

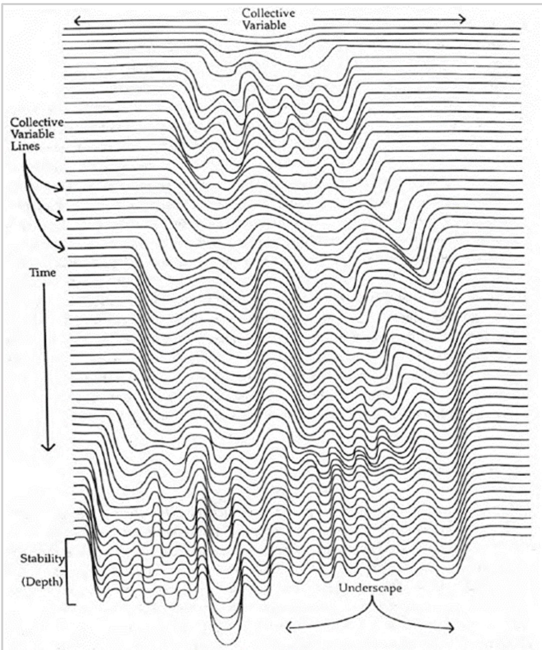
Variations in the frequency of observation of a given behavior indicate an increase or decrease in the stability of the attractor state. At a given moment, the system suffers a loss of stability, which reflects in increased fluctuation and inability to maintain a stable state, which is called the period of instability(ZANONE; KELSO; JEKA, 1993). In dynamic systems, the origin of these periods is a quantitative change in the bases of the attractors that influence the stability of the state and contribute to qualitative changes in the behavior pattern(ZANONE; KELSO; JEKA, 1993). Then, this loss of stability in a more stable behavior (predominant) indicates a change of pattern in the system, characterized by a decrease in fluctuations and the transition to a new stable state (a new predominant one) (ZANONE; KELSO; JEKA, 1993).

Figure 2.4 – An example of the frequency distribution of behavioral patterns throughout time



Source: ZANONE, KELSO, JEKA, 1993

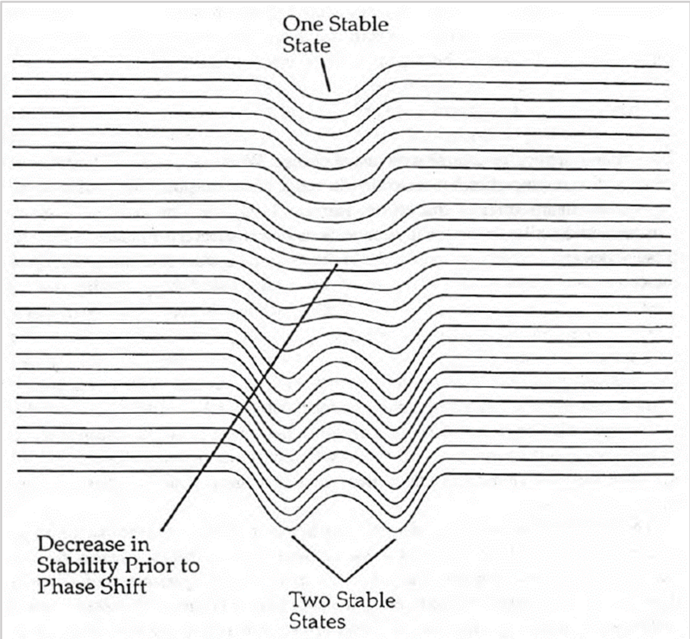
Figure 2.5 – Epigenetic landscape from dynamic systems view



Source: MUCHISKY et al., 1996

In motor development, a transition is characterized by a greater behavioral variation near the time point of change, that is oscillation, as well as delayed recovery of equilibrium after a disturbance (VAN DER MAAS; HOPKINS, 1998). According to Zanone, Kelso, and Jeka (1993), these phase shifts also named bifurcations are associated with the emergence or extinction of stable states in the system dynamics (Figure 2.6). Transitions are discontinuous, marked by periods of stability and instability, and this is why the dynamic of the system is nonlinear (VAN DER MAAS; HOPKINS, 1998). Hence, to investigate development through this theoretical approach implies considering that behavioral transition starts from a stable period interrupted by an abrupt change in the organization of the order parameter with loss of stability, leading to a new behavioral stable state (THELEN, 1995). Hence, from a dynamic systems view, development entails the emergence of new stable states, the transition between stable states, and multistability (KAMM; THELEN; JENSEN, 1990).

Figure 2.6 – A bifurcation event in the dynamical landscape



Source: MUCHISKY et al., 1996

From dynamic systems, two mechanisms explain the behavioral change. On the one hand, self-organization matches with spontaneous changes that lead to the emergence of more complex patterns of behavior (SCHÖNER; KELSO, 1988; THELEN, 1995). It is a product of the tendency of system subcomponents to interact coherently and stably (ZANONE; KELSO; JEKA, 1993). Adaptation, on the other hand, is a mechanism that leads the system to a new state, which, however, could not emerge spontaneously and depends on extrinsic influences of the control parameters (ZANONE; KELSO; JEKA, 1993). In other words, adaptation is the ability of the system to provide a motor solution to any specific constraints. Finally, when the adaptive motor response is acquired by the system so that the intrinsic dynamic is modified, it can be said that a learning process occurred (ZANONE; KELSO; JEKA, 1993).

The assumption for the adaptation is that the system must at some point be flexible enough to explore and solve motor problems (THELEN, 1995). Further, while some system components preserve stability, others allow for some flexibility regarding functional demands (THELEN, 1986). Flexibility is what enables the organism to use old strategies to solve new problems or to create motor solutions (ADOLPH, 2019). Yet, this flexibility, also called variability, is needed to lead the system to a loss of stability in motor behavior, and hence, to a transition between states(MANOEL; CONNOLLY, 1995).

An additional way to investigate variability in motor development is from the Neuronal Group Selection Theory (SPORNS; EDELMAN, 1993). From this view, there are two distinct phases in motor development. The phase of primary variability (variation) initiates during the fetal period and continues into infancy marked by a variable motor repertoire not adjusted to environmental conditions. This phase is fundamental because it allows the exploration of all possibilities of movement available for a specific function and provides self-generated afferent information to the individual (HADDERS-ALGRA, 2000). When the organism starts to use this afferent information to select the most appropriate motor behavior for a specific situation there is the onset of the phase of secondary variability (HADDERS-ALGRA, 2010). In this phase, also called adaptability, a new variable motor repertoire is created, allowing the system to produce an efficient motor function for the specific conditions of a task; or generate multiple efficient motor strategies for a single task (HADDERS-ALGRA, 2000).

One of the implications of the dynamic perspective is that development occurs towards a more adapted state. This means that the increase in the motor repertoire as a product of development is due to a process of differentiation/diversification from simpler and more homogeneous states to more complex and heterogeneous states (CONNOLLY, 1986). Thus, studying the trajectory of the system (succession of stable states over time) (ZANONE; KELSO; JEKA, 1993), reflects its flow in that direction. The metaphor of epigenetic landscapes together with the concepts presented in this review topic design a useful tool for the present investigation.

This thesis conceives motor development as an epigenetic process. Given what was presented earlier, this means that development entails changes in the organization of a system led by multilevel organism-environment coaction resulting in novelty in motor behavior. Furthermore, it designates a dynamic nature for this process including changes over time and on different time scales. Moreover, it also brings the notion that the product of development at a given time is the substrate for the changes that will happen later. In conclusion, this requires recognizing the probabilistic element in developmental changes, meaning different chances of occurrence for behaviors and diversity of possibilities for developmental paths.

The concepts contemplated in this bibliographical review such as emergence, transition, state, and stability were adopted in operational concepts for the investigation of the development paths of locomotion in the first year of life. These operational descriptions, found in the method chapter of this thesis, were used to analyze the changes in the locomotion development of the infants included in the sample and were observed recurrently and systematically. The next section intends to review the literature on infant locomotion development and the environmental elements associated with this process.

2.2 LOCOMOTION DIVERSITY IN MOTOR DEVELOPMENT

The action of moving a body from one place to another, that is locomotion, appears in the infant´s motor repertoire as various possibilities of behaviors such as rolling, crawling on the belly, on hands and knees or feet, walking on knees or feet, and other. Regardless of the behavior form, locomotion activity is complex, whereas it involves the whole body and requires interaction between sensory and motor systems, and coordination between many muscles and joints. Besides that, locomotion ability represents a crucial advance in development, as it marks an infant´s independence for moving around and dramatically changes its relationship with the environment (THURMAN; CORBETTA, 2017, 2019).

Movement precursors of locomotion such as weight-bearing stepping, kicking, and coordinated arms and legs quadrupedal motion are presented since fetal life and in infants from the newborn period (FORMA *et al.*, 2018, 2019; HINNEKENS *et al.*, 2023; SYLOS-LABINI *et al.*, 2020). Researchers agree that experience with kicking in fetal life contributes to locomotion patterns observed in the newborn, but also that there are intrinsic circuits of locomotion developed up to birth (FORMA *et al.*, 2019; SYLOS-LABINI *et al.*, 2020). Moreover, there is evidence of coupling between locomotion and vision in human newborns indicating that supra-spinal control of these movements is presented from birth (FORMA *et al.*, 2018). Regarding the pattern, newborns over a mini skateboard show diagonal and in-phase limb movements consistent with mature crawling locomotor behavior (FORMA *et al.*, 2019). Likewise, kicking presents an adult-like temporal activation pattern since birth, whereas ground-stepping similarity to a mature locomotor behavior is achieved only with the infant´s age progression (SYLOS-LABINI *et al.*, 2020). Finally, despite some coordination consistency with locomotion in adults, these newborn movements are highly variable and flexible and will progress to a selective activation with time (HINNEKENS *et al.*, 2023).

Independent rolling is one of the first ways infants use to orient posture but can also be used to move around the environment. According to the literature, the ages at which this behavior appears vary, from 3.6 to 5.7 months for rolling from prone to supine; and from supine to prone between 4.8 and 5.1 months of life(ALLEN; ALEXANDER, 1990; NELSON *et al.*, 2004). It is interesting to note that while some authors found that infants first learn to roll from prone to supine (CAPUTE *et al.*, 1985), others report first, the beginning of rolling from supine to prone (NELSON *et al.*, 2004; TOGARI *et al.*, 2000).

Gesell and Ames (1940) studied the development of the motor behavior of infants in the prone position and described the ages of emergence and the different patterns of locomotion in this posture. The authors refer to the beginning of locomotion in the prone position through pivoting and crawling movements from seven months of chronological age, ending with the mature crawling that can appear up to 11 months of the infant (GESELL; AMES, 1940). Other studies, including one with the Brazilian population (LOPES; DE LIMA; TUDELLA, 2009), observed that the onset of crawling varied from six months up to 11 months old (THURMAN; CORBETTA, 2019; YAMAMOTO et al., 2020).

Locomotion emergence in prone posture is rich in behaviors where the infant can start by pivoting, then belly crawl forward or backward, also, swing on hands and knees posture, and crawl on hands and knees or hands and feet (ADOLPH; VEREIJKEN; DENNY, 1998a). Additionally, it is known that smaller and lighter infants tend to crawl earlier than the bigger ones (ADOLPH; VEREIJKEN; DENNY, 1998a). Crawling is not experienced by all infants in in pathways of locomotion development (MCEWAN; DIHOFF; BROSVIC, 1991), especially in the belly (YAMAMOTO *et al.*, 2021). In sum, the emergence of crawling locomotion is variable and diverse intra- and inter-individual in terms of onset age, interlimb coordination, and behavior patterns (FREEDLAND; BERTENTHAL, 1994; PATRICK; ADAM NOAH; YANG, 2012; YAMAMOTO et al., 2020). Crawling does not follow a strict stage-like progression where while some infants crawl on the belly before doing it on hands-and-knees, others firstly craw symmetrically on hands-and-knees, and others asymmetrically on both hands, one foot and one knee(ADOLPH; VEREIJKEN; DENNY, 1998). Also, there is high variability in combinations of body parts for propulsion resulting in different patterns among infants, but also intra-individual, where an infant can show a different pattern movement during crawling from one cycle to another or from one locomotion bout to another (ADOLPH; VEREIJKEN; DENNY, 1998). In the prone position, infants can crawl with the belly in contact with the ground (belly crawl, D)(PATRICK; ADAM NOAH; YANG, 2012). Quadrupedally, infants can crawl symmetrically on hands and knees (standard crawl, A) or hands and feet (bear crawl, B); and asymmetrically, by using both hands, one knee, and one foot (step-crawl, C) (PATRICK; ADAM NOAH; YANG, 2012). In the sitting posture, crawling can be performed by the infant seated on one haunch and using ipsilateral propulsion of one hand and one knee (step-scoot, F) or by using the legs to pull the body forward (scooting, E) (PATRICK; ADAM NOAH; YANG, 2012) (Figure 2.7).

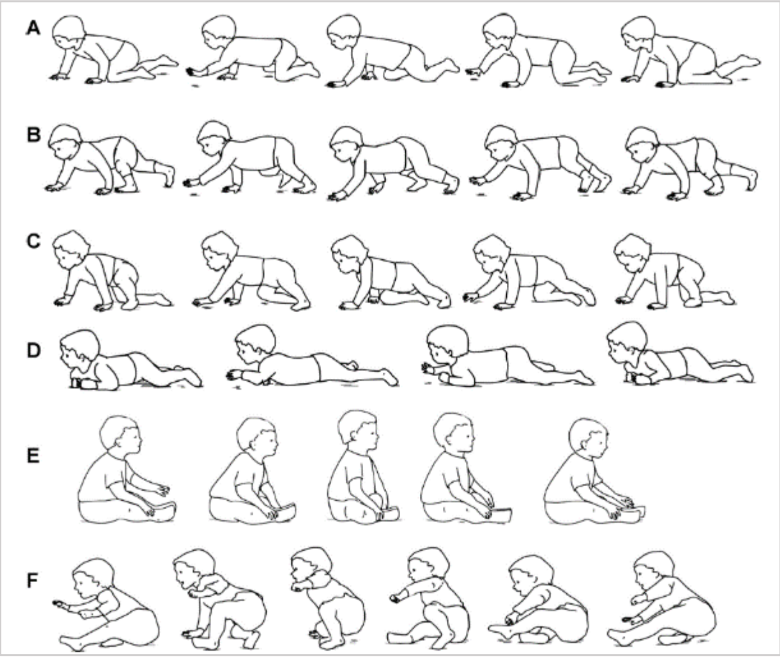
Freedland and Bertenthal (1994) claim that the challenge for the organism is to select the most efficient and flexible interlimb coordination pattern based on infant abilities and the particularity of the task. In this sense, the authors present three possible coordination patterns. The first is where the ipsilateral limbs move together (left arm and leg), the second is where homologous limbs move together (both arms or both legs), and the third, is where diagonally opposite limbs move together (right leg and left arm) (FREEDLAND; BERTENTHAL, 1994). Among these possibilities, diagonal interlimb coordination is the most efficient pattern, especially for hands-and-knee crawling, because it minimizes the center of mass displacement from one side to the other (ADOLPH; VEREIJKEN; DENNY, 1998).

Concerning proficiency measures such as the speed of the locomotion behavior, crawling on hands and knees is faster than crawling on the belly(ADOLPH; VEREIJKEN; DENNY, 1998). Regardless of the pattern, infants who start to crawl at an earlier age use more trial-and-error experiences in learning by expressing more varied combinations of body movement, when compared to those that crawled at later age (YAMAMOTO *et al.*, 2020b). Interestingly, Adolph, Vereijken, and Denny (1998) found that infants that performed belly crawling are more consistent in terms of using the diagonal gait in the first weeks of hands-and-knees crawling in comparison with those that never crawled on the belly before (ADOLPH; VEREIJKEN; DENNY, 1998a). Yamamoto et al., (2021) found similar results and suggested a learning process in which infants that experienced belly crawling are more efficient in selecting the pattern from their previous repertoire. It is noteworthy that these locomotor behaviors are specific to the prone posture. Thus, these studies evidence that experience matters in locomotion development and indicate that infants seem to use knowledge from trying a previous behavior to a new one in the same posture.

The locomotion development in the standing posture usually starts from the infant’s first attempts to cruise with support on furniture and reach the final state with independent walking.

Interestingly, a study found that while some infants started to crawl 2 weeks before the onset of cruising, others presented these locomotion behaviors for the first time within a two-week window (ADOLPH; BERGER; LEO, 2011). Even more, for some infants, cruising behavior had emerged at least 2 weeks before the crawling onset. In summary, the authors verified a correlation between the onset ages of some locomotion behaviors, whereas cruising was a better predictor of age at independent walking in comparison with crawling (ADOLPH; BERGER; LEO, 2011).

Figure 2.7 – Crawling patterns illustration



Source: PATRICK et al., 2012

The emergence of walking without support has been indicated to vary from 9 to 15 months in typical infants (THURMAN; CORBETTA, 2019). On independent walking, changes in movement pattern include a progression from a wide base of support with high-guard arms positioning to a narrow path and arms relaxed throughout the body. Adolph et al., (2003) noted that the walking experience (measured in days since the onset) was the most relevant factor contributing to balance in gait pattern characterized by longer steps, a narrow support base formed by feet, and straight paths. Furthermore, these authors observed that when normalized by leg length there are no differences in step length and width between kindergarten child and adult´s (ADOLPH; VEREIJKEN; SHROUT, 2003).

Whereas step length and speed can predict postural control in upright locomotion, variable routes duration, shape, and omnidirectional steps seem to mark an infant´s walking during free play regardless of experience (LEE *et al.*, 2017). Lee et al., (2017) state that these characteristics entails a learning process to make walking flexible, that is, a behavior that allows the infant to do what is intended. In other words, behavioral flexibility grants an appropriate response for each specific situation (ADOLPH, 2019).

Thelen (1986) points out that the emergence of locomotor behavior in motor development is determined by a dynamic combination of components within a context. The author hypothesized some critical components for locomotion emergence such as pattern generation, articulator differentiation, postural and tonus control, visual flow sensitivity, extensor strength, body constraints, and motivation. Further, in a developing human, it is supposed that each component has its path and rhythm to reach critical functioning, and the locomotion behavior will appear merely when the context which includes the particularities of the task and of the physical constraints are appropriate in relation to individual characteristics(THELEN, 1986). One element may act as a rate limiter preventing the behavior expression through the interaction of other components, for instance, the muscle strength for an infant to lift a leg in the supine posture (THELEN, 1995). In sum, behavior is not determined by one element, but in a dynamical combination, one element can facilitate, support, inhibit or mask the action of another element.

The results of the studies presented in this review showed inter-individual variation in locomotion development. Thus, considering the principle of equifinality and the metaphor of epigenetic landscapes presented in topic 2.1 of this review, the development of locomotion in typical infants can follow different developmental paths, and end with the same final achievement: independent walking. From the dynamic perspective, variations in these pathways are the result of the coaction of multilevel elements (organism, task, and environment) changing in multiple timescales. It is supposed that variations of the developmental paths are influenced by the affordances produced by the infant´s relationship with its environment, as well as the caregivers' beliefs, body positioning, and home experiences. It is assumed that the characteristics of the individual-environment relationship can act as facilitators, as well as barriers for the emergence and transition of locomotion in typical infants.

2.2.1 **Affordances for human locomotion development**

Gibson (1979) defines affordances as an action possibility enabled by a relationship between the environment and the organism. In other words, the author considers that affordances result from what the environment offers as a possibility to a particular animal (GIBSON, 1979). The affordances can vary between individuals (GIBSON, 1979).

Environment underlies affordance by physical characteristics such as the medium (gaseous, aquatic), surfaces, layouts of places, objects, and presence of people (GIBSON, 1979). However, the fit between an organism and its surroundings is what settles the possible actions or behaviors. For instance, usually, there is the affordance of sitting down when an adult sees a chair; while for an infant who crawls on the floor and comes across the same chair, there is the possibility to pull and stand up. Thus, the affordances are not a property of the environment, but rather must always be figured out relative to a unique organism in a specific moment and context.

Actions are enabled by affordances, and these movements generate new information for perceptual systems (GIBSON, 1979). Thereafter, affordances connect the action to perception (GIBSON, 1988). Moreover, perceiving affordances is what allows behavior to be adaptive (ADOLPH, 2019). Here it is necessary to bring definitions for action and perception, as well as to clarify the relationship between them. Von Hofsten (2004) considers that actions are initiated by motivation, defined by an intention, and guided by information(VON HOFSTEN, 2004). The intention, present since birth, is understood as a goal to produce an effect from an action, that is, to reach a final state from that action (BRUNER, 1973).

In addition to being linked to an intention, the action is always directed to the future and involves predicting what might happen in the new moment (VON HOFSTEN, 2004). So, according to this view, the action involves the environment in two senses: first, the perception of it; and second, a plan concerning it. Perception corresponds to the process of obtaining information about the world (GIBSON, 1966). Such a definition designates an active character of the individual in the perception process, which depends on attention directed to the environment. Thus, it is from the perception that an individual can decide what to do, where to go, and how to go somewhere or do something (GIBSON, 1988).

While action participates in perception(GIBSON, 1988), perception guides action; and the result of the action-perception coupling is what is called the prospective control (PC)(VON HOFSTEN, 1993). PC relies on an individual´s knowledge about regularities in the environment and the ability to extract future-oriented information from the body's senses (VON HOFSTEN, 2004). In this way, the PC is determined by perceptual information and allows the individual to decide whether a certain action is possible and to predict its consequences (TURVEY, 1992).

The perception of affordances for locomotion is a process that must be learned by infants through subsequent adjustments to exploratory activity (ADOLPH; EPPLER; GIBSON, 1993). Exploratory activities are defined as self-initiated visual, haptic, and locomotor behaviors which include some level of attention, and serve to yield important knowledge for planning future actions(ADOLPH; AVOLIO, 2000). Particularly in locomotion, there is evidence that experience that entails a process through the time of one organism doing, seeing, and interacting with the environment, influences the quality of the activity of exploration and hence the perception of affordances. For instance, studies show that the self-produced locomotor experience improves infants' perception of visual motion at 11 – 12 months old characterized by faster recruitment and activation of the neuronal networks specific to this function(AGYEI *et al.*, 2015; AGYEI; VAN DER WEEL; VAN DER MEER, 2016a). As a result of the locomotor experience, there is an improvement in the infant´s ability to recognize danger and perform a prospective action to prevent danger (e.g., collision)(AGYEI; VAN DER WEEL; VAN DER MEER, 2016b). Moreover, the greater the walking experience in months, the most efficient exploratory behaviors are in terms of needing and choosing between low-cost (visual) and high-cost (touching) strategies, and consequently, the better infants can use perceptual information to move around safely (KRETCH; ADOLPH, 2016).

Concerning the transfer of perceptual learning from experience in one locomotor behavior to another, as for crawling to walking, literature shows no consensus. Whereas a longitudinal study found no transfer of perceiving affordances from crawling to walking on avoidance behaviors (ADOLPH *et al.*, 1997), cross-sectional results were different (BURNAY *et al.*, 2020). Burnay et al., (2020) verified that the crawling experience was associated with affordance perception on real and water cliffs during walking. The author assumes that infants can “recalibrate” perceptual knowledge from previous experience for the new upright locomotion skill (BURNAY *et al.*, 2020). However, this issue needs further investigation since a longitudinal design is necessary to evidence whether infants with crawling experience that succeeded to avoid falling would do the same when starting to walk (BURNAY *et al.*, 2020).

From the results gathered in a series of previous experiments, Adolph et al. (2000) defines three types of exploratory behaviors used by infants for affordance perception during locomotion: exploration at a distance, via direct contact, and by alternative means. Distance exploration allows the infant that is moving on a certain surface to adjust posture before shifting to a new surface (ADOLPH; AVOLIO, 2000). The main sense used for this form of exploration is vision, through which the infant can identify depth through texture gradients, inclination, and location of the new surface. The type of exploration via direct contact consists of the use of touch, by hands or feet, as a strategy to gather information about depth, friction, rigidity, or texture of the environment, and allows the infant to decide whether it is safe to move on a surface (ADOLPH; AVOLIO, 2000). In exploration by alternative means, the infant uses trial and error to choose the most suitable mode of locomotion (ADOLPH; AVOLIO, 2000). Thus, during this kind of exploration, the infant may sometimes change position, for example, from standing to sitting, or to hands and knees, until deciding the best way to move around on a new surface (ADOLPH; AVOLIO, 2000).

Although infants sometimes locomote toward a goal, such as reaching for a toy, or the caregiver; they often just use the locomotion to explore the environment (HOCH; O'GRADY; ADOLPH, 2019). This type of locomotor activity called self-motivated by Hoch, O'Grady, and Adolph (2019) provides the infant with opportunities to learn about its body and the environment. So, locomotion can sometimes be adopted to an end (intention), and sometimes as an end (for exploration). Finally, this has to do with the idea of a "reciprocal relationship" between locomotion and perception-cognition where its developmental trajectories influence one another (BERGER; ADOLPH, 2007).

Exploratory activity depends on postural repertoire as it will influence the interactions the infant has with the environment (THURMAN; CORBETTA, 2019). Infant posture is influenced by parents' handling practices of body positioning in the first few months post-term. Parental practices are defined as the specific behaviors that fathers/mothers/caregivers present when performing take caring tasks (DARLING; STEINBERG, 1993). These practices include body manipulations that people do with infants, positioning, as well as the places where the infant is let to stay during the awake and sleep periods. Therefore, the next topic addresses the infant's body positioning as a parental practice, as well as the beliefs and expectations about development that can influence such practices.

2.2.2 Body positioning and motor development

Locomotion entails a dynamic posture in orientation to gravity (REED, 1982). Posture comprises the body's position in space and ensures balance in static and dynamic conditions (CARINI *et al.*, 2017). Moreover, posture and movement form the basic components of the action, where the former consists of the persistent orientation of the animal relative to its environment, and the latter the shifts between postures (REED, 1982). Hereupon, the achievement of new postures in motor development provides possibilities for new actions by constraining the infant´s relationship with the surroundings, like changing its worldview (KRETCH; FRANCHAK; ADOLPH, 2014).

Biomechanical alignment of the body in different positions creates different configurations for the infant-environment interactions yielding diverse sensory (proprioceptive, tactile, auditory, and visual) afferences and relations of action of gravity. For instance, it is known that infants produce more manual, oral, and visual object exploration when sitting than when positioned in prone or supine (SOSKA; ADOLPH, 2014). Or still, up to 4 months old, hand-to-hand, and hand-to-mouth behaviors are more observed in prone or lateral positions, and little in supine (ROCHA; TUDELLA, 2008). In this sense, the opportunities for the development of postural control and motor behaviors are specific to each posture experienced by the infant (MILLER *et al.*, 2011).

Recently, researchers are greatly interested in investigating prone positioning in infancy (HESKETH; JANSSEN, 2022; HEWITT *et al.*, 2020; MOREA; JESSEL, 2020; ZHANG *et al.*, 2023). This is an outcome of the campaign for the prevention of sudden infant death syndrome that states that the infant must sleep in the supine position and play in the prone (AMERICAN ACADEMY OF PEDIATRICS, 2000; SHEPHERD *et al.*, 2018; SPERHAKE; JORCH; BAJANOWSKI, 2017). Tummy time is associated with increased muscle activation of the infant´s spine in comparison with supine, sitting with support, and parent´s lap (SIDDICKY *et al.*, 2020). Furthermore, this practice is recognized for promoting motor acquisition, energy expenditure, and physical activity in infants (CARSON *et al.*, 2022; GRACIOSA *et al.*, 2018; GROSS *et al.*, 2017; HESKETH *et al.*, 2015; KOREN *et al.*, 2018). The recommendation is that infants must play in the prone position (tummy time) for at least 15 minutes up to 2 months old (HEWITT; STANLEY; OKELY, 2017) and more than 30 minutes up to one year old (TREMBLAY *et al.*, 2017). At last, a recent paper showed that from 6 months old infants´ development can be benefited from longer periods in prone practice (from 45 to 120 min/day) indicating that guidelines must consider age variations (ZHANG *et al.*, 2023).

Parents are much more adherent to guidelines concerning sleeping practices (76.2%) than those relative to playing in the prone position (30%) (HESKETH; JANSSEN, 2022). Indeed, a study with a Brazilian sample found that 47.8% of mothers of infants from 1 to 6 months old stated that they do not place their babies in the prone position at any time of the day (GRACIOSA *et al.*, 2022). The authors suggest that this practice (or rather the lack of it) might be associated with the lack of precise information on the frequency and duration of tummy time practice offered by pediatric doctors (PINTO; FALCI; MORAIS, 2017) as well as the Society of Pediatrics (BRAZILIAN SOCIETY OF PEDIATRICS, 2018) in Brazil. Therefore, as variability of motor development is explained by caregiving practices and family knowledge about it in the Brazilian population (PEREIRA; VALENTINI; SACCANI, 2016), there is a need to invest in the education of parents for them have more strategies to position their infants.

A systematic review showed that tummy time in infancy is associated with the development of early locomotion behaviors specific to this posture, such as belly and hands and knees crawling (HEWITT *et al.*, 2020). For instance, Kuo et al. (2008) followed 288 infants from four to 24 months and observed that prone duration significantly affected the onset age of crawling (KUO *et al.*, 2008). In this context, it is pertinent to suppose that the frequency on which the infant is placed in each posture is not only associated with emergence but also with the transition in locomotion acquisition.

Since postural control (that is, strategies of controlling the body's position) depends on the variable practice in different postures and maximizes the opportunities for environmental exploration forming the basis for the development of action systems (DUSING; HARBOURNE, 2010), it is suggested that the infant must experiment various positions for one day. There is evidence (GOMES et al., 2017; OUDGENOEG-PAZ; ATUN-EINY; VAN SCHAIK, 2020; VAN SCHAIK; OUDGENOEG-PAZ; ATUN-EINY, 2018) that the belief that parents or caregivers have about development is one of the factors that can influence the positioning, as well as other parental practices in infant daily care. Thus, the next item aimed to address parental beliefs on motor development, as well as present findings from previous studies of this subject relevant to this thesis.

2.2.3 Parental beliefs on motor development

Parental beliefs are the ideas, values, and goals parents have about their children growth and development (DARLING; STEINBERG, 1992). These beliefs are implicit in judgments and influence parents' decision-making regarding choices about activities performed in the daily care of the infant (HARKNESS; SUPER, 1992). In Brazil, this was evidenced by Gomes et al. (2017) that found that most activities reported as practiced by 27 parents were significantly associated with their beliefs about what was important for the motor development of the 12- and 24-month-old infants included in the sample (GOMES *et al.*, 2017). Therefore, parental beliefs must be considered in studying the elements that interact to shape the epigenetic landscape of development.

Oudgenoeg-paz, Atun-einy, and Van Schaik (2020) found an association between the beliefs and practices of Dutch and Israeli parents of infants. Based on a regression model, the results of this study for both groups indicated that the belief about the importance of stimulating motor development can predict the practice of these caregivers (OUDGENOEG-PAZ; ATUN-EINY; VAN SCHAIK, 2020). Hence, caregivers who believe stimulation is important for motor development adopted more formal techniques they judged proper for this purpose, such as passive stretching and flexing the infant's limbs and changing the infant's body position.

Formal daily care practices that target motor behavior adopted by parents can also serve as a source of knowledge for the mother or the father about the infant's body and its possibilities of movement. This was demonstrated by Hopkins and Westra (1990) who investigated the association between formal manipulation practices performed by Jamaican mothers, with their estimates on the age of onset of sitting, crawling, and walking in infants, and with the actual age of these acquisitions. The formal manipulation practices included massage and passive stretch movements and provoking active stepping by holding the infant in the standing posture. As a result, the authors observed that the greater the mother's involvement in this handling routine, the more accurate her prediction of the infant's motor acquisition was(HOPKINS; WESTRA, 1990). In this way, the formal practice of handling can make more accurate maternal expectations on the infant’s age of motor acquisition.

The fact that the authors above mentioned found that handling practices are relevant for parental prediction of infants' motor acquisition implies that this investigation should also account for different cultural backgrounds. When their infant was one month old, English, Jamaican, and Indian mothers had to estimate the age their offspring would reach independent sitting, crawling, and walking (HOPKINS; WESTRA, 1989). Results showed differences between the three groups where, the ages at which Jamaican mothers believed their infants would learn to sit, crawl, and walk were the lowest; while Indian mothers' age estimates were the highest (HOPKINS; WESTRA, 1989).

Cultural factors associated with parental beliefs about development also influence how parents prepare the environment and provide opportunities for infants´ experiences (VAN SCHAIK; OUDGENOEG-PAZ; ATUN-EINY, 2018). This was verified by Karasik et al. (2015) who assessed variations in the sitting experience offered to five-month-old infants by mothers from five groups in different countries: the United States, Argentina, South Korea, Italy, Kenya, and Cameroon. The evaluation occurred for one hour in the home environment and in the freest and most spontaneous way possible for mothers and infants. In summary, the authors found great variety between the groups regarding the place where the caregivers provided opportunities to sit (lap, benches, sofa, with or without the support of the infant's hands), the time in which they positioned the infants, and how this practice was carried out (with assistance, without assistance) (KARASIK *et al.*, 2015).

Oudgenoeg-paz, Atun-einy, and Van Schaik (2020) observed that parents of Israeli infants tend to leave them free on the floor to play longer than Dutch parents. Despite being placed on the floor for a period, infants from Dutch parents remain most of the time in a playpen or sofa (OUDGENOEG-PAZ; ATUN-EINY; VAN SCHAIK, 2020). Additionally, another study showed that Dutch parents believed that infants have their rhythm of development and that there is no need for specific stimulation; while Israeli caregivers considered that such incentives were essential for motor acquisition (VAN SCHAIK; OUDGENOEG-PAZ; ATUN-EINY, 2018). Thus, these results indicate that the variations related to cultural aspects of caregiving practices are associated with parental beliefs on motor development.

It should be noted that, in addition to the above-mentioned factors, maternal or paternal beliefs can be influenced by gender bias. Particularly for locomotion, Mondschein, Adolph, and Tamis-Lemonda (2000) saw variations in maternal expectations for crawling ability among infants of different gender, while mothers of female underestimated, mothers of male infants overestimated the performance of infants during tests (MONDSCHEIN; ADOLPH; TAMIS-LEMONDA, 2000). Furthermore, gender bias was also found in practices about crawling in parents of the same infant where mothers tend to adopt safer choices, and fathers emphasize challenges to the child (ISHAK; TAMIS-LEMONDA; ADOLPH, 2007).

This topic showed how parental handling practices are affected by cultural aspects. Moreover, it was evidenced that parents' knowledge or expectations about specific aspects of development can also influence how they encourage the infant or prepare the environment for the emergence of certain behavior. The development of independent locomotion in the infant's first year of life is an important emotional milestone for parents, and this can lead them to create environmental conditions to anticipate or promote its emergence (HENDRIX; THOMPSON, 2011). Whence, this thesis intends to consider parents' beliefs and expectations about development in the investigation of emergence and transitions of locomotion behaviors in infancy.

2.2.4 Locomotion experience

The acquisition of locomotion in early life is influenced by factors such as quantity, distribution, and variety of experiences lived by the infant (ADOLPH *et al.*, 2012). From the dictionary, experience refers to a process of getting knowledge or skill from seeing, feeling, and doing things(CAMBRIDGE DICTIONARY, 2023). In relation to a specific behavior, experience includes effects of the spontaneous or evoked activity of both sensory (exteroceptive, interoceptive, and proprioceptive) and motor neural systems during the expression of the behavior (GOTTLIEB, 1976).

Usually, the amount of experience for a behavior is reported as the counted time (in days) from the behavior onset in an infant´s repertoire up to the present moment. In the case of independent standing locomotion, for example, authors use the 'walking age' as a measure of experience (number of days since the emergence of walking) (CLARK; WHITALL; PHILLIPS, 1988). The number of days can predict changes in the functionality of locomotion (fluency, flexibility) because, as time passes, infants use afferent information for adaptation (ADOLPH; HOCH; COLE, 2018). However, Adolph, Hoch, and Cole (2018) warn that this measure is inadequate since experience cannot be treated as just the passage of time and that a description of the content accumulated in the days the infant locomoted is necessary. In this sense, some measures are helpful to quantify and qualify the locomotor experience, such as the number of steps, distances, paths covered, the number of falls, support surfaces, or other characteristics of the environment explored by the infant (ADOLPH *et al.*, 2012).

Another consideration by Adolph, Hoch, and Cole (2018) for the locomotion development study is that standardized tests are not able to represent the richness and complexity of these behaviors in infants. This conclusion was obtained based on the study by Adolph et al. (2012) who investigated infants locomoting during free play in an environment that simulated a habitual place for them. From this study, one important implication is that during locomotion, infants often walk and stop, creating bouts of walking (periods of action where behavior is observed, separated by periods of rest where behavior is not expressed) (ADOLPH *et al.*, 2012). The method of segmentation into locomotion bouts can provide information on many aspects such as exploratory activity, as well as on why infants start or stop moving (COLE; ROBINSON; ADOLPH, 2016).

This thesis considered the experience of locomotor behaviors in two different configurations. One is experience as one of the elements that shape the epigenetic landscape (frequency of a locomotor behavior observed by parents at home). The other is the experience characterized by locomotion bout classification, either quantitative (frequency, duration…) or qualitative (behavior type…) corresponding to the order parameter and behavioral states in the dynamic epigenetic landscape.

2.3 SUMMARY

This thesis considers development as an epigenetic process where changes result from coactions of the unity formed by the individual and the environment. Behavioral changes are the result of and the substrate for development. Emergence and transition compose the probabilistic epigenetic landscape of development where each new motor skill changes the infant´s relationship with the environment enabling new possibilities for action. From what was presented in this review, locomotion repertoire in infancy is characterized by diversification. Product-oriented studies found some patterns regarding progressions in the emergence of these locomotion behaviors. There is a progression from locomotion behaviors in lying postures (roll or crawl on the belly, for instance), where the infant's center of gravity is closer to the floor and there is a greater area of contact with the surface, to increasingly more unstable postures where the contact with support surfaces is minimal (hands-and-knees crawling, independent walking). Moreover, the reviewed literature showed that there is a variation in the developmental paths these progressions compose and pinpointed some elements related to locomotion development.

By adopting the epigenetic landscape metaphor this thesis proposes that the different pathways in locomotion development, that is, how the landscape is shaped, (i) are a function of distinct categories of change – emergence, and transition, and (ii) results from coaction between the different elements: infant´s characteristics and body positioning, parental beliefs, and aspects of home experience (the place where the infants stay and locomotor repertoire observed at home). The present research intended to investigate how these variables can interfere with the emergence and transition of locomotion behaviors in typical motor development from a longitudinal design. To capture the complexity of the locomotion experience in infancy, the methodology presented in the next chapter contemplates the observation of infants' spontaneous movement in a familiar environment.

3 METHOD

3.1 STUDY DESIGN

It is worth saying that the present research was conducted during the COVID-19 Pandemic that imposed social restrictions and lock downs everywhere in the world and in São Paulo was no exception. These restrictions made redesign of the research according to lines that started being proposed by developmental psychologists in virtual academic meetings, such as the Virtual International Congress of Infant Studies 2020. The study group on motor action and intervention from University of Sao Paulo took part in this meeting in which some sections were dedicated to discussing how to conduct research online having parents as co-researchers. Hence, in the present study a design for online research was developed using internet resources for online video calls and offline videos recording infant behavior. This online data collection was carried out with a prospective longitudinal design (HOCHMAN *et al.*, 2005) where infants were followed over time. The present research combines quantitative as well as qualitative features. It is quantitative because it studied motor behavior by observation, description, categorization, and analysis with math (TURATO, 2005). It is qualitative because it uses meanings and theories to understand the dynamics of the phenomenon under investigation (TURATO, 2005). Concerning the goals, this research is descriptive because of the observation and description of specific population characteristics(GIL, 2008; HADDAD, 2004).

3.2 PARTICIPANTS

Full-term infants aged 5 to 18 months (± 10 days) with typical motor development and their parents (mostly mothers) participated in this research. Infants were recruited by convenience in a non-probabilistic way through folders spread by emails, cell phones, social media, and health professionals' contacts in Brazil. Infants were divided into groups by age cohorts. Group 1 (G1) consisted of infants that were included in the study at 5 months old and were followed up to 11 months old, group 2 (G2) comprised infants followed from 9 to 15 months old, and group 3 (G3), from 13 to 18 months old.

3.2.1 Inclusion criteria

The infants who were eligible for the study had a gestational age at birth ≥37 weeks, birth weight >2500g, and Apgar score>7 in the fifth minute. Further, the infants must not have a history of complications during the birth or any neurological, physical, sensorial, respiratory, or cardiac impairments. For participating in the present investigation parents must have access to an internet connection, a cellphone, or a computer with access to some conversation app, and a digital camera (it could be from the cellphone, from the computer, or any equipment able to record videos).

3.2.2 Exclusion criteria

Infants with atypical motor development determined by the Alberta Infant Motor Scale (AIMS) percentile <25% in any assessment of the follow-up should be excluded from the study. In addition, infants participating in any kind of motor intervention program during the follow-up were also excluded from the sample.

3.2.3 Ethical Approval

This investigation was approved by the Ethics Committee of Research with Human Beings of the School of Physical Education and Sports of the University of Sao Paulo (CAAE 25789319.5.0000.5391) (ANNEX 1). The parents of the infants that participated in the study were completely informed about its aims, procedures, benefits, risks, freedom of choice to participate, and the possibility of dropping out at any time during the follow-up. Their consent for participation in the research was ensured by signing two terms, the Consent Term (APPENDIX A) and Consent for photographs, videos, and recordings (APPENDIX B).

3.3 ASSESSMENTS

3.3.1 Assessment form

The online assessment form was used to collect data on sample characterization, inclusion, and exclusion criteria), the infant´s health and home environment, parental practices and beliefs on motor development, and locomotor experience at home (APPENDIX C). The first section of the form included the consent term and questions about the participants' personal data, parents´ education, family income, infant´s health (weight, height, and other), and gestational and birth information.

3.3.1.1 Infant´s body positioning and home care

The second section included questions on the infant´s care such as places for play and body positioning throughout a usual day in the previous week of the assessment date, and if they were attending the daycare or receiving care from other people. In addition, this section asked parents if they had ever received any guidance on motor development as well as if they were afraid of placing the infant in some position. A 5-point Likert scale was adopted to investigate the weekly frequency of the infant experience in some places (floor, lap, cradle, baby carriage, or seat) and in positions (prone, supine, lateral position, quadruped, sitting, standing). Usual terms and illustrations were used in the items of the assessment form to ensure caregivers' comprehension concerning questions.

3.3.1.2 Parental beliefs on motor development

The third section included some items from the Parental Beliefs on Motor Development scale (ATUN-EINY; OUDGENOEG-PAZ; VAN SCHAIK, 2017). This instrument assesses parents' beliefs on motor development by four conceptual themes: the importance given to motor development, stimulation, the role of parents in promoting motor development, and the need for expert advice. The present investigation included in the form four statements from the section "Thoughts and ideas about motor development and parenting", that present conceptions for parents that should state their agreement on a 5-point-scale from 1 (disagree) to 5 (strongly agree) (ATUN-EINY; OUDGENOEG-PAZ; VAN SCHAIK, 2017):

(1) Motor development is one of the most important things during the first year of life.
(2) In typically developing infants, motor development occurs naturally and there is no need to actively stimulate it.
(3) It is important for a baby to reach motor milestones as early as possible.
(4) Parents should only actively stimulate their baby´s motor development if they think their baby might be behind in motor development.

These statements were translated into the Portuguese language by the present author. Also, parents were asked on what source of knowledge about motor development they used (observation, family opinion, expertise/professional guidance, books, internet) and with which frequency (never/rarely/sometimes/frequently/always). In addition, parents were requested to report the age (in months) they believed their child would achieve independent locomotion (regardless of the behavioral form) and independent walking. When they stated that the infant had already acquired locomotion and/or walking ability, the parent´s report of the month of the onset was registered. The answers on age expectations were categorized for posterior analysis.

3.3.1.3 Locomotor home experience

In the last section data was gathered about aspects of the locomotor motor repertoire of infants in the week before the assessment date. For answering the questions, parents were instructed to have in mind that locomotion is the displacement of the body from one place to another and to consider that the infant can locomote when moving a minimum distance (approximately 3 times its body length). In this section, parents had to assign on a 5-point Likert scale the frequency of observation of locomotion behaviors (crawling on the belly, on hands-and-knees, and hands-and-feet; and walking with and without support).

3.3.2 Alberta Infant Motor Scale (AIMS)

The Portuguese version (HERRERO; MASSETTI, 2020) of AIMS (PIPER, M. C.; DARRAH, 1994) was used to assess and classify the motor development status of the infants (ANNEX 2). This instrument presents a good to excellent interrater reliability with values between 0.76 to 0.99 of the Correlation Intraclass Coefficient for the AIMS sub-scores for the Brazilian population (ALMEIDA *et al.*, 2008). In addition, Canadian and Brazilian samples are similar regarding the age and sequence of acquisition of scale items (postures), which implies that the original curves can be used for research with Brazilian infants (GONTIJO; MAMBRINI; MANCINI, 2021).

The AIMS can be applied for preterm and full-term infants from 0 to 18 months old and considers for analyses three aspects of infant behavior (posture alignment, weight-bearing, and antigravity movements) with 58 items divided into four subscales: prone (21), supine (9), sitting (12), and standing (16) (PIPER, M. C.; DARRAH, 1994). Each subscale generates a score representing the sum of the punctuation of items acquired by the infant. The total score is obtained by the sum of these subitems scores and ranges between 0 and 58 points, while the higher the score, the better the motor development. Thus, the AIMS percentile is determined by using Canadian normative sample curves, the infant's age, and the total score in the assessment(PIPER, M. C.; DARRAH, 1994). In the present investigation infants with a percentile ≥ 25% were classified with typical motor development.

3.3.3 Locomotion assessment

Locomotion assessment was performed by coding behavior by an observational analysis of a video recorded by the parents and sent to the researcher every 15 days. Videos should be registered at home in a room of preference of parents, with the infant placed on the floor and over a mat. The camera should be static and be placed at a distance sufficient to provide a field view with the infant and his or her surroundings. Parents were instructed to record the infant during 8 minutes of free play and were advised to interact with the infant to evoke the locomotion behaviors that she or he commonly presented during daily routine at home.

3.4 PROCEDURES

Infants and their parents participated in this research remotely, and communication with the researcher was performed by video calls, online form assessments, and conversation apps. All procedures were performed by a single previously trained researcher physical therapist with seven years of experience in evaluating and intervening in motor development. After the recruitment, a first meeting (meeting 1) was scheduled by video call where the researcher explained in detail all procedures from the acceptance of participation up to the end of the follow-up period. Parents or caregivers were informed about the possibility of withdrawing from the study at any time. Upon acceptance, the researcher sent the assessment form for the parents to fill in the consent term and the other questions.

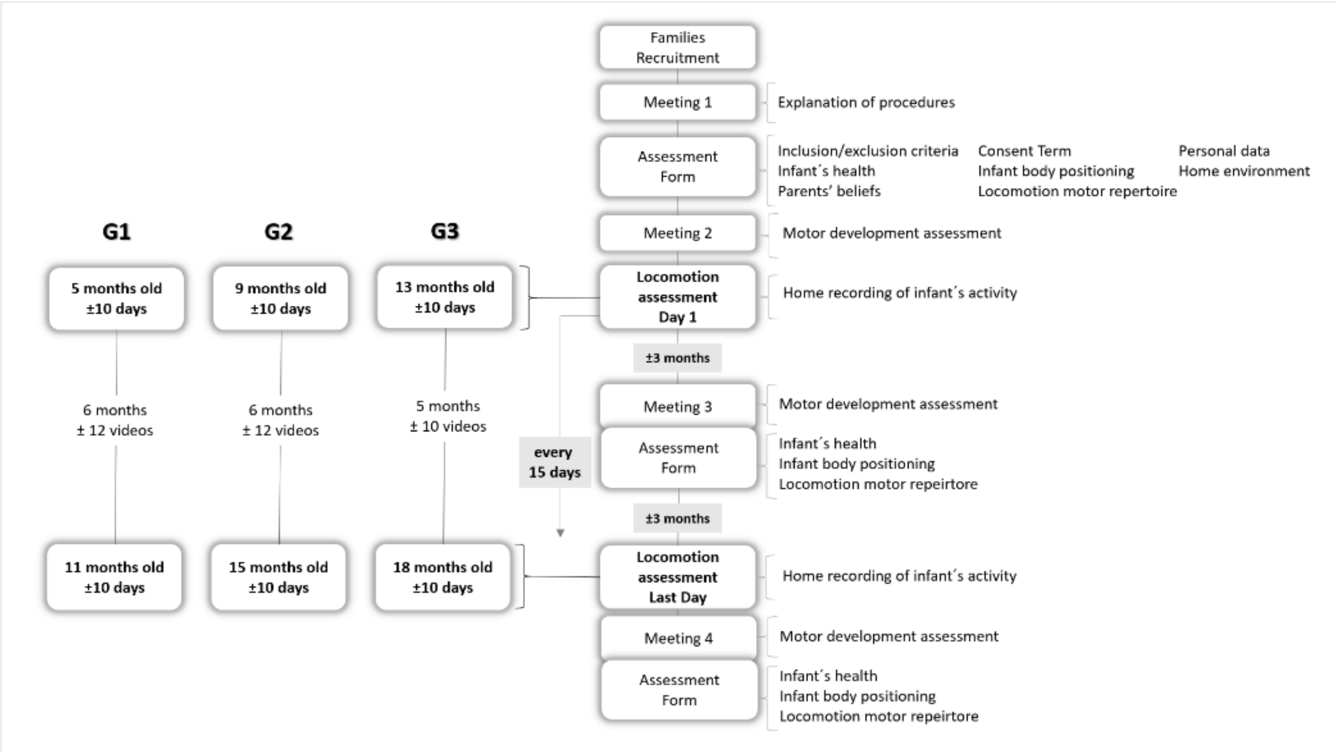
Next, a second meeting (meeting 2) was scheduled for the remote application of the AIMS. The examiner assessed the infant´s spontaneous movements in prone, supine, sitting, and standing postures. For this assessment, infants were placed by caregivers preferentially on the floor over a mat. Parents positioned the camera under the researcher's instruction to afford an appropriate visualization of the infant. Then, the examiner provided feedback based on AIMS´ total score and percentile to the parents. Parents of infants with a percentile ≥25% were invited to participate in all procedures of the follow-up, while caregivers of infants with a percentile <25% despite being excluded from the sample received guidance on motor development and were assisted by the researcher until the infant reached the 25%.

At the end of meeting 2, the researcher detailed instructions for the parents about the recordings of the infant´s locomotion activity. The camera positioning for this record was set by parents and researcher together, as well as the date of the first recording. Parents were instructed to position the infant in a preferred position in the middle of the space for filming, preferentially without clothes, shoes, and socks, with electronic equipment turned off (e.g., television, tablets, …), and with only a few toys around the infant. In addition, parents were warned to avoid touching and holding the infant during the record except for the case where the infant is off the camera's view field or was under any kind of discomfort or risk.

The videos were sent via email to the researcher every 15 days (±3 days) from day one (Day 1) up to the last day of the follow-up. During the follow-up, the researcher sent a message on the cell phone of parents with a reminder of the specific dates for the new recording and with feedback on the quality of the previous recordings. Moreover, the researcher kept in touch with parents to check if any new locomotion behavior had appeared in the infant's motor repertoire. In the affirmative case, parents were instructed to encourage the new locomotion behavior in the next recording if the infant did not present it spontaneously.

The AIMS and some parts of the assessment form were applied twice again, one in the middle, after approximately 3 months from day 1 (meeting 3), and the other at the end of the follow-up, after approximately 5 to 6 months from day 1 (meeting 4). Figure 3.1 presents an organogram with procedures and cohort age groups.

Figure 3.1 – Procedures organogram



Source: the present author.

3.5 DATA ANALYSIS

Analysis was performed by the single same examiner that accomplished all other procedures of this study. The primary analysis comprised the video processing and behavioral codification to generate variables for the secondary analysis. The secondary analysis was performed to characterize the locomotion motor repertoire of the infant in each video record and to identify changes throughout time by adopting theoretical concepts from DST.

3.5.1 Primary analysis: video processing and behavior coding

Locomotion recordings were processed by Datavyu software, a tool for behavioral analysis that allows the codification of observations from video data sources (**www.datavyu.org**). This is an open-source program that offers the user the implement to identify behaviors, set codes to generate categorical variables and register durations and other time parameters(HOCH; O'GRADY; ADOLPH, 2019). This analysis consisted of the identification and subsequent classification of periods where the locomotion behavior was expressed (COLE; ROBINSON; ADOLPH, 2016) during the whole recording, that is, the locomotion bout (LB). The present investigation considers the LB as the period in which any behaviors that result in the displacement of the infant's body are recorded and separated by rest periods (HOCH; O'GRADY; ADOLPH, 2019).

3.5.1.1 Step 1

The first step was to set the onset and the close of each LB. The onset was determined by the first frame of the video where one of the infant's feet or knees left contact with the floor or changed position by sliding on the support surface, and the offset, the first frame in which the four limbs or both feet of the infant were simultaneously on the floor or at rest for at least 500 ms (COLE; ROBINSON; ADOLPH, 2016). Previous studies indicate high interrater reliability for LB duration analysis performed between different coders with a correlation coefficient of 0.97 (COLE; ROBINSON; ADOLPH, 2016) and 0.94 (HOCH; O'GRADY; ADOLPH, 2019). The coder did not separate LB if, on the highspeed playback, the infant appeared to be still locomoting despite a pause of less than 500ms (see details in HOCH; O'GRADY; ADOLPH, 2019). The LB was split when a pause of 500ms was not identified but the infant changed the category of behavior. In this case, the close of the first LB was set just before the onset of the second LB (the first frame of the video when the different behavior of the locomotion appeared), and the close of the second one followed the 500ms pause criteria.

In the present study, the coder only analyzed the LB that attended to the following inclusion criteria: (1) It must be composed of at least 1 complete cycle of a locomotion behavior (see cycle definitions below); (2) The infant must have moved independently in the LB, without the assistance of any person or equipment. If the infant used an instrument with wheels for locomotion such as a tricycle this LB was not analyzed. However, if the infant used some apparatus with wheels for hand support, the behavior was considered a valid LB. LB was excluded from the analysis if the coder could not appropriately see or classify the behavior considering the viewing, the recording quality, and other aspects that could bias the analysis.

3.5.1.2 Step 2

The second step was to classify the LB in a behavior category and calculate the number of locomotion cycles in each bout. Locomotion behavior could be assigned into various categories: crawling (belly, hands-and-knees, hands-and-feet, asymmetrical), walking on knees (supported or unsupported), and on feet (supported or unsupported). Table 3.1 shows the description for each of the behaviors.

Next, the number of complete locomotion cycles per LB was counted. A cycle involves the progression of the four limbs through a swing phase and a stance phase of the locomotion behavior. For all crawling behaviors, the complete cycle consisted of the period between the beginning of the stance phase of one upper limb (the one that started on a stance phase) and the start of the stance phase of the same upper limb (see more details in PATRICK; ADAM NOAH; YANG, 2012). For bipedal behaviors such as walking on knees or feet, the cycle was the period between the start of the stance phase of one lower limb (the one that started on a stance phase) and the start of the stance phase of the same lower limb (FORRESTER; PHILLIPS; CLARK, 1993). When it was not possible for the coder to appropriately see and count the cycle, it was not registered and was given as missing data.

The interrater reliability for the behavior categorization and cycle counting were tested between the present researcher and another physical therapist for 150 LB of 50 videos (3 LB for each video). For behavior categorization, Cohen´s kappa coefficient (k) (MCHUGH, 2012) showed an almost perfect level of agreement between raters ($k= 0.972$, $p>0.001$). An Intraclass Correlation Coefficient (ICC) (KOO; LI, 2016) demonstrated excellent reliability on cycle counting between the raters by two-way mixed effects (absolute agreement, and single rater/measurement) ($ICC=0.97$, 95% CI 0.96 to 0.98, $F=75.302$, $p<0.001$).

Table 3.1 – Behaviors category and descriptions

Belly-crawling	crawl with belly in contact with the surface
Hands-and-knees crawling	crawl with hands and knees in contact with the surface
Hands-and-feet crawling	crawl with hands and feet in contact with the surface
Asymmetrical crawling	crawl with one or both hands, one foot, and one knee in contact with the surface
Walking on knees supported	walk on knees using hand support on furniture, or wall, or by pushing objects (chair, stroller, …)
Continues on the next page	

Walking on knees unsupported	walk on knees without hand support
Walking on feet supported	walk on feet using hands support in furniture, wall, or by pushing objects (chair, stroller, …)
Walking on feet unsupported	walk on feet without hand support

3.5.1.3 Step 3

The third step consisted of exporting the codes generated by the video processing and LB classification to a spreadsheet in Microsoft Excel and generating some parameters for the general recording as follows:

- LB events: number of occurrences of LB.
- Locomotion time (s): the sum of the LB time.
- Locomotion rate (%): percentage of locomotion time in relation to the recording time.

For each behavior category there was also the calculation of other parameters such as:

- Behavior frequency: number of LB where the behavior category appeared.
- Relative frequency (%): percentage of the behavior frequency in relation to the total of LB events.
- Behavior time (s): sum of the duration of all LB where the behavior category appeared.
- Relative time (%): percentage of the behavior time in relation to the total locomotion time.
- Cycle maximum: the number of the maximum of cycles.

3.5.2 Secondary analysis: behavioral change characterization

In the present study, DST provides a formal framework to investigate events of change in locomotion development such as emergence and transition. The concepts adopted for this analysis are operationalized in measures that correspond to the object of investigation to guarantee its objectivity, reliability, and validity. The following operational definitions (table 3.2) are supported by a fundamental idea from DST when applied to motor behavior which implies that the dynamic of a system can be characterized by mapping the behavioral patterns onto states (attractors) and by studying its stability (ZANONE; KELSO; JEKA, 1993).

The secondary analysis attended two goals. The first one was to characterize the locomotion motor repertoire of infants by mapping the behavioral states and defining its stability at each recording. The second one was to identify the occurrence of events such as emergence, and transition between the recordings. Both emergence and transition were treated as categoric dichotomic variables. The locomotion onset was registered when a first event of emergence was observed for the infants that were not able to locomote at the inclusion date on the follow-up.

Table 3.2 – Operational definitions and theoretical concepts adopted for the present analysis.

Terms	Theoretical concepts	Operational definitions
States	Behavioral patterns the system presented at a point in time (ZANONE; KELSO; JEKA, 1993).	Categories of locomotion behaviors.
Stability	Characterizes the tendency of the system to dwell in a state in a way that the higher the stability of a certain state, the more the system dwells in it. Hence, the frequency distribution is indicated to assess the stability of a state (ZANONE; KELSO; JEKA, 1993).	Measured by the relative frequency (%) of observation of the locomotion behavior on the recording day. The locomotion behavior with the higher frequency was defined as **predominant**.
Emergence	The appearance of a novel stable state in the system's repertoire (ZANONE; KELSO; JEKA, 1993).	An emergence event was registered when a new behavior appeared in the locomotor repertoire attending to the following criteria: At least 2 consecutive cycles in the LB for crawling behaviors and 3 for bipedal locomotion behaviors. This criterion for locomotor behavior onset is supported by definitions adopted from the

		Infant Motor Scale (see details in HADDERS-ALGRA; HEINEMAN, 2021)
Transition	The qualitative and abrupt change in the system´s stability regime results in a switch to a new pattern (bifurcation). This change is marked by a new and more stable pattern and the relative loss of stability of the previous stable pattern (ZANONE; KELSO; JEKA, 1993).	A transition event was registered when there was a change in the predominance among states toward a new predominant behavior. That is an increase in the frequency of certain behavior, that turns into a new predominant behavior, that overcomes the frequency of the previous predominant behavior.

3.5.3 Statistical Analysis

Analysis was performed using Statistical Package for the Social Science version 20.0 (IBM Corporation, Armonk. NY, USA), with a significance level of 5%. Descriptive statistics were calculated using frequencies (%), mean values, standard deviation (SD or ±), and 95% confidence interval (CI). Data distribution was verified by using the Shapiro-Wilk test.

Friedman test was used to verify differences over time for each group. For this analysis, four points in time were used as follows: for G1 and G2 comparisons were performed among measures of videos 1, 5, 8, and 12; and for G3 among videos 1, 4, 7, and 10 (see table 4.4 of the results section to check the corresponding age). In the case of significative statistical difference for the Friedman test ($p \leq 0.05$), the Wilcoxon test was used for pairwise comparison with the level of significance adjusted ($p \leq 0.016$).

The Independent t-test or Mann-Whitney U test was performed for comparison between two independent variables according to data distribution. Kruskal-Wallis was adopted to verify differences between more than two independent variables for non-parametric data. For parametric data, analysis of variance (ANOVA) with one or more factors was adopted to verify differences on more than two independent variables, with the Bonferroni post-hoc test, and to test the interaction between variables. For ANOVA analysis, Levene´s test was used to check the homogeneity of variances ($p > 0.05$), and the partial eta squared (η_p^2) was used as a measure of the effect size that estimates the proportion of explained variance for this analysis classified as small 2% ($\eta_p^2 = 0.02$), medium 6% ($\eta_p^2 = 0.06$), or 14% large ($\eta_p^2 = 0.14$) (COHEN, 2013).

The correlation Spearman test was run to check associations between quantitative continuous variables. Spearman's coefficient, rho (ρ), was used to the classification of the magnitude of this correlation: very weak ($\rho < 0.20$), weak ($0.20 < \rho \leq 0.39$), moderate ($0.40 < \rho \leq 0.69$), strong ($0.70 < \rho \leq 0.89$) and very strong ($0.90 < \rho \leq 1.0$). The Chi-square test was used to determine whether there is a association between categorical variables.

4 RESULTS

This chapter is divided into two sections. The first section presents results on infant characterization and of environment and locomotion. The second section shows results to answer objectives 1 and 2 of the present investigation.

4.1 CHARACTERIZATION OF INFANT, ENVIRONMENT AND LOCOMOTION

4.1.1 Infant´s characteristics: birth information, personal data, and motor developmental status

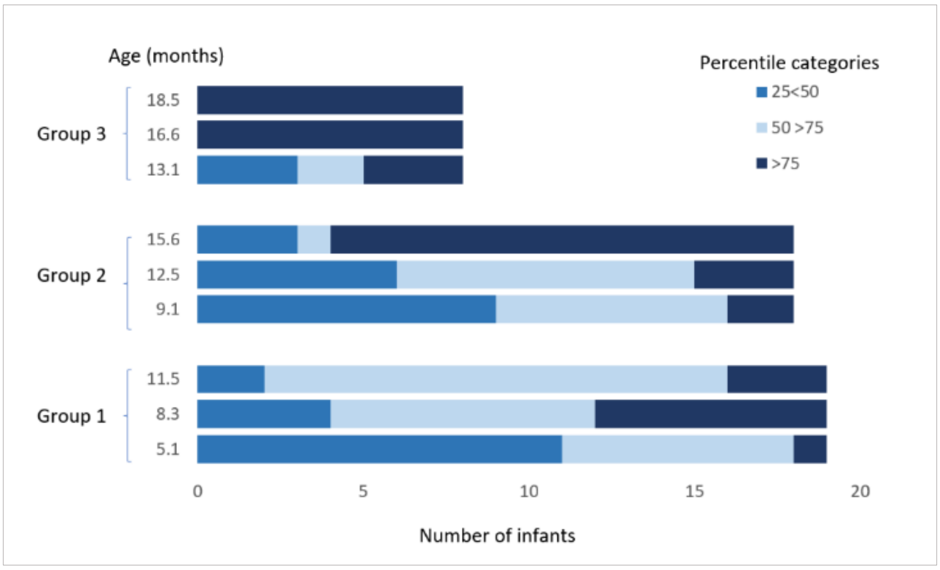
A total of 55 infants (G1, n=24; G2, n=20, G3, n= 11) and their respective parents were initially included in the sample. Of these, 12.8% dropped out of the study (G1, n=2; G2, n=2, G3, n=3), and 3 infants were excluded for living outside Brazil. The lack of time to perform research procedures was the main reason for the parents that drop out. The final sample consisted of 45 infants (25 female, 20 male); with a mean birth weight of 3.26±0.60 kg; mean birth height of 48.66cm±2.49cm; and mean gestational age of 38.87±1.12weeks. Motor development total scores and infants' characteristics at birth and during the follow-up for each age cohort group are presented in Table 4.1. At the first motor development assessment, most infants (51.1%) presented an AIMS percentile from 25 to >50; whereas at the second assessment, most infants´ (37.8%) percentile was between 50 to >75, and at the third, 55.6% of infants´ percentile was over 75. Figure 4.1 shows infant distribution in each percentile category according to age cohort groups.

Table 4.1 Infant´s characteristics at birth and during the follow-up (at the inclusion date, at the middle, and at the end).

		Group 1	Group 2	Group 3
Age cohort months		5 to 11 (n=19)	9 to 15 (n=18)	13 to 18 (n=8)
Birth weight kilogram, mean (SD)		3.25 (0.52)	3.17 (0.49)	3.51 (0.91)
Birth height centimeter, mean (SD)		48.63 (2.38)	48.33 (2.30)	49.50 (3.25)
Gestational age weeks, mean (SD)		38.95 (0.97)	38.61 (1.19)	39.25 (1.28)
Sex n, female/male		13/6	11/7	1/7
Age months, mean (SD)	Inclusion	5.07 (0.24)	9.07 (0.23)	13.07 (0.35)
	Middle	8.31 (0.28)	12.46 (0.34)	16.56 (0.56)
	End	11.51 (0.14)	15.58 (0.30)	18.53 (0.73)
Age weeks, mean (SD)	Inclusion	21.73 (1.04)	39.00 (1.18)	56.12 (1.35)
	Middle	35.63 (1.30)	53.55 (1.58)	70.87 (2.53)
	End	49.03 (0.68)	66.77 (1.35)	79.37 (3.29)
Weight kilogram, mean (SD)	Inclusion	6.91 (0.73)	8.28 (0.74)	9.80 (1.23)
	Middle	8.47 (0.85)	9.22 (0.85)	11.41 (2.20)
	End	9.40 (1.15)	9.99 (1.06)	11.17 (1.38)
Height centimeter, mean (SD)	Inclusion	63.63 (2.85)	68.41 (3.12)	76.75 (2.37)
	Middle	68.63 (3.21)	73.94 (3.09)	79.50 (5.68)
	End	72.35 (4.19)	76.81 (2.01)	79.86 (4.94)
Motor development AIMS total score	Inclusion	19.95 (2.39)	42.89 (3.66)	55.38 (2.61)
	Middle	39.68 (5.52)	53.72 (1.70)	58.00 (0.00)
	End	52.58 (2.54)	57.67 (0.68)	58.00 (0.00)

Note: AIMS, Alberta Infant Motor Scale; n, number of infants; SD, standard deviation.

Figure 4.1 Infant distribution in Alberta Infant Motor Scale percentiles category according to age cohort groups during the follow-up (at the inclusion date, at the middle, and at the end).

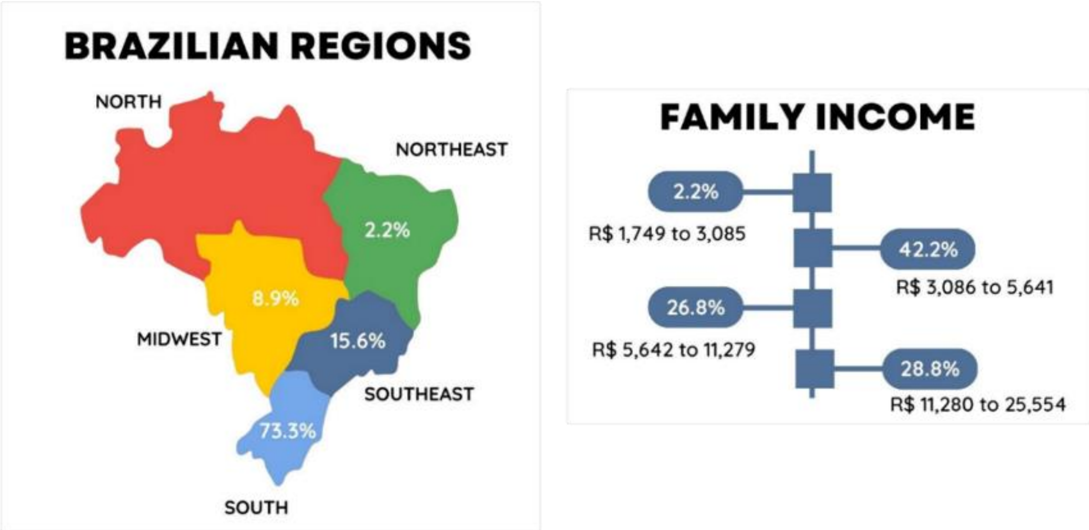


4.1.2 Environment: demographic data, infant care, body positioning, places for play, and parental beliefs/expectation on infant´s motor development

The majority (71.1%) of the sample was composed of infants of primiparous mothers. At the inclusion date of the research, the care of the infant was done prevalently by the mother for all groups (G1=94.7%; G2=83.3%; G3=75.0%). For the whole sample mean age for mothers was 34.62 years old (min 25, max 43, SD 4.34), and for fathers was 37.36 years old (min 27, max 60, SD 5.67)**.** All groups were homogeneous regarding maternal (p=0.073) and paternal age (p=0.254) as indicated by the Kruskal-Wallis test. Most parents completed higher education with a prevalence of 95.6% for mothers and 80.0% for fathers. Figure 4.2 shows sample distribution in Brazilian regions and family income.

Most parents reported receiving, at least once, guidance on motor development (62.2%) and infant body positioning (64.4%). Opinions of professionals (68.9%) and the internet, websites, and social media (73.4%) were most indicated as frequently/always used by parents as sources of information on motor development. Table 4.2 presents detailed information for each age cohort group on professional guidance received by parents, knowledge sources they assessed on motor development, infant´s time spent with the mother, and daycare attendance at the inclusion date, middle, and end of the follow-up.

Figure 4.2 Infants distribution according to Brazilian regions and family income.



The frequency with which the infant experienced different places/apparatus and body positioning for each age cohort's groups at the inclusion date, middle, and end of the follow-up are presented in Figures 4.3 and 4.4. Frequency categories were organized as never/rarely (1); sometimes (2) and frequently/always (3). The floor and a person´s lap were generally indicated as locals where the infants frequently/always experimented. In general, unsupported sitting was one of the postures most reported as adopted frequently/always by infants, except G1 which prevalently reported adoption of the supine, prone, and supported sitting positions at the inclusion date on the follow-up. Hands-and-knee position was more frequently/always adopted by G1 from the middle assessment up to the end, and by G2 at the inclusion up to the middle assessment. Standing with support was more frequently/always adopted by G1 at the end assessment, for G2 at the inclusion date and middle registers, and for G3 only at the inclusion date. Finally, for G2 at the middle and end assessment and G3 at all registers, unsupported standing was highly reported as frequently/always adopted by infants.

Table 4.2 Information on professional guidance, knowledge sources on motor development, infant´s time spent with the mother, and daycare attendance at the inclusion date, middle, and end of the follow-up.

		Group 1	Group 2	Group 3
Age cohort **months**		5 to 11 (n=19)	9 to 15 (n=18)	13 to 18 (n=8)
Parents that received professional guidance over, (frequency, %)				
Motor development		57.9	66.7	62.5
Infant body positioning		73.7	66.7	37.5
Information sources on motor development, frequently/always (frequency, %)				
Observations of other infants		15.8	11.2	12.5
Experienced family members		10.6	11.1	0.0
Other infant´s parent´s opinion		10.5	22.3	0.0
Professionals		73.7	72.3	50.0
Books		36.8	38.9	50.0
Internet, websites, and social media		78.9	66.7	75.0
Time spent with the mother for a day, frequency %				
Inclusion	<12 hours	15.8	27.8	25.0
	12 to 18 hours	10.5	11.1	25.0
	>18 hours	73.7	61.1	50.0
Middle	<12 hours	21.1	38.9	37.5
	12 to 18 hours	15.8	11.1	0.0
	>18 hours	63.2	50.0	62.5
End	<12 hours	26.3	44.4	50.0
	12 to 18 hours	31.6	22.2	25.0
	>18 hours	42.1	33.3	25.0
Daycare attendance, frequency %				
	Inclusion	0.0	11.1	25.0
	Middle	5.3	22.2	50.0
	End	5.3	33.3	50.0

Note: n, number of infants.

Figure 4.3 Frequency of infant body positioning for each age cohort group (G1, G2, G3) at the inclusion date, middle, and end of the follow-up.

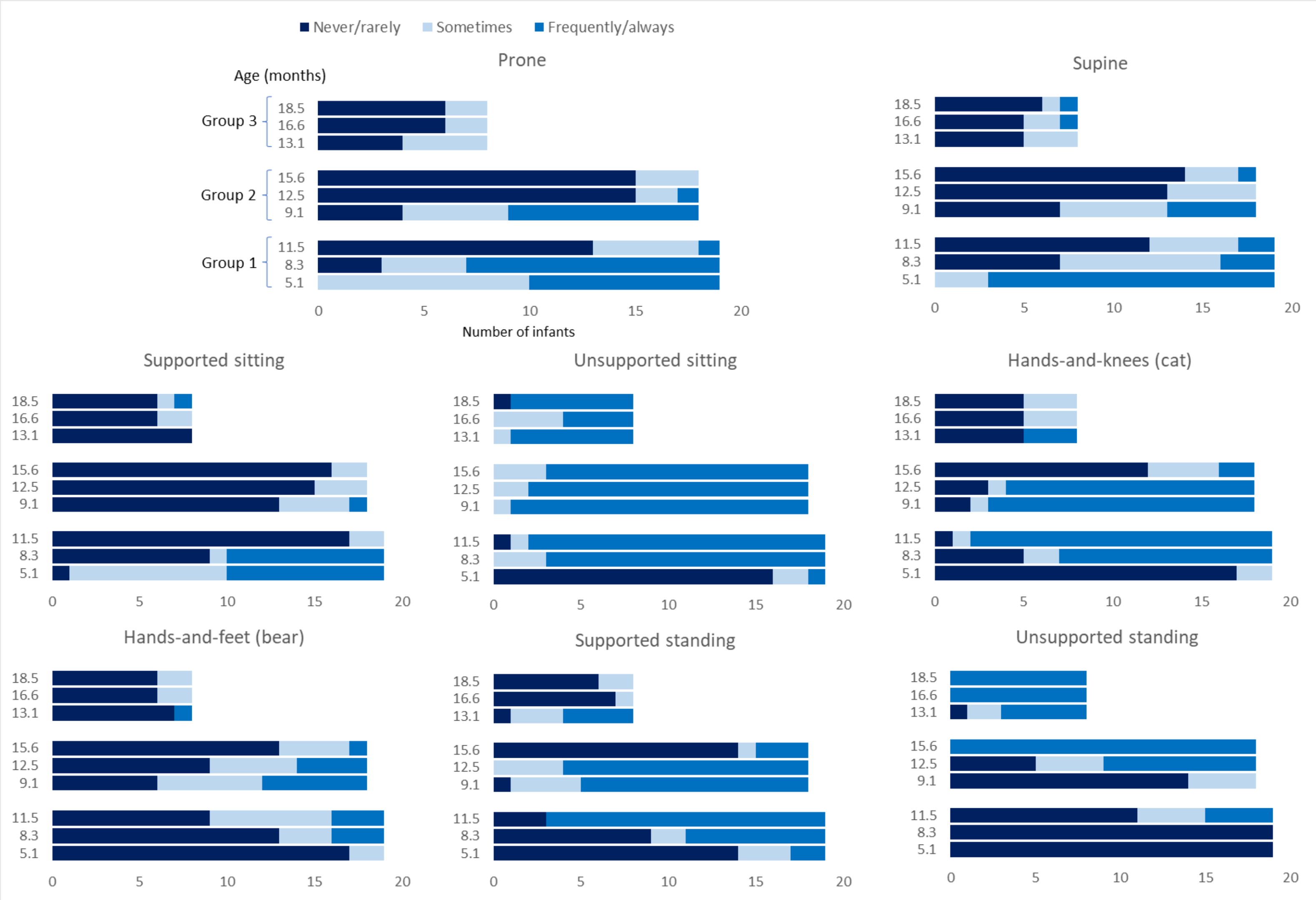
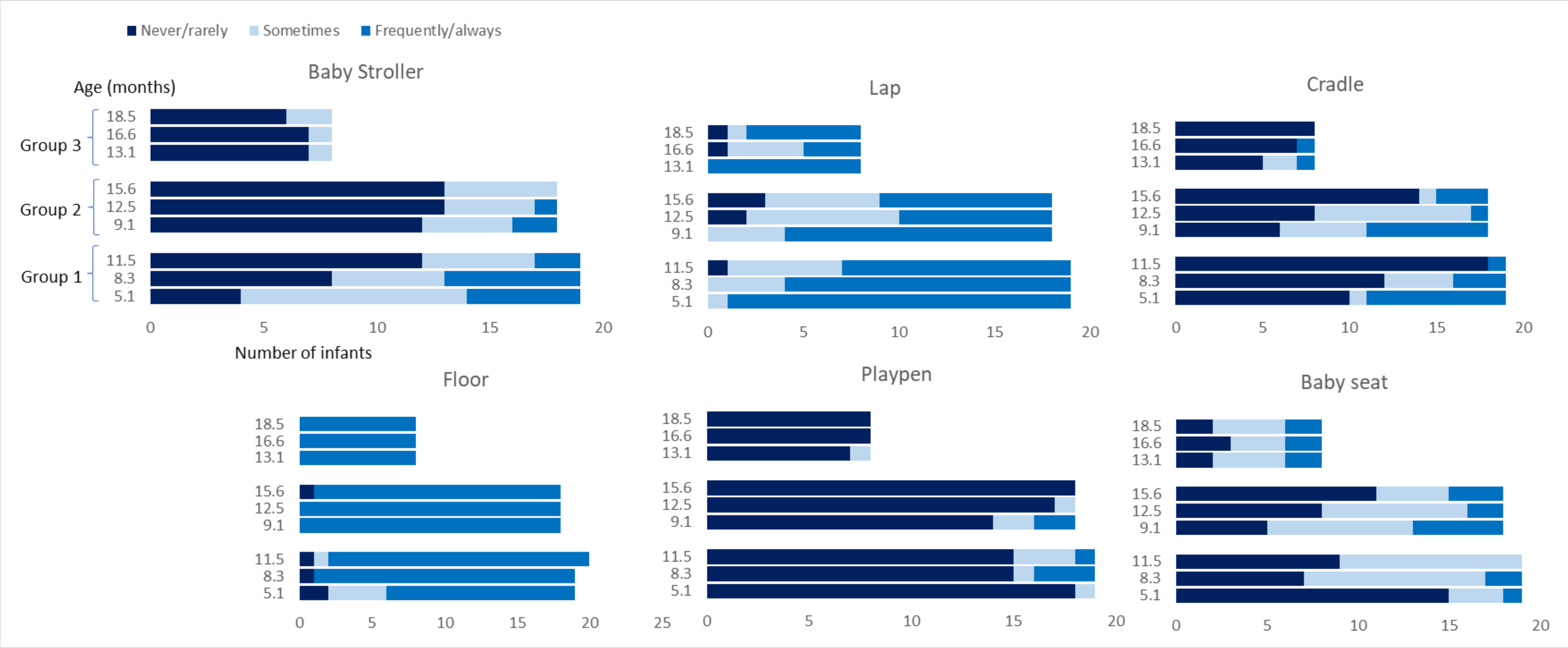


Figure 4.4 Frequency that the infant stayed in different locals for each age cohort group (G1, G2, G3) at the inclusion date, middle, and end of the follow-up.



For characterization of parental beliefs on motor development frequency categories of agreement on conceptions about motor development were organized as strongly disagree/disagree (1); indifferent (2), and strongly agree/agree (3). In regard the parents whose infants could not locomote at the date of inclusion in the study, 66.7% reported expecting the onset between 7 and <9 months old. For the onset of independent walking on feet, most parents (88.9%) of infants not able to walk at the beginning of the follow-up expected an onset between 11 and >13 months old (Table 4.3).

Table 4.3 Parental agreement with conceptions about motor development and expected age for locomotion and independent walking onset for each age cohort group at the inclusion date in the follow-up.

		Group 1	**Group 2**	**Group 3**
Age cohort months		5 to 11 (n=19)	9 to 15 (n=18)	13 to 18 (n=8)
Conceptions about motor development, (frequency, %)				
Motor development is one of the most important things during the first year of life.				
	Disagree	0.00	0.00	0.00
	Indifferent	0.0	0.0	0.0
	Agree	100	100	100
In typically developing infants, motor development occurs naturally and there is no need to actively stimulate it.				
	Disagree	36.8	27.8	25.0
	Indifferent	42.1	33.3	12.5
	Agree	21.1	38.9	62.5
It is important for a baby to reach motor milestones as early as possible.				
	Disagree	57.9	44.5	50.0
	Indifferent	42.1	33.3	37.5
	Agree	0.0	22.2	12.5
Parents should only actively stimulate their baby´s motor development if they think their baby might be behind in motor development.				
	Disagree	89.5	83.3	62.5
	Indifferent	10.5	5.5	25.0
	Agree	0.0	11.2	12.5

*Continues on the next page

Locomotion onset			
Non-locomotor infants (inclusion date)	(n=18)	(n=0)	(n=0)
Expected age (months), frequency %			
6 to <7	16.7	-	-
7 to <8	38.9	-	-
8 to <9	27.8	-	-
9 and above	16.7	-	-
Independent walking onset			
Non-walker infants (inclusion date)	(n=19)	(n=18)	(n=2)
Expected age (months), frequency %			
10 to <11	5.6	16.7	0.0
11 to <12	33.3	38.9	0.0
12 to <13	55.6	44.4	0.0
13 to <14	5.6	0.0	0.0
14 and above	0.0	0.0	100

N=number of infants

4.1.3 Locomotion data characterization: motor repertoire at home and video observation

4.1.3.1 Locomotion repertoire

According to the parent's report, 57.8% of the sample, that is, all infants from G2 and G3 and one infant from G1 were able to locomote independently at the inclusion date of the follow-up. Of these, 14.8% started to locomote under 6 months old, 29.7% between 6 to < 7 months old, 33.3% from 7 to <8 months old, and 22.2% between 8 to 10 months old. Among all infants able to locomote, belly-crawling (48.1%) and hands-and-knees crawling (51.9%) were reported as the first behavior observed at the onset. Six infants, all from G3, could walk on their feet independently at the inclusion date. Of these, 1 infant started to walk without support at 9 months old, 1 at 10 months old, 2 at 11 months old, and 2 at 12 months old.

Parents' report on locomotion repertoire for each age cohort group (G1, G2, G3) at the inclusion date, middle, and end of the follow-up is illustrated in Figure 4.5. At the end of the follow-up, some parents didn´t answer the questionnaire resulting in missing values (G1, n=2; G2, n=1; G3, n=3). The behavior most obsverved by parents always/frequently at the inclusion date was belly crawl (5.3%) for G1, hands-and-knees crawl (55.6%) for G2, and unsupported walk on feet (75.0%) for G3. In the middle of the follow-up, hands-and-knees crawl (44.4%) was prevalently reported as always/frequently for G1, supported walk on feet (77.8%) for G2, and unsupported walk on feet (100.0%) for G3. For G1, both hands-and-knee crawl (88.2%) and supported walk on feet (88.2%) behaviors were mostly reported as always/frequently observed at the end of the follow-up, and the unsupported walk on feet was predominant for G2 (82.4%) and G3 (100.0%).

4.1.3.2 Locomotion video observation

A total of 484 videos were analyzed, with a mean of 10.75 records (min=9, max=12, SD=1.13) for each infant and a mean interval of 17.75 days (min=12, max=35, SD=3.85) between them. The videos were distributed according to the infant's age at the date of the record. This strategy was used in the analysis because some parents took more than 22 days for recording a new video. In these cases, in the age range where there was no video record for an infant in the age range, a missing value was reported. Table 4.4 details the total of infants´ locomotion observations and missing values about each age. There was an overlap between the age cohort groups resulting in more locomotion observations in the interval between 9.45 to 11.04 months old, and 13.57 to 14.80 months old (table 4.4).

Each video lasted a mean of 7.73 minutes (min=3.6, max=14.0, SD=1.21). For longer recordings (>8min) only the first 8 minutes were analyzed, whereas for shorter videos (<8min) all minutes were analyzed. A total of 6922 locomotion bouts were analyzed with a minimum of 0 and a maximum of 52 per video. Over the follow-up (all measures), there was a mean of 153.82 (min= 21, max=357, SD=97.01) locomotion bouts analyzed per infant.

Figure 4.6 shows the mean locomotion rate for each age cohort group along with the follow-up. Friedman's test showed that the locomotion rate did not change over time for G2 (p=0.054) and G3 (p=0.401) and that there was a significant increase in locomotion rate (p=0.000) for G1, from 5.5 months old (video 1) to 11 months old (video 12) (p=0.007). For these infants, the locomotion rate was higher at 9.0 months old (video 8) in comparison with the age of 7.5 months old (video 5, p=0.001). At 11 months old, the locomotion rate was higher when compared to other measures (videos 1, 5, and 8, p=0.000).

Table 4.4 Total (count frequency) of infant´s locomotion observations and missing values in relation to each age in mean and 95% of confidence interval (CI 95%).

		Group 1 5 to 11 (n=19)		**Group 2** 9 to 15 (n=18)		**Group 3** 13 to 18 (n=8)		
Age months, mean (CI 95%)	**Ordinal measure**	Video Position	Missing Values (n)	Video position	Missing Values (n)	Video position	Missing Values (n)	Observations per age, total
5.35 (5.28 – 5.43)	1	1	0					19
5.85 (5.80 – 5.91)	2	2	3					16
6.34 (6.27 – 6.41)	3	3	1					18
6.86 (6.78 – 6.94)	4	4	0					19
7.36 (7.27 – 7.44)	5	5	2					17
7.88 (7.79 – 7.96)	6	6	2					17
8.45 (8.35 – 8.54)	7	7	1					18
8.98 (8.88 – 9.08)	8	8	1					18
9.45 (9.37 – 9.52)	9	9	2	1	0			**35***
10.02 (9.95 – 10.09)	10	10	0	2	2			**35***
10.61 (10.53 – 10.69)	11	11	0	3	5			**32***
11.04 (10.85 – 11.24)	12	12	0	4	1			**36***
11.48 (11.39 – 11.57)	13			5	2			16
11.99 (11.88 – 12.09)	14			6	4			14
12.50 (12.38 – 12.63)	15			7	4			14
13.04 (12.93 – 13.16)	16			8	1			17
13.57 (13.49 – 13.65)	17			9	1	1	0	**25***
14.14 (14.05 – 14.22)	18			10	0	2	0	**26***
14.75 (14.63 – 14.86)	19			11	1	3	0	**25***
15.34 (15.20 – 15.47)	20			12	1	4	2	**23***
15.43 (15.20 – 15.67)	21					5	1	7
15.87 (15.64 – 16.10)	22					6	1	7
16.40 (16.19 – 16.61)	23					7	1	7
17.05 (16.88 – 17.23)	24					8	0	8
17.70 (17.52 – 17.88)	25					9	1	7
18.32 (18.18 – 18.47)	26					10	0	8

*Total number of observations for overlap between age groups

Figure 4.5 Frequency of locomotion behaviors observed and reported by parents for each age cohort group (G1, G2, G3) at the inclusion date, middle, and end of the follow-up.

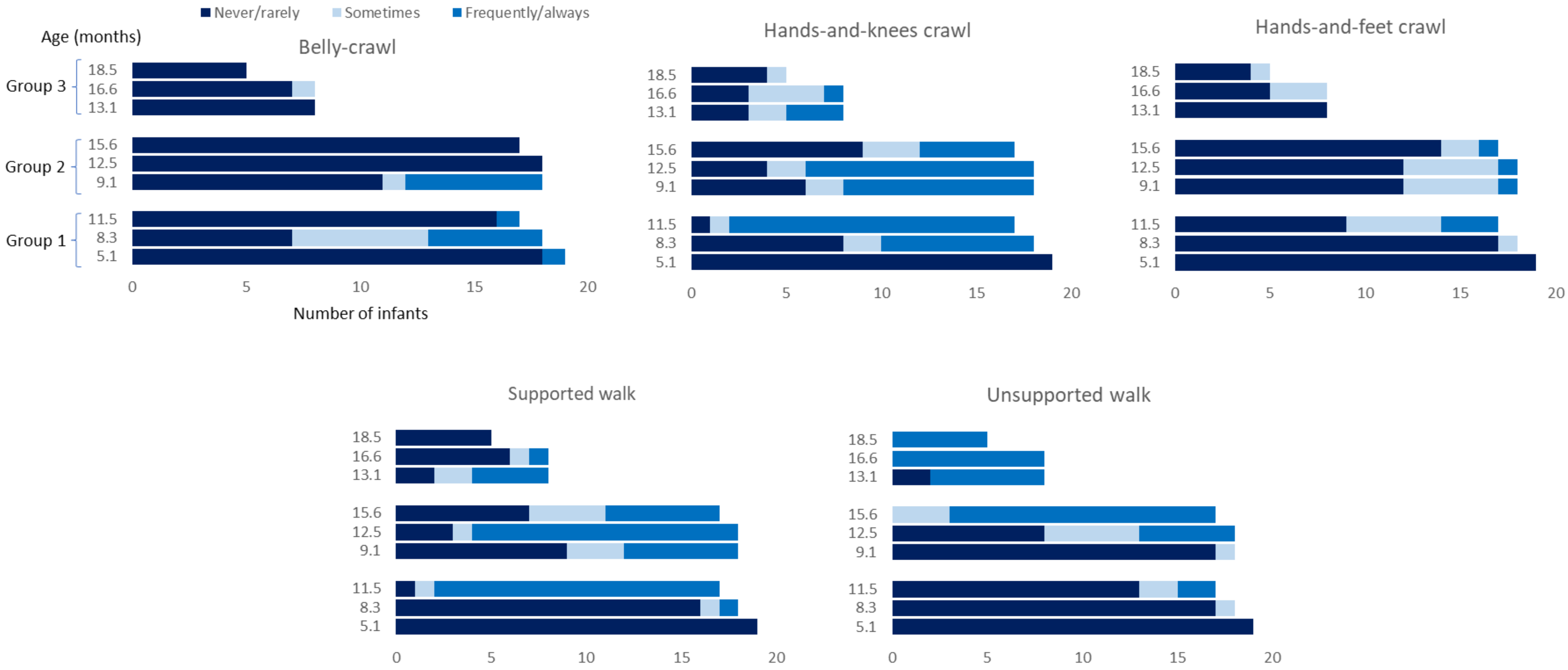
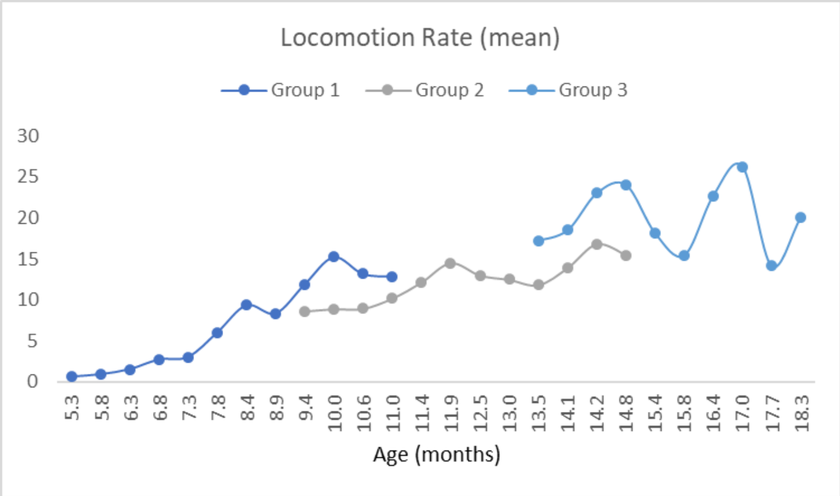


Figure 4.6 Mean of locomotion rate (%) for each age cohort group along with the follow-up.



As relative time and relative frequency of all locomotor behaviors were very strongly correlated by Spearman test (rho>0.90, p<0.05) only one of these variables was presented. The relative frequency of locomotor behaviors for all infants over the follow-up is displayed in Figures 4.7 and 4.8. These figures show the mean of all locomotion patterns for each time point about the infant´s age in months (check details in the number of infants for each time point in Table 4.4). A Friedman Test was run to check for significant differences in the relative frequency of locomotion patterns between measures in time for each age group. There were no significant differences over time for belly crawl, asymmetrical crawling, and walking on knees with and without support (p>0.05). The relative frequency of crawling on hands and knees changed over time for infants of G1 and G2 (p=0.000) but not for infants of G3 (p=0.888). For G1, at 9.0 months old the relative frequency of hands-and-knees crawling was higher than at 5.5 (p=0.002) and 7.5 months old (p=0.013). For G2, the relative frequency of hands-and-knees crawling decreased at 15.0 months old when compared to other time points (video 1, p=0.001; video 5, p=0.004; video 8, p=0.008). The relative frequency of supported walking on feet decreased from 13.57 to 17.70 months old for G3 (p=0.0018) and increased for G1 from 7.5 to 11.0 months old (p=0.001) whereas, for infants from G2, there was an increase from 9.5 to 11.5 months old (p=0.000) and a decrease from 11.5 to 15.0 (p=0.002). The relative frequency of unsupported walking on feet changed over time (p=0.000) only for G2 with a significant increase from 9.5 to 13.0 months old (p=0.012) and from 11.5 to 15.0 (p=0.001).

Figure 4.7 Mean of the relative frequency of crawling behaviors for all infants (n=45) at each time point (in months) from 5 to 18 months old.

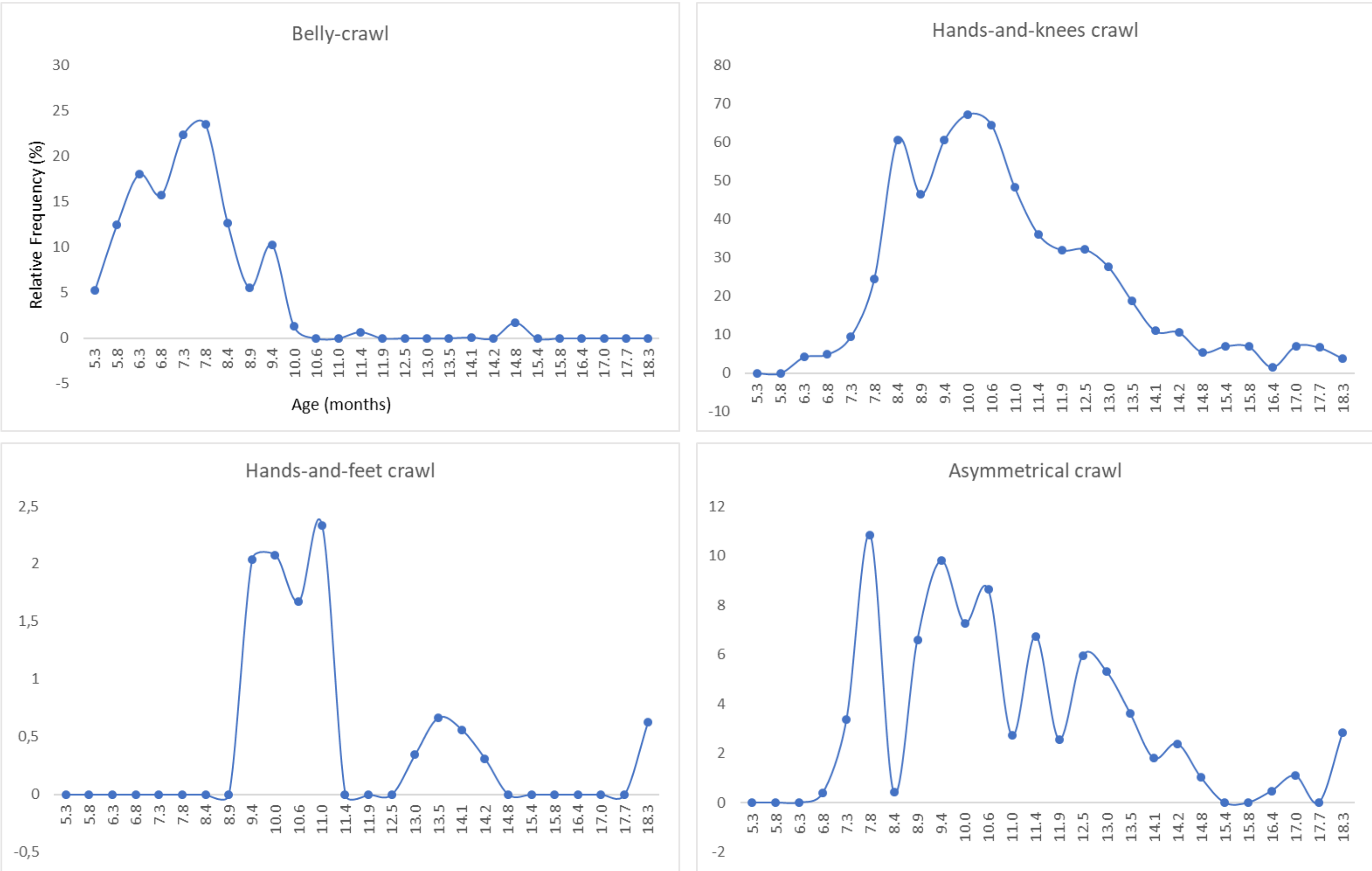
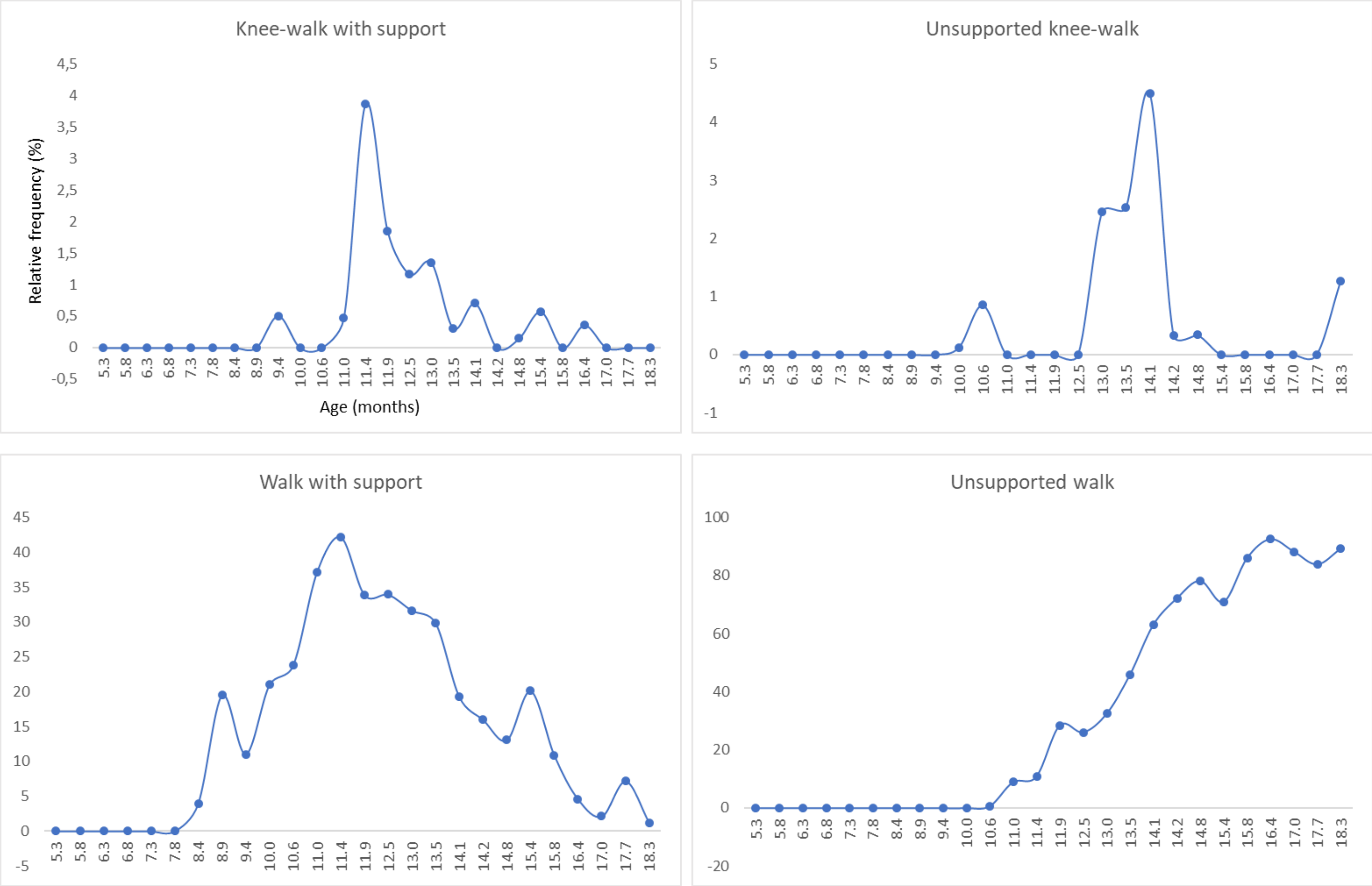


Figure 4.8 Mean of the relative frequency of bipedal locomotion behaviors for all infants (n=45) at each time point (in months) from 5 to 18 months old.



This first section of results intended to characterize the infants included in the study, as well as relevant aspects about their parents, their environment and locomotion repertoire. The sample consisted mostly of infants whose parents had a high level of education and predominantly lived in the southern region of Brazil during the data collection. In general, parents reported having access to information about the infant´s motor development. When questioned about beliefs related to conceptions of motor development and expectations about age of acquisitions, the results showed diversity in the answers given by parents of different infants. According to the parents' report, a great part of infants from all groups frequently remains on the floor and in the lap of a person. Concerning locomotion observations, the relative frequency of belly crawling was higher around 5 to 7 months of infant´s age, and of the other types of crawling such as hands-and-knees, asymmetrical and hands-and-feet crawling were more common from 7 months and less common after the 11 months old. The relative frequency of walking on knees with support was higher around 11 months old and without support next to 13 months old. For walking on feet with support, the relative frequency increased from the 9 months and decreased from 11 months where unsupported walking on feet relative frequency started to increase. The next section characterized events of emergence and transition in pathways of locomotion development of these infants.

4.2 EMERGENCE AND TRANSITION IN LOCOMOTION DEVELOPMENT

4.2.1 Characterization of emergence and transition

This section intended to answer the primary objective of this thesis that was to characterize the emergence and transition of locomotion behaviors in the developmental pathways of typical infants from five to 18 months old.

4.2.1.1 Emergence (appearance of a new behavior in the locomotor repertoire)

Locomotion onset

For the infants that were not able to locomote independently at the inclusion date of the study (n=18, G1), the first event of emergence was by belly-crawling (n=7, mean age 7.38 months old, SD=1.03, min=5.90, max=8.67), hands-and-knees crawling (n=9, mean age 8.78 months old, SD=1.04, min=7.17, max=10.57) or asymmetrical crawling (n=2, ages of 7.80 and 7.90 months old). The age at locomotion onset by belly crawling was significantly lower than for those infants who did it by hands-and-knees crawling as indicated by the Independent t-test (p=0.018, 95% CI of difference 0.27 to 2.52). The only infant of the G1 that could locomote independently at the inclusion date (5.37 months old) did it by crawling on the belly.

The emergence of locomotor behaviors over the follow-up

The total number of emergence occurrences for all locomotor behaviors at each age cohort group over the follow-up is presented in Table 4.5. Hands-and-knees crawling was the one behavior that emerged for all infants in G1, while asymmetrical crawling emerged for 63.1% of these infants, belly crawling for 15.5%, and supported walking on feet for 79.0%. Of the infants of G1 that started to walk on feet without support (n=3), one did it at 10.83 months old (age of locomotion emergence 8.37 months old by hands and knees crawling). For the other two infants, the emergence of independent walking on feet occurred at 11.30 months old, and for both, locomotion emergence occurred by belly-crawling, one at 6.4 months old, and another before the inclusion date of the study (<5.37 months old).

Hands-and-feet crawling (6.6%) and walking on knees with support (4.4%) or without support (6.6%) emerged only for a few infants representing a small percentage of all the sample. For all infants of G2 there was the emergence of walking on feet, both supported and unsupported. For the same group, the emergence of hands-and-knees (15.7%) and asymmetrical (15.7%) crawling occurred for a few of them. For G3, there was the emergence of unsupported walking on feet for 3 infants, one at 13.87 months old, another at 13.97 months old, and the last at 16.2 months old (mean 14.67, 95%CI 11.37 – 17.97).

Pathways of emergence

The different pathways of the emergence of locomotor behaviors for infants from age cohort groups 1 and 2 over the follow-up are presented in Figure 4.9. There were 15 different pathways of emergence for G1 and 8 for G2. For both groups, some behaviors emerged together at the same time point. In general, hands-and-knees crawling emergence occurred after belly crawling and before supported walking on feet. For one infant of G1 hands-and-knees crawling emerged at the same time point that supported walking on feet. For both groups, the emergence of asymmetrical crawling varied from before, together, and after the emergence of hands-and-knees crawling and supported walking on feet. Crawling on hands and feet behavior emerged simultaneously as supported or unsupported walking on feet for different infants. Unsupported walking on knees emerged for the two infants after the emergence of walking on feet with support and for one after unsupported walking on feet. Unsupported walking on feet emerged after walking on feet with support, except for one infant from G2 where emergence occurred simultaneously for these behaviors. The behaviors that emerged most frequently together were asymmetrical crawling and walking on feet with support for 8 infants.

Table 4.5 Total of emergence events and corresponding age (in months) for groups 1 and 2 over the follow-up.

	Group 1		Group 2		
Age cohort, months	5 to 11 (n=19)		9 to 15 (n=18)		
Crawling	n	Age Mean, 95% CI	n	Age Mean, 95% CI	Total
Belly	7	7.34 (6.39 – 8.30)	0		7
Hands-and-knees	19	8.61 (8.08 – 9.15)	3	9.92 (9.53 – 10.31)	22
Hands-and-feet	2	10.60 (1.32 – 19.88)	1	10.67*	3
Asymmetrical	12	9.31 (8.66 – 9.97)	3	9.85 (9.65 – 10.05)	15
Walk on knees					
supported	0		2	11.15 (8.86 – 13.44)	2
unsupported	1	10.37*	2	13.35 (10.55 – 16.15)	3
Walk on feet					
supported	15	9.54 (9.12 – 9.96)	18	10.88 (10.38 – 11.37)	33
unsupported	3	11.15 (10.46 – 11.85)	18	13.33 (12.65 – 14.00)	21

Note: age in months; n, count frequency; 95% CI, 95% confidence interval for a mean; *absolute value of age corresponding to one infant.

Figure 4.9 Different pathways of the emergence of locomotor behaviors for infants from age cohort groups 1 (n=19) and 2 (n=18) over the follow-up.

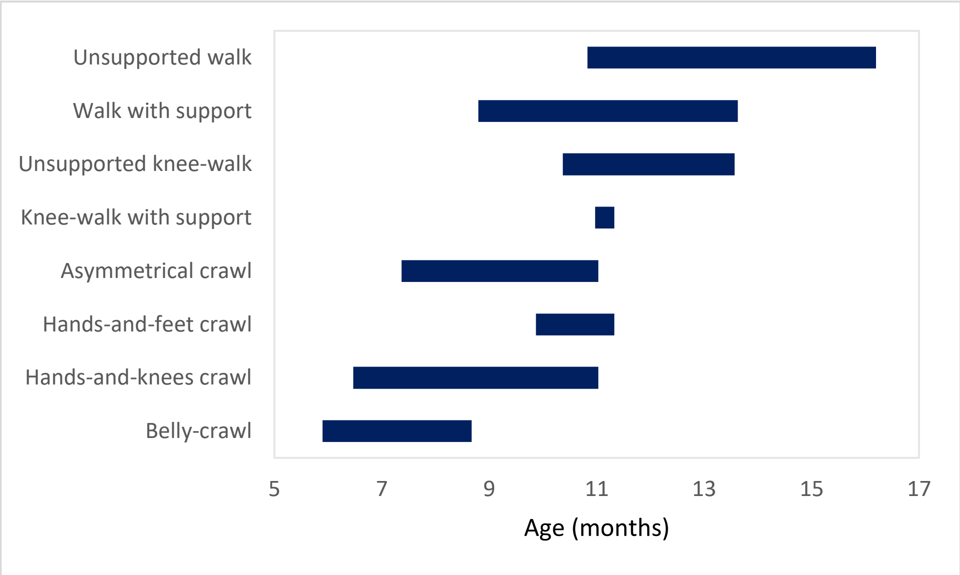
Note: Circle represents an emergence event with the color corresponding to a behavior category; Arrows represent a new emergence in another time point; More than 1 circle together means that more than 1 behavior emerged in a certain time point; n is the number of infants who presented a certain pathway. Group 3 was not included in the figure because there was emergence only for unsupported walking on feet behavior.

Emergence age

The range of emergence age found for each locomotor behavior for all infants (G1, G2, G3 together) during the follow-up is illustrated in Figure 4.10. Walking on feet with support (range=4.83) and without support (range=5.37), and hands-and-knees crawling (range=4.56) were the behaviors with the widest age range for emergence. The behavior category (belly, hands-and-knees, or asymmetrical crawling) presented at the locomotion onset of infants from G1 was not associated with the age of walking on feet with support emergence as indicated by the Mann-Whitney U test ($p>0.05$).

The spearman correlation test showed that the emergence age of supported walking on feet was significantly associated with the emergence age of crawling on hands and knees ($p=0.011$) and asymmetrically ($p=0.022$). It was found that the lower the emergence age of hands-and-knees (rho=0.584, moderate correlation) or asymmetrical crawling (rho=0.604, moderate correlation), the sooner the emergence of walking on feet with support. No correlation was found between the emergence age of supported walking on feet and crawling on the belly (p=0.208) and unsupported walking on feet (p=0.160).

Figure 4.10 Age range in months (minimum and maximum) for emergence events for all infants (n=45) during the follow-up.



4.2.1.2 Transition (a change in the predominance among states toward a new predominant behavior)

<u>The transition to locomotor behaviors over the follow-up</u>

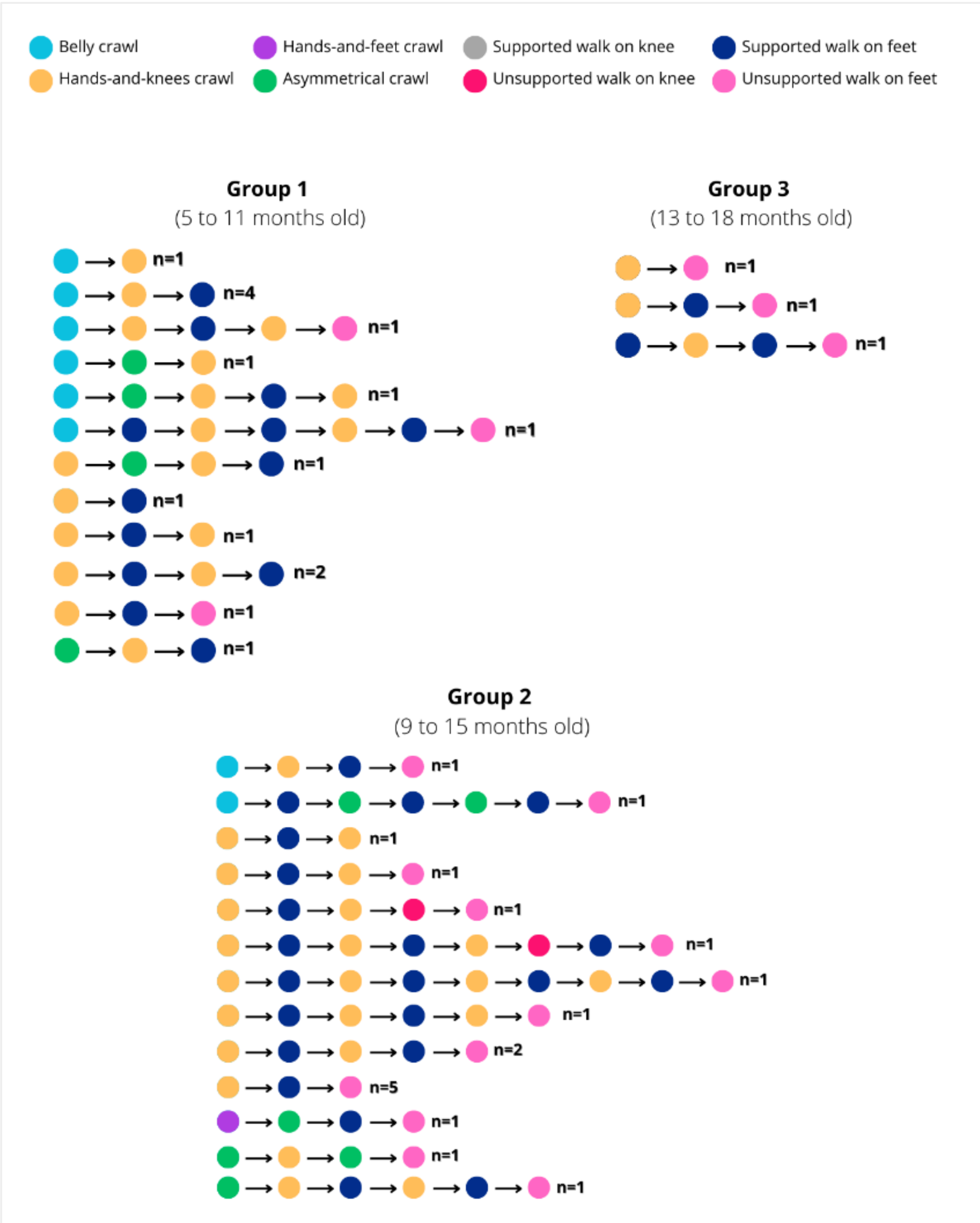
In total, there were 115 events of transition between locomotor behaviors (G1, 42 events, min=0 and max=6 for an infant; G2, 67 events, min=2 and max=8 for an infant; G3, 6 events, min=0 and max=3 for an infant). For 3 infants from G1, there was no transition event over the follow-up (these infants presented only one emergence event, hands-and-knees crawling at ages 9.40, 9.66, and 11.03 months old). There were transition events for all infants from G2 and for 3 infants from G3.

The number of transition events for each behavior category according to age cohort groups is shown in Table 4.6. Most transition events were to hands-and-knees crawling (30.5%), supported walking on feet (41.7%), and unsupported walking on feet (20.0%). For infants from G1, the transition to hands-and-knees crawling and walking on feet with support were equally prevalent (42.9%). There was a transition to unsupported walking on feet for 3 infants of G1. For 2 of them, the emergence of this behavior was registered at the same time point of the transition (note that these 2 infants have no missing data). For one of them, unsupported walk emergence was registered at one point in time (penultimate video) and the transition at the next point (last video). Most transition events for G2 were to walk on feet with support (41.8%) and without support (25.4%) and to crawl on hands and knees (23.9%). Only 1 infant of G2 did not present the transition to unsupported walking on feet, although this behavior had emerged at 14.97 months old (penultimate video). There were only 2 transition events for unsupported walking on knee behavior, for 2 infants from G2, and no transition to belly and hands and feet crawling and walking on knees with support. Most transition events in G3 were to walk on feet without support (50.0%). Spearman correlation test showed a positive association between the number of transition events to hands-and-knees crawl and to walking on feet with support both for G1 ($p=0.033$; $rho=0.491$, moderate) and G2 ($p=0.029$; $rho=0.514$, moderate).

Transition pathways

The different pathways of transition between locomotor behaviors for infants from age cohort groups 1, 2, and 3 over the follow-up are displayed in Figure 4.11. There were 12 different transition pathways for infants from G1, 13 for G2, and 3 for G3. Transition events from crawling on the belly were more frequent to hands-and-knees or asymmetrical crawling behaviors, except for 2 infants that did it to walk on feet with support (one from G1, and the other from G2). From hands-and-knees crawling behavior the most frequent transition occurrence was to walking on feet with support. The transition from asymmetrical crawling occurred mostly to hands-and-knees crawling or supported walking on feet. The most frequent transition events from walking on feet with support were to the hands-and-knees crawling behavior and to unsupported walking on feet. Transitions from hands-and-knees crawling to walking on feet with support and vice-e-versa were observed recurrently for all groups showing cycles of predominance of these two behaviors (see yellow and dark blue circles in Figure 4.11). There was no transition event to crawling on hands and feet and supported walking on knees. Transition events to unsupported walk-on-feet behavior were in the majority from walking on feet with support but also occurred from hands-and-knees or asymmetrical crawling and walking on knees without support. There was no transition event after the transition to unsupported walking on feet. The crawling on hands and feet was the predominant behavior in the locomotor repertoire for only one infant at the inclusion date of the research with a transition event to asymmetrical crawl behavior (note that this was the first infant in which unsupported walking on feet behavior emerged for G2 at 10.93 months old).

Figure 4.11 Different pathways of transition between locomotor behaviors for infants from age cohort groups 1 (n=16), 2 (n=18), and 3 (n=3) over the follow-up.



Note: Circle represents the predominant locomotor behavior with the color corresponding to a category; The circle to the left represents the first predominant locomotor behavior observed in the infant´s motor repertoire; Arrows represent a transition event; n is the number of infants that presented a certain pathway.

Table 4.6 Total number of transition events to crawling and walking on feet behaviors for groups 1, 2, and 3 over the follow-up.

	Group 1			**Group 2**			**Group 3**			
Age cohort, months	5 to 11 (n=16)			9 to 15 (n=18)			13 to 18 (n=3)			
	Infants	Transition events	Min/max for infant	Infants	Transition events	Min/max for infant	Infants	Transition events	Min/max for infant	Total transition events
Crawling	n*	n		n*	n		n*	n		n
Hands-and-knees	13	18	0 – 2	11	16	0 – 3	1	1	0 – 1	35
Asymmetrical	3	3	0 – 1	3	4	0 – 2	0	0		7
Walk on feet										
Supported	14	18	0 – 3	17	28	0 – 4	2	2	0 – 1	48
Unsupported	3	3	0 – 1	17	17	0 – 1	3	3	0 – 1	23

Note: n, count frequency; min, minimum; max, maximum; n*, number of infants that presented at least 1 event of transition to the corresponding behavior category.

Age at the first event of transition to walking on feet (supported and unsupported)

The age at the first event of transition to walking on feet with and without support was calculated for infants from G1 and G2. For infants from G3, only the age at the first event of transition to unsupported walking on feet was considered. The mean age for the first event of transition to the supported walking on feet behavior was 10.35 months old (SD=1.01, Min=8.53, Max=11.70) for infants from G1 and, 11.34 months old (SD=0.80, Min=9.77, Max=13.20) for infants from G2. For the first event of transition to unsupported walking on feet, the mean age was 11.34 months old (SD=0.05, Min=11.30, Max=11.40) for G1, 13.46 months old (SD=1.39, Min=11.27, Max=15.50) for G2 and 15.13 months old (SD=1.17, Min=13.87, Max=16.20) for G3. Considering all the infants from the sample that over the follow-up presented a first transition event both to supported and unsupported walk on feet (n=19), it was found that the lower the age for the first event to transition to walk on feet with support, the lower the age for transition to unsupported walk on feet (p=0.009 by spearman correlation test, rho=0.580, moderate correlation). For infants from G2, results showed that the higher the number of transitions to supported walk on feet over the follow-up, the later the transition to unsupported walk on feet occurred (p=0.011 by spearman correlation test, rho=0.597, moderate correlation).

Transition and emergence

The emergence ages for locomotion, hands-and-knees, and belly crawling for infants from G1 according to transition events to the supported walk on feet behavior is shown in Table 4.7. It was found that the infants from G1 who presented at least 1 event of transition to supported walk on feet had a lower age at locomotion onset, and at the emergence of hands-and-knees, and belly crawl when compared to those who did not present any transition event to this behavior as showed the Independent t-test analysis ($p<0.05$). There was no association between the emergence age for the other behaviors and the transition to supported walking on feet ($p>0.05$ by the Independent t-test).

Spearman´s correlation test analysis showed that the age of emergence of some behaviors was significantly associated with the age for the first transition event to walking on feet with and without support. This analysis considered infants from G1 and G2 together that presented both events, emergence, and transition (first event) for the behaviors presented as follows. It was found that the lower the age for the emergence of walking on feet with support, the lower the age for the first event of transition to the same behavior (n=31, p=0.018, rho=0.421, moderate correlation). It was found that the lower the emergence age of walking on feet unsupported, the lower the age for the first transition event both to supported (n=20, p=0.011, rho=0.555, moderate correlation) or unsupported walk on feet (n=20, p=0.000, rho=0.831, strong correlation). Also, the sooner the emergence of hands-and-knees crawling, the sooner the first event of transition to walking on feet without support (n=6, p=0.042, rho=0.829).

Table 4.7 Emergence age for locomotion, hands-and-knees, and asymmetrical crawling for infants from group 1 (n=19) according to transition event to the supported walking on feet (SW) behavior.

	Emergence age (months)					
	Locomotion		Hands-and-knees crawling		Belly Crawling	
Transition Event to SW	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Yes	14	7.66 (0.90)	14	8.18 (0.87)	5	6.84 (0.70)
No	5	9.36 (0.82)	5	9.83 (0.70)	2	8.60 (0.09)
Comparison	p-value	Difference mean (95%CI)	p-value	Difference mean (95%CI)	p-value	Difference mean (95%CI)
	0.002	-1.69 (2.68 – 0.71)	0.002	-1.64 (2.56 – 0.72)	0.021	-1.76 (3.11 – 0.40)

Note: Independent t-test was performed for comparison; n, number of infants; SD, standard deviation; CI, confidence interval; statistical significance ($p<0.05$).

4.2.2 Variations in emergence and transitions in locomotion development according to infants' characteristics, parental beliefs, body positioning, and home experiences

This item attends to the secondary objective of the thesis and presents the analysis of the association of infant´s characteristics (sex, anthropometric data, and motor developmental status), body positioning, and home experience at the inclusion date of the follow-up with emergence and transition of behaviors to investigate if and how these elements shape the epigenetic landscape of locomotion in typical infants from 5 to 18 months old. This section is divided in three parts. The first part presents the results of the analysis for locomotion onset including only infants from G1 that could not locomote independently at the inclusion date on the follow-up (n=18). The second and third parts, present the data analysis about the association of these elements, respectively, with the emergence and transition of locomotor behaviors (infants from G1 and G2). For these analyses, the categories of frequency of permanence in different positions and experience in different places or locomotor behaviors were divided into less frequently (never/rarely/sometimes) and more frequently (always/frequently).

4.2.2.1 Locomotion onset: first event of emergence

Infant´s characteristics

The infant´s sex, weight/ height at birth, and anthropometric data at the inclusion date on the follow-up were not associated with the age at the locomotion onset ($p>0.05$). The Spearman correlation test showed that the higher the AIMS scores in sitting (rho= -0.541, p=0.020) and total (rho= -0.544, p=0.020) subscales at 5.07 months old (mean) the lower the age at locomotion onset (moderate correlation). Concerning the AIMS percentile category, the age at locomotion onset was lower for the infants classified in 50<75% (mean=7.28, 95%CI 6.39 – 8.16) in comparison to those classified in 25<50% (mean=8.68, 95%CI 8.05 – 9.32) at the inclusion date on the follow-up by Independent t-test (p=0.007, mean of difference= 1.40, 95% CI 0.43 – 2.38).

The comparison of motor development scores at the inclusion date on the follow-up between the behavior categories presented by infants at the locomotion onset is presented in Table 4.8. This analysis was not performed for asymmetrical crawling because of the insufficient number of infants that presented this behavior at locomotion onset. The scores in prone and total subscales at 5.07 months old were higher for infants that presented belly crawling at the locomotion onset as indicated by the Mann-Whitney U test ($p<0.05$).

Parental beliefs

Agreement on conceptions about motor development was not associated with age and behavior category at the first event of emergence (locomotion onset) ($p>0.05$). Kruskal-Wallis test showed no difference in the age of locomotion onset between the categories of parents' expectations on the age for locomotion onset ($p>0.05$) (table 4.9).

Infant body positioning

The frequency that the parents reported that the infant stayed in prone, supine, and sitting with support positions at the inclusion date in the follow-up was not associated with the age (Independent t-test) and the behavior category (Chi-square test) presented at the locomotion onset ($p>0.05$).

Table 4.8 Motor development scores at 5.3 months old (mean age) in relation to the behavior presented at the locomotion emergence for infants from group 1 that were not able to locomote independently at the inclusion date of the follow-up (n=18).

	Behavior at locomotion emergence		
	Belly-crawl n=7	Hands-and-knees crawl n=9	Mann-Whitney U test
AIMS scores, points	Mean (95%CI)	Mean (95%CI)	p-value
Prone	8.14 (7.15 – 9.13)	6.67 (6.28 – 7.05)	0.008*
Supine	6.71 (5.55 – 7.87)	6.78 (6.27 – 7.29)	0.820
Sitting	3.43 (2.53 – 4.33)	3.11 (2.65 – 3.57)	0.480
Standing	2.43 (1.93 – 2.92)	2.78 (2.44 – 3.12)	0.166
Total	20.71 (18.53 – 22.90)	19.33 (18.56 – 20.10)	0.046*

Note: AIMS, Alberta Infant Motor Scale; n, number of infants; CI, confidence interval; *statistical significance (p<0.05).

Table 4.9 Age at locomotion onset (months) according to parents' expectations

Parents expectation for locomotion onset (months)	Age at actual locomotion onset (months)		
	n	Mean (SD)	95%CI
6 to <7	3	7.52 (0.99)	5.06 – 9.98
7 to <8	7	8.36 (1.52)	6.95 – 9.77
8 to <9	5	8.17 (0.86)	7.10 – 9.25
9 and above	3	8. 18 (1.12)	5.37 – 10.98
Kruskal-Wallis test (p-value)	0.824		

Note: n, number of infants; CI, confidence interval; SD, standard deviation; statistical significance (p<0.05).

Home experiences

Concerning the frequency that the parents reported that the infant stayed in different places at the inclusion date on the follow-up there was no association both with the age (Independent t-test) and behavior category (Chi-square test) at the locomotion onset (p>0.05), except for the floor location. It was found that infants who were on the floor less frequently (n=6, mean age 8.91±1.08), showed locomotion onset later than the infants who were more frequently on this place as indicated by the Independent t-test (n=12, mean age 7.75±1.03) ($p=0.041$, mean difference 1.16, 95% CI 0.53 – 2.27).

Interaction between variables

A two-way ANOVA test was performed with the age of locomotion onset as the dependent variable and AIMS percentile (2 categories) and the frequency that the infant was placed on the floor (2 categories) as independent variables. It was found homogeneity of variances in Levene´s test ($p=0.554$). There was no interaction effect of independent variables ($p=0.782$) and no factor effect of frequency on the floor ($p=0.254$) on the age of locomotion onset. The result indicated that 25.3% of the variation in age of locomotion onset was explained by AIMS percentile categories at 5.07 months old ($\eta_p^2=0.253$; $p=0.047$).

4.2.2.2 Emergence of locomotor behaviors

This analysis was performed for the behaviors in which most emergence events occurred over the follow-up according to age cohort groups. For G1, analysis was performed for the emergence of crawling behaviors (belly, hands-and-knees, and asymmetrical) and supported walking on feet. For infants from G2, the analysis considered the emergence of supported and unsupported walking on feet. This analysis was not performed for infants from G3 due to the minor number of emergence events for this group.

Infant´s characteristics

For all infants, sex, weight, and height at birth, and anthropometric data at the inclusion date of the follow-up were not associated with the emergence (occurrence and age) of any locomotor behavior ($p>0.05$). There was no association of AIMS scores with asymmetrical crawling emergence ($p>0.05$).

Belly crawl: group 1

For infants who presented an emergence event of belly crawl (n=7) during the follow-up, the AIMS score in the prone subscale at 5.07 months old (inclusion date) was higher (mean 8.14 points, 95% CI 7.15 – 9.14) than for others (n=12, mean 6.92 points, 95%CI 5.82 – 8.02 points) as showed by the analysis with the Mann-Whitney U test (p=0.022). Spearman test showed a negative association between some AIMS scores and the age at emergence of belly crawling. It was found that the higher the AIMS total score at the inclusion date, the younger the infants started to belly crawl (p=0.029, rho=-0.805, strong correlation). The age at belly crawl emergence was higher for infants that at 5.07 months old were classified in the 25<50% AIMS percentile (n=3, mean=8.30±0.52) when compared to those classified in the 50<75% category (n=4, mean=6.62±0.59) according to the Independent t-test (p=0.034).

Hands-and-knees crawl: group 1

Spearman correlation test showed that the higher the total AIMS score at 5.07 months old, the sooner the emergence of hands-and-knees crawling occurred (p=0.049, rho=-0.455, moderate correlation).

Supported walking on feet: groups 1 and 2

The AIMS total score at 5.07 months old was higher for infants from G1 that presented an emergence event of supported walking on feet over the follow-up (n=15, mean= 20.47 95%CI=19.16 – 21.77 points) in comparison with infants of this group that did not (n=4, mean=18.00 95%CI=15.75 – 20.25 points) as indicated by the Mann-Whitney U test (p=0.038). It was observed by the Spearman test that the higher the AIMS sitting score at 5.07 months old for infants from G1, the younger they walked on feet with support (p=0.019, rho=-0.597, moderate correlation). Analysis for infants from G2 showed no association of AIMS scores and percentiles with the emergence of this behavior (p>0.05).

Unsupported walking on feet: group 2

For infants from G2, the higher the AIMS scores in standing (p=0.006, rho=-0.622) and total (p= 0.041, rho=-0.485) subscales at 9.07 months old (inclusion date of the follow-up) the sooner the emergence of unsupported walk on feet occurred as showed by the Spearman test.

Parental beliefs

Categories of agreement on conceptions about motor development were not associated with the age (Independent t-test) and occurrence (Chi-square test) of the emergence of crawling behaviors (belly, hands-and-knees, asymmetrical) and supported walking on feet (p>0.05).

Unsupported walking on feet: group 2

Independent t-test showed that the age at the emergence of unsupported walking on feet was higher for infants whose parents agreed (n=7, mean=14.29, 95%CI=13.72 – 14.87) with the statement "In typically developing infants, motor development occurs naturally and there is no need to actively stimulate it" in comparison with infant´s parents that stated disagreement/indifferent (n=11, mean=12.70, 95%CI=11.80 – 13.61) (p=0.004, mean difference 1.58 95%CI=2.58 – 0.59). One-way ANOVA test (homogeneity of variances, Levene´s test, p=0.254) showed that the age for the emergence of unsupported walking on feet was lower for infants whose parents' expectations for walk onset were between 10 to 11 months old in comparison to others (p<0.05, F=6.107, see details in table 4.10). It was found that 49.9% of the variation in the age of emergence of walking unsupported on feet is explained by categories of parental expectation.

Table 4.10 Emergence age of unsupported walking on feet (months) according to parental expectations.

Expected age for unsupported walking on feet onset (months)		Emergence age of locomotion (months)		Pairwise comparison Bonferroni post hoc test p-value
	n	Mean (SD)	95%CI	
10<11	3	11.35 (0.61)	(10.04 – 12.67)	0.018[a]
11<12	7	13.71 (0.40)	(12.85 – 14.58)	0.016[b]
12<13	8	13.72 (0.37)	(12.91 – 14.53)	
One-way ANOVA test (p-value)		0.011		
Partial eta squared		0.499		

Note: n, number of infants; CI, confidence interval; SD, standard deviation; statistical significance (p<0.05); a, pairwise comparison 10<11 versus 11<12; b, pairwise comparison 10<11 versus 12<13.

Infant body positioning

There was no association between the frequency in different positions with the age at emergence of crawling behaviors (belly, hands-and-knees, asymmetrical) ($p>0.05$ by Independent-t-test).

Supported walking on feet: groups 1 and 2

There was no significant association for G1. For infants of G2 who stayed more frequently in the supine position at 9.07 months old, the emergence age of walking on feet with support was higher (mean 11.62±1.23 months) than those who stayed less frequently (mean 10.59±0.75 months old) in this position as showed by the Independent t-test ($p=0.046$).

Unsupported walking on feet: group 2

Independent t-test showed that the age at the emergence of unsupported walking on feet was lower for infants that at 9.07 months old stayed less frequently (mean 13.00±1.44 months) than more frequently (mean 14.16±0.56 months) in the supine position ($p=0.026$). Also, the emergence of unsupported walking on feet was earlier for infants who stayed more frequently (mean 12.79±1.18 months) in supported standing than less frequently (14.71±0.47 months) as showed by the Independent t-test ($p=0.000$).

Home experiences

Experience was considered in two ways. One was about the frequency that infants experienced different places and the other was about the frequency of locomotor behaviors observations at home both cases reported by parents at the inclusion date of the follow-up.

Places

Crawling behaviors (belly, hands-and-knees, asymmetrical): group 1

The emergence of belly and asymmetrical crawling was not associated with the frequency in which infants experienced different places ($p>0.05$). The Independent t-test showed that emergence of hands-and-knees crawling occurred sooner for infants that stayed more frequently (mean 8.18±0.93 months) on the floor at 5.07 months old in comparison to those that stayed in less frequently (9.55±0.86 months) in this position ($p=0.007$,).

Supported walking on feet: groups 1 and 2

Different locals were not associated with the emergence event of this behavior for infants from G1 (p>0.05). Infants from G2 who stayed less frequently in the cradle at 9.07 months old presented a lower age (mean 10.51±0.79 months) for the supported walk-on-feet behavior emergence in comparison to those that stayed more frequently (11.45±1.04 months) as indicated by the Independent t-test (p=0.046).

Unsupported walking on feet: group 2

There was no association between the places the infant stayed and the age at the emergence of unsupported walking on feet (p>0.05).

Locomotor experience:

The frequency of locomotor experience over the follow-up was not related to the emergence event of asymmetrical crawling and supported walking on feet. There was no association of home locomotor experience with the emergence of crawling or unsupported walking on feet behaviors.

Unsupported walking on feet: group 2

Home experience in hands-and-knees crawling at 9.07 months old was not associated with the emergence age of unsupported walking on feet as indicated by the Independent t-test (p=0.609). The Independent t-test showed that the unsupported walking on feet emerged earlier for infants who experienced the supported walking on feet behavior more frequently (mean 12.23±1.24 months) than those less frequently (mean 13.87±1.07 months) at 9.07 months old (p=0.011).

<u>Interaction between variables</u>

A two-way ANOVA test was performed to investigate the interaction effect between categories of parental expectation on age of unsupported walk onset and frequency categories of experience in the supported walk on feet at 9.07months old, in the emergence age of unsupported walk on feet (dependent variable) of infants from G2 (homogeneity of variances by Levene´s test, p=0.557). It was found that parental expectations explain 43.7% (F=4.660, p=0.032), experience in supported walking on feet

28.1% (F=4.686, p=0.050) of the variance of the dependent variable (factor effect). There was no interaction effect between independent variables (p>0.05).

4.2.2.3 Transition to locomotor behaviors

This analysis was performed for the behaviors to which most transition events occurred over the follow-up according to age cohort groups. For G1, analysis was performed for the transition to hands-and-knees crawling and supported walking-on-feet behaviors. For infants from G2, the analysis considered transitions to hands-and-knee crawling and supported and unsupported walking on feet. This analysis was not performed for infants from G3 due to this group's minor number of transition events.

Infant´s characteristics

The number of total events of transitions and the age at the first event of transition of any behavior analyzed were not associated with weight, height at birth, and anthropometric data at the inclusion date (p>0.05). There was no association of the infant´s characteristics at the beginning of the follow-up with the transition to crawling behaviors and unsupported walking on feet. For infants from G2, it was found that males (mean 10.72±0.57 months) presented a first event of transition to walking on feet with support sooner than females (11.68±0.70 months) as indicated by the Independent t-test (p=0.012).

Supported walking on feet: groups 1 and 2

The number of transition events to this behavior was higher for infants of G1 classified in the AIMS percentile of 50<75% (mean 1.37±0.74 transition events) at 5.07 months old in comparison to those in 25<50% (mean 0.63±0.67 transition events) as indicated by the Mann-Whitney U test (p=0.036). No association was found for infants in G2.

Parental beliefs

There was no association between variables of transition events with parental beliefs for infants from G1.

Crawling on hands and knees, supported and unsupported walking on feet: group 2

The comparison of the number of transition events and age ate the first event of transition of behaviors between categories of parental agreement with conceptions about motor development for infants from G2 is presented in Table 4.11. Infants whose parents reported agreement with the statement "In typically developing infants, motor development occurs naturally and there is no need to actively stimulate it" presented more transition events to hands-and-knees crawling and supported walking on feet and a higher age for the transition to unsupported walking on feet in comparison to others (who disagree or were indifferent) ($p<0.05$). Agreement with the statement "It is important for a baby to reach motor milestones as early as possible" was associated with no events of transition to hands and knees crawling ($p<0.05$). One-way ANOVA (homogeneity of variances by Levene´s test $p=0.076$) showed that the age at the transition to unsupported walking on feet was lower for infants whose parents reported expectation of the emergence of this behavior from 10<11 months (mean 11.51±0.31 months) in comparison with 11<12 (14.00±1.28, $p=0.016$) and 12<13 months old (13.76±1.06, $p=0.030$) ($p=0.014$, $F=5.847$).

Infant body positioning

There was no association between infant body positioning at the inclusion date of the follow-up and the transition to unsupported walking on feet ($p>0.05$).

Crawling on hands and knees: group 1

The number of transitions to hands-and-knees crawling over the follow-up was higher for infants from G1 that stayed more frequently (mean 1.33±0.50 transition events) in the prone position at 5.07 months old in comparison to those who stayed less frequently in this position (mean 0.60±0.69 transition events) as indicated by the Mann-Whitney U test ($p=0.035$).

Supported walking on feet: groups 1 and 2

For infants from G1, the number of transition events to walking on feet with support was higher for those who stayed more frequently (mean 1.33±0.86 transition events) in the prone position at 5.07 months old when compared to those who stayed in less frequently (0.60±0.51 transition events) in these positions as indicated by the Mann-Whitney U test (p=0.043). No association was found for G2.

Table 4.11 Number of transition events and age at the first event of transition to hands-and-knees crawling and walking on feet with and without support according to parents´ agreement with conceptions about motor development (MD) for infants from group 2 (n=18).

	Conceptions about MD		
	In typically developing infants, motor development occurs naturally and there is no need to actively stimulate it.		
Transition events	Agreement (n=7) Mean (SD)	Disagreement/indifference (n=11) Mean (SD)	Comparison p-value
Hands-and-knees crawling, count	1.57 (0.97)	0.45 (0.52)	0.014[a]
Supported Walking on feet, count	2.28 (1.25)	1.09 (0.30)	0.009[a]
Unsupported walking on feet, age in months	14.60 (0.74)	12.66 (1.15)*	0.001[b]
	It is important for a baby to reach motor milestones as early as possible.		
	Agreement (n=4) Mean (SD)	Disagreement/indifference (n=14) Mean (SD)	
Hands and knees crawling, count	0.00 (0.00)	1.14 (0.86)	0.013[a]
Supported Walking on feet, count	1.50 (1.00)	1.57 (1.01)	0.814
Unsupported walking on feet, age in months	13.21 (1.11)	13.50 (1.50)	0.825[b]

Note: n, number of infants; SD, standard deviation; [a]Mann-Whitney U test; [b]Independent t-test; *n=10 for this specific observation; statistical significance (p<0.05).

<u>Home experiences</u>

This item is divided into two subitems, one about the frequency that infants experienced different places and the other about the frequency of locomotor behaviors observations at home, both reported by parents at the inclusion date of the follow-up.

Places:

There were no variations in number of transition events and age at the first event of transition to crawling behaviors and to unsupported walking on feet according to the frequency of the infants staying in different places ($p>0.05$).

Supported walking on feet: groups 1 and 2

Independent t-test showed that the age at the first event of transition to the supported walking on feet behavior was higher for infants from G1 that at 5.07 months old stayed more frequently (mean 10.87±0.79 months) in the cradle in comparison to those less frequently (9.82± 0.97 months) (p=0.048).

Locomotion Experience

Home experiences with locomotion at the inclusion date of the follow-up were not associated with the transition to all crawling behaviors and supported walking on feet ($p>0.05$).

Unsupported walking on feet: group 2

The transition to unsupported walking on feet occurred earlier for infants who at 9.07 months old experienced the supported walking on feet behavior more frequently (mean 12.42±1.31 months) than less frequently (mean 14.03±1.10 months) as indicated by the Independent t-test (p=0.017). There was no association of hands-and-knees crawling experience with age at the transition to unsupported walking on feet behavior (p=0.896).

<u>Interaction between variables</u>

The analysis of variance ANOVA with 3 factors was performed to investigate the interaction effect between some independent variables in the age of transition to unsupported walking on feet (dependent variable) of infants from G2 (homogeneity of variances by Levene´s test, p=0.400). The independent variables were (1) the experience in the supported walk on feet and in (2) supported standing positioning at 9.07 months old, and (3) parental agreement with the statement "In typically developing infants, motor development occurs naturally and there is no need to actively stimulate it." There was no factor effect of the experience in the supported walk on feet (p=0.264) or of standing positioning (p=0.532) on the dependent variable. The analysis showed that 52.7% of the dependent variable was explained by parental beliefs, where infants whose parents disagreed with the statement presented a transition to unsupported walking on feet sooner than others (F=13.382, p=0.003). There was no interaction effect between independent variables in the age of transition to unsupported walking on feet (p=0.237).

This section showed that the variations in the emergence and transition of behaviors in pathways of locomotion development of the infants included in this sample were associated with some elements of infant´s characteristics, environment, and experience. Motor developmental status of the infant was associated with emergence and transition of most behaviors analyzed. The frequency of playing on the floor at 5 months old was associated with locomotion onset, and hence, crawling behaviors, whereas the frequency of permanence in the cradle or in the supine position at 9 months old was related to upright locomotor behaviors. Parental beliefs and expectations on motor development were only associated with unsupported walking behavior. The next section presented the interpretation of these results contrasting with the literature and pinpointing practical and theoretical implications.

5 DISCUSSION

The purpose of this thesis was to characterize the development of infant locomotion as a process with emergences and transitions that are constrained by a set of elements, in the case of the present study they were: the infant’s characteristics (among them their developmental status), parents’ beliefs, body positioning, places where infants are allowed to stay, locomotor repertoire and home experiences that infants build together with all the previous elements. The window of developmental time this research managed to look at was for infants from 5 to 18 months of age. As far as the author knows this is the first study aimed to investigate locomotion development conceived as an epigenetic landscape in the Brazilian population by a longitudinal design that considered the complexity of infant behavior observed at home and during spontaneous free play. As expected, the emergence and transition of locomotor behaviors settled different pathways toward upright locomotion evidencing diversity in typical development. However, some consistency among infants was also noticeable whereas most events of emergence and transition occurred for hands and knees crawling and supported or unsupported walking on feet behaviors. Furthermore, the analysis revealed that emergence and transition are related events and that their occurrence is indeed associated with the elements that form the underscape of the epigenetic landscape such as developmental status and some factors as parental beliefs and practices including the infant body positioning and places or apparatus where the infant are let to stay, and locomotor behaviors experienced by the infant.

5.1 LOCOMOTION ONSET: FIRST EVENT OF EMERGENCE

Locomotion onset was characterized by an interindividual variability with different behavior patterns presented at the first event of emergence in accord with previous studies (ADOLPH; VEREIJKEN; DENNY, 1998; FREEDLAND; BERTENTHAL, 1994; YAMAMOTO *et al.*, 2021). The present analysis showed that the locomotion onset occurred sooner for infants that crawled on the belly when compared to those that did it by hands-and-knees crawling which could be expected since the ability for the latter demand more muscle strength and balance to keep the body off the support surface (FREEDLAND; BERTENTHAL, 1994). Differently, Adolph, Vereijken, and Denny et al., (1998) found no statistically significant difference in age at the onset of locomotion between belly and non-belly crawlers' groups. Moreover, the authors did not see a difference in age at the onset of precursor crawling movements among these groups (ADOLPH; VEREIJKEN; DENNY, 1998). In the present sample, infants who started to locomote by belly crawling presented higher developmental scores in the prone subscale at baseline. There are similar results in the literature showing that prone experience affected only belly crawl onset(KUO *et al.*, 2008). Thus, it is suggested that prone posture-specific muscle control such as arm, head, trunk, and upper limb extensors (SIDDICKY *et al.*, 2020) at 5.07 months old can favor the emergence of belly crawling.

When looking at the age of locomotion onset regardless of the behavioral form, higher developmental scores in the sitting posture were associated with lower ages at the first event of emergence. Indeed, the results of a study performed with the Brazilian population suggested that the development of postural control in sitting and prone postures seems to be related due to similar antigravitational muscle activation (GRACIOSA *et al.*, 2018) which was also confirmed by another authors (KUO *et al.*, 2008). In addition, shifts from sitting to prone and from prone to sitting positions has been identified as one of the precursors of crawling onset (ADOLPH; VEREIJKEN; DENNY, 1998). Therefore, it seems that at some level, the trunk control observed in sitting posture is also required when an infant intends to move forward on hands and knees, on the belly, or asymmetrically.

Concerning anthropometric data of the infants included in the study, there was no association with the age at locomotion onset. In contrast, it has been found that infants who are heavier, taller and have greater head circumference will start to crawl later in comparison with other infants who are lighter, not as taller and have lesser head circumference (ADOLPH; VEREIJKEN; DENNY, 1998). There are three important differences between our method and Adolph´s that can explain the different results. The first one is that the present thesis collected only 3 measures of the infant´s body over the follow-up, while the mentioned study measured the infant during each session of observation. Second, the records of the infant´s body measures in the present sample were not performed on the exact day of locomotion onset as in the other study. And, finally, the body measurements used in the present study were provided by the parents who checked the pediatrician's records produced during the regular visits to follow the postnatal infant development. Hence, the method adopted for the present investigation has less precision in tracking infant's body changes which raises the caution in the conclusions made about the role of these changes in the overall locomotion development.

Playing in head upright postures such as in the prone position is known to benefit infants' development through antigravitational muscle activation, improved hand-eye-hand coordination, and consequently enhanced visual motor perception(BORGE BLYSTAD; VAN DER MEER, 2022). According to previous findings from the literature indicating an association between experience in the prone and the development of locomotion skills specific to this posture (HEWITT *et al.*, 2020; KUO *et al.*, 2008), it was expected that the frequency in which the infants from the sample stayed in this position at 5.07 months old would be associated with the first event of locomotion, however it was not confirmed by the present results. Contrasting to this investigation, one study assessed prone duration also by questionnaire but with a 6-point Likert scale where parents should indicate time spent (from 0 minutes to more than 2 hours) and found that the longer the infant played in the position, the sooner the onset of crawling(KUO *et al.*, 2008). The contrasting results may indicate that the time spent in the prone posture may be more precise than the frequency, thus being a parameter that can better represent experience and predict locomotion onset.

It was also expected that a higher frequency in restricted places such as a stroller, playpen, lap, cradle, or baby seat could be associated with a later locomotion onset. In the same vein, it would be expected when infants are let to stay and act in unrestricted places such as the floor, they would show the first event of emergence sooner. The results of the present study confirmed that infants who stayed on the floor more frequently at 5.07 months old presented the locomotion onset sooner than those who stayed less often in this place, regardless of the behavioral form. This is in accordance with the previous finding in Brazilian infants that a predominant practice on the floor is associated with higher developmental scores at 9.0 months old (SILVA; SANTOS; GONÇALVES, 2006). However, the present investigation found no association of age at locomotion onset with the frequency of stay in other assessed places such as a stroller, playpen, lap, cradle, or baby seat. It is important to mention that at 5.07 months old a lot of infants in this sample also stayed frequently in some restricted places such as the baby stroller, lap, and cradle. From these results, it is possible to wonder if playing on the floor more frequently, where an infant's movements have fewer barriers may create more opportunities to operate the perception-action cycle and to explore affordances. This would be an example of the experience being built by the infant together with the caregiver who intentionally or not set a place that is richer for action development. Also, it allows questioning whether this practice would counteract the risks of depreciating motor acquisition due to longer periods at other periods of the day in other restricted places.

5.2 EMERGENCE AND TRANSITION OF LOCOMOTOR BEHAVIORS OVER THE FOLLOW-UP

Over the follow-up, most emergence and transition events were for hands-and-knees crawling and walking on feet supported/unsupported. Moreover, the age range for the emergence of these three behaviors was the widest in comparison to others. The predominance of these behaviors in the emergence and transition pathways indicates that these are the most stable states in the landscape of locomotion development since they were the patterns more expressed from a variety of initial conditions (THELEN, 1995). It is apparent from the results, then, that crawling on hands and knees and upright locomotion are the most stable solution in typical development given the infant´s biological functions and demands of the environment and task.

Hands-and-knees crawling was predominant at least at one point in time for almost all infants from G1 and G2 and for the three infants of G3 who could not walk on feet independently at the beginning of the follow-up. It corroborates Muchisky et al.´s (1996) theoretical model of locomotion landscape that considers symmetrical crawling on hands and knees as the preferred motor solution until the infant can walk independently. In addition, for infants who presented belly crawling as the first predominant behavior in the motor repertoire (except 1 from G2) at least one event of transition to crawling on hands-and-knees occurred over the follow-up. The great stability of the hands-and-knees crawl evidenced by these results agrees with the literature showing that this behavior is more proficient in comparison to other types of crawling from a biomechanical standpoint(ADOLPH; VEREIJKEN; DENNY, 1998; FREEDLAND; BERTENTHAL, 1994).

Even though hands-and-knees crawling is shown to be the preferred locomotor behavior in early typical locomotion, some common variants with asymmetrical use of limbs have been described in the literature (PATRICK; ADAM NOAH; YANG, 2012). In the present study, asymmetrical crawling emerged for almost all infants of G1 and was observed predominantly for some infants over the follow-up. From the dynamical view, the frequency in which a behavior is expressed in the infant´s repertoire indicates its stability (ZANONE; KELSO; JEKA, 1993). Hence, it is apparent that this asymmetrical behavior seems to be a more stable state in the locomotor landscape of typical infants in comparison to other symmetric behaviors that emerged for a few infants such as walking on knees and hands-and-feet crawling. This result agrees with previous evidence that shows that asymmetry as leg preference is present in typical development in early motor skill acquisition (ATUN-EINY, 2015).

Interestingly, there was no pattern in the timing of the emergence of asymmetrical crawling that occurred before, after, or together with hands-and-knees crawling and walking on feet with support. Hands-and-feet crawling emerged near or together with upright locomotor behaviors. These results contradict the idea that asymmetrical use of limbs during crawling represents a stage-like pattern that precedes hands-and-knees crawling and that with neural maturation this behavior would not be expressed again(MCGRAW, 1941). Instead, these findings accord with those of Patrick et al. (2012) as one infant from their sample crawled with hand-and-knees indoors, and with hands-and-feet on the grass indicating that variations in crawling patterns designate multiple strategies for infants to move around. In the present study, infants were assessed only on the floor of a room, meaning that other conditions of the environment may have influenced the different patterns to emerge.

It is interesting to note how the behavioral elements of actions are interchanging in time and in different contexts. Although there is not enough data to test for statistical significance, the present results showed that some behavioral elements of bipedal patterns are presented in locomotory quadruped actions. This was the case for hands and feet crawling and asymmetrical crawling. In both cases, the feet element is performed closely like the way it will be performed when the infants walk with support or without support. In fact, when crawling is performed in both ways, the forces generated in the interaction infant-physical environment tend to facilitate the transition from quadruped to bipedal positions. It is as if the infant was motivated to create and explore conditions that allow them to change body posture to favor standing and walking. One important thing to mention is that the only infant of the present study who predominantly presented hands-and-feet crawling as a locomotor solution was the first one to be able to walk independently in G2. McGraw (1941) made a similar observation by evidencing some postural-specific motivation for locomotion since some infants learning the ability to sit also had some “urge” (in the author’s words) to progress in this posture.

For all infants, hands-and-knees crawling emerged before walking on feet with support except for one infant from G1 who presented the emergence of both behaviors at the same time point. Similarly, most infants from Adolph, Berger, and Leo´s (2011) sample started to crawl before or within a two-week window of the onset of cruising behavior. After the emergence of supported walking on feet, the present results showed cycles of transitions between this behavior and hands-and-knees crawling until the infant could walk independently. Moreover, there was a positive association between the number of transitions directed to both behaviors. Other studies evidenced an overlapping experience of crawling and supported upright locomotion before walking (ADOLPH; BERGER; LEO, 2011; SCHNEIDER; IVERSON, 2022). One explanation for that is the similar functionality between these two behaviors which demands the use of arms for support and coordination among all limbs (ADOLPH; BERGER; LEO, 2011). The present results provide further evidence of the relationship between hands-and-knees crawling and supported walking of feet by showing these multiple transition events.

There was no pattern for transitions to the supported walking on feet behavior over the follow-up for all groups; some infants transitioned from belly crawling, others from hands-and-knees, or still from asymmetrical crawling. The age and not the behavioral form at the locomotion onset was associated with the timing both at emergence and at the first event of transition to walking on feet. The sooner infants started to crawl regardless of the pattern, the sooner they started to walk on feet with support. Infants from G1 that presented at least 1 transition event to walk on feet with support started to locomote earlier than those that did not. This association between ages at the emergence of crawling and cruising was reported by literature (ADOLPH; BERGER; LEO, 2011).

It means that the experience of environmental exploration enabled by locomotion onset seems to play a role in the emergence of supported upright locomotion. One study showed that infants crawl not only to reach destinations but also to explore the surroundings gaining information about the fit between their bodies, skills, and environment(HOCH; O'GRADY; ADOLPH, 2019). Furthermore, the increase in spatial locomotor exploration over time promoted by the crawling experience is associated with further distances traveled and more places visited especially furniture in rooms(THURMAN; CORBETTA, 2017). Therefore, when infants start to move around, they reach places in the home they did not before, and then they can try and practice standing up, and consequently take their first steps while holding on to the sofa or on the television stand, for instance.

The sooner walking on feet with support emerged the sooner the infant presented the first event of transition to this same behavior, and for some infants, the emergence and transition of/to this behavior occurred at the same time point. Further, infants who started to walk with support sooner presented an emergence of and transition to unsupported walking on feet earlier. Findings from another study showed that despite a temporal relationship between these two behaviors the cruising practice is not a transitional skill for learning to walk without support (ADOLPH; BERGER; LEO, 2011). Cruising is a behavior that goes only in the lateral direction, and infants' independent walking is complex and occurs in multiple directions. The present study considered the upright supported locomotion in all directions, not only lateral (as in cruising), and with the support of one or both hands. As soon as infants practice standing up and cruising and gain balance and muscle control, they can walk forward supporting only one hand on the furniture, or even by pushing a chair or walker over the place. Thus, it is possible to suggest that to some extent the variable practice in upright locomotion with support but not only in cruising can promote the necessary postural control encouraging infants to walk without hand support.

An additional explanation is that the cruising experience can play a role in the infant´s motivation to walk independently (ADOLPH; BERGER; LEO, 2011). When infants stand up and start to move upright, there is a change in the way they see and hear the world, in the places they can reach and explore, and more importantly, in the way people see and interact with them. Indeed, this conquest produces a cascade of multidirectional interactions improving infant´s development of communication and language(IVERSON, 2021). The emergence of walking (with or without support) brings a new set of communication where caregivers provide richer social messages by language or gestures about actions and objects when the infant is walking when compared to when they are crawling (SCHNEIDER; IVERSON, 2022). These links between language and locomotor skills acquisition illustrate some notions from the Developmental System theoretical framework such as probabilistic epigenesis (GOTTLIEB, 2003), the interdependence among subsystem elements and the ontogeny of information (OYAMA, 2000b).

In the present sample, after the occurrence of one transition to unsupported walking on feet, no other event of transition was observed at all. Adolph et al., (2012) found that even with a high percentage of falls, increased efficiency (e.g., moving faster) may have motivated novice walkers to prefer walking rather than crawling. Therefore, these results provide further evidence that independent walking is the greatest stable state in a developmental landscape for typical infants, and according to the literature, it seems to be not only due to the biomechanical efficiency of this behavior but also an important "social appeal" that entails the complex dyad infant-caregiver.

According to the equifinality axiom (GOTTLIEB, 2003), this thesis hypothesized that pathways of locomotion development would be diverse with the same final state of independent walking. Indeed, the results showed that the temporal order of events of emergence and transition of all behaviors observed in the infant´s motor repertoire over the follow-up settled diverse paths toward the acquisition of upright locomotion (with or without support). Moreover, there was an interindividual variability concerning which locomotor behaviors emerged or were predominant in the infant´s motor repertoire. For instance, some behavioral forms such as crawling on the belly or hands-and-feet and walking on the knees with or without support emerged only for a few infants. One implication from the results is that there is no sequence in the development of the locomotion of typical infants bringing evidence to the probabilistic element in this process as suggested by the epigenetic view (CONNOLLY, 1986).

The transitions observed in the results did not come only directed from less to more complex behaviors in terms of postural control (e.g., from crawling to walking). Instead, transitions occurred from many directions not following a strict order and showed multiple cycles between hands-and-knees crawling and walking on feet with support up to the independent walk. It shows that the stability of crawling and supported walking, as behavioral states in the locomotion landscape, fluctuates over time while the infant is not able to walk without support. These bidirectional cycles of transitions between these two behaviors also evidence the multi-stability property, which is when more than one stable state is observed (NEWELL; LIU; MAYER-KRESS, 2003). These results bring further evidence of the non-linearity of the developmental process by characterizing the discontinuity in behavioral changes(VAN DER MAAS; HOPKINS, 1998).

This thesis also hypothesized that the variations in emergence and transition in pathways of locomotion development would be in part a result of the association between multilevel components of the individual and the environment. It is these associations presented in the results that will be discussed next considering the infant´s characteristics, parental beliefs, body positioning, and home experiences.

5.2.1 Infant´s characteristics

The developmental status of the infants at the inclusion date on the follow-up turned out to be the most important individual component associated with events of emergence and transition in locomotion development. This was expected since literature shows that AIMS scores can predict motor development acquisitions after 2 to 6 months intervals for reassessment (CHARITOU; ASONITOU; KOUTSOUKI, 2010). In general, higher total AIMS scores were associated with sooner emergence events for belly or hands-and-knees crawling, and supported, and unsupported walking. Postural specificity in association with AIMS scores was observed only for emergence age at belly crawling (prone scores) and unsupported walking (standing scores). Higher scores in the sitting subscale at 5.07 months old were associated with a sooner emergence of supported walking on feet indicating that trunk control may play a role in the acquisition of this behavior. But the fact that associations were found with the total score for all behaviors analyzed, except for asymmetrical crawl, needs to be underscored. From a contextual view of motor development, an emergent motor skill depends on and interacts with the product of other domains of development (KARASIK; ROBINSON, 2022). Thus, it can be inferred that the timing of the emergence of locomotor behaviors goes beyond the specific postural control displayed by the infant but depends on its broad developmental state that results from the dyad of changes in biology (e.g., neural maturation, physical growth) and experience (e.g., child-rearing practices).

In this study, the emergence or transitions of locomotor behaviors were not associated with anthropometric data of infants, but with biological sex where male infants of G2 presented a sooner first event of transition to walking on feet with support compared to female infants. This difference did not seem to be relevant over time since the ages at the emergence of unsupported walking on feet or the transition to this behavior were similar between males and females for this group. In addition, there were more female than male infants in this group implying more variation in data influencing the mean used for comparison. However, previous studies show that differences related to sex in motor development may be associated with gender issues. A study showed that while female infants tend to be underestimated, males are overestimated by mothers in the performance of locomotor behaviors (MONDSCHEIN; ADOLPH; TAMIS-LEMONDA, 2000). Furthermore, while males are provided with more practice for gross motor development, females receive more opportunities for fine motor skills acquisition(DINKEL; SNYDER, 2020). The findings from other studies presented above support an explanation for the difference found between males and females in the present results showing that parental expectations and beliefs regarding gender can constrain the opportunities offered by families for infants in locomotion development.

5.2.2 Parental beliefs

Parental beliefs on motor development and expectations related to the emergence of behaviors in locomotion development were associated only with the emergence and transition of the unsupported walking on feet behavior. A later emergence of independent walking was observed for infants whose parents agreed that development is a natural process and occurs independent of practice or stimulation. This relationship was also evidenced in more transitions between hands-and-knees crawling and supported walking for these infants, and, consequently, a later transition to independent walking for these infants. Indeed, previous literature shows that when caregivers believe that stimulation is necessary, they adopt more formal practices they judge as proper for motor development (OUDGENOEG-PAZ; ATUN-EINY; VAN SCHAIK, 2020). In addition, a study with a Brazilian sample found that placing the infant in a standing posture is a common practice from the first term of life and tends to increase with age (GOMES et al., 2017). In the present investigation, there was no transition to hands-and-knees crawling for infants whose parents reported believing that motor milestones should be reached as early as possible. It means a predominance of supported walking on feet behavior in the locomotor repertoire of these infants up to the transition to independent walking. So, it seems that opportunities offered by parents for the infant to practice unsupported standing and upright locomotion are mediated by parental beliefs on motor development influencing the emergence and transition of independent walking.

It is known that expectations of parents on infant´s motor acquisitions depend on culture (HOPKINS; WESTRA, 1989). In this study, there was no association of parental expectations with locomotion onset age. Expectations of walking onset showed a wide range from 10 and over 14 months old of age for this Brazilian sample, but most parents reported expecting infants to achieve this behavior between 11 to 13 months old. Infants of G2 whose parents expected to start to walk independently between 10 and 11 months old presented a sooner emergence and transition of this behavior than those whose expectations were above 11 months. This could be related to specific practices adopted by these parents to promote independent walking since it is known that the transition to walking is a significant event for them (HENDRIX; THOMPSON, 2011). However, this is a result of a small statistical power because there were only three infants in this expectation category (10 to 11 months old). In general, data showed no difference in age at emergence and transition between categories of expectation for walking onset. Previous studies accordingly showed that maternal expectations are more accurate for sitting onset, and less for locomotion behaviors such as crawling or walking (HOPKINS; WESTRA, 1989, 1990). Therefore, the present investigation indicates that Brazilian parental expectations on age for acquisitions in locomotion development are not associated with the actual timing that these events are observed for the first time in an infant´s repertoire.

One possible explanation for the lack of a direct relationship between parental expectations and the emergence of locomotor behaviors in motor development is that the foundation of beliefs on motor development is tricky. This was evidenced in the Brazilian population by Gomes et al., (2017) showing that while there is a match between some activities offered for the infant and parental beliefs, there is a divergence for others (GOMES *et al.*, 2017). The fact that in the present investigation, parental beliefs were associated only with independent walking and not with other behaviors, such as crawling, for instance, deserves attention. It might indicate that parental practices to promote motor development may be focusing more independent walking which needs further investigation. The findings presented in this topic suggest that social aspects, at least in part, collaborate to set independent walking as the most stable state in the locomotion epigenetic landscape.

5.2.3 Infant body positioning

Typically, parents in Brazil do not frequently place infants in prone position to play because of the fear of suffocation (SILVA *et al.*, 2023). Because of this, not all infants are used to play in this posture. For infants from G1, staying more frequently in the prone position at 5.07 months old was associated with a higher mean of transition events to hands-and-knees crawling and supported walking on feet. It can be hypothesized from this result that infants with more practice in the prone position may prefer to move in this posture by crawling resulting in more transition events to this behavior over the follow-up.

While prone positioning is positive for motor development, excessive time spent in a supine posture seems to be negative for skill acquisition(GRACIOSA *et al.*, 2018; HEWITT *et al.*, 2020; KOREN *et al.*, 2018). The present results agree with previous literature showing that staying more frequently in supine positioning at 9.07 months old was associated with a later age at the emergence of upright locomotion both supported and unsupported for infants from G2. Further, infants of this group who stayed more frequently in the standing posture at the beginning of the follow-up started to walk independently earlier than those who stayed in that posture less frequently. There is the assumption that infants prefer to play in positions reflecting their motor repertoire(BARTLETT; FANNING, 2003). Indeed, six-month-old Brazilian infants spend less time in the supine position, and more time in the prone and sitting posture when compared to younger ones(GRACIOSA *et al.*, 2022). At 9 months of age, most typical infants can choose what position they want to stay, and therefore, these results provide further evidence of the association between postural preferences and skill acquisition in motor development.

5.2.4 Home experience

5.2.4.1 Places

In general, results showed that while playing on the floor seems positive, staying in the cradle seems negative for the emergence and transition of some locomotor behaviors in infancy. As expected, a higher frequency of staying on the floor at 5.07 months was associated with a sooner emergence of hands-and-knees crawling behavior. This finding adds to the previous literature showing that unrestrained time on the floor is not only beneficial for energy expenditure and physical activity (GROSS *et al.*, 2017) but can also enable locomotion.

Interestingly, the frequency of stay in the cradle was associated with the transition for G1 and emergence for G2, both related to the supported walking on feet behavior. Staying more frequently in the cradle at 5.07 months old was associated with a later first event of transition to this behavior over the follow-up, whereas at 9.07 months old with a later emergence of this behavior. Similar results were found by Carson et al., (2022) showing that higher restrained time (in the stroller, car seat, baby carrier, or chair) is associated with a later acquisition of supported walking behavior (CARSON *et al.*, 2022). One possible reason is that some places (e.g., car seats) restrict infant´s spontaneous leg movements (JIANG; DE ARMENDI; SMITH, 2016), and as it is known the frequency of kicking is associated with walking onset (ULRICH; ULRICH, 1995). In the present study, this association was not found for other restraining places such as the baby stroller and seat. Furthermore, it is not possible to affirm with the actual data if the cradle was a place that exerted restriction on the infant’s actions. Depending upon the design of the cradle it can allow a variety of dimensions that can not only influence infants´ freedom to move but also what they can see in the environment. Therefore, the present results evidence a relationship between where infants stay and timing in locomotion development, and future studies should investigate how specific details of the cradle constrain infants´ movements and exploration.

5.2.4.2 Locomotor experience

The only association found between home locomotor experience reported by parents at the inclusion date on the follow-up and emergence and transition was for the unsupported walking on feet behavior. Crawling experience was not associated with the emergence and transition of any locomotor behavior. Results showed that the more frequently experience in supported walking on feet at 9.07 months old was associated with a sooner emergence and transition to independent walking over the follow-up. Despite the notion that cruising entails a different balance control system than independent walking because of the manual support, it has been recognized that its experience can strengthen specific muscles needed for the infant to weight bear in the upright posture (ADOLPH; BERGER; LEO, 2011). An experiment showed that a greater cruising experience was related to a minor influence of unweighting by a support system in changing an infant´s behavior which can indicate more motor control to locomote in the standing posture (KORNAFEL; PAREMSKI; PROSSER, 2023). Moreover, the authors of this experiment concluded that the emergence of independent walking is rate-limited by the strength of the lower limbs that needs refinement with experience(KORNAFEL; PAREMSKI; PROSSER, 2023). The present results add to the previous evidence demonstrating that the amount of experience in supported walk behavior observed at 9 months old can be an indicator of an infant´s skill and drive to walk independently.

Development is an interesting phenomenon. As a term, development has various meanings as mentioned by Valsiner & Connolly (2003) such as “to bring into existence, to cause progress from simple to complex…to unfold…”. However, as these two developmental scientists argue: development involves novelty arising in “a process of change with direction”, moving away from a known state to a projected future state. The thesis of the present work was to show that the development of locomotion was not the unfolding of a couple of locomotor patterns in a sequence. Instead, locomotion development was marked by the emergence of new behaviors that when stable went through transitions. Hence, the investigation looked at (1) the appearance of a new behavioral state, that is ***emergence***; and (2) the increase in the stability leading to a switch toward a new and more stable state, namely ***transition.*** This way of characterizing the infant´s locomotion development evidenced variability and non-linearity in the developmental pathways of Brazilian typical infants. Variability was evidenced by various pathways of emergence (e.g., hands-and-feet crawling emerged before, together, or after supported walking on feet) and transition (e.g., from belly crawling some infants transitioned to crawling on hands-and-knees or asymmetrically or still to walking on feet with support). Transitions occurred in many directions even from more to less complex behaviors (e.g., from supported walking on feet to asymmetrical crawling) showing non-linearity. The analysis of the present results indicates that there are preferred (attractor) behavioral states in these pathways such as crawling on hands and knees and walking independently. There were also alternative stable behavioral states for instance asymmetrical crawling emerged and was predominant in the locomotor repertoire and direction of transitions for some infants. For instance, there were transitions from belly or hands-and-knees crawling to the asymmetrical crawling behavioral state. In this sense, this thesis provides evidence with concrete data for the idea of developmental paths that comes from Waddington´s (1957) proposal of landscape.

Another feature of the present work was to expand the epigenetic landscape metaphor by adopting the Muchisky *et al.* (1996) model of locomotion development**.** In their model, the underscape design is the dimension in which control parameters constrain the emergence of behaviors. Likewise, Muchisky et al (1996) proposed that biophysical properties of the infant such as body mass and muscle strength would act as control parameters in the underscape of the epigenetic landscape. In the present research, there is the proposition that there are other elements composing control parameters in the underscape: the infant´s developmental status, parental beliefs, and some features of how the experiences unfold such as place (with its possibilities for affordances, particularly those for locomotion), the frequency the infant played in some posture or body position or experienced a locomotor behavior. All these elements are proposed as a thesis to the design of the underscape of the epigenetic landscape which, as a set, will operate dynamically emergences and transitions in locomotion development.

The findings about some elements of the underscape, such as the relationship between the frequency that infants were placed in different positions and places or apparatus with behavioral changes in locomotion, give rise to support in empirical terms to the notion of the "field of promoted action" proposed by Brill and Reed (1986). These authors proposed that the source of diversity in human action development is a function of a subset of selected settings of environmental characteristics and opportunities for experience and action, that is the field of action (REED; BRIL, 1996). As it was possible to observe from the present data, for instance, parents that placed their infants on the floor more frequently at 5 months old were offering opportunities to their infants that in some way turned into a field of promoted action that favored locomotion onset. Therefore, environmental settings determined by parents specify which motor problems will be exposed to infants creating a field of promoted actions.

5.3 FINAL REMARKS

5.3.1 Limitations

This study has several limitations. Infant locomotor activity was recorded in an uncontrolled situation without standardization of camera sit, objects and environment disposition, luminosity, and infant´s wear. However, the method adopted was an effective way of looking at the dynamics of developmental phenomena capturing the richness of the infant´s behaviors in a real environment. Some data as the infant´s frequency of body positioning, place of stay, home locomotor experience, and anthropometric data were based on the parents' report which can be not accurate and is subject to recall. Because of the viability of this study, it was not possible to follow infants from 5 to 18 months old which resulted in the cohort age groups that prevented the observation of long-term outcomes. There was a small number of infants in each group which compromises the statistical power of the analysis performed. Data collection was carried out during the COVID-19 pandemic (from January to December 2021) when most people, including infants, were restricted to their home environments. It is pertinent to consider that the context of the pandemic may have influenced the infant´s environment in an unknown way. Finally, participating infants were mostly from the southern region of Brazil, middle economic class, and highly educated parents, which limits generalizability to other populations.

5.3.2 Theoretical and practical implications

Emergence and transition characterized various pathways in locomotion development marked by non-linearity. While locomotion development goes in the direction of the most stable state in the landscape, that is independent walking, transition events occur in all directions from less to more complex behaviors and vice e versa. Locomotion onset takes place through different behaviors, and the age at this event showed to be more important for subsequent events of emergence and transition than the pattern of movement. It means that experience in locomotion, as the ability to move from one place to another, is more relevant than the configuration of the body when moving in early development. These findings bring light to the notion that there is no normality in motor development, there is no right pattern of locomotion, especially when it comes to crawling behaviors. An important implication underscored by these results is that conclusions about motor development cannot be drawn based on a single point in time, and assessment instruments such as motor scales must be designed to account for non-linearity in infant screening. Further research on development seen as a dynamic process must distinguish which categories of behavioral changes are under investigation and ensure that the design properly allows the observation of these changes given the characterization of emergence and transition presented by the present study.

Even with the overwhelming evidence on cultural influences in child rearing shaping behavioral changes (HOPKINS; WESTRA, 1989, 1990; OUDGENOEG-PAZ; ATUN-EINY; VAN SCHAIK, 2020; VAN SCHAIK; OUDGENOEG-PAZ; ATUN-EINY, 2018), health professionals in Brazil still treat motor development as a linear process marked by sequenced acquisitions of age-dependent motor milestones. In locomotion development, for instance, rolling or bottom-shuffling are not considered relevant skills on milestones charts, even with evidence of the prevalence of these behavioral forms in typical development in some cultures(KARASIK; ROBINSON, 2022). In the present study, asymmetrical crawling was prevalent in different sites of pathways of locomotion development and was not associated with motor delays. Thus, physical therapists in the Brazilian population should not look at this as an atypical behavior as has been done until the present moment. Since variability is the rule and not the exception in motor development (ADOLPH, 2019), professionals must worry more about repetitive and stereotyped movement patterns than about a certain specific behavior that emerges in a developmental context. Further studies on proficiency and biomechanical constraints of variants of crawling such as asymmetrical and hands-and-feet patterns may help to answer why some infants choose different behaviors even in the same environmental situation as was shown in the present results.

Motor developmental status of infants was closely associated with the emergence and transitions of behaviors indicating that postural control, muscle strength, and other aspects of the individual may be the rate-limiting factors (THELEN, 1995) of behavioral change in locomotor development. Experience is shown to be associated with changes in locomotion development by associations between emergence and transition events. Parental expectations and beliefs were only related to independent walking meaning that their practices might be focused on this behavior. Health professionals’ guidance for families must highlight the importance of experience in motor development, including providing infants with free time on the floor in the first months of age.

6 CONCLUSION

This was the first time that Brazilian typical infants aged five to 18 months from highly educated parents were observed longitudinally immersed in the complexity of their home environment during free play. Emergence and transition of locomotor behaviors composed various pathways toward independent walking. Most emergence and transition events were related to hands-and-knees crawling and walking on feet (with or without support) showing that these are the most stable states in the epigenetic landscape of locomotion development for this population. Even with the predominance of these three behaviors, there was diversity and variability in emergence and transition where variations of crawling (belly, asymmetrical, hands-and-feet) and walking (on knees with or without support) were present in pathways. As all infants showed typical motor development and no delay over the follow-up, the variations of behavioral forms of locomotion and the temporal order of emergence and transition must not be treated by health professionals as a feature of the atypical pattern of movement. Instead, one should recognize the diversification of locomotor behaviors as an inherent feature of typical development, and hence, these results suggest that instruments for assessing motor skill acquisition considering non-linearity and behavioral variability are needed.

The experience proved to be important in the development of locomotion since emergence and transition were closely related events on the pathways. Age at locomotion onset and not the behavioral form presented at this event was related to emergence and transition events in pathways showing that the experience of just moving around is more relevant than practicing a specific movement pattern for subsequent changes in development. Some parents showed to be not aware of the relevance of experience for motor skill acquisition since they reported believing that development is a natural process with no need for stimulation and this was associated with a later emergence and transition of unsupported walking on feet. Parental expectations were not associated with the timing of the emergence of locomotion onset or unsupported walking on feet. The fact that parental beliefs were only related to unsupported walking on feet shows that opportunities offered for them to infants may be focused on this acquisition, and more, that besides biomechanical aspects, there is a social reason for this behavior to be the most stable state in the epigenetic landscape of locomotion.

Infant characteristics such as biological sex and anthropometric data were not associated with emergence and transition in pathways, but the motor developmental status was related to these events, indicating that individual aspects such as postural control, strength, and antigravitational muscle activity are relevant for the acquisition of locomotor behavioral patterns. The frequency of playing on the floor is more relevant than the position being positive for locomotion onset and the emergence of hands-and-knees crawling whereas staying in the cradle, or the supine position is negative for the emergence and transition of upright locomotor behaviors. Parents should be informed of the importance of early locomotion experiences no matter the behavioral form reasoned by enhancing the infant´s autonomy and opportunities to exercise their agency in their own developmental pathway. This awareness must be valued and promoted since this may play down the importance parents give, perhaps wrongly, to normative motor expectations given by popular developmental charts that emphasized development as a sequence of stages as the only path to reach the so desirable motor milestones.

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APPENDICES AND ANNEXES

APPENDIX A – The Consent Term

ERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

I - DADOS DE IDENTIFICAÇÃO DO SUJEITO DA PESQUISA E RESPONSÁVEL LEGAL

1. DADOS DO INDIVÍDUO

Nome completo ______________________________

Sexo ☐ Masculino
☐ Feminino

RG ______________________________

Data de nascimento ______________________________

Endereço completo ______________________________

CEP ______________________________

Fone ______________________________

E-mail ______________________________

2. RESPONSÁVEL LEGAL

Nome completo ______________________________

Natureza (grau de parentesco, tutor, curador, etc.) ______________________________

Sexo ☐ Masculino

☐ Feminino

RG	
Data de nascimento	
Endereço completo	
CEP	
Fone	
E-mail	

II - DADOS SOBRE A PESQUISA CIENTÍFICA

1. Título do Projeto de Pesquisa

Emergências, transições e adaptações dos comportamentos de locomoção em lactentes com desenvolvimento motor típico entre os cinco e 18 meses de vida.

2. Pesquisador Responsável

Professor Doutor Edison de Jesus Manoel

3. Cargo/Função

Titular da Universidade de São Paulo – Escola de Educação Física e Esporte

4. Avaliação do risco da pesquisa:

x	RISCO MÍNIMO		RISCO BAIXO		RISCO MÉDIO		RISCO MAIOR

(probabilidade de que o indivíduo sofra algum dano como conseqüência imediata ou tardia do estudo)

5. Duração da Pesquisa

6 a 13 meses

III - EXPLICAÇÕES DO PESQUISADOR AO INDIVÍDUO OU SEU REPRESENTANTE LEGAL SOBRE A PESQUISA, DE FORMA CLARA E SIMPLES, CONSIGNANDO:

1. Justificativa e os objetivos da pesquisa;

No desenvolvimento motor durante o primeiro ano de vida, a conquista da capacidade do seu bebê de se mover no ambiente de forma independente é importante. Quando seu bebê está se movendo, ele interage com o seu entorno e aprende sobre seu próprio corpo e sobre o ambiente. Sabe-se que as crenças e expectativas dos pais sobre o desenvolvimento motor influenciam no cuidado e interação com seus bebês e podem interferir na oportunidade que a criança tem de se mover no espaço. Por este motivo é importante estudar o desenvolvimento da locomoção (rastejar, engatinhar, andar) no bebê e a relação deste desenvolvimento com as crenças e expectativas dos pais.

Os objetivos deste estudo são:

a- Investigar processos de desenvolvimento (emergências, transições e adaptações) da locomoção em bebês saudáveis entre cinco e 18 meses de vida.
b- Estudar a relação da crença dos pais com o desenvolvimento da locomoção do bebê.

2. Procedimentos que serão utilizados e propósitos, incluindo a identificação dos procedimentos que são experimentais;

Primeiro, vamos realizar uma avaliação do desenvolvimento motor do seu bebê e uma entrevista com você (s). Em seguida, você (s) receberá (ão) orientações domiciliares para estimular o desenvolvimento do seu bebê. Caso necessário, você (s) receberá (ão) uma carta detalhada para o pediatra que acompanha o seu bebê sugerindo o encaminhamento para a intervenção motora fisioterapêutica. Se o seu bebê se enquadrar nos critérios de inclusão desta pesquisa, você (s) será (ão) convidado (s) a participar de todas as avaliações, onde seu bebê será avaliado a cada 15 dias por meio de filmagens de vídeo captadas por você na sua casa. Em cada avaliação, seu bebê será filmado por 15 minutos enquanto se movimenta livremente em uma sala do selecionada por você (s) em domicílio. As avaliações serão iniciadas a partir da data de inclusão do seu bebê no estudo até aproximadamente os 18 meses de idade. Uma vez por mês o desenvolvimento motor do seu bebê será reavaliado por meio de vídeo-chamadas, e você (s) responderá (ão) a questionários em formulários digitais sobre posicionamento corporal, ambiente domiciliar e cuidados com o seu bebê. Você (s) terá (ão) liberdade de interromper a participação na pesquisa a qualquer momento sem quaisquer prejuízos a assistência oferecida.

3. Desconfortos e riscos esperados;

Os riscos esperados são mínimos. O risco mínimo corresponde ao fato de que o seu bebê pode se sentir cansado ou indisposto durante as avaliações, bem como chorar. Nesse caso, a avaliação deve ser interrompida imediatamente para o descanso do seu bebê e conforto junto aos cuidadores. Após isso, a avaliação será retomada somente mediante sua (s) autorização (ões) e manifestação de bem-estar do bebê. Caso contrário a avaliação será adiada.

4. Benefícios que poderão ser obtidos; e 5. Procedimentos alternativos que possam ser vantajosos para o indivíduo.

Durante a (s) sua (s) participação (ões) na pesquisa, você (s) receberá (ão) um relatório com informações sobre o acompanhamento do desenvolvimento motor global do seu bebê. Você(s) também receberá (ão) orientações domiciliares sobre posicionamento corporal, estímulos motores e sensoriais, bem como esclarecimento de dúvidas sobre o desenvolvimento do seu bebê. Caso necessário, você(s) receberá(ão) uma carta detalhada para o pediatra que acompanha o seu bebê sugerindo o encaminhamento para a intervenção motora fisioterapêutica.

IV - ESCLARECIMENTOS DADOS PELO PESQUISADOR SOBRE GARANTIAS DO SUJEITO DA PESQUISA:

1. Você (s) terá (ão) acesso, a qualquer tempo, às informações sobre procedimentos, riscos e benefícios relacionados à pesquisa, inclusive para dirimir eventuais dúvidas;

2. também terão liberdade de retirar seu consentimento a qualquer momento e de deixar de participar do estudo, sem que isto traga prejuízo à continuidade da assistência;

3. salvaguarda da confidencialidade, sigilo e privacidade (os bebês não serão identificados por nome ou rosto em qualquer uma das vias de publicação da pesquisa ou uso, e as fotografias, vídeos e gravações ficarão sob a propriedade e guarda do grupo de pesquisadores do estudo).

4. o(s) participante(s) do estudo terá(ão) disponibilidade de assistência no HU ou HCFMUSP, por eventuais danos à saúde, decorrentes da pesquisa.

V - INFORMAÇÕES DE NOMES, ENDEREÇOS E TELEFONES DOS RESPONSÁVEIS PELO ACOMPANHAMENTO DA PESQUISA, PARA CONTATO EM CASO DE INTERCORRÊNCIAS CLÍNICAS E REAÇÕES ADVERSAS.

Avaliadora: Maylli Daiani Graciosa

Telefone: (48)99679-2077

E-mail: maygraciosa@gmail.com

Pesquisador Responsável: Edison de Jesus Manoel

Telefone: (11)99973-7119

E-mail: ejmanoel@usp.br

VI. - OBSERVAÇÕES COMPLEMENTARES

Comitê de Ética da EEFE-USP

Escola de Educação Física e Esporte - USP

Av. Prof. Mello Moraes, 65 - Cidade Universitária

CEP: 05508-030 - São Paulo – SP

Telefone (011) 3091-3097

E-mail: cep39@usp.br

VII - CONSENTIMENTO PÓS-ESCLARECIDO

Declaro que, após convenientemente esclarecido pelo pesquisador e ter entendido o que me foi explicado, consinto em participar do presente Projeto de Pesquisa.

São Paulo, _____/_____/_____

____________________________ Assinatura do responsável legal

____________________________ Assinatura do pesquisador

APPENDIX B – Consent for photographs, videos, and recordings

CONSENTIMENTO PARA FOTOGRAFIAS, VÍDEOS E GRAVAÇÕES

Permito que sejam realizadas fotografia, filmagem ou gravação de meu filho/dependente para fins da pesquisa científica intitulada "Emergências, transições e adaptações nos comportamentos de locomoção em lactentes com desenvolvimento motor típico entre cinco e 18 meses de vida", e concordo que o material e informações obtidas relacionadas ao meu filho/dependente possam ser publicados eventos científicos ou publicações científicas. Porém, o meu filho/dependente não devem ser identificados por nome ou rosto em qualquer uma das vias de publicação ou uso, e que as fotografias, vídeos e gravações ficarão sob a propriedade e guarda do grupo de pesquisadores do estudo.

___________________, _____ de _____________ de _______

Local e Data

____

Nome do Sujeito Responsável pelo Sujeito Pesquisado

____

Assinatura do Sujeito Responsável pelo Sujeito Pesquisado

APPENDIX C – Online Assessment Form

Link to access: https://forms.gle/gzhB7vxSEg1hGTcm7

Pesquisa: Desenvolvimento da Locomoção no Primeiro Ano de vida - Questionário 1

Olá papai, olá mamãe, tudo bem? Este é o primeiro questionário que você vai responder.

Você vai levar aproximadamente 15 minutos para preenchê-lo completamente.

Algumas dessas questões serão perguntadas somente agora no início da pesquisa. Outras, eu vou perguntar novamente daqui um tempo. Se você tiver dúvidas, pode me perguntar pelo Whatsapp (48996792077).

- Primeiro, você poderá ler os Termos de Consentimento Livre e Esclarecido e para fotografias e filmagens e registrar o seu aceite para a participação na pesquisa.

- Depois, vou fazer umas perguntas para obter informações sobre os cuidadores do bebê (pai, mãe ou outro), a gestação do seu bebê e a saúde atual dele.

- Por último, você responderá algumas perguntinhas sobre o que você pensa sobre o desenvolvimento motor, sobre quais posições o bebê geralmente fica e sobre as experiência de locomoção que ele já teve, ou não.

É isso!

ANNEX 1 – Approval by the Ethics Committee of Research with Human Beings of the School of Physical Education and Sports of the University of Sao Paulo

Link to access:
https://drive.google.com/file/d/1EJIJbYrYfKJnKaSLwLeymPVLN_JXkcZS/view?usp=sharing

USP - ESCOLA DE EDUCAÇÃO FÍSICA E ESPORTE DA UNIVERSIDADE DE SÃO PAULO / EEFE-USP

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DA EMENDA

Título da Pesquisa: Emergências, transições e adaptações dos comportamentos de locomoção em lactentes com desenvolvimento motor típico entre cinco e 18 meses de vida.

Pesquisador: Edison de Jesus Manoel

Área Temática:

Versão: 4

CAAE: 25789319.5.0000.5391

Instituição Proponente: UNIVERSIDADE DE SAO PAULO

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 4.935.737

ANNEX 2 – Portuguese version of Alberta Infant Motor Scale

Link to access:
https://drive.google.com/file/d/1O49nEK79N_zuovoIuUVWOyVCDVHP62sj/view?usp=sharing

ALBERTA INFANT MOTOR SCALE

Record Booklet

Nome ____________________

Número de Identificação ____________________

Examinador ____________________

Local da Avaliação ____________________

	Ano	Mês	Dia
Data da Avaliação	/	/	
Data de Nascimento	/	/	
Idade Cronológica	/	/	
Idade Corrigida	/	/	

	Itens Creditados Previamente	Itens Creditados na Janela	Escore de Sub-escala
Prono			
Supino			
Sentado			
Em Pé			

Pontuação Total ☐ Percentil ☐

Comentários / Recomendações