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Infants' relationship with drop-offs and water environments

Carolina Burnay Rodrigues de Morais
Edith Cowan University

Infants' Relationship with
Drop-offs and Water Environments

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Carolina Burnay Rodrigues de Morais
(Carolina Burnay)

BSc (Hons), M.Sc

Principal Supervisor:
Assoc/Prof. Chris Abbiss (Edith Cowan University)

Co-Supervisors:

Prof. Chris Button, Ph.D. (University of Otago)

Dr. David I. Anderson, Ph.D. (San Francisco State University)

Dr. James L. Croft, Ph.D. (University of Calgary)

Dr. Rita Cordovil, Ph.D. (University of Lisbon)

Edith Cowan University
School of Exercise & Health Science

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ABSTRACT

Underpinned by the ecological approach to perceptual-motor development, this Thesis aims to contribute to the understanding of the organization of infants' behaviour during encounters with drop-offs and water environments. Previous studies have linked locomotor experience to infants' avoidance of falling from heights. Using the Real Cliff / Water Cliff apparatus, Burnay and Cordovil (2016) confirmed the effect of locomotor experience on crawlers' avoidance of drop-offs and linked locomotor experience to infants' avoidance of falling into the water for the first time. However, the effect of other specific locomotor experiences on infants' approach to aquatic environments has not been addressed. This Thesis investigated the effect of specific locomotor experiences and the transition from skilled crawling to novice walking on infants' behaviour when they encounter real cliffs and two different ways to access the water: a cliff and a slope.

Using a cross-sectional design, Study One examined the effect of specific locomotor experiences on 102 infants' (58 crawlers, 44 walkers) avoidance of falling from a real and a water cliff (tank of water attached to the edge of a drop-off). Crawling and total self-produced locomotor experiences were associated with crawling and walking infants' behaviour. No association between walking experience and walking infants' avoidance behaviour was found. Study Two examined 25 infants' behaviour on the real and the water cliff in a longitudinal design. Infants were tested as experienced crawlers, new walkers and again as experienced walkers. The majority of infants avoided equally or more consistently when tested as new walkers than as experienced crawlers and even more consistently when tested as experienced walkers. Combining results from Study One and Two indicates that some degree of what infants learn through crawling experience about navigating drop-offs transfers to a new walking locomotor pattern.

For new walkers, adaptive behaviour requires a recalibration process, and a longer duration of crawling experience facilitates this process.

To investigate if perceptual-motor development influences infants' avoidance of submersion when a sloped entrance to the water is offered in the same way it does when a drop-off is presented, Study Three examined 77 infants' (43 crawlers, 34 walkers) avoidance of submersion on a 10^0 sloped surface leading to deep water. No association between infants' avoidance of submersion and locomotor experiences was found. Comparison with the results of Study One revealed that the proportion of infants that reached submersion on the slope was greater than the proportion of infants that fell into the water cliff. With self-produced locomotor experience, infants become attuned to relevant perceptual information about threats posed by cliffs (filled with water or not) but locomotor experience does not teach them to perceive water as unsafe when it can be approached via a sloped pathway.

Outcomes of this Thesis can be applied to educate caregivers about sensitive periods when infants are more susceptible to engage in behaviour that heightens drowning risk and to inform them about the potential increased drowning risk posed by swimming pools with sloping access.

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Awards

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1 Introduction

1.1 Overview

The primary aim of this doctoral thesis is to contribute to the prevention of falling and drowning incidents among young children by improving understanding of infants' behaviour around drop-offs and water environments. Underpinned by the ecological psychology approach, this thesis presents the results of three applied research studies focusing on the relationship between infants' perceptual-motor development and their behaviour around drop-offs and water environments. Study One examined crawling and walking infants' behaviour on a real cliff and a "water cliff" (drop-off filled with water) to investigate the effect of specific self-produced locomotor experiences on infants' avoidance of falling and exploratory behaviours. In Study Two, infants' avoidance of falling on the real and the water cliff was examined on a longitudinal study designed to investigate the effect of the transition from an experienced locomotor solution (i.e., crawling) to a newly acquired one (i.e., walking) on infants' avoidance of falling. Study Three examined the effect of specific self-produced locomotor experiences on crawling and walking infants' behaviour and avoidance of submersion on a ramp offered to access deep water. Finally, infants' avoidance of exposure to potential drowning incidents on a water drop-off (affording a fall into the water) and an underwater slope (affording a smooth and gradual access to deep water) was compared.

1.2 Background

Drowning, one of the leading causes of preventable injury among young children, is a neglected and pressing public health issue that requires urgent attention (WHO, 2017). In 2009, the World Health Organization and UNICEF published the World Report on Child Injury Prevention (Peden et al., 2009) identifying drowning as the leading cause of unintentional deaths among children 1-4 years-old worldwide. Later, the World Health Organization (WHO, 2014) undertook a first comprehensive assessment of global drowning incidents, confirming that the highest drowning rates worldwide are among young children aged 1–4 years.

A large body of work on children's drowning prevention has been conducted adopting an epidemiological approach through drowning statistics (Peden et al., 2009), but little is known about how and when infants' behaviour becomes attuned to the risks present in aquatic environments. As stated by the World Health Organization (2014), "Drowning […] has been largely overlooked, and there are a number of areas where further research is urgently needed". The focus of global drowning research should be potentially innovative interventions (WHO, 2014). To further the understanding of how infants act around bodies of water, there is a need for carefully designed, experimental research capable of addressing the dynamic relationship between the child (who is constantly developing) and aquatic environments.

In the late 1950s, Eleanor Gibson and Richard Walk created the "visual cliff" apparatus (cliff covered by transparent glass) to investigate how animals perceive depth at an edge. This pioneering study opened a new line of research on the effect of perceptual-motor development on infants' adaptive behaviour and a large body of research using the visual cliff apparatus and its adaptations has been produced to investigate the effect of self-produced locomotor experience on infants' avoidance of drop-offs. However, it was not until 2016 that the ecological approach was used to examine the dynamic relationship between infants and water environments. Inspired by the visual cliff paradigm, Burnay and Cordovil (2016) created the Real Cliff / Water Cliff apparatus (75cm high and 2m long platform, with a real drop-off on one side and a water cliff on the opposite side), to investigate infants' relationship with aquatic environments. The novel paradigm confirmed the effect of self-produced locomotor experience on infants' avoidance of falling from real cliffs and linked self-produced locomotor experience to infants' avoidance of falling into bodies of water for the first time.

In 2000, in light of a series of studies showing that infants with weeks of specific locomotor experience behaved more adaptively on drop-offs than infants tested shortly after acquiring new locomotor skills, Karen Adolph proposed a sway model to explain the effect of the emergence of new locomotor skills on infants' perception and action on risky scenarios. The central construct of the model was that as infants explore new locomotor postures, they have to relearn all over again how to avoid falling from drop-offs as no transfer of perception of the affordances of the environment is observed when new locomotor solutions are acquired (Adolph, 2019). However, in 2005, a study by Witherington and colleagues showed that infants avoided traversing the deep side of the visual cliff more consistently than experienced crawlers, indicating a transfer of what infants learned through crawling experience to newly walking infants and challenging the posture-specific affordance learning hypothesis of Adolph. In the first study using the Real Cliff / Water Cliff apparatus, Burnay and Cordovil (2016) tested only crawling infants and, to date, no assessment has been made of the effect of other specific locomotor experiences (i.e., walking) on infants' approach to aquatic environments. In addition, the Real Cliff / Water Cliff paradigm examined only infants' behaviour around water drop-offs. Infants' relationship with aquatic environments that do not offer a fall into the water is still to be investigated. The ecological approach to infants' relationship with water environments is not limited to falls into the water and has the potential to contribute to the development of more effective strategies to enhance water safety and the prevention of drowning among young children.

1.3 Significance of the Research

The overall aim of this doctoral thesis is to contribute to an improved understanding about the dynamical relationship between infants' perceptual-motor development and environments that do not afford safe locomotion, such as drop-offs and bodies of water. Results from this research will contribute to improve polices and guidelines focused on young children's safety by revealing sensitive periods when infants are more susceptible to engage in falling and drowning incidents. Understanding how infants approach drop-offs and ramps leading to aquatic environments may also help to inform the optimal design of swimming pools to prevent drowning incidents.

1.4 Research Aims

This thesis aimed to examine the effect of perceptual-motor development on infants' behaviour around drop-offs and aquatic environments.

1.4.1 Study One

Aimed to examine to what degree specific self-produced locomotor experiences influence infants' avoidance of falls from heights and into the water. An additional aim of Study One was to compare infants' behaviours between these two different, but equally risky, situations (real and water cliffs) that do not afford safe locomotion.

1.4.2 Study Two

Aimed to examine the effect of the transition from an experienced crawling to a newly-acquired walking locomotor solution on infants' avoidance of falling from heights and into bodies of water.

1.4.3 Study Three

Aimed to investigate the effect of specific self-produced locomotor experiences on infants' avoidance of submersion when a sloped entrance to deep water is offered. An additional aim of Study Three was to compare infants' perception and action when a sloping ramp (that offers a smooth and gradual entrance to the water) and a drop-off (that could invite a sudden fall) are offered to access the water.

1.5 Research Questions & Hypotheses

The research questions (denoted “Q”) and corresponding hypotheses (denoted “H”) for each study of this thesis are outlined below.

1.5.1 Study One

Q1: How are specific self-produced locomotor experiences associated with crawling and walking infants’ avoidance of falling on a real and a water cliff?

H1: Crawling experience will be associated with crawling infants’ avoidance of falling and walking experience will be associated with walking infants’ avoidance of falling on the real and the water cliff.

Q2: Is infants’ avoidance behaviour different between the real and the water cliff?

H2: Infants will fall more on the water cliff than on the real cliff.

Q3: Are there differences in infants’ exploratory behaviours between the real and the water cliff?

H3: Infants will engage in more tactile exploration on the water cliff than on the real cliff and move away more from the edge of real cliff than from the edge of the water cliff.

1.5.2 Study Two

Q1: What is the effect of the transition from experienced crawling to newly-acquired walking locomotor solution on infants’ avoidance of falling on the real and the water cliff?

H1: Infants will fall more on the real and the water cliff when tested as new walkers than when tested as experienced crawlers.

1.5.3 Study Three

Q1: Does specific self-produced locomotor experience influence infants' avoidance of submersion when sloped access is offered to enter water environments?

H1: Crawling experience will be associated with crawling infants' avoidance of submersion and walking experience will be associated with walking infants' avoidance of submersion.

Q2: Is infants' avoidance of submersion different between drop-offs and sloped access to water environments?

H2: More infants will avoid submersion when accessing a body of water from a drop-off than from a sloped entrance.

1.6 Definition of Abbreviations

Abbreviation	Unit or Term
°C	Degrees Celsius
AIC	Akaike information criterion
cm	Centimetre
h	Hour (time)
m	Meter
min	Minute (time)
s	second (time)
SD	Standard deviation
RC	Real cliff
WC	Water cliff
WHO	World Health Organization
WS	Water Slope

“The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill.” (J. J. Gibson, 1979, p. 127).

2 Review of Literature

2.1 Introduction

At the onset of self-locomotion, a whole new world opens up for infants, they can pursue new goals at a distance, change their location at any time, adopt new vantage points for viewing the environment, and explore objects, events, and people that were previously inaccessible. This exploratory activity has an important role in development, leading to great advances in perceptual and psychological functioning (Campos et al., 2000; Cordovil, Araujo, Pepping, & Barreiros, 2015; E. J. Gibson, 1988; E. J. Gibson & Pick, 2000). Infants have an innate drive to explore their environment and bodies of water offer inviting and playful opportunities to discover the local surroundings (Cordovil et al., 2015). However, in their urge to explore the world, infants sometimes engage in unsafe behaviours and drop-offs or bodies of water pose increased risks for infants. In fact, drowning and falls are, respectively, the second and fourth causes of unintentional injury deaths among children worldwide (Peden et al., 2009) and sometimes falling and drowning occur together. In Australia, for instance, the vast majority of drowning deaths in children under 5 occur due to a fall into the water (Royal Life Saving Society-Australia, 2016).

Instead of only reporting how many infants engage in falling and drowning incidents, it is important to investigate why infants engage in falling and drowning incidents. When do infants start showing adult-like adaptive behaviours around heights and bodies of water and what factors contribute to the development of these adaptive behaviours? The ecological approach is a framework for studying the relationship between animals and the environment, with a special focus on development. It is particularly well suited to studying the development of adaptive behaviour in novel environments because its focus is on the mutuality of the animal and the environment and on the mutuality of perception and action. Researchers who have adopted the ecological approach have provided valuable insights into how perceptual-motor changes in the child in relation to the properties of the environment co-create developmental advances. By understanding how perceptual-motor development impacts infants' adaptive behaviour, we can better understand the development of the dynamic relationship between young children and environments that do not afford safe locomotion and that can lead to falls from heights and into bodies of water.

2.2 Self-produced locomotion and infants' avoidance of drop-offs

Over the course of development, infants learn to adapt while moving through different environments – they learn to perceive what J. J. Gibson (1979) termed "affordances". Affordances are essentially possibilities for action and depend on the relations between the infants' body and skills and the relevant properties of the environment. For example, a stool might afford sitting on for an older child but might only afford pulling to a standing position for a younger, smaller child who has not yet learned to stand independently. During the first months of life, infant's size, body's proportions and action capabilities change dramatically. As new motor skills are acquired, new affordances emerge because new relations between body and environment are established (Franchak & Adolph, 2014). For an infant to locomote independently the surface must provide a safe support for the body. However, even if the pathway is safe for locomotion and the infant possesses the appropriate attributes and capabilities to move from place to place, he or she needs to learn how to detect and respond to meaningful, relevant information from the rich landscape of affordances (Rietveld & Kiverstein, 2014). Avoidance of risky situations ultimately helps to keep us alive but, paradoxically, the infant's curiosity and need to explore the environment may be one of the driving forces behind skill development and adaptive behaviour (Cordovil et al., 2015). Moreover, for the human baby key developmental events (e.g., onset of different locomotor solutions) play an important role in their perception and action in the environment.

Since the ground-breaking work of Eleanor J. Gibson and Richard Walk (1960), the "Visual Cliff" paradigm, and its variations, have been primarily used to investigate infants' adaptive behaviour on settings that can lead to dangerous falls (i.e., impossible heights, steep slopes, bodies of water). The Visual Cliff apparatus consists of a large flat surface (i.e., table) with an apparent drop-off covered with transparent safety glass on the "deep side" and with a checkerboard pattern cloth placed immediately beneath the glass surface, specifying a solid surface, on the "shallow side". E. J. Gibson and Walk (1960) first used the visual cliff apparatus to investigate the development of visual depth perception and avoidance of drop-offs in various animal species. This first study suggested that the animals' reaction to a perceived cliff was a function of the species' adaptation for survival in the environment, driven by evolutionary pressures. Some species (e.g., goats) avoided the visual cliff as soon as they were able to locomote, showing an apparently instinctive and innate response to the danger of falling over drop-offs. E. J. Gibson and Walk (1960) reported that most human infants avoided crawling over the visual cliff deep side.

The authors interpreted the infants' refusal to transverse the visual drop-off in terms of the infant's heavy dependence on vision, which, by the time the infant starts self-locomoting, provides reliable information about depth (Timney, 1988).

This phylogenetic perspective may help to understand why a rat crosses a visual cliff without hesitation (rather than vision the rat relies primarily on tactile information from its paws and whiskers to move around). However, for the human infant this explanation may not be sufficient. Humans are altricial animals (i.e., incapable of self-locomoting at birth) and each infant is unique, develops over a specific timescale and learns how to locomote and deal with the environment at different rates. In addition, humans are the only terrestrial animals that employ different locomotor strategies during their development (i.e., crawling, walking). As J. J. Gibson once wrote: "The human young must learn to perceive these affordances, in some degree at least, but the young of some animals do not have time to learn the ones that are crucial for survival." (J. J. Gibson, 1979, p. 406).

Subsequent studies using the visual cliff paradigm to test the infants' avoidance of heights favoured a maturation-based explanation pointing to age or crawling-onset age as the major predictors of avoidance behaviour. Walk (1966) tested crawling infants on the visual cliff and reported that infants older than 300 days of age showed a greater tendency to avoid the deep side of the visual cliff than the younger ones. When analysing the influence of crawling experience on the avoidance of the cliff, half of the infants (46%) who started crawling after nine months of age (considered new crawlers) crossed the visual cliff; whereas only 20% of the infants who started crawling earlier than nine months of age (considered experienced crawlers) did so. However, Walk's (1966) research has been criticized for using a variety of patterns (e.g., homogeneous grey, 1/4 inch checker, 3 inch checker), placed at various distances beneath the glass (0, 10, 20, or 40 inches), thus manipulating the available depth information (Richards & Rader, 1981), and for splitting infants into two groups by age (older and younger than 10 months), confounding age and experience (Adolph, 1997). Another study by Scarr and Salapatek (1970), pointed to age as a predictor of the avoidance of the visual cliff, reporting that older infants were more likely to display signs of fear of the visual cliff deep side than younger ones.

Richards and Rader (1981, 1983) reported crawling onset-age as the best predictor of infants' avoidance behaviour on the visual cliff. The authors tested 7 to 13-month-old infants with 30 or 60 days of crawling experience and found that infants who began crawling at younger ages (before 6.5 months) crossed the visual cliff more than infants who began crawling at older ages (Richards & Rader, 1981). The authors also reported a negative relationship between crawling experience and avoidance behaviour (i.e., infants with more crawling experience showed greater tendency to cross the deep side). The crawling onset age effect was proposed to support a maturational explanation of the onset of infants' adaptive avoidance responses. The authors reasoned that "the crawling-onset age effect occurs because crawling during the tactile phase of infancy interferes with later visual control of locomotion" (Richards & Rader, 1981, p.382). However, the authors only tested infants with a narrow range of crawling experience (i.e., 30 or 60 days) failing to assess infants with a very limited or considerable self-produced locomotor experience. Therefore, the negative relation they found between locomotor experience and avoidance on the visual cliff was likely spurious (Bertenthal & Campos, 1984) as subsequent studies would confirm (Campos, Bertenthal, & Kermoian, 1992).

In a series of studies, Joseph J. Campos and colleagues used the visual cliff paradigm to study infants' emotional development, in particular the emergence of fear as indexed by avoidance of heights. In a first study, fear of heights was related to age (Schwartz, Campos, & Baisel Jr, 1973). The authors placed infants directly atop the visual cliff and 9-month-old infants showed heart rate acceleration (taken as an indicator of fear) while younger 5-month-old infants did not (Schwartz et al., 1973). However, in subsequent studies considering the specific role of crawling experience, Campos and colleagues found that crawling experience was the strongest predictor of fear and avoidance of the visual cliff (e.g., Bertenthal & Campos, 1984; Campos et al., 1992; Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978). In a lag-sequential longitudinal design, crawling (but not pre-crawling) infants showed significant cardiac acceleration when lowered onto the deep side of the visual cliff, suggesting that locomotor experience contributed significantly to the development of wariness of heights (Campos et al., 1992). In addition, Campos et al. (1992) reported that regardless of the age infants started crawling, 60-80% of experienced crawlers (with 41 days crawling experience) avoided the visual cliff but only 30-50% of new crawlers (with 11 days experience) did so.

Another set of studies assessed the influence of self-produced locomotion on visual proprioception and how it related to avoidance of the visual cliff (Dahl et al., 2013; Ueno et al., 2018). Visual proprioception is the optically produced awareness of self-motion that stems from the covariation between self-motion and patterns of optic flow (J. J. Gibson, 1979). Visual proprioception is often tested in infants by exposing them to different patterns of optic flow in a 'moving room', in which the front and sidewalls can be moved independently. Confronted with a moving room, self-locomoting infants showed greater postural compensation to the sidewall movement (peripheral optic flow) than pre-locomotor infants (Dahl et al., 2013; Uchiyama et al., 2008). In a second study, pre-crawling infants were trained to drive a powered baby go-cart, providing them with self-produced locomotor experience, while a control group of infants received no training. The data revealed that infants who used the baby go-cart showed a significant increase in postural compensation to sidewall movement in the moving room from pre-test to post-test and an acceleration of heart rate when confronted with the visual cliff, while infants in the control group did not (Dahl et al., 2013; Uchiyama et al., 2008).

Studies using adaptations of the classical visual cliff have confirmed that although avoidance of drop-offs is highly adaptive, infants do not reliably avoid falling until after they have acquired weeks of experience with independent locomotion. Adolph (1997) tested infants longitudinally when descending slopes and reported that infants' motor decisions became more accurate over weeks of crawling experience: inexperienced crawlers crossed headfirst down risky slopes but, after weeks of crawling experience, they only crawled down safe slopes and slid down or avoided risky ones. Likewise, when infants were tested on a real cliff (Kretch & Adolph, 2013), experienced crawlers avoided drop-offs that were too high to navigate. Similar behaviour has been reported over water cliffs. Burnay and Cordovil (2016) reported that crawling experience was the strongest predictor of crawlers' avoidance not only of a real cliff but also of a water cliff. This study linked self-produced locomotion to infants' avoidance of falling into bodies of water for the first time.

2.3 Transition from experienced locomotor solutions to newly acquired ones

The link between self-produced locomotor experience and infants' perception and action in potentially dangerous environments (whether visual cliffs, impossible steep slopes, actual drop-offs or water drop-offs) is now well established and universally accepted among researchers (see Anderson, 2018). Over weeks of everyday crawling, infants start avoiding dangerous falls (Campos et al., 1992; Adolph, 1997; Kretch & Adolph, 2013), but when they first start walking a new perspective on the world emerges. The dynamic relation between what the environment presents and the constant change in body dimensions and capabilities sculpts the infants' behaviour (Thelen, 2005). Walking is a new perceptual-motor challenge. When infants start walking, the upright posture leads to a new point of view, infants move around without touching the surface of support with their hands anymore and this new bipedal locomotion changes balance. Do infants need to relearn all over again how to perceive and adapt their behaviour when a new locomotor solution emerges? Or is there a transfer of the perception of the possibilities for action offered by environments that can lead to potentially dangerous falls?

One interpretation offered is that a major reorganization and refinement of visual proprioception that occurs after several weeks of crawling experience is the reason infants start avoiding dangerous drop-offs (e.g., Campos et al., 2000). Avoidance is one index that the infant has become wary of the drop-off (Bertenthal & Campos, 1984; Campos et al., 2000; Dahl et al., 2013; Ueno et al., 2018). Researchers favouring this view suggest that a developmental transfer of wariness of heights occurs across postural milestones. When comparing a group of experienced crawlers' avoidance of the visual cliff with a group of same-aged novice walking infants, Witherington, Campos, Anderson, Lejeune and Seah (2005) reported that new walkers avoided moving onto the deep side even more consistently than the experienced crawlers. The authors argue that a developmental transfer of wariness of heights occurs across postural milestones. Once avoidance of drop-offs is established through crawling experience it is developmentally maintained when infants begin walking (Witherington et al., 2005).

An alternate view of the role of locomotor experience on the avoidance of risky scenarios is adopted by Karen Adolph and colleagues. Avoiding dangerous falls is explained as a progressive learning of affordances by the infants to displace their bodies on a specific surface, in relation to the specific strategy used to locomote with the infant's body characteristics at the moment. A functional discontinuity between postural and locomotor milestones was shown in various studies that addressed the role of specific postural experience on infants' adaptive avoidance of potentially falling scenarios. For instance, infants tested in an experienced sitting posture avoided reaching for a toy placed on the opposite side of a 90 cm gap in the support surface but, when tested with a newly-acquired crawling posture, the same infants misjudged the situation and repeatedly tried to cross the impossible gap (Adolph, 2000). When comparing crawling and walking infants' behaviour on increasingly steeper slopes (Adolph, 1997; Adolph, Tamis-LeMonda, Ishak, Karasik, & Lobo, 2008) and on an adjustable drop-off apparatus (Kretch & Adolph, 2013) new crawlers tended to crawl right over impossibly steep slopes (Adolph, 1997), but experienced crawlers avoided approaching the same impossible slopes (Adolph, 1997; Adolph et al., 2008) and the 90 cm high real cliff (Kretch & Adolph, 2013). These results are consistent with those of Joseph Campos and colleagues on the influence of crawling experience on infants' avoidance of drop-offs (Bertenthal & Campos, 1984; Campos et al., 1992). However, contrary to the results reported by Witherington et al. (2005), when Adolph and colleagues tested infants with a newly acquired walking posture, novice walkers tried to march straight over the edge of impossible-to-traverse cliffs and steep slopes and only after weeks of everyday walking experience did they regain their adaptive avoidance responses (Adolph, 1997; Kretch & Adolph, 2013).

Adolph (2000) proposed a "sway model" to interpret these findings, arguing that "the coordination between perception and action is organized within postural systems, so that experience with an earlier-developing skill does not transfer automatically to a later-developing skill" (Adolph, 2000, p. 291). The idea is that there are four different learning curves in development as infants learn to sit, to crawl, to cruise and to walk, and not a general wariness of heights (Adolph, 2019). From this dynamical systems view of development, every new locomotor achievement alters motor and perceptual stability and, therefore, the infant needs to relearn how to perceive the new relations between their new characteristics (size, strength, ability to maintain balance, or even ability to use optical flow information) and the environment (Adolph, Kretch, & LoBue, 2014). Thus, avoiding cliffs is described as a postural specific affordance learning, not transferable between different postures (Adolph, 2019).

2.4 Different experimental paradigms, different outcomes

The contradictory results on the transfer of learning from a crawling posture to a walking posture may be at least partly due to differences in experimental paradigms. These differences are especially apparent when comparisons are made between the visual cliff used by Witherington et al. (2005) and the real cliff used by Kretch and Adolph (2013). First, the experimental paradigms were different. The visual cliff apparatus used by Witherington et al. (2015) is a drop-off covered by glass, inspired by the classical "Visual Cliff" study (E. J. Gibson & Walk, 1960). Although it has the advantage of being safe if the infant crawls onto the deep side, it has been criticized because the transparent glass creates a conflict between visual and haptic information: vision specifies a drop-off, whereas haptic information specifies a rigid and traversable surface (Adolph & Kretch, 2012). The safety glass also limits the infants' possibilities for exploratory behaviour on the deep side as it prevents them from stretching their arms and legs toward the floor in search of information about the height of the cliff. To avoid these problems, Kretch and Adolph (2013) used a real cliff paradigm where the real cliff is identical to the visual cliff, except that there is no glass on the deep side. However, to ensure the infants' safety, an experimenter stays close to them and catches them if they begin to fall. While testing infants on gaps in the supporting surface and using the same procedure to ensure infants safety, Adolph (2000) claimed that the spotter's presence does not lead infants to behave rashly because infants who were repeatedly rescued from falling in a crawling posture refused to venture over impossibly wide gaps when placed in an experienced sitting posture minutes later. However, this procedure makes it difficult to determine how infants would behave in the absence of an adult hovering so close to them. In addition, “crossings” in the visual cliff were coded differently from “fallings” in the real cliff. When infants lean their weight onto the safety glass while trying to explore it, the attempt is not coded as a crossing, but in a real cliff they would have fallen, so the use of glass might lead to an underestimation of the infants’ errors (Adolph & Kretch, 2012; Adolph et al., 2014). Second, Witherington et al. (2005) and Kretch and Adolph (2013) used different study designs. Witherington et al. (2005) tested infants only once on the visual cliff in order not to induce any progressive learning; while Kretch and Adolph (2013) used a psychophysical staircase procedure, where infants were progressively introduced to deeper and deeper stairs until there was a reversal in behaviour. The staircase procedure has the advantages of testing the capacity of the infants to explore the apparatus and progressively learning the affordances for traversing. It also allows avoiding drawing conclusions based only on just one trial, which might be an issue due to the natural inconsistency of infants’ behaviour. However, this procedure may not be suitable to directly test avoidance behaviour of infants when facing a dangerous cliff in a real environment for the first time, where there is not an option of testing bigger and smaller steps until an impossible drop-off appears.

One similarity between the Kretch and Adolph (2013) and Witherington et al. (2005) approaches is that both tested age-matched experienced crawlers and new walkers. By comparing the behaviour of one group of experienced crawlers with one group of newly walking infants, holding age constant, the extended effects of age and specific locomotor experiences cannot be accessed. New walkers may avoid the deep side of a visual cliff more consistently or they may fall more from the real cliff than experienced crawlers, but it is unclear whether the reason for this difference is the amount of walking experience specifically or total self-produced locomotor experience.

2.5 Infants' perception and action around WATER environments

> '…a horizontal, flat, extended surface that is nonrigid, a stream or lake, does not afford support for standing, or for walking and running. There is no footing, as we say. It may afford floating or swimming, but you have to be equipped for that, by nature or by learning.'
>
> J. J. Gibson (1979, p. 132).

"Water cliffs" (i.e., drop-offs filled with water), such as lakes or swimming pools, are another type of physical cliff that poses a specific risky scenario for children. Water surfaces do not afford safe locomotion to an infant who does not have the ability to swim, but it is drinkable, and most infants associate it with fun experiences (e.g., bath time or summer playing situations). As J. J. Gibson (1979) highlighted 'water has many kinds of meanings' (p. 38). Terrestrial animals are always in danger of drowning, but they must drink, so they need to recognize water when they encounter it. In fact, previous research has shown that infants recognise and tend to mouth glossier/wet objects more frequently than dull objects (Coss, Ruff, & Simms, 2003). However, the question of whether infants recognise bodies of water as environments to avoid has received little attention.

Water has different characteristics than air that specify it as a non-support surface: it is fluid and deformable and often times it is transparent. Water is visually different than air, though light can be reflected from a body of water in such a way that it appears like a drop-off. When an infant encounters a water surface, the loss of visual information probably does not happen in the same way that it happens at the edge of a cliff, but the reflected light from the water surface may provide a less reliable source of visual proprioception (i.e., visual information about own body's movements in relation to the environment) for the control of balance and locomotion than the light reflected from a rigid surface. The open air at the brink of a cliff and water offer different visual and tactile information but they are both "preventer(s) of locomotion" (J. J. Gibson, 1979, p.36) and dangerous to the infants' safety.

Children's water safety and drowning prevention are issues that concern societies around the world, and infants' attraction to bodies of water poses challenges to education and policymaking. Preventing children from drowning is a longstanding, complex social issue (Stallman, Moran, Quan, & Langendorfer, 2017). Although preventable, drowning is among the ten leading causes of children's and young people's unintentional death in every region of the world (WHO, 2014). In fact, drowning is reported as the leading cause of unintentional death among 1-4-year-old children worldwide (Peden et al., 2009).

The supervision of young children around any body of water and installation of safety barriers to control children's access to water are primary recommendations for drowning prevention (e.g., WHO, 2014, 2017). As stated by the World Health Organization (2014, p.9): "Children who are mobile but too young to recognize danger or to get out of water are at risk, especially in the absence of barriers and capable supervision". However, it is not uncommon that children find themselves close to a body of water with limited adult supervision (Moran, 2010) and safety barriers are not always an option nor absolutely childproof. In fact, a study addressing the effect of local pool-fencing regulations in Los Angeles County, California (Morgenstern, Bingham, & Reza, 2000) concluded that there was no association between the pool-fencing ordinances and a reduction of childhood drowning rate. The efficacy of safety barriers to prevent or delay children (aged 19-75 months) from crossing has also been examined (Cordovil, Barreiros, Vieira, & Neto, 2009). Cordovil et al. (2009) examined children attempting to cross different safety barriers, analysing time to cross and crossing techniques, and reported that none of the barriers used in the study assured a considerable protective delay. What happens when infants manage to overcome safety barriers, assuming they are there in the first place, and face a body of water with no adult supervision?

Most studies in the field of children's drowning prevention have adopted an epidemiological approach by examining drowning statistics (Peden et al., 2009). However, these studies do not explain when and why children start perceiving the danger of a body of water and adopting an adult-like behaviour by avoiding drowning situations. Understanding how infants detect and use the available information to guide their behaviour nearby aquatic environments and what is the role of development in this relationship should be paramount to those interested in behavioural interventions to help prevent drowning injuries among young children.

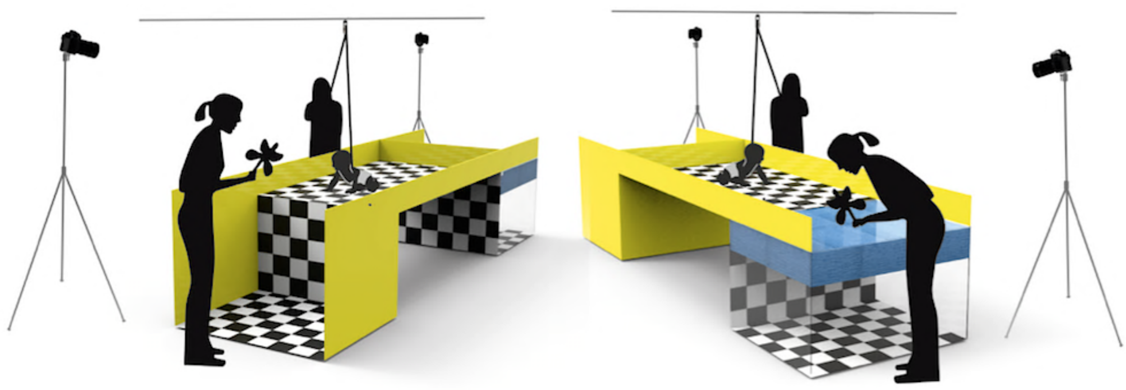
Some studies have analysed the behaviour of infants on surfaces offering tactile or visual cues for water. For instance, E. J. Gibson et al. (1987) tested the avoidance and exploratory behaviour of infants on a deformable waterbed versus a rigid plywood surface. Crawlers showed similar latency for initiation of traversal between the two different surfaces, a similar amount of visual and haptic exploratory behaviour, and crossed them both in equal numbers. Rader (2003) reported having tested infants on the visual cliff with water under the glass in three conditions: opaque water with waves, opaque water without waves, and a normal shallow side (without water). The results showed that infants' latency to leave the centreboard was shortest in the moving water condition. The author concluded that infants do not always respond to the affordance of non-support even when visual information specifies a non-rigid surface. However, in neither study (i.e., E. J. Gibson et al., 1987; Rader, 2003) did the infant have the opportunity to touch the water and, in both situations, the surfaces (waterbed and glass) were safe for quadruped locomotion, not inviting an actual fall into the water.

One specific study by Cordovil, Santos, and Barreiros (2012) has analysed children's risk-taking and exploratory behaviour nearby actual water surfaces. Cordovil et al. (2012) investigated 1-4 years-old' (all walkers) behaviour in a task of retrieving a toy (rubber duck) out of the water from the edge of a swimming pool. When the toy was placed beyond the children's reaching limit, 69% of them fell or jumped into the water to grasp it. The results support the relation between children's overestimation of their capabilities and their proneness to accidents (Plumert, 1995), showing that their behaviour around water is no exception. However, this study focused on the perception of reaching limits in a swimming pool and not on the role of locomotor experience in the avoidance of falling into the water. Moreover, even though the authors reported that locomotor experience was not significantly related to children's behaviour, of the 68 children tested only one had less than 30 days of walking experience, so newly walking infants' behaviour could not be addressed (Cordovil et al., 2012).

2.6 Real Cliffs vs. Water Cliffs

As previously established, accurate perception of which surfaces and media can be safely traversed is fundamental for adaptive movement. Self-produced locomotor experience teaches infants to better detect the properties of the surface of support, to perceive the affordances of risky scenarios and to avoid dangerous falls. To investigate if self-produced locomotor experience influences infants' adaptive behaviour around bodies of water, Burnay and Cordovil (2016) created the Real Cliff / Water Cliff apparatus. As shown in Figure 1, the apparatus is a solid 2 m-long platform (0.75 m high), covered with a black-and-white checkerboard pattern, with real cliff at one end and a plexiglass tub filled with water ("water cliff") on the opposite side. The "Real Cliff / Water Cliff" paradigm (Burnay & Cordovil, 2016), was designed to overcome some of the limitations pointed to in previous studies addressing the relationship between perceptual-motor development and infants' avoidance of falls. First, the transparent glass (used in visual cliff studies) and the presence of an experimenter alongside the infant (used by Adolph and colleagues) were substituted by a harness system to ensure the infants' safety. In this case, the infants had no bias either from the glass or the proximity of a spotter and they could freely explore the cliff edge and drop-off or the water both visually and haptically. Rader (1997) reported a previous study conducted by Rader and Ashley, in 1983, where a harness system was used to analyse tactile exploratory behaviour on an actual cliff. However, that full study was not formally published, so few details are available. The second design feature used by Burnay & Cordovil (2016) was that infants were tested only once on each cliff, in order to avoid any progressive learning that a staircase procedure may induce. Finally, to provide a reliable estimate of the amount of locomotor experience required for infants to start avoiding drop-offs, crawling experience was allowed to vary considerably. The main goal of the study was to analyse, in a more ecological situation, the behaviour of infants when they encounter a body of water (e.g., swimming pool, water tank).

FIGURE 1 | Real Cliff (left) / Water Cliff (right) experimental set-up. Illustrated here side-by-side for contrast but conducted independently. From Burnay, C., & Cordovil, R. (2016). Crawling experience predicts avoidance of real cliffs and water cliffs: Insights from a new paradigm. Infancy, 21(5), 677-684. Copyright © 2016, John Wiley and Sons, reprinted with permission.



Burnay and Cordovil (2016) tested 31 infants, with crawling experience varying between 16 days and 7.4 months, once on each cliff type. When age, crawling onset age, and crawling experience were entered into a logistic regression analysis, crawling experience was shown to be the best predictor of crawling infants' avoidance behaviour, on both cliffs. This study confirmed the link between self-produced locomotor experience and infants' avoidance of falling on dangerous drop-offs and showed the same link with crawlers' avoidance of falling into bodies of water. When comparing infants' behaviour between the real cliff and the water cliff, the majority of infants (71%) showed the same avoidance behaviour on both cliffs (Burnay & Cordovil, 2016), suggesting that similar perception and action processes underpin the two scenarios.

Results from the first Real Cliff / Water Cliff study indicate that locomotor experience has an important effect on infants' avoidance of falling into the water, but the evidence is limited and needs to be further investigated. Burnay and Cordovil (2016) only tested crawling infants and the effect of the transition between crawling and walking locomotor postures is still to be addressed. In addition, although infants showed similar avoidance behaviour on the real and the water cliff, it is not clear if the infants' behaviour on the water cliff was only influenced by the perception of affordance of a fall or if infants perceive a body of water as a risky environment. In order to understand the dynamical relationship between infants' perceptual-motor development and aquatic environments, the investigation should not be limited to water drop-offs alone.

2.7 Summary and Conclusions

Infants' adaptive behaviour is the result of a dynamic relationship between their perception and capability for action and the specific opportunities offered by the environment. Self-produced locomotor experience has been linked to infants' avoidance of surfaces that do not afford safe locomotion, like drop-offs and bodies of water. However, the effect of the transition from crawling to walking and the degree to which specific locomotor experiences impact infants' avoidance of dryland drop-offs remain to be confirmed. In addition, the effect of the acquisition of walking and experience locomoting in the upright posture on infants' avoidance of bodies of water has not been addressed. The ecological approach to the relationship between infants' behaviour and water environments is new and has the potential to contribute to the promotion of more efficient strategies to enhance water safety and prevent young children from drowning.

3 STUDY ONE

Effect of Specific Locomotor Experiences on Infants' Behaviour on Real and Water Cliffs

3.1 Abstract

Infants' avoidance of cliffs has been described as an affordance learning that is not transferable between different locomotor postures. In addition, there is evidence that infants perceive and act similarly around real and water cliffs. This cross-sectional study investigated the effect of specific locomotor experiences on infants' avoidance and exploratory behaviours using the Real Cliff / Water Cliff paradigm. The experiment included one group of 58 crawling, but pre-walking, infants (M_{age}= 11.57 months, SD = 1.65) with crawling experience ranging between 0.03 and 7.4 months (M = 2.16, SD = 1.71) and another group of 44 walking infants, (M = 14.82 months, SD = 1.99), with walking experience ranging between 0.13 and 5.2 months (M = 1.86, SD = 1.28). Results confirmed no difference in infants' avoidance of falling on the real and the water cliff. However, infants explored the water cliff more than the real cliff, revealing a greater attraction for bodies of water than for drop-offs. The association between crawling experience and crawlers' avoidance of falling on real and water cliffs also was confirmed. Importantly, crawling and total self-produced locomotor experience, and not walking experience, were associated with walkers' avoidance behaviour on both cliffs. The results indicate some degree of perceptual learning acquired through crawling experience was developmentally transferred to the walking posture. With weeks of crawling experience infants become attuned to relevant perceptual information about cliffs (filled or not with water) and calibrate it to their action capabilities in the service of adaptive behaviour. It seems that a longer duration of crawling experience facilitates a more rapid recalibration to the new walking capability.

Keywords: real cliff, water cliff, infants, affordance, locomotor experience.

3.2 Introduction

When infants first start self-locomoting, they show very little concern for drop-offs. It is not until infants have accumulated several weeks of crawling experience that they start adapting their behaviour to safely avoid crawling over the edge of drop-offs (Adolph, 1997; Campos et al. 1992; Kretch & Adolph, 2013). The novel Real Cliff / Water Cliff paradigm created by Burnay and Cordovil (2016) has reinforced the importance of crawling experience on infants' adaptive behaviour on real cliffs and shown the same importance of crawling experience on water cliffs. Regarding the acquisition of walking skill, some studies have shown that infants who were responding adaptively when tested on steep slopes as experienced crawlers would fall when tested as new walkers (Adolph, 1997) and that newly walking infants walked over drop-offs more than experienced crawlers (Kretch & Adolph, 2013). Kretch and Adolph's (2013) interpretation of these results was that "crawling experience teaches infants to perceive affordances for crawling and walking experience teaches infants to perceive affordances for walking" (Kretch & Adolph, 2013, p. 236). However, one piece of evidence is contradictory to this posture-specific interpretation. Witherington et al. (2005) reported that new walkers avoided crossing a visual cliff more consistently than experienced crawlers. According to the authors, "once avoidance of drop-offs is established under conditions of crawling, it is developmentally maintained once infants begin walking." (Witherington et al., 2005, p.286).

Following the line of studies initiated by Burnay and Cordovil (2016), the present study examined crawling and walking infants' avoidance of falling from heights and into the water using the Real Cliff / Water Cliff paradigm. The main aim of this study was to investigate the effect of specific locomotor experiences on infants' perception and action around real and water cliffs. If infants' adaptive behaviour on drop-offs is learned in a posture-specific way (Adolph, 2019), crawling infants' avoidance behaviour on the real and the water cliff should be linked to the amount of crawling experience and walking infants' avoidance behaviour should be linked to the amount of walking experience. On the other hand, if avoidance of falling from drop-offs is established through self-produced locomotor experience and developmentally maintained once infants begin walking (Witherington et al., 2005), then the amount of crawling and/or total self-produced locomotor experience should determine crawlers' and walkers' avoidance of falling on the real and the water cliff.

A second goal was to compare infants' avoidance and exploratory behaviours on the real and the water cliffs while searching for information to decide whether or not to crawl/walk over the edges. A real cliff (filled with air) and a water cliff (filled with water) are visually and haptically different, but they are both preventers of safe terrestrial locomotion. Infants' similar behaviours on the real and the water cliffs would indicate a similar perception of affordances on both drop-offs.

3.3 Methods

3.3.1 Participants

A total of 102 infants were tested on the Real Cliff / Water Cliff apparatus. Of these, 58 (30 boys and 28 girls) were crawling on their hands-and-knees (but not walking) and 44 (25 boys and 19 girls) had started walking. Note that the sample of crawling infants from Burnay and Cordovil (2016) was enlarged from 31 to 58, to improve confidence in original findings (see Lukits, 2016). Six additional crawlers and seven walkers were excluded from the sample due to compulsive crying or fussiness prior to or during the first 60 s of the trials. Families were recruited through referrals, social network advertisements, and local schools, in the metropolitan area of Lisbon, Portugal.

Forty crawling infants started self-locomotion by belly-crawling, 17 by hands-and-knees crawling and only one crawler used cruising as a first self-locomotor strategy. Ten crawlers started cruising prior to hands-and-knees crawling. For 19 walkers, belly-crawling was the first self-locomotor strategy adopted, 19 started locomotion by hands-and-knees crawling and six by cruising. Twenty-five walking infants never belly-crawled, two never hands-and-knees crawled and two never cruised.

Walkers were older and had more crawling, cruising and total self-produced locomotor experience than crawlers (see Table 1). Crawlers' crawling experience was not significantly different from walkers' walking experience (t = 0.989, p = .325).

TABLE 1 | Difference in age and locomotor experience durations (in months) between crawlers (N=58) and walkers (N=44).

		Min	Max	Mean	SD	t	P
Age	Crawlers	8.51	16.13	11.57	1.65	-8.99	<.001
	Walkers	10.35	18.56	14.82	1.99		
Belly-Crawling experience	Crawlers	0.00	4.50	1.12	1.18	1.44	0.154
	Walkers	0.00	7.46	0.75	1.41		
Crawling experience	Crawlers	0.03	7.36	2.16	1.71	-5.87	<.001
	Walkers	0.00	6.74	4.09	1.55		
Cruising experience	Crawlers	0.00	6.80	1.15	1.27	-6.27	<.001
	Walkers	0.00	7.92	3.23	1.90		
Walking experience	Crawlers	-	-	-	-		
	Walkers	0.13	5.19	1.86	1.28		
Total Self-Locomotor experience	Crawlers	0.39	7.36	3.28	1.93	-8.71	<.001
	Walkers	0.13	5.19	6.73	2.04		

The amounts of specific locomotor experiences were calculated (in months) from the onset dates reported by the mothers:

- Belly-crawling experience – since the day the infant first belly-crawled (crawled with the belly touching the floor for at least five continuous cycles) until the day the infant first hands-and-knees crawled (for at least five consecutive cycles without the belly touching the floor);
- Crawling experience – since the day the infant first hands-and-knees crawled until the trial day, in the case of pre-walking infants, and until the day the infant first walked (for at least ten consecutive steps with no external support), in the case of walking infants;
- Cruising experience – since the day the infant first walked with the support of home furniture (lateral locomotion, for at least ten consecutive steps) until

the trial day, in the case of pre-walking infants, and until the day the infant first walked, in the case of walking infants;

- Walking experience – since the day the infant first walked independently until the trial day;
- Total self-produced locomotor experience – since the day the infant first self-locomoted (by belly-crawling, hands-and-knees crawling, cruising, or walking) until the trial day.

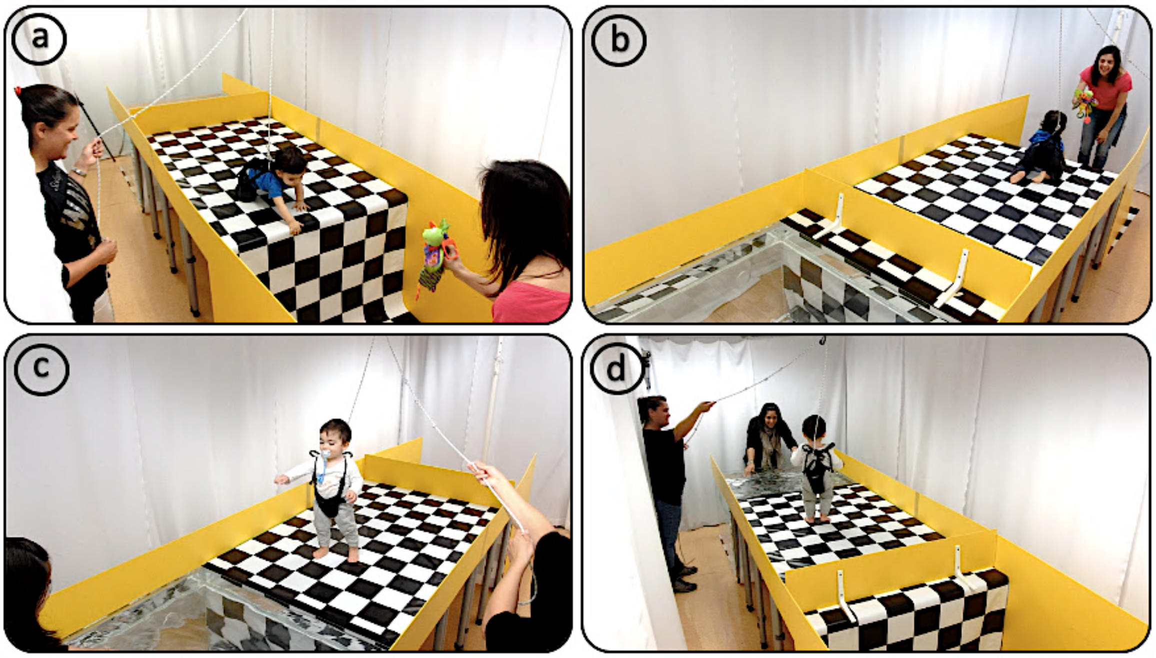
The criterion used to determine the onset of locomotor skills was functional, deriving from task-specific variables, as observed in previous studies (e.g., Adolph, 1997; Witherington et al., 2005). The five-cycle criterion used for the onset of belly-crawling and crawling (as in Burnay and Cordovil, 2016), and ten-steps for walking onset correspond approximately to the 2 m-length infants had to crawl or walk on the platform to get to the edge. Adolph (1997) defined crawling onset as the day infants could travel 91 cm along a flat path. Therefore, it is likely that an infant with one week of experience on Adolph's (1997) criterion is less experienced that an infant with one week of experience in the present study. Regarding the criteria used to determine walking onset, Adolph (1997) used 321 cm while Witherington used 184 cm. Therefore, walking experience would be similar between infants in the present study and those in Witherington et al.'s (2005) study but an infant with one week of walking experience in the present study would have less walking experience than infants with one week of walking experience in Adolph's (1997) study. Note that to the date, whatever the criteria used to determine specific locomotor onset day, the real extent of locomotor experience was a variable with a degree of error. For instance, an infant who has been crawling for ten days and is allowed to crawl around at will has more crawling experience than an infant who has been crawling for ten days but spends long periods in limited spaces with restricted locomotor activity.

The Human Ethical Research Committees at Edith Cowan University and at the University of Lisbon approved this study. Parents were asked to sign informed consents before their babies were tested.

3.3.2 Real Cliff / Water Cliff apparatus

The Real Cliff / Water Cliff apparatus, created by Burnay and Cordovil (2016), consists of a 120x200 cm platform coated with a black and white checkerboard pattern and with side protections. At one end, the real cliff side, there is no protection from a fall, just the same checkerboard pattern covering the entire wall of the cliff to the ground (75 cm high), continuing for an additional 100 cm on the ground. At the opposite end of the platform is a 20 cm deep water tub made of transparent plexiglass, resting on a 55 cm high base, also made of transparent plexiglass, giving the infants the optical illusion of a 75 cm deep water tub. The water level is continuous with the level of the platform, therefore, when the solid platform ends, the water surface starts. The checkerboard pattern also covers the entire wall of the water cliff to the ground (75 cm high), continuing for an additional 100 cm on the ground (i.e., below the water tank) being visible from above due to the water's transparency. The side protections are 20 cm high alongside the platform and extend to the end of the water tub and 100 cm beyond the opposite end (real cliff) to provide a sense of continuity. The entire perimeter of the apparatus is surrounded with white fabric, from the ceiling to the floor, to avoid any external visual influences. The 75 cm height was chosen because it corresponds to the common height of home tables. In addition, 75 cm is more than two times the 30 cm-height drop-off defined by Sorce, Emde, Campos, and Klinnert (1985) as a threshold of uncertainty at which infants would rely on mothers' social information to decide whether or not to cross the deep side of the visual cliff and beyond which avoiding infants would not go over the visual cliff even when the mothers were encouraging them to do so.

FIGURE 2 | Synchronised camera views of Real Cliff / Water Cliff apparatus: a) Front view of Real Cliff. b) Back view of Real Cliff. c) Front view of Water Cliff. d) Back view of Water Cliff.



In order to minimize the possible effects of a spotter's presence nearby the infants, climbing equipment, that did not constrain the infants' movements but prevented them from falling, was used. A "lifeline" was installed above the apparatus with a sheave that moved along its entire length, following the infants' movements. Another rope passing through the sheave was tied on one side to the infants' adapted harness and was held at the other end by the researcher responsible for the infants' safety. During the time infants were exploring the setting and until the moment they started falling, the rope attached to the harness hanged loose, not supporting the infants' weight. When the infants fell, a safety mechanism limited the fall to a maximum of 5 cm (see Figures 1 and 2).

3.3.3 Procedure

All the procedures were the same as those used by Burnay and Cordovil (2016). Before visiting the laboratory, information about the study was sent to the mothers, who were asked to use their baby books, photos and films in order to remember the different onset-dates of their infants' achievements. Mothers reported their infants' postural and locomotor onset dates in a structured interview.

Infants were tested once on the real cliff and once on the water cliff, with conditions and trial order counterbalanced across infants. Mothers were asked to help the examiner put the harness on the infants and to hold the infants on their laps while the examiner attached the safety rope to the harness. Then, to familiarize the infants with the setting, the mothers first placed the infants on the platform (150 cm away from the edge) and played with them. When the infants were calm and showing no signs of distress, mothers went to the opposite end of the platform facing the infants, out of their reach (standing beyond the end of the checkerboard pattern on the ground, about 1.20 m from the platform end on the real cliff side; or at the far side of the water cliff, also about 1.20 m distant from the platform end). Next, the experimenter placed the infants close to the opposite edge of the platform (2m away from the edge of the cliff that was tested) in a hands-and-knees crawling posture, if the infant was a crawler, or in a standing-up posture, if the infant was a walker, and initiated the trial. Mothers were instructed to encourage their infants using a toy and positive verbal and gestural language. In the water cliff situation, mothers were instructed to touch the water so the infant could perceive the visual information of water. Infants were tested wearing their typical clothing. The water was at room temperature (about 20°C).

The experimenter followed the babies' movements by moving alongside the platform and staying approximately 50 cm away from the platform. After the trial was initiated, the experimenter only interfered with the infants' movements or touched them when they did not move from the starting position during the first minute, in which case the experimenter placed the infants near the platform edge (hands, in the case of crawlers, or feet, in the case of walkers, touching the platform within 10 cm from the edge). The trials ended: i) after 180 s, if the infant had moved from the starting position but had not reached the platform edge; ii) 150 s after the infant reached the platform edge; iii) when the infant fell off or descended from the platform edge; iv) when the infant started showing signs of distress or fussiness. If the infant showed signs of distress or fussiness during the first 60 s of the trial, the test was ended and the infant was excluded from subsequent analyses. If the infant showed signs of distress or fussiness after 60 s of reaching the edge, the test was ended, and the infant was coded as an avoider. After completion of the trial, the experimenter changed the platform end-barrier to the opposite end, and the procedure was repeated on the other type of cliff (water or real).

During the tests, infants had the opportunity to freely explore the platform while their mothers were calling them. They could adopt any posture of exploration they decided, move around on the platform, stop, detour, sit down, stand up again, approaching or retreating from the edge, touch the water (on the water cliff) or stretch their arms and feet to the floor (on the real cliff) and look around while testing their capabilities and seeking information about the possibilities (or impossibilities) of action the setup was offering. Ultimately, they avoided (or not) falling or crawling/walking over the cliff.

3.3.4 Data Reduction

Trials were filmed by 2 cameras (Casio Exilim EX-ZR200 HS) for subsequent data analysis. The cameras were placed 1.9 meters high on 2 lateral tops of the apparatus (frontal and back view, see Figure 1). From analysis of video, infants were classified as ‘fallers’ or as ‘avoiders’. Infants who fell from the platform, due to loss of balance while exploring the edge or because they tried to locomote over the edge, were coded as fallers. Infants who stayed on the platform until the end of the trial or adapted their behaviour by turning around, laying their bellies on the platform and safely descending feet first were coded as avoiders.

Infants’ exploratory behaviours were also coded from the footage:

- Approaching time (seconds): starting from the moment the infants were placed in the starting position and ending when they reached the edge. If the infants did not leave the starting position 60 s after the trial started, the experimenter placed them on the edge of the platform and the approaching time was coded as missing.

- Latency time (seconds): from the moment the infant reached the platform edge until the end of the trial. If the infants moved from the starting position but 180 s after the trial started, they never got to the platform edge, the trial was ended and latency time was coded as missing;
- Posture of exploration (percentage of the total latency time): accumulated duration of periods in which infants assumed a "sitting", "prone" (lying with the belly touching the platform), "crawling" (quadruped posture with hands and knees or feet touching the platform), "squatting", or "standing-up" posture;
- Tactile exploration time (percentage of the total latency time): accumulated duration of periods in which infants' hands or feet went below the line of the platform, touching the water or reaching down towards the floor, until the moment they touched any other surface (apparatus or own body).
- Pre-Fall posture (sitting, lying prone, quadruped posture, squatting or standing-up) was the posture adopted at the moment the infants fell from the platform;
- Visual Exploration during approaching time and latency time (yes/no): if the infants looked at least once to the mother and/or to the cliff;
- Visual Exploration at the moment of the fall (mother/cliff/other): whether the infants were looking to the edge, mother or other than those locations at the moment they started falling;

- Retreat behaviour (yes/no): if after getting to the platform edge infants moved away from it at least once.

Avoidance and exploratory behaviours were coded separately for the real cliff and the water cliff conditions. Two observers coded 54% of the crawlers' data (31 crawlers out of 58) and 45% (19 of 42) of the walkers' data to ensure interrater reliability. Percentage of interobserver agreement was 100% (k=1.00) for avoidance and retreat behaviours both for crawlers and walkers. Falling posture percentage of agreement for walkers on both cliffs and crawlers on the real cliff was 100% (k=1.00); for crawlers, in the water cliff condition, percentage of agreement for falling posture was 91% (k=0.76). The ICC values for the postures of exploration, tactile exploration, latency time and approaching time were all greater than .97 for crawlers and greater than .95 for walkers. For visual exploration, coders agreed on at least 93% of cases: 100% on 7 variables ("look at mother during real cliff approaching time", "look at mother during real cliff latency time", "look at cliff during real cliff approaching time", "look at the cliff during latency time" on both cliff and "looking during fall" on both cliffs). For "look at cliff during real cliff approaching time" coders agreed on 93%, "look at mother during water cliff approaching time" on 95.5% and "look at mother during water cliff latency time" on 97% of the cases.

3.3.5 Statistical analysis

Shapiro-Wilk tests were used to assess the normality of data. Independent *t*-tests were performed to compare age and specific locomotor experiences between crawlers and walkers. Mann-Whitney *U* tests were used to compare differences between two independent groups (avoiders, fallers) when the dependent variable was continuous but not normally distributed (approaching time, tactile exploration time, posture of exploration). Reported as *U* statistic value, *p* = p value.

Two-way ANOVA were performed to examine the effect of cliff type (real cliff, water cliff) and avoidance behaviour (fall, avoid) and the on continuous exploratory variables (i.e., approaching time, tactile exploration time, posture of exploration time).

Wilcoxon signed-rank tests were used to compare differences between the two repeated conditions (real cliff, water cliff) when the dependent variable was continuous but not normally distributed (approaching time, tactile exploration time, posture of exploration). Reported as Z statistic value, *p* = *p* value.

Pearson's chi-squared tests were performed to investigate if there were differences in the proportion of infants that avoided the fall between sexes (two groups: male, female), trial order (two groups: first test - real cliff, first test - water cliff), visual exploration (two groups: looked, did not look), retreat behaviour (two groups: retreated, did not retreat) and paired clusters of locomotor experiences (crawlers, walkers, new crawlers, experienced crawlers, new walkers, experienced walkers). Reported as χ^2 statistic value (degrees of freedom), *p* = *p* value.

McNemar’s tests were performed to determine if there were differences in avoidance behaviour (two groups: avoiders, fallers), retreat behaviour (two groups: retreated, did not retreat) and visual exploration (two groups: looked, did not look) between the testing conditions (real cliff, water cliff).

Pearson's correlation coefficient tests were performed to measure the strength of linear relationships between paired independent variables (i.e., age and specific locomotor experiences). Strength of the correlation was described using the guide suggested by Evans (1996) for the absolute value of r (i.e., .00 - .19: "very weak"; .20 - .39: "weak"; .40 - .59: "moderate"; .60 - .79: "strong"; .80 – 1.0: "very strong").

Logistic regressions were performed to investigate whether avoidance behaviour on the real cliff and the water cliff can be predicted based on age and specific locomotor experiences. The Akaike Information Criterion (AIC) was used to assess model adequacy, whereby a lower AIC indicates a more parsimonious fit. AIC scores are estimators of the relative quality of statistical models for a given set of data and differences in the AIC (Delta AIC) reflect comparative model fit. The standard rule of thumb to consider models within two AIC units of the AIC-best model to have substantial support was used (Burnham & Anderson, 2004). Researchers have recently called for greater use of the AIC to assess the adequacy of statistical models in motor behaviour research (Lohse, Shen & Kozlowski, 2020; Symonds & Moussalli, 2011). Analysis of multicollinearity between independent variables was performed and a VIF value of 10 was used as cut-off value beyond which the associated regression coefficients are considered poorly estimated because of severe multicollinearity (Midi, Imon & Bagheri, 2010).

The null hypothesis was rejected at an alpha level of $p < 0.05$. The imprecision of parameter estimates was expressed using 95% confidence intervals [95% CI]. Statistical analysis was performed using IBM SPSS Statistics 24 program.

3.4 Results

Nine infants on the real cliff (five crawlers and four walkers) and two crawling infants on the water cliff started showing signs of distress after 60 s from the trial start. These infants were coded as avoiders and their exploratory behaviours were analysed in percentage of total latency time.

Due to technical errors with filming a small percentage of data was lost. Three crawlers (5%) on the water cliff condition were not coded for tactile exploration, two crawlers (3%) on the water cliff were not coded for posture of exploration, two crawlers (3%) and one walker (2%) on the water cliff were not coded for visual exploration during approaching time and one walker (2%) on the water cliff condition was not coded for visual exploration during the entire trial.

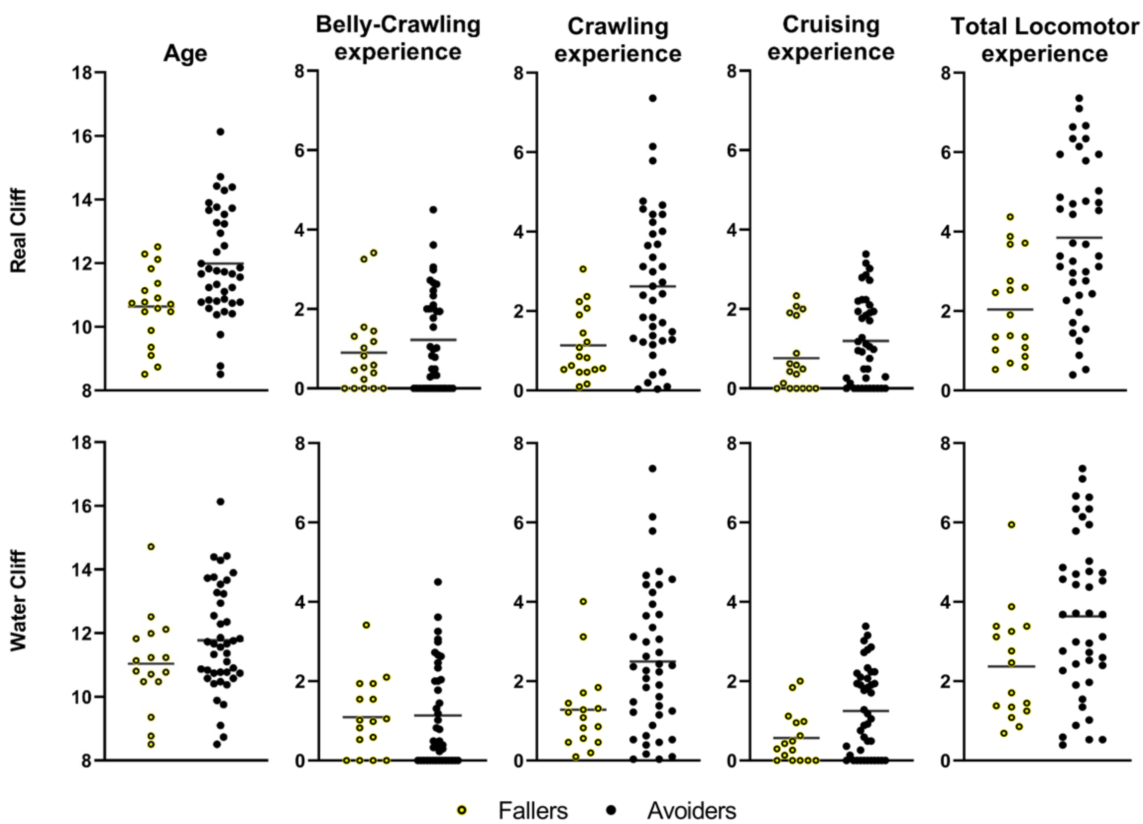
3.4.1 Crawlers

Preliminary analyses revealed no effect of sex ($\chi^2_{(1)}$ = 0.92, p = .337) or trial order ($\chi^2_{(1)}$ = 0.55, p = .457) on the crawlers' avoidance behaviour on the real cliff nor an effect of infant's sex ($\chi^2_{(1)}$ = 1.03, p = .311) or trial order ($\chi^2_{(1)}$ = 0.56, p = .453) on the avoidance of falling on the water cliff. As such, these variables were collapsed for subsequent analyses.

3.4.1.1 Avoidance behaviour

Of the 58 crawling infants tested, eight (14%) fell over the edge of both cliffs and 32 (55%) avoided falling on both sides, ten (17%) fell only on the real cliff and eight (14%) fell only on the water cliff. Therefore, 69% of the crawlers showed the same avoidance behaviour on both cliffs. A McNemar's test showed no significant differences in the crawlers' avoidance behaviour between the real cliff and the water cliff (p = .815). Two avoiders on the real cliff and one on the water cliff tried to safely descend from the platform feet first with belly down. Figure 3 shows the age and posture-specific locomotor experience of avoiding and falling crawlers on the real and the water cliff.

FIGURE 3 | Age and posture-specific locomotor experiences (in months) of avoiding and falling crawlers on the real and water cliff.



Correlation tests revealed a positive but weak correlation between age and cruising experience and between total self-produced locomotor experience and belly-crawling and cruising experiences; positive and moderate correlation between age and crawling and total self-produced locomotor experiences and between crawling and cruising experiences; and a positive and strong correlation between crawling and total self-produced locomotor experience (see Table 2).

TABLE 2 | Correlation values between crawlers' age and locomotor experiences.

	1	2	3	4	5
1.Age	1	0.100	.645**	.503**	.634**
2. Belly-Crawling experience	0.100	1	-0.147	-0.066	.479**
3. Crawling experience	.645**	-0.147	1	.632**	.798**
4. Cruising experience	.503**	-0.066	.632**	1	.521**
5. Total Self-Produced Locomotor experience	.634**	.479**	.798**	.521**	1

** $p < .001$.

Assumption of collinearity tests indicated that multicollinearity was not a concern (all VIF values < 4). Therefore, Logistic regression models were performed to ascertain the effects of age and specific locomotor experiences on the likelihood that crawlers avoid falling on the real cliff and on the water cliff. On the real cliff, the logistic regression models with age, crawling experience and total self-produced locomotor experience were statistically significant (see Table 3).

On the water cliff, logistic regression models with crawling, cruising and total self-produced locomotor experience were statistically significant (Table 4).

AIC values of the likelihood of a model to estimate crawlers' avoidance of falling on the real cliff, indicate that the models with crawling experience alone and with the combination of crawling and self-produced locomotor experience are both within two units of the best-AIC model and have support from the data (see Table 5).

TABLE 3 | Summary of Logistic Regression analysis for age and locomotor experiences predicting crawling infants' avoidance of falling on the real cliff (N = 58).

							95% CI OR	
	B	S.E.	χ^2	df	*p*	OR	Lower	Upper
Age	0.647	0.243	7.11	1	0.008	1.91	1.19	3.07
Belly-Crawling experience	0.254	0.262	0.94	1	0.333	1.29	0.77	2.16
Crawling experience	0.781	0.279	7.82	1	0.005	2.18	1.26	3.78
Cruising experience	0.460	0.308	2.23	1	0.136	1.58	0.87	2.90
Total Self-Produced locomotor experience	0.656	0.218	9.03	1	0.003	1.93	1.26	2.96

Note. B = co-efficient for the constant. OR = odds ratio. CI = confidence interval.

TABLE 4 | Summary of Logistic Regression analysis for age and locomotor experiences predicting crawling infants' avoidance of falling on the water cliff (N = 58).

							95% CI OR	
	B	S.E.	χ^2	df	*p*	OR	Lower	Upper
Age	0.297	0.200	2.21	1	.137	1.35	0.91	1.99
Belly-Crawling experience	0.031	0.254	0.02	1	.903	1.03	0.63	1.70
Crawling experience	0.577	0.252	5.26	1	.022	1.78	1.09	2.92
Cruising experience	0.791	0.368	4.62	1	.032	2.21	1.07	4.54
Total Self-Produced locomotor experience	0.400	0.187	4.61	1	.032	1.49	1.04	2.15

Note. B = co-efficient for the constant. OR = odds ratio. CI = confidence interval.

TABLE 5 | AIC scores for logistic regression models for crawling infants' avoidance behaviour on the real and the water cliff.

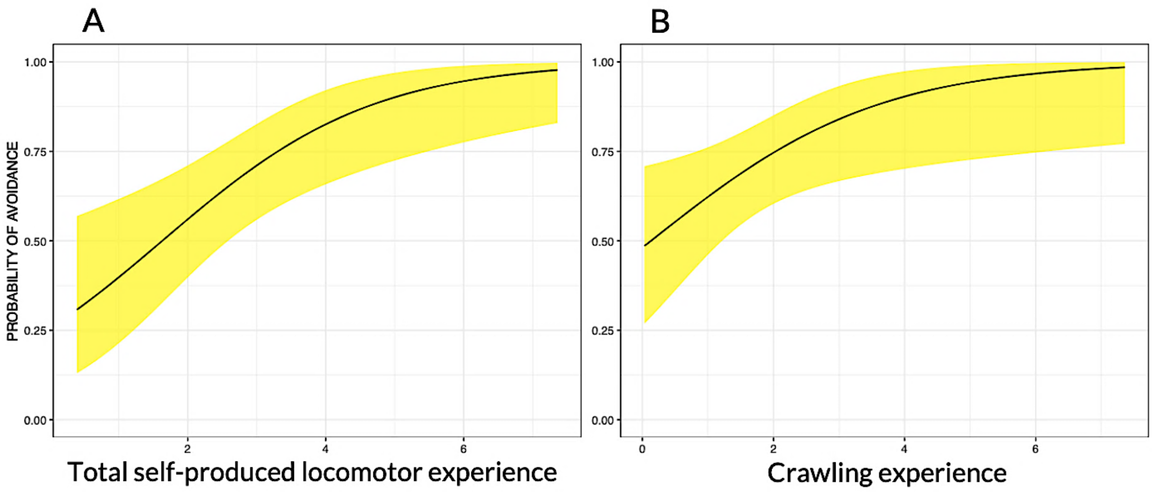
Real Cliff			Water Cliff		
	AIC	Delta AIC		AIC	Delta AIC
Age	66.23	3.19	Age	69.91	4.70
Belly-Crawling experience	74.86	11.82	Belly-Crawling experience	72.31	7.10
Crawling experience (Ce)	63.93	0.89	Crawling experience	65.21	0
Cruising experience (Cru.e)	73.42	10.38	Cruising experience	66.60	1.39
Self-produced Loc. exp. (SLe)	63.04	0	Self-produced Loc. exp.	66.85	1.64
Ce + SLe + Age†	65.39	2.35	Ce + Cru.e + SLe†	68.06	2.90
Ce + SLe‡	63.87	0.83	Ce + Cru.e‡	66.20	0.99

† Model including variables with significant effect on the likelihood that crawlers avoid falling.

‡ Model including variables with two lowest AIC values when analysed alone.

The AIC-best model of the odds of crawling infants' avoidance of falling on the real cliff is the one with total self-produced locomotor experience as single predictor, explaining 28% of the cases (Nagelkerke R^2) of the variance in avoidance behaviour and correctly classified 74% of cases (see Figure 4.A). For the water cliff, models with cruising and self-produced locomotor experiences alone and the combinations of crawling and cruising experiences cannot be discounted (see Table 5), and the model with crawling experience alone is the AIC-best model of crawling infants' avoidance of falling on the water cliff. The model explains 17% of the cases (Nagelkerke R^2) of the variance in avoidance behaviour and correctly classified 69% of cases (see Figure 4.B).

FIGURE 4 | Fitted AIC-best logistic models for crawlers' avoidance of the real cliff (A) and water cliff (B). For the real cliff (A), self-produced locomotor experience (in months) is the predictor of probability of avoidance, while for the water cliff (B), the predictor is crawling experience (in months). In both plots, the solid black line gives the fitted value with 95% confidence interval in yellow.



3.4.1.1 Approaching time

Four crawlers on the real cliff (one faller and three avoiders) and 11 on the water cliff (all avoiders) did not move from the starting position during the first 60 s of testing and were placed on the cliff edge; the approaching time was coded as missing for these infants. One avoiding crawler on the real cliff moved away from the starting position but never got to the edge; approaching time for this infant was coded as 180 s and latency time and exploratory behaviours during latency time were coded as missing. Two (behaviour) x 2 (cliff type) ANOVA was conducted to ascertain the difference in approaching time between avoiders and fallers and between the real and the water cliff conditions. Crawlers approached the water cliff faster (M = 21.91 s, SD = 22.98) than the real cliff (M = 36.03 s, SD = 42.38), F (1, 97) = 4.34, *p* = .040. No significant effect of avoidance behaviour in approaching time to the cliffs was found between avoiders (M = 31.99 s, SD = 36.37) and fallers (M = 24.24 s, SD = 32.86) (F (1, 97) = 1.04, *p* = .310). There was also no significant interaction between the effects of cliff type and avoidance behaviour on approaching time, $F_{(1, 97)} = 0.34$, *p* = .560. When analysing the difference in the approaching time between avoiders and fallers on each cliff specifically, no significant differences were found on the real cliff (avoiders: M = 37.05 s, SD = 43.29; fallers: M = 33.82 s, SD = 41.5; U = 304, *p* = .845) nor on the water cliff (avoiders: M = 25.96 s, SD = 25.21; fallers: M = 14.06 s, SD = 15.79, U = 163, *p* = .056).

3.4.1.2 Latency time

For three avoiding crawlers on the real cliff (61 s, 62 s, 95 s) and for two avoiders on the water cliff (60 s, 101 s) latency time was smaller than 150 s as they started crying after 60 s of testing. Two avoiders tried to safely descend 53 s and 54 s after getting to the edge of the real cliff and one 81 s after getting to the edge of the water cliff. Regarding the falling crawlers, five on the water cliff fell less than 10 s after getting to the platform edge whereas only one on the real cliff did so. However, latency time was not significantly different between the real cliff (M = 45.62 s, SD = 30.42) and the water cliff (M = 45.46 s, SD = 41.51) for falling crawlers, Z = -0.280, *p* = .779.

3.4.1.3 Tactile exploration time

In the real cliff condition, five avoiders and one faller never engaged in tactile exploration. In the water cliff condition, of the six crawlers that never touched the water, two were fallers who fell under 2 s after getting to the edge. Two (behaviour) x 2 (cliff type) ANOVA showed no significant interaction between the effects of cliff type and avoidance behaviour in the time infants spent in tactile exploration, (F (1, 108) = 2.02, p = .158) but significant effects of cliff type and avoidance behaviour in crawlers' tactile exploration time. Crawlers engaged in more tactile exploration on the water cliff (M = 44.13%, SD = 29.31) than on the real cliff (M = 29.90%, SD = 28.26), (F(1, 108) = 4.72, p = .032), and fallers (M = 51.86%, SD = 31.07) engaged in more tactile exploration than avoiders (M = 19.77%, SD = 20.28), F (1, 108) = 20.13, p < .001. When analysing the differences in tactile exploration time between avoiders and fallers on the real cliff specifically, fallers spent more time engaging in tactile exploratory behaviours (M = 51.86%, SD = 31.07) than avoiders (M = 19.77%, SD = 20.28), U = 136.5, p <.001. However, on the water cliff, the difference between fallers (M = 55.94%, SD = 29.46) and avoiders (M = 39.28%, SD = 28.20) was not significant, U = 207, p = .052. There was no significant difference in tactile exploration time between fallers on the real cliff (M = 51.86%, SD = 31.07) and falls on the water cliff (M = 55.94%, SD = 29.46), U = 128, p = .581. However, avoiders engaged in more tactile exploration on the water cliff (M = 34.40, SD = 22.87) than on the real cliff (M = 23.61, SD = 27.55), U = 449.5, p = .002.

3.4.1.4 Posture of exploration

Three 2 (behaviour) x 2 (cliff type) ANOVA was conducted to ascertain the effect of avoidance behaviour and cliff type on the time crawlers spent in different postures of exploration (i.e., sitting, lying prone, quadrupedal postures). No effect of cliff type was found on the time crawlers spent on different exploratory postures (see Table 6).

TABLE 6 | Crawling infants' descriptive statistics and effect of cliff type (RC, WC) on time spent in different exploratory postures (percentage of latency time).

		N	N≠0	Mean	SD	Min	Max	F	*p*
Time sitting	RC	57	44	43.02	33.55	0.0	100	0.29	.591
	WC	56	40	43.10	37.92	0.0	100		
Time lying prone	RC	57	12	8.26	21.55	0.0	93.3	0.81	.369
	WC	56	9	5.16	18.66	0.0	100		
Time on hands-and-knees	RC	57	56	43.91	31.67	0.0	100	1.54	.217
	WC	56	50	47.32	36.81	0.0	100		

A significant effect of behaviour was observed when analysing the differences in the time adopting different postures of exploration between avoiders and fallers, on both cliffs. Crawlers that fell adopted the quadrupedal posture more than avoiders and crawlers that avoided falling adopted the sitting posture more than fallers (see Table 7). Only one crawler ever adopted the squatting and upright posture during the real cliff testing condition.

TABLE 7 | Crawling infants' descriptive statistics and effect of avoidance behaviour (fall, avoid) on time spent in different exploratory postures (percentage of latency time).

		N	N≠0	Mean	SD	Min	Max	F	*p*
Time sitting	fallers	34	14	13.92	21.36	0	79.0	45.42	<.001
	avoiders	79	70	55.60	33.16	0	100		
Time lying prone	fallers	34	7	6.20	14.21	0	52.0	0.05	.827
	avoiders	79	14	6.95	22.29	0	100		
Time on hands-and-knees	fallers	34	34	76.62	24.34	17.0	100	62.50	<.001
	avoiders	79	74	32.25	28.80	0	100		

There was no significant interaction between the effects of cliff type and avoidance behaviour in the time infants spent on a sitting (F (1, 109) = 0.78, *p* = .381), lying prone (F (1, 109) = 0.15, *p* = .703) or quadrupedal (F (1, 109) = 1.01, *p* = .318) postures.

3.4.1.5 Falling posture

Fourteen of the 18 crawlers that fell on the real cliff (78%) and 13 of the 16 water cliff fallers (81%) fell when exploring the edge in a quadrupedal posture. Three crawlers on the real cliff and two on the water cliff fell when adopting a sitting posture and one on each cliff fell while adopting a lying prone posture.

3.4.1.6 Retreat behaviour

One crawler was not coded for retreat behaviour on the real cliff as he never got to the edge during the 180 s of testing. Crawlers retreated more from the edge of the real cliff (63%) than from the edge of the water cliff (40%) (*p* = .015, McNemar's test). More avoiding (82%) than falling crawlers (22%) moved away from the edge of the real cliff ($\chi^2_{(1)}$ = 18.946, $p < .001$). Likewise, on the water cliff, more avoiders (50%) than fallers (19%) retreated from the edge ($\chi^2_{(1)}$ = 4.665, *p* = .031).

3.4.1.7 Visual exploration

Differences in visual exploration between real and water cliffs – the proportion of crawling infants that looked to the mother during the approaching time and latency time - was not different between the real cliff and water cliff testing conditions (see Table 8). However, more crawlers looked to the cliff while approaching the water cliff (98%) than the real cliff (80%). Of the 11 crawlers that never looked to the cliff during the approaching time, nine ended falling from the platform.

When analysing where the infants were looking in the moment they lost balance and fell, most water cliff fallers were looking toward the cliff (81%) while on the real cliff only 28% of fallers were looking toward the cliff. Nine (50%) of the crawlers that fell on the real cliff were looking to their mothers and four fell when looking to other areas than the cliff or the mother. On the water cliff condition, three crawlers fell when looking to something other than the mother or cliff and none were looking to the mother when they fell.

TABLE 8 | Differences in crawling infants' visual exploration during approaching time and latency time between real cliff (RC) and water cliff (WC) trial conditions.

		N	Yes	No	*P*
Looked to the mother during Approaching time	RC	54	53	1	.125
	WC	45	39	6	
Looked to the cliff during Approaching time	RC	54	43	11	.012
	WC	45	44	1	
Looked to the mother during Latency time	RC	57	56	1	.219
	WC	58	53	5	
Looked to the cliff during Latency time	RC	57	57	0	
	WC	58	57	1	

Differences in visual exploration between fallers and avoiders (see Table 9) – On the real cliff condition, there were no significant differences in the proportion of falling and avoiding crawlers who looked to the mother and toward the cliff during approaching time and latency time. On the water cliff, there were no significant differences in the proportion of falling and avoiding crawlers that looked to the cliff during approaching and latency time and that looked to the mother during approaching time. However, more avoiders (100%) than fallers (69%) looked to the mother during the latency time.

TABLE 9 | Differences in crawling infants' visual exploration during approaching time and latency time on the real and water cliffs between avoiders and fallers.

		REAL CLIFF			
		Yes	No	χ^2	*p*
Looked to the mother during Approaching time	fallers	15	0	0.47	0.494
	avoiders	22	4		
Looked to the cliff during Approaching time	fallers	14	1	1.13	0.287
	avoiders	26	0		
Looked to the mother during Latency time	fallers	16	0	2.21	0.138
	avoiders	24	4		
Looked to the cliff during Latency time	fallers	15	1		
	avoiders	27	1		
		WATER CLIFF			
		Yes	No	χ^2	*p*
Looked to the mother during Approaching time	fallers	12	4	2.92	0.087
	avoiders	27	2		
Looked to the cliff during Approaching time	fallers	16	0	0.56	0.453
	avoiders	28	1		
Looked to the mother during Latency time	fallers	11	5	14.36	<.001
	avoiders	42	0		
Looked to the cliff during Latency time	fallers	15	1	2.67	0.102
	avoiders	42	0		

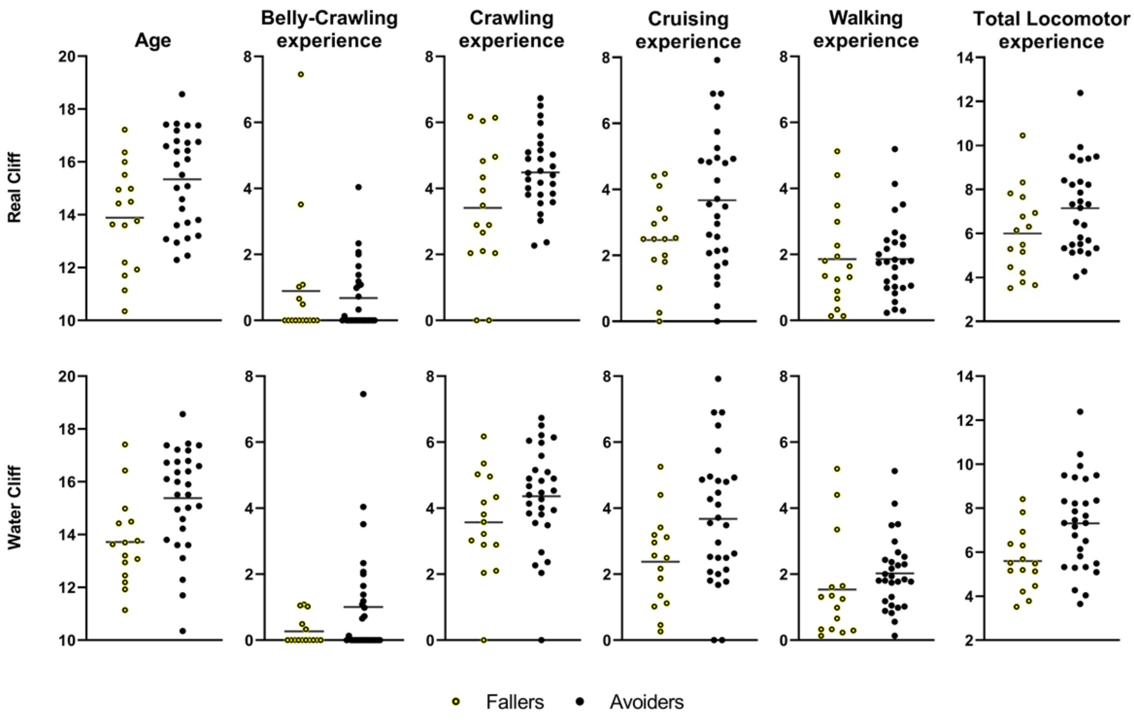
3.4.2 Walkers

Preliminary analyses revealed no effect of sex on walkers' avoidance of falling on the real cliff ($\chi^2_{(1)} = 0.48$, $p = .490$) or on the water cliff ($\chi^2_{(1)} = 0.29$, $p = .592$) nor an effect of trial order on walkers' avoidance of falling on the real cliff ($\chi^2_{(1)} = 0.05$, $p = .820$) or on the water cliff ($\chi^2_{(1)} = 0.29$, $p = .592$). As such, these variables were collapsed for subsequent analyses.

3.4.2.1 Avoidance behaviour

Of the 44 walkers tested, eight (18%) fell on both cliffs, 21 (48%) avoided falling on both cliffs, eight (18%) fell only on the real cliff and seven (16%) fell only on the water cliff. Mean and individual values of age and locomotor experiences of avoiding and falling walkers on the real and the water cliff are represented in Figure 5 .

FIGURE 5 | Age and specific-locomotor experience (in months) for falling and avoiding walking infants on the real and the water cliff.



The majority of walkers (66%) showed the same avoidance behaviour on both cliffs. Statistically, there was no difference in walkers' avoidance behaviour between the real and the water cliff (p = 1.000, McNemar test). Twelve (43%) real cliff avoiding walkers and three (10%) water cliff avoiding walkers avoided the fall by safely descending from the platform. Statistically, there were no significant differences in age (p = .100) or any of the locomotor experiences (all p > .200) between walking avoiders that stayed on the platform and those who descended on the real cliff.

A positive but weak correlation was observed between age and crawling experience; positive and moderate correlations between cruising experience and age and crawling experience, between total self-produced locomotor experience and belly-crawling, cruising and walking experiences and a positive and strong correlation between age and walking experience and between total self-produced locomotor experience and age and crawling experience (see Table 10).

TABLE 10 | Correlation values between walkers' age and locomotor experiences.

	1	2	3	4	5	6
1. Age	1	0.057	.370*	.404**	.704**	.705**
2. Belly-Crawling experience	0.057	1	0.21	0.268	0.011	.484**
3. Crawling experience	.370*	0.21	1	.523**	0.004	.697**
4. Cruising experience	.404**	0.268	.523**	1	0.029	.578**
5. Walking experience	.704**	0.011	0.004	0.029	1	.533**
6. Total Self-Produced Locomotor experience	.705**	.484**	.697**	.578**	.533**	1

* p < 0.05, **, p < 0.01.

Analysis of multicollinearity among the independent variables revealed that it was not a concern (all VIF values < 6). Logistic regression models showed a significant effect of age and crawling experiences on the likelihood that walkers avoided falling on the real cliff (see Table 11) and of age, cruising and total self-produced locomotor experience on the odds that walkers avoided falling on the water cliff (see Table 12).

TABLE 11 | Summary of Logistic Regression analysis for age and locomotor experiences predicting walking infants' avoidance of falling on the real cliff (N = 44).

							95% CI OR	
	B	S.E.	χ^2	df	*p*	OR	Lower	Upper
Age	0.408	0.182	5.01	1	.025	1.50	1.052	2.151
Belly-Crawling experience	-0.110	0.219	0.23	1	.632	0.90	0.586	1.383
Crawling experience	0.496	0.238	4.35	1	.037	1.64	1.030	2.615
Cruising experience	0.390	0.2	3.79	1	.052	1.48	0.997	2.187
Walking experience	0.000	0.248	0.00	1	1.000	1.00	0.615	1.627
Total Self-Produced locomotor experience	0.318	0.181	3. 10	1	.078	1.37	0.965	1.958

Note. B = co-efficient for the constant. OR = odds ratio. CI = confidence interval.

The logistic regression models including walking experience were not significant, indicating no effect of walking experience on the likelihood that walkers avoid falling on the real cliff (see Table 11, Figure 6.A) and the water cliff (see Table 12, Figure 6.B). In fact, on the real cliff, mean values of walking experience were the same for avoiding and falling walkers (1.86 months). There was also no significant difference in the amount of walking experience between walkers who fell (M = 1.54 months, SD

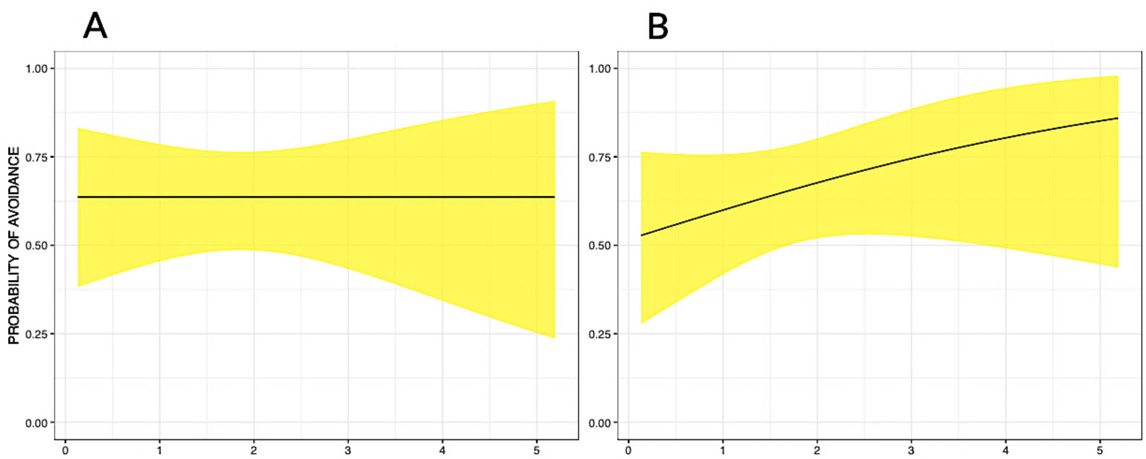
= 1.56) and those who avoided falling (M = 2.02 months, SD = 1.09) on the water cliff ($t(42) = -1.20$, $p = .238$).

TABLE 12 | Summary of Logistic Regression analysis for age and locomotor experiences predicting walking infants' avoidance of falling on the water cliff (N = 44).

							95% CI OR	
	B	S.E.	χ^2	df	*p*	OR	Lower	Upper
Age	0.481	0.194	6.134	1	.013	1.617	1.105	2.365
Belly-Crawling experience	0.809	0.519	2.431	1	.119	2.246	0.812	6.213
Crawling experience	0.342	0.219	2.436	1	.119	1.408	0.916	2.165
Cruising experience	0.432	0.21	4.217	1	.040	1.541	1.02	2.327
Walking experience	0.336	0.284	1.393	1	.238	1.399	0.801	2.443
Total Self-Produced locomotor experience	0.542	0.219	6.157	1	.013	1.72	1.121	2.64

Note. B = co-efficient for the constant. OR = odds ratio. CI = confidence interval.

FIGURE 6 | Logistic model with walking experience (in months) as predictor for walkers' avoidance of falling on the real cliff (A) and on the water cliff (B). The solid black line gives the fitted value with 95% confidence interval in yellow.



The AIC model values show that although age, crawling and cruising experiences alone and the combination of the three cannot be discarded (see Table 13), the overall AIC-best model was an additive model with age and crawling experience as predictors.

TABLE 13 | AIC scores for logistic regression models for walking infants' avoidance behaviour on the real and the water cliff.

Real Cliff			Water Cliff		
	AIC	Delta AIC		AIC	Delta AIC
Age	55.91	0.43	Age	53.04	0.75
Belly-Crawling experience	61.45	5.97	Belly-Crawling experience	56.21	3.92
Crawling experience (Ce)	56.53	1.05	Crawling experience	57.84	5.55
Cruising experience (Cru.e)	57.21	1.73	Cruising experience	55.33	3.04
Walking experience	61.68	6.20	Walking experience	58.93	6.64
Self-produced Loc. exp. (SLe)	58.15	2.67	Self-produced Loc. exp.	52.29	0
			Age + Cru.e + SLe †	54.36	2.07
Age + Ce†‡	55.48	0	SLe + Age ‡	53.35	1.06

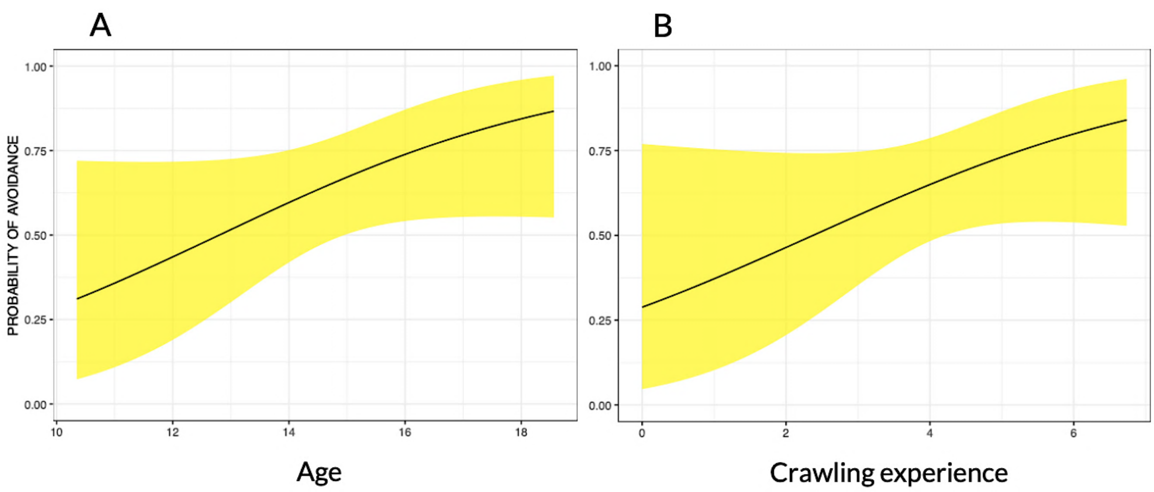
† Model including variables with significant effect on the likelihood that walkers avoid falling.

‡ Model including variables with two lowest AIC values when analysed alone.

The logistic regression model including age and crawling experience as predictors of the odds that walking infants avoid falling on the water cliff ($\chi^2(2) = 8.206$, $p = .017$) explains 23% of the cases (Nagelkerke R^2) of the variance and correctly classified 73% of cases. The estimated odds of not falling on the real cliff are 1.38 times higher when age is increased by 1 month and crawling experience is held fixed; 95%

confidence interval (0.95, 2.02) (see Figure 7.A) and 1.46 times higher when crawling experience is increased by 1 month and age is held fixed; 95% confidence interval (0.89, 2.42) (see Fig.7.B).

FIGURE 7 | Fitted AIC-best logistic model for walkers' avoidance of the real cliff. The plots represent the effect of age on probability of avoidance with crawling experience set to the mean value of 4.09 months (A) and the effect of crawling experience on probability of avoidance with age set to the mean value of 14.82 months (B). In both plots the solid black line gives the fitted value with 95% confidence interval in yellow.



In the water cliff condition, models with age alone and the combination of age and total self-produced locomotor experience cannot be dismissed (see Table 13) but the model that best represents the set of data on the odds of walking infants' avoidance of falling on the water cliff is the one with total self-produced locomotor experience alone. The model explains 24% of the cases (Nagelkerke R^2) of the variance in avoidance behaviour and correctly classified 71% of cases (see Figure 8). AIC values confirmed the non-effect of walking on walkers' avoidance behaviour on both the real and the water cliffs, as the value for the AIC models with walking experience alone were more than 2 units higher than the AIC-best model.

FIGURE 8 | Fitted AIC-best logistic model for walkers' avoidance of the water cliff with total self-produced locomotor experience (in months) as predictor. The solid black line gives the fitted value with 95% confidence interval in yellow.

3.4.2.2 Approaching time

In the real cliff condition, three walking infants (one faller and two avoiders) did not move from the starting position within the first 60 s of testing and were placed on the edge by the experimenter. Approaching times for those walking infants were coded as missing. Two (behaviour) x 2 (cliff) ANOVA was conducted to ascertain the effect of cliff type and avoidance behaviour on walkers' approaching time to the cliffs edge. No significant effect of cliff type ($F(1, 81) = 0.26$, $p = .610$) was found on walkers' approaching time to the real (M = 21.85 s, SD = 30.12) and to the water cliff (M = 17.67 s, SD = 22.00). There was also no effect of avoidance behaviour ($F(1, 81) = 3.84$, $p = .053$) between fallers (M = 12.39 s; SD = 13.67) and avoiders (M = 23.67 s;

SD = 30.30) on walkers' approaching time to the cliffs' edges and no significant interaction between the effects of cliff type and avoidance behaviour (F (1, 81) = 0.72, p = .398). When analysing the approaching time to the water cliff separately, there were no significant differences between falling (M = 11.39 s, SD = 12.55) and avoiding (M = 27.89 s, SD = 35.49) walkers on the real cliff (U = 149, p = .213). On the water cliff the difference between fallers (M = 13.38 s, SD = 15.09) and avoiders (M = 19.89 s, SD = 24.79) was also not significant, U = 181, p = .366.

3.4.2.3 *Latency time*

Three of the 28 real cliff avoiders did not complete the 150 s of the trial after getting to the edge due to compulsive crying. Latency time for those walkers was 85 s, 86 s and 124 s. Of the 16 falling walkers on the real cliff, four fell less than 10 s after getting to the edge, while on the water cliff, of the 15 fallers, ten did so in less than 10 s after getting to the edge. Statistically, there was no significant difference in latency time between real cliff (M = 40.00 s, SD = 39.32) and water cliff (M = 14.03 s, SD = 18.00) for falling walkers, Z = -0.070, p = .944.

3.4.2.4 *Tactile exploration time*

Nine real cliff avoiding walkers never engaged in tactile exploration and two only touched the water for less than 1 s. Five falling walkers also never engaged in tactile exploration before falling on the real cliff. In the water cliff condition, nine walkers (one avoider and eight fallers) never touched the water. The eight fallers that never engaged in tactile exploration of the water got to the edge and fell in under 4 s. Two additional fallers engaged in less than 1 s of tactile exploration of the water and fell less than 5 s after getting to the edge. Two (cliff) x 2 (behaviour) ANOVA showed no effect of cliff type (RC: M = 22.00%, SD = 26.64; WC: M = 28.38%, SD = 24.98; F (1, 84) = 0.54, *p* = .464), avoidance behaviour (Avoiders: M = 29.10%, SD = 25.64; Fallers: M = 17.98, SD = 25.14; F (1, 84) = 3.82, *p* = .054), or interaction between the effects of cliff type and avoidance behaviour (F (1, 84) = 1.37, *p* = .264) on walkers' tactile exploration time. There was also no significant difference in tactile exploration between fallers (M = 19.17%, SD = 25.59) and avoiders (M = 23.61%, SD = 27.55) on the real cliff (U = 207.5, *p* = .682). However, in the water cliff condition, avoiding walkers engaged in significantly more tactile exploration (M = 34.40%, SD = 22.87) than fallers (M = 16.72%, SD = 25.48), U = 105, *p* = .005. There was no significant difference in tactile exploration between fallers on the real cliff (M = 19.17%, SD = 25.59) and water cliff fallers (M = 16.72, SD = 25.48), U = 105, *p* = .538. However, walking avoiders spent statistically more time engaging in tactile exploration on the water cliff (M = 23.61%, SD = 27.55) than on the real cliff (M = 34.40%, SD = 22.87), U = 279.5, *p* = .043.

3.4.2.5 Posture of exploration

No walker ever adopted the lying prone posture to explore the water cliff, while eight did so on the real cliff condition. All the eight walkers that adopted a lying prone posture to explore the real cliff ended up avoiding the fall. Five 2 (cliff) x 2 (behaviour) ANOVAs were performed to ascertain the effect of cliff type and avoidance behaviour in time walkers spent on each posture of exploration. No significant effect of cliff type was found (see table 14).

TABLE 14 | Walking infants' descriptive statistics and effect of cliff type (RC, WC) on time spent in different exploratory postures (percentage of latency time).

		N	N≠0	Mean	SD	Min	Max	F	*p*
Time sitting	RC	44	15	10.95	20.90	0	95.0	1.10	.297
	WC	44	21	21.31	31.27	0	100		
Time lying prone	RC	44	8	7.13	18.10	0	84.3		
	WC	44	0	-	-	-	-		
Time on hands-and-knees	RC	44	17	16.54	25.87	0	96.3	0.98	.326
	WC	44	13	11.52	23.63	0	86.0		
Time squatting	RC	44	7	4.87	14.57	0	54.9	0.98	.375
	WC	44	20	9.47	16.11	0	56.0		
Time standing-up	RC	44	37	54.31	40.76	0	100	0.18	.675
	WC	44	41	52.42	38.85	0	100		

On the effect of avoidance behaviour on posture of exploration time, fallers spent more time on an upright posture than avoiders and avoiders spent more time exploring the cliffs on a sitting posture (see Table 15). No significant effect of interaction between cliff type and avoidance behaviour was found.

TABLE 15 | Waling infants' descriptive statistics and effect of avoidance behaviour (fall, avoid) on time spent in different exploratory postures (percentage of latency time).

		N	N≠0	Mean	SD	Min	Max	F	*p*
Time sitting	fallers	31	3	4.39	14.46	0	64.3	10.96	.001
	avoiders	57	33	22.52	29.98	0	100		
Time lying prone	fallers	31	0	-	-	-	-		
	avoiders	57	29	5.51	16.15	0	84.3		
Time on hands-and-knees	fallers	31	6	12.04	26.94	0	96.3	0.33	.566
	avoiders	57	24	15.12	23.68	0	86.0		
Time squatting	fallers	31	6	8.01	18.26	0	55.0	0.15	.697
	avoiders	57	21	6.71	13.83	0	56.0		
Time standing-up	fallers	31	30	72.87	38.48	0	103.6	13.68	<.001
	avoiders	57	49	42.76	39.60	0	100		

3.4.2.6 Falling posture

Nine of the 16 walking infants that fell on the real cliff (56%) and 12 of the 15 water cliff fallers (80%) fell while adopting a standing-up posture. On the real cliff, three walkers fell while sitting, two while squatting and two fell from a quadrupedal posture. On the water cliff, two walkers fell from a quadrupedal posture and one while squatting.

3.4.2.7 Retreat behaviour

The number of walkers that retreated from the edges was not significantly different between the real cliff (17 of 44, 39%) and the water cliff (12 of 44, 27%) (p = .359, McNemar's test). In the real cliff condition, there was no significant difference in the proportion of fallers (5, 31%) and avoiders (12, 43%) who moved away from the edge, $\chi^2_{(1)}$ = 0.579, p = .447. However, on the water cliff, avoiders moved away from the edge (11 of 29, 40%) significantly more than fallers (1 of 15, 7%), $\chi^2_{(1)}$ = 4.872, *p* = .027.

3.4.2.8 Visual exploration

No significant differences in the walkers' visual exploration between real cliff and water cliff conditions were found (see Table 16). Most walkers that fell on the water cliff did so while looking toward the cliff (71%); 21% fell while looking to the mother and 7% while looking to an area other than the mother or the cliff. In the real cliff condition, 44% of the walkers that fell did so when looking toward the cliff, 31% while looking to the mother and 25% while looking to an area other than the cliff or the mother.

TABLE 16 | Differences in walking infants' visual exploration during approaching time and latency time between real cliff (RC) and water cliff (WC) trial conditions.

		N	Yes	No	*P*
Looked to the mother during Approaching time	RC	41	37	4	1.000
	WC	42	38	4	
Looked to the cliff during Approaching time	RC	41	40	1	1.000
	WC	42	41	1	
Looked to the mother during Latency time	RC	44	44	4	.388
	WC	43	35	8	
Looked to the cliff during Latency time	RC	44	42	2	1.000
	WC	43	42	1	

Differences in visual exploration between fallers and avoiders (see Table 17) – In the real cliff condition, there were no significant differences in the visual exploration between falling and avoiding walkers. In the water cliff condition, the only significant difference in the visual exploration between fallers and avoiders was the fact that more avoiders than fallers looked to the mother during latency time.

TABLE 17 | Differences in walking infants' visual exploration during approaching time and latency time on the real and water cliffs between avoiders and fallers.

		REAL CLIFF			
		Yes	No	χ^2	*p*
Looked to the mother during Approaching time	fallers	15	0	2.56	.110
	avoiders	22	4		
Looked to the cliff during Approaching time	fallers	14	1	1.78	.183
	avoiders	26	0		
Looked to the mother during Latency time	fallers	16	0	2.51	.113
	avoiders	24	4		
Looked to the cliff during Latency time	fallers	15	1	0.17	.682
	avoiders	27	1		
		WATER CLIFF			
		Yes	No	χ^2	*P*
Looked to the mother during Approaching time	fallers	11	3	3.45	.063
	avoiders	27	1		
Looked to the cliff during Approaching time	fallers	13	1	2.05	.152
	avoiders	28	0		
Looked to the mother during Latency time	fallers	7	7	13.51	<.001
	avoiders	28	1		
Looked to the cliff during Latency time	fallers	13	1	2.12	.145
	avoiders	29	0		

3.5 Discussion

This study investigated the effect of age and specific locomotor experiences on infants' ability to perceive the risk and adapt their behaviour to safely navigate a real and water drop-off.

Infants' avoidance behaviour and the posture-specific affordance learning hypothesis

Results of the present study confirmed those of Burnay and Cordovil (2016) linking crawling experience and total self-produced locomotor experience (i.e., belly-crawling and hands-and-knees crawling experiences summed) to crawling infants' avoidance behaviour on the real and the water cliff. Although strongly correlated, crawling experience and total self-produced locomotor experience alone were the best predictors of the odds of crawlers' avoidance of falling on the water and the real cliff, respectively. These results are also in line with those of previous studies showing that avoidance of visual cliffs (Bertenthal & Campos, 1984; Campos et al., 1992; Ueno, Uchiyama, Campos, Dahl, & Anderson, 2012) and drop-offs (Adolph, 1997, 2000; Kretch & Adolph, 2013) becomes more probable after weeks of crawling experience. Through crawling and self-produced locomotor experience, infants learn to appreciate the meaning in the information they pick up and to distinguish surfaces that afford from those that do not afford locomotion. Experienced crawlers educate their attention, or become attuned, to the relevant information in the environment that specifies the affordances for locomotion, and they learn how to scale, or calibrate, their own action capabilities to the information offered by the surface of support (see van Andel, Cole, & Pepping, 2017).

For walkers, an increase in age and self-produced locomotor experience increased the odds of not falling on both cliffs and an increase in crawling experience, together with an increase in age, increased the odds of walkers' avoidance behaviour on the real cliff. Surprisingly, although walking experience was strongly correlated with age and moderately correlated with total self-produced locomotor experience, the increase in walking experience had no effect on the prediction of walkers' avoidance behaviour on either cliff. The Sway Model proposed by Adolph (2000) and posture-specificity hypothesis (Adolph & Robinson, 2015) suggest that to behave adaptively on drop-offs, crawling infants need weeks of crawling experience, walking infants need weeks of walking experience and there is little or no transfer of what is learned in one posture to a newly acquired posture (Adolph & Robinson, 2015; Kretch & Adolph, 2013). However, our findings do not support the idea that when infants start walking, they need weeks of walking experience to avoid falling from cliffs. Walking infants who had more crawling and total self-produced locomotor experience showed more adaptive behaviours; they recalibrated their new locomotor capability faster to avoid falling over the cliffs while walking. These results are consistent with the idea that there is some degree of "learning how to learn" (see Adolph, 2005) across what have been considered modularized systems of postural control and what infants learned while crawling is developmentally maintained or increased and makes a positive contribution to behaving adaptively in the walking posture.

Kretch and Adolph (2013), reported that none of the experienced crawlers attempted to crawl over a 90 cm height drop-off while 63% of the new walkers did so. As there was no association of walking experience with walkers' avoidance behaviour, there is evidence that although transferable between action capabilities, perceptual-motor calibration is a dynamical and ongoing process that needs to be tuned when a new action capability emerges (see Withagen & Michaels, 2002). It seems that, by exploring the environment in a crawling locomotor posture, infants become experts at crawling and self-locomoting and they become capable of perceiving the affordance and adapting their behaviour to safely navigate drop-offs. However, when the walking skill emerges, infants need to recalibrate the perceptual information according to their new action capability. Much as expert athletes can recalibrate to variations in tasks and the environment more rapidly than less experienced athletes (Seifert, Button, & Davids, 2013), expert crawlers (i.e., more experienced crawlers) seem able to recalibrate their behaviour to the new walking skill faster than infants with less previous crawling experience.

Posture of exploration

Infants (crawlers and walkers) who fell did so mostly while adopting the last acquired posture (i.e., quadrupedal posture for crawlers and upright posture for walkers), and they also explored the setting adopting primarily the less experienced posture while avoiders explored more from a sitting posture (i.e., more experienced posture), on both cliffs. These results could be interpreted as evidence that while adopting a new locomotor solution, infants are less capable of perceiving the affordances of the environment and of adapting their behaviour accordingly. However, because the infants were free to explore the settings and adopt any exploratory posture they decided, this argument would be circular. It is unclear if because the infants sat down, adopting a more experienced posture of exploration, they perceived the affordance of the drop-off and avoided the fall, or if because they perceived the affordance, they decided not to go over the edge and sat down.

Exploratory behaviours

To developing infants, a drop-off (filled with air) and a body of still water may be difficult to distinguish visually. Hence, mothers were instructed to touch and move the water, thus offering the infants the visual information of a water surface, which does not occur on the real cliff. Therefore, the information provided by the two cliffs were haptically and visually different, but both were consistent with a non-supportive surface. Yet, the great majority of infants showed the same avoidance behaviour on both cliffs, indicating that infants perceived the non-supportable affordance of a body of water and a drop-off similarly.

Some of the exploratory behaviours provided further evidence of infants' similar perception of the non-supportive affordance of the real and the water cliff. Walkers took similar amounts of time to approach either cliff, infants' (crawlers and walkers) amount of time spent in each posture of exploration did not differ between cliffs and latency to fall was also not different between cliff for both crawlers and walkers. However, common sense would say that infants would be more interested in playing with water than playing nearby a drop-off, regardless of their developmental stage. In fact, some exploratory behaviours provide evidence of a greater attraction to bodies of water than real drop-offs. For instance, crawlers approached the water cliff faster than the real cliff, engaged in more tactile exploration on the water cliff than the real cliff and retreated more from the edge of the real cliff than from the edge of the water cliff. In addition, whereas falling infants engaged in similar tactile exploration on the real and the water cliff, avoiding infants (crawlers and walkers) stood near the water, playing with it and, consequently, enhancing the risk of an accidental fall. This greater attraction for bodies of water may help to explain the higher vulnerability of infants to experience fatal drowning incidents from unanticipated immersion than to experience falling incidents (Peden et al., 2009).

3.6 Conclusions

The current study suggests that infants perceive the non-supportive affordance of real and water drop-offs similarly and, although their behaviour may be more dangerous around bodies of water, they avoid both cliffs similarly. Crawling and total self-produced locomotor experiences informed not only crawling but also walking infants' adaptive behaviour. Importantly, walking experience alone had no effect on walkers' avoidance of falling from cliffs, filled with water or not. These outcomes refute the idea that infants' behaviour at a drop-off is learned in a posture-specific way and that no transfer occurs when a new locomotor skill emerges. Instead, these findings indicate that through weeks of crawling experience, infants learn to perceive affordances for locomotion and this learning informs their behaviour in the walking posture. The evidence for transfer is strong but not yet strong enough to provide insight into the degree of transfer. Because the research design was cross-sectional, it is impossible to gauge the extent of transfer between postures and to know whether the new walkers who were classified as "fallers" would have been classified as "avoiders" if they had also been tested as experienced crawlers. A longitudinal study is required to clarify whether experienced crawlers who avoid falling from the cliffs continue to avoid falling when they become new walkers.

4 STUDY TWO

Transition from Crawling to Walking Locomotor Solutions and Infants’ Avoidance of Real and Water Cliffs: a longitudinal study

4.1 Abstract

Previous research has linked self-produced locomotor experience to infants' avoidance of environments that present risk for falling from heights or into bodies of water. When analysing the effect of specific locomotor experiences on infants' avoidance behaviour (Study One), results showed that crawling and self-produced locomotor experiences predicted crawlers and walkers' avoidance of falling from both cliffs. No effect of walking experience was found on walkers' avoidance behaviour. In the current experiment, 25 infants' avoidance behaviour was tested on the Real Cliff / Water Cliff apparatus, using a longitudinal study design. Infants were tested as experienced crawlers (M_{age} = 11.93 months, SD = 1.70, $M_{cralwing\_experience}$ = 2.93 months, SD = 1.07), new walkers (M_{age} = 13.98 months, SD = 1.52, $M_{walking\_experience}$ = 0.68 months, SD = 0.29), and as experienced walkers (M_{age} = 18.22 months, SD = 1.76, $M_{walking\_experience}$ = 4.90 months, SD = 0.92). Infants avoided falling on both cliffs when tested as experienced crawlers and their behaviour was not significantly different when tested as new or experienced walkers. These findings confirmed that crawling experience plays a role in infants' avoidance of falls from heights and into water. Prior crawling seems to facilitate perceptual-motor recalibration when infants begin walking.

Keywords: infants, real cliff, water cliff, avoidance, locomotor experience

4.2 Introduction

Previous studies have shown that new walking infants fall on steep slopes (Adolph, 1997) and from drop-offs (Kretch & Adolph, 2013) more than experienced crawlers and only after weeks of walking experience do they start showing adaptive behaviour again (Adolph, 1997; Kretch & Adolph, 2013). However, the results from Study One show that walking experience has no effect on walking infants' avoidance of falling on the real and the water cliff. Instead, crawling and total self-produced locomotor experiences explained walkers' avoidance behaviour.

These findings suggest that instead of needing to relearn all over again to avoid drop-offs, some degree of what infants learned through crawling experience is transferred to the new walking posture, informing walkers' adaptive behaviour. However, in Study One, crawling and walking infants' avoidance behaviour was investigated using a cross-sectional design, which failed to directly investigate the extent of transfer from experienced crawling to new walking. While the majority of motor development research has used a cross-sectional approach (e.g., Campos et al., 1992; Kretch & Adolph, 2013; Witherington et al., 2005), this method yields only average differences across groups and not individual changes across developmental stages (Goodway, Ozmun & Gallahue, 2019). Longitudinal research studies, on the other hand, investigate individual or group change for the length of the period of interest (Haywood & Getchell, 2019).

In the present study, infants' avoidance behaviour was tested on the Real Cliff / Water Cliff paradigm with a longitudinal study design. Infants were tested as experienced crawlers, new walkers and again as experienced walkers. If, indeed, the increase in crawling and total self-produced locomotor experience increases the odds of infants avoiding falling on the real cliff and the water cliff and is developmentally transferred when infants begin walking, infants should avoid falls equally or more consistently when tested as new walkers than when tested as experienced crawlers and even more consistently when tested as experienced walkers. On the other hand, if there is no transfer of what infants learn through crawling experience about navigating a drop-off to a newly-acquired walking posture, then new walkers should fall considerably more than they did as experienced crawlers.

4.3 Methods

4.3.1 Participants

Twenty-five infants (9 girls and 16 boys) were first tested as experienced crawlers, when they had at least 1.7 months (i.e., 7 weeks) of crawling experience, a second time as new walkers, within 41 days of walking onset, and a third time as experienced walkers, with at least 2.76 months (i.e., 12 weeks) of walking experience (see Table 18 for descriptive statistics for age and locomotor experiences at each test).

TABLE 18 | Infants' age and locomotor experience (in months) at first, second and third tests.

		Min	Max	Mean	SD
First test Experienced Crawlers N = 25	Age	9.10	15.47	11.93	1.70
	Belly-Crawling experience	0.00	3.19	0.91	1.13
	Crawling experience	1.71	5.42	2.93	1.07
	Cruising experience	0.00	4.44	1.69	1.07
	Total Self-Locomotor experience	1.94	5.42	3.85	1.16
Second test New Walkers N = 25	Age	10.81	16.33	13.98	1.52
	Belly-Crawling experience	0.00	3.19	0.91	1.13
	Crawling experience	2.30	6.77	4.31	1.33
	Cruising experience	0.39	5.75	2.94	1.31
	Walking experience	0.13	1.35	0.68	0.29
	Total Self-Locomotor experience	3.42	8.48	5.90	1.16
Third test Experienced Walkers N = 16	Age	15.24	20.6	18.22	1.76
	Belly-Crawling experience	0.00	3.19	0.91	1.13
	Crawling experience	2.30	6.77	4.31	1.33
	Cruising experience	0.39	5.75	2.94	1.31
	Walking experience	2.76	6.87	4.90	0.92
	Total Self-Locomotor experience	7.85	11.93	10.13	1.29

The criteria to determine the onsets of locomotor skills were the same as those used in Study One. When tested as new walkers, infants had accrued significantly more crawling experience than when tested as experienced crawlers (t = -4.03, p < .001). When tested as experienced crawlers, infants had more crawling experience (M = 2.93 months, SD = 1.07) than Campos et al.'s (1992) categorisation of experienced crawlers (41 days of mean crawling experience) but less crawling experience than Kretch and Adolph's (2013) (M = 4.2 months, SD = 1.63) and Witherington et al.'s (2005) (M = 3.55 months, SD = 1.81) experienced crawlers. When tested as new walkers, infants had more walking experience (M = 0.68 months, SD = 0.29) than Witherington et al.'s (2005) new walkers (walking experience <= 0.5 months) but less walking experience than the new walkers in Kretch and Adolph's (2013) report (M = 1.20 months, SD = 0.80). When tested as experienced walkers, infants walking experience (M = 4.90 months, SD = 0.92) was similar to Kretch and Adolph's (2013) experienced walkers' walking experience (M = 5.21 months, SD = 1.71).

Nine families withdrew from the study after the second test, hence of those 25 infants initially tested, 16 were tested a third time as experienced walkers. Families were recruited from local swimming pools and through other families' referral. Eight additional infants were excluded: five due to compulsive crying when tested as experienced crawlers, two due to compulsive crying when tested as new walkers and one due to late walking onset (only started walking after 18 months of age).

The Human Ethical Research Committees at Edith Cowan University and at the University of Lisbon approved this study. Parents were asked to sign informed consents before their babies were tested for the first time.

4.3.2 Real Cliff / Water Cliff apparatus and Procedure

As in Study One, infants were tested on the Real Cliff / Water Cliff apparatus, using the same testing procedure. However, instead of being tested only once on each cliff as was the case in Study One, in the present study infants visited the laboratory facility and were tested once on each cliff at three occasions. At the first test, infants were tested with trial order counterbalanced across infants. In subsequent tests, infants were first tested on the second testing condition used during the previous test.

4.3.3 Data Reduction

As in study one, infants were coded as 'fallers' (infants who fell from the platform) or as 'avoiders' (infants who stayed on the platform until the end of the trial or adapted their behaviour to safely descend from the platform).

4.3.4 Statistical analysis

Shapiro-Wilk tests were used to assess the normality of data.

Independent *t*-tests were performed to compare mean age and specific locomotor experiences between crawlers and walkers.

McNemar tests were performed to determine differences in avoidance behaviour (two groups: avoiders, fallers) between tests.

Logistic regressions were performed to ascertain the effects of age and specific locomotor experiences on the likelihood that infants would avoid falling from the cliffs.

The null hypothesis was rejected at an alpha level of $p < 0.05$. The imprecision of parameter estimates was expressed using 95% confidence intervals [95% CI]. Statistical analysis was performed using IBM SPSS Statistics 24 program.

4.4 Results

4.4.1 Real Cliff

As shown in Table 19, in the real cliff condition, six (24%) infants fell when tested as experienced crawlers, five (20%) as new walkers and two (12.5%) as experienced walkers. One infant fell as an experienced crawler, new walker and again as an experienced walker. Another infant only avoided falling on the real cliff when tested as experienced walker. Four infants (16%) fell when tested as experienced crawlers, avoided as new walkers and two of them avoided again as experienced walkers. Sixteen infants (64%) avoided falling on the real cliff as experienced crawlers and as new walkers; nine of the ten infants tested as experienced walkers avoided falling again. Three infants (12%) avoided falling as experienced crawlers but fell as new walkers. Two of those were tested as experienced walkers and avoided falling again.

Seven infants (28%) showed different real cliff avoidance behaviours between the first and second trials and four (25% of the infants tested as experienced walkers) between the second and third trials. McNemar's test showed no significant difference in infants' avoidance behaviour between the first and second test (*p* = 1.000), between the second and third test (*p* = .625), nor between the first and third tests (*p* = .625).

Logistic regressions showed no association between age and specific locomotor experiences (i.e., belly-crawling, crawling, cruising and total self-produced locomotor experiences) and infants' avoidance when tested as experienced crawlers on the real cliff. Logistic regression models with age, belly-crawling, crawling, cruising and walking experiences showed that these variables were not significant predictors of new walkers' avoidance of the real cliff. However, a logistic regression model performed to ascertain the effects of total self-produced locomotor experience on the likelihood that new walkers avoid falling on the real cliff was statistically significant, $\chi^2(1) = 3.975$, $p = .046$. The model explained 31.0% (Nagelkerke R^2) of the variance in avoidance behaviour and correctly classified 92.0% of cases. Exp(B) values indicated that when total self-produced locomotor experience increased by 1 month, the avoidance probability increased by 3.30 times, 95% confidence interval (1.02, 10.65). Note that the sample size of new walkers who fell was small (N = 5) and these results have to be interpreted with caution. Because only two infants fell on the real cliff when tested as experienced walkers, logistic regression was not performed.

TABLE 19 | Infants' avoidance behaviour when tested on the Real Cliff as experienced crawlers, new walkers and experienced walkers. Each row represents one infant.

Experienced Crawler	New Walker	Experienced Walker
fell	fell	fell
fell	fell	avoided†
fell	avoided	avoided
fell	avoided	avoided
fell	avoided	
fell	avoided†	
avoided	fell	avoided
avoided†	fell	avoided
avoided	fell	
avoided†	avoided†	fell
avoided	avoided	avoided
avoided	avoided	avoided
avoided	avoided	avoided
avoided	avoided	avoided
avoided	avoided	avoided
avoided	avoided	avoided†
avoided	avoided	avoided†
avoided†	avoided	avoided
avoided†	avoided	avoided†
avoided	avoided	
avoided	avoided	
avoided	avoided	
avoided	avoided	
avoided	avoided†	
avoided	avoided†	

†Avoided falling and tried to safely descend from the platform.

4.4.2 *Water Cliff*

On the water cliff, three (12%) infants fell as experienced crawlers, five (20%) as new walkers and two (12%) as experienced walkers (see Table 20). The infant who fell on the three trials on the real cliff is the same infant who fell on the three trials on the water cliff. Two infants (8%) fell as experienced crawlers and avoided as new and experienced walkers. Eighteen infants (72%) avoided as experienced crawlers and again as new walkers. Of those, ten were tested as experienced walkers and nine (90%) avoided falling again on the water cliff. Four infants (16%) avoided falling when tested as experienced crawlers and fell as new walkers. Three of them were tested as experienced walkers and avoided again the fall on the water cliff.

Six infants (24%) showed different avoidance behaviour between the first and the second test and four (25%) showed different avoidance behaviour on the water cliff between the second and the third tests. McNemar's test showed no significant difference in infants' avoidance of falling on the water cliff between the first and the second (p = .687), between the second and the third tests (p = .625), nor between the first and third tests (p = 1.000).

Neither age, nor any of the specific locomotor experiences (i.e., belly-crawling, crawling, cruising, walking or total self-produced locomotor experiences) were associated with the likelihood that infants would avoid falling on the water cliff, on any of the tests.

TABLE 20 | Infants' avoidance behaviour when tested on the Water Cliff as experienced crawlers, new walkers and experienced walkers. Each row represents one infant.

Experienced Crawler	New Walker	Experienced Walker
fell	fell	Fell
fell	avoided	avoided
fell	avoided	avoided
avoided	fell	avoided
avoided	fell	avoided
avoided	fell	avoided
avoided	fell	
avoided	avoided	fell
avoided	avoided	avoided†
avoided	avoided	avoided
avoided	avoided	avoided
avoided	avoided	avoided
avoided	avoided	avoided
avoided	avoided	avoided
avoided†	avoided	avoided
avoided	avoided†	avoided†
avoided	avoided†	avoided
avoided	avoided	
avoided	avoided	
avoided	avoided	
avoided	avoided	
avoided	avoided	
avoided	avoided	
avoided	avoided†	
avoided	avoided†	

†Avoided falling and tried to safely descend from the platform.

Note. Table 21 and Table 22 do not present infants in same order.

4.5 Discussion

This study investigated the effect of the transition from an experienced crawling solution to a newly-acquired and then experienced walking skill on infants' avoidance of falling from the real cliff and into the water drop-off. The findings of the present study are in accordance with the conclusions reached in Study One but provide even stronger evidence for the transfer of what infants learn through crawling experience to the walking posture. In line with the results reported by Witherington et al. (2005), the great majority of infants avoided the fall equally or even more consistently when tested as new walkers than as experienced crawlers. Only three infants on the real cliff and four on the water cliff showed a less adaptive behaviour (i.e., fell) when tested as new walkers than when tested as experienced crawlers. Of those infants, all who were tested as experienced walkers avoided falling again. Although all the infants in this study had considerable crawling experience and were consequently considered experienced crawlers, when analysing the effect of locomotor experiences on new walkers' avoidance behaviour, those who fell on the real cliff had less total self-produced locomotor experience. In other words, when infants began walking, those with more total self-produced locomotor experience were capable of recalibrating their perception to the new locomotor solution and start showing adaptive behaviours around drop-offs again. The infants with more locomotor experience were faster to adapt than those with less previous locomotor experience.

4.6 Conclusions

The results of Study Two confirm and strengthen those found in Study One. By self-locomoting and exploring the environment on their own, infants become attuned to relevant information specifying the affordances of risky features of the environment. When the walking skill emerges, infants need to recalibrate the perceptual information according to their new action capabilities and the amount of experience they had in a crawling locomotor posture facilitates the recalibration process.

Infants' avoidance behaviour on the real and the water cliff was similar on both cliffs, indicating that infants either do or do not perceive both features as preventers of locomotion. However, whether infants perceive any body of water as a risky environment that should be avoided remains unclear. Investigating infants' relationship with aquatic environments when a gradual entrance to deep water is offered will help to clarify if what infants perceive as a function of locomotor experience is the non-supportive affordance of the water or if locomotor experience also has an effect on their perception of the risk of going into deep water.

5 STUDY THREE

Effects of Specific Locomotor Experiences and Accessways to a Body of Water (drop-off or ramp) on Infants' Avoidance of Submersion

5.1 Abstract

Ramps used in swimming pools to access the water are designed with a shallow slope that affords locomotion for all, including infants. Locomotor experience has been linked to infants' avoidance of falling into the water from drop-offs (water cliffs). However, the effect of perceptual-motor development on infants' behaviour when a slope is offered to access the water has not been addressed. The avoidance of submersion was tested in 43 crawling infants (M_{age} = 10.63 months, SD = 1.91), with crawling experience ranging between 0.3 and 8.2 months (M = 2.38 months, SD = 1.77), and 34 walking infants (M_{age} = 14.90, SD = 2.18 months), with walking experience ranging between 0.4 and 6 months (M = 2.59 months, SD = 1.56) on a new Water Slope paradigm, a sloped surface (10°) leading to deep water. No associations between infants' avoidance of submersion and self-produced locomotor experience were found. Comparison with the results of infants' avoidance of falling on the Water Cliff (Study One) revealed a greater proportion of infants reached the submersion point on the Water Slope than fell into the Water Cliff. Collectively, these results indicate that with self-produced locomotor experience, infants become attuned to relevant perceptual information about threats posed by cliffs (filled with water or not) but locomotor experience does not teach them to perceive water as unsafe when it can be approached via a slope. Importantly, sloped access to deep water appears to increase the risk of infants engaging in drowning incidents.

Keywords: water slope; water cliff; infants; perceptual-motor development; drowning.

5.2 Introduction

The Real Cliff / Water Cliff studies (Studies One and Two) presented evidence that locomotor experience has an important effect on infants' avoidance of falling into the water. However, it is not clear if the infants' behaviour was influenced by the perception of water as a risky environment or if it was the perception of the risk of a fall motivating the infants' adaptive behaviour.

Different features in the environment can influence infants' potentially risky behaviour (Cordovil et al., 2015). For example, a range of features in swimming pool environments such as ladders, cliffs, slides, diving boards and barriers invite or constrain different means to enter the water (i.e., climbing, jumping, sliding, diving, etc.). Although some of the measures suggested to prevent drowning among young children in swimming pools are related with the designs of pool fences and grilles on drain gates that prevent hair entrapment (WHO, 2006), to our knowledge, no suggestions have been made about the type of accessway designs that could enhance infants' avoidance of bodies of water and, ultimately, their avoidance of drowning incidents. From a water safety perspective, it is of paramount importance to understand if and how pool designs and accessways contribute to infants' perception of the risk of deep water and the adaptiveness of their behaviour.

The most common means to enter the water of a swimming pool is from a sudden drop-off (i.e., the edge of the pool - a water cliff) but ramps with a shallow slope that affords locomotion for all users, including infants, are becoming more and more common. For instance, in 2010, the U.S. Department of Justice, under the Americans with Disabilities Act (ADA), issued regulations requiring that "pools (…) provide at least one accessible means of entry/exit, which must be either a fixed pool lift or a sloped entry" (U.S. Department of Justice, 2010). In addition, swimming pool designs with a shallow slope into the water, so-called 'beach-entry' or 'zero-entry' pools, are becoming increasingly common due partly to their aesthetically pleasing design but also because they ensure that people with motor disabilities can access public swimming pools more easily. Indeed, increasing attention to the concept of universal design has seen increasing advocacy for the construction of zero entry pools. It should be noted that although universal design has the noble motivation to open access to those people who might otherwise be excluded, it may also unintentionally increase the risk for unattended infants to enter swimming pools.

As previously reported, dry-land slopes have been used to examine the effect of self-produced locomotor experience on infants' adaptive behaviour. When tested on increasingly steep slopes ranging from 4° to 36° in a longitudinal study design, novice crawling and walking infants failed to distinguish slopes beyond their slope boundaries, i.e., slopes that could be negotiated without falling, but when tested in experienced crawling and walking postures, infants' motor decisions became more accurate and they managed to navigate only the slopes that would be safe (Adolph, 1997). However, the impact of sloping pathways into the water on infants' perception and behaviour and the associated risk of drowning has received little or no attention thus far.

To investigate if self-produced locomotion has the same effect on infants' perception and action when they are presented with a sloped entrance to a body of water, we tested crawling and walking infants' behaviour on the "Water Slope" apparatus - a slope leading to deep water. If locomotor experience teaches infants to perceive water as an environment to avoid, locomotor experience should be linked to infants' avoidance of submersion on the Water Slope as it was linked to the avoidance of falling into the water on the Water Cliff. In addition, to investigate if the nature of the accessway to swimming pools influences infants' adaptive behaviour and avoidance of drowning incidents, infants' avoidance of submersion on the Water Slope was compared with infants' avoidance of falling into the water on the Water Cliff (Study One). If infants avoided falling into the water on the Water Cliff because they perceived water as an environment to avoid, they should likewise avoid entering deep water via the Water Slope. On the other hand, if infants avoided falling on the water cliff because they perceived the setting as not affording locomotion rather than water as a risky environment to avoid, more infants might venture down the water slope and reach deep water than infants who fell on the water cliff.

5.3 Methods

5.3.1 Participants

Seventy-seven infants, 43 crawlers (18 girls, 25 boys) and 34 walkers (12 girls, 22 boys) were recruited from local day-cares, swimming centres and other mothers' referrals. Walkers were older and had more crawling, cruising and total self-produced locomotor experiences than crawlers (see Table 21). Infants' locomotor onset-dates and experiences were determined following the same criterion used in Studies One and Two. Six additional infants, two crawlers and four walkers, were excluded due to compulsive crying or fussiness before or within the first 60 s of testing.

TABLE 21 | Difference in age and locomotor experience durations (in months) between crawlers (N=43) and walkers (N=34).

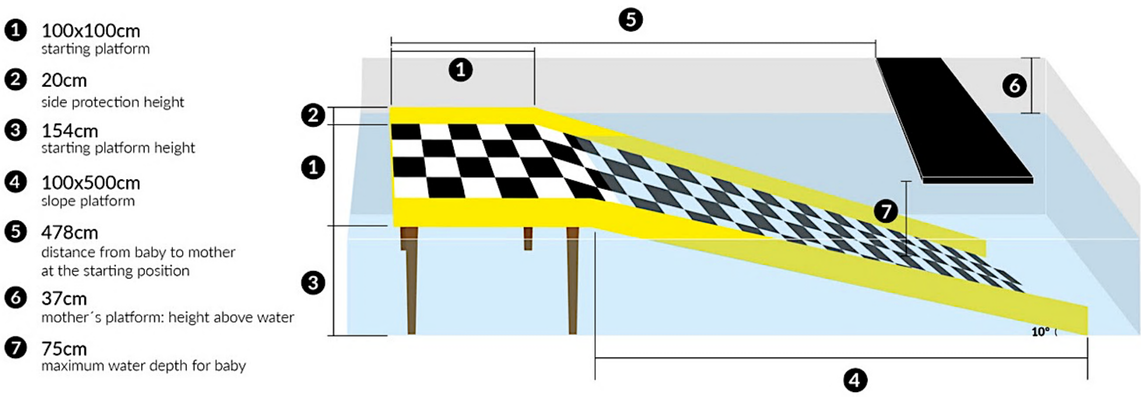
		Min	Max	Mean	SD	*t*	*p*
Age	Crawlers	7.59	14.95	10.63	1.91	-9.14	<.001
	Walkers	11.1	20.07	14.9	2.18		
Belly-Crawling experience	Crawlers	0	4.57	0.82	1.08	-0.09	0.928
	Walkers	0	3.68	0.84	0.87		
Crawling experience	Crawlers	0.26	8.18	2.38	1.77	-4.66	<.001
	Walkers	1.02	7.03	4.14	1.47		
Cruising experience	Crawlers	0	6.18	1.17	1.55	-4.05	<.001
	Walkers	0	5.09	2.61	1.51		
Walking experience	Crawlers	-	-	-	-		
	Walkers	0.36	5.88	2.59	1.56		
Total Self-Locomotor experience	Crawlers	0.76	9.36	3.2	1.98	-9.27	<.001
	Walkers	4.21	12.88	7.57	2.15		

The Human Ethical Research Committees at Edith Cowan University and at the University of Otago approved this study. Parents were asked to sign informed consents before their babies were tested.

5.3.2 Water Slope apparatus

The Water Slope apparatus consisted of a horizontal starting platform attached to a 10° inclined ramp installed in a swimming flume (10x2.5x1.5 m) (see Figure 9). The one-meter-long starting platform was above the water level and the 5m-long ramp began out of the water (5 cm above water level), leading to a water depth of 75 cm (below the mothers' feet). The 10° slope was created because it was less steep than the average boundary dry-land slope beyond which most infants would fall (Adolph, 1997; Adolph et al., 2008; Tamis-LeMonda et al., 2008). For new walkers, 10° may impose an increased challenge to walk down (Adolph, 1997) but they were free to use any locomotor solution to overcome the slope if they decided to.

FIGURE 9 | Representation and measures of Water Slope apparatus.



The Water Slope apparatus was designed to be as similar as possible to the Real Cliff / Water Cliff apparatus (Burnay & Cordovil, 2016; Studies One and Two). The entire apparatus (starting platform and ramp) was coated with a uniform black and white checkerboard pattern and surrounded by 20 cm high side protections (from the starting platform and extending to the end of the ramp). The infants wore a small harness attached to a rope and pulley system to ensure their safety, without constraining their movements. The pulley system was installed on a sliding track in the ceiling above the apparatus. The pulley could move the entire length of the track, following the infants' movements along the slope. A rope (tether) passing through the pulley was tied to the infants' custom-sized harness and was held at its other end by the experimenter responsible for the infants' safety. During the tests, mothers sat on a platform installed 5 m away from the infants' starting position and 37 cm above the water level, with their feet touching the water.

5.3.3 Procedure

Before visiting the laboratory, information about the study was sent to the infant's parents, who were asked to consult their baby diaries/books, photos and films to help them remember the different onset-dates of their infants' locomotor achievements. For consistency, the remainder of testing involved just the infant and their mother, although the fathers could watch if they desired. Upon arrival at the laboratory, mothers reported their infants' locomotor onset-dates in a structured interview and signed informed consents on behalf of their child. Mothers then helped the experimenter to put the custom-sized harness on their infants and held them on their laps while the experimenter attached the safety rope to the harness.

FIGURE 10 | Synchronised camera views. a) Front view; b) Back view.

To familiarize infants with the general characteristics of the setting, mothers first sat with their infants on the starting platform, playing with them until they were calm and comfortable. Then, mothers moved to the opposite side of the flume and sat on the platform (5m away from the infants' starting position) facing the infants. Next, the experimenter placed the infants in a quadrupedal posture (in the case of crawlers) or in an upright posture (in the case of walkers) on the starting platform (one meter away from the ramp) and initiated the trial. Mothers were instructed to touch and move the water with their feet and to encourage their infants to get to them by showing them a toy and using positive verbal and gestural language (see

Figure 10). As in the Real Cliff / Water Cliff paradigm, infants were tested wearing their normal daily clothes, except shoes. The ambient room temperature was approximately 23°C and the water temperature was approximately 28°C.

During the tests, infants had the opportunity to freely explore the apparatus while their mothers were calling for them. They could move around, sit, belly-crawl, crawl, cruise (supported by the lateral protections), walk, or engage in any other exploratory behaviours as they were testing their capabilities and seeking information about the environment. To first touch the water, infants had to cross the one-meter-long starting platform and 30 cm dry slope. Some infants moved straight to the ramp, but others took their time exploring the starting platform or even bending over the side protections to touch the water surrounding the apparatus. After touching the water accessible by the ramp, infants chose whether or not to wade into the water. Some infants just stood nearby the water playing, some ventured straight into the water and some showed avoidance behaviours, such as shaking the head as a "no" sign or retreating to the starting platform. Infants who crossed the water line on the ramp (from the dry to the wet part of the ramp), were free to decide whether to move to the submersion point (i.e., water touching their chin), stay in the shallow water playing or retreat to the dry part of the apparatus. When the infants' chin touched the water, the experimenter pulled them out of the water and gently transported them to the mothers' lap while suspended by the safety rope. The only situations in which the experimenter modified the infants' movements were in the rare cases when the infants bent over the lateral protections and the experimenter prevented them from falling into the surrounding water or if, 60 s after the trial started, the infants had not moved from the initial position, in which case the experimenter placed them next to the water line (i.e., line separating the dry from the wet part of the ramp), assuring that the babies touched the water.

The trials ended (a) after 180 s, if the infant had moved from the starting position but had never touched the water; (b) 150 s after the infant touched the water; (c) when the infant reached the submersion point; (d) when the infant started compulsively crying and could not be calmed down. If the infant started compulsively crying during the first 60 s of the trial, the test was ended and the infant was excluded from all subsequent analyses. If the infant started crying 60 s or more after the start of the trial, the test was ended, and the infant was coded as an avoider.

5.3.4 Data Reduction

Trials were filmed by 2 cameras (GoPro Hero 5) (see Figure 8 for cameras position) and video data were coded for:

- Avoidance behaviour: infants who avoided the submersion point were coded as 'avoiders' and those who reached the submersion point were coded as 'non-avoiders'.
- Approaching time (in seconds): from the moment the experimenter released the infants until the moment the infants touched the water with any part of their body. Infants who did not move from the starting position during the first 60 s of the trial were placed by the experimenter next to the water line with hands (in the case of crawlers) or feet (in the case of walkers) touching the water.

- Latency to submersion (in seconds): from the moment the infants touched the water (with any part of their body) until their chin touched the water. The maximum latency time allowed was 150 s.
- Retreat behaviour (yes/no): infants were coded as retreating when i) after touching the water they moved away from the water, placing the whole body on the dry platform at least once, and when ii) after crossing the water line they moved away from the wet part of the apparatus to the dry part at least once.
- Distress (never; before touching the water; after touching the water; when in the water; right before reaching submersion point): if the infants showed any signs of distress (e.g., fussiness, crying) during the trial, but could be calmed down and the trial proceeded.
- Posture of submersion (sitting, lying prone, squatting, quadrupedal posture, upright): posture adopted when the infants' chin touched the water.

5.3.5 Statistical analysis

Shapiro-Wilk tests were used to assess the normality of data.

Independent *t*-tests were performed to compare mean age and specific locomotor experiences between crawlers and walkers.

Pearson's chi-squared tests were used to investigate the effect of sex (two groups: female, male) on infants' avoidance behaviour (two groups: avoiders, non-avoiders). Pearson Chi-Square tests were also performed to investigate the difference in the proportion of infants that avoided falling in the Water Cliff and the proportion of infants that avoided the submersion point on the Water Slope.

Mann-Whitney U tests were used to compare differences in approaching time (continuous but not normally distributed dependent variable) between avoiders and non-avoiders. Reported as *U* statistics and *p* value.

Spearman's rank-order correlation (the nonparametric version of the Pearson correlation) was used to measure the strength and direction of association between ranked variables (i.e., age / locomotor experiences and approaching time). Strength of correlation was described using the same guide suggested by Evans (1996) for the absolute value of r.

Logistic regressions were performed to analyse the probability of infants avoiding the submersion based on age or any of the specific locomotor experiences.

Statistical analysis was conducted using IBM SPSS Version 24. The imprecision of parameter estimates was expressed using 95% confidence intervals [95% CI]. And statistical significance was accepted at $p < 0.05$.

5.4 Results

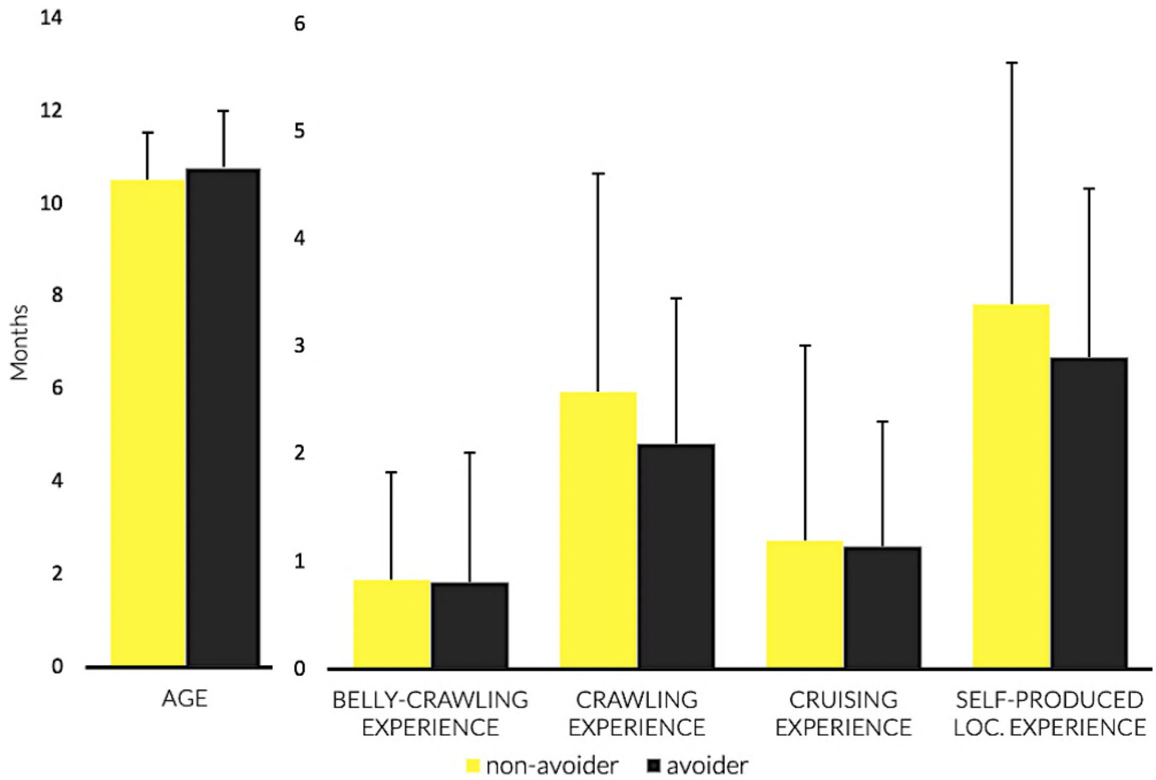
Preliminary analysis showed no effect of sex on crawlers' avoidance ($\chi^2_{(1)}$ = 0.85, *p* = .771) or walkers' avoidance behaviour, $\chi^2_{(1)}$ = 0.74, *p* = .391.

5.4.1 *Crawlers*

5.4.1.1 Avoidance behaviour

Of the 43 crawlers tested, 25 (58%) reached and 18 (42%) avoided the submersion point. Logistic regressions were performed to analyse the probability of crawlers avoiding the submersion based on age or specific locomotor experiences (see Figure 11 for mean values and standard deviations).

FIGURE 11 | Avoiding and non-avoiding crawlers' age and locomotor experiences (in months). Error bars represent standard deviations.



The logistic regression models were statistically not significant (see Table 24). Therefore, there was insufficient evidence that crawlers' avoidance of submersion can be predicted based on age or locomotor experiences.

TABLE 22 | Summary of Logistic Regression analysis for age and locomotor experiences predicting crawling infants' avoidance behaviour (N = 43).

Deleted:

							95% CI OR	
	B	S.E.	χ^2	df	*p*	OR	Lower	Upper
Age	0.073	0.164	0.197	1	0.657	1.075	0.78	1.48
Belly-Crawling experience	-0.015	0.291	0.003	1	0.96	0.985	0.56	1.74
Crawling experience	-0.166	0.189	0.769	1	0.381	0.847	0.59	1.23
Cruising experience	-0.026	0.203	0.016	1	0.898	0.974	0.66	1.45
Total Self-Produced locomotor experience	-0.134	0.166	0.648	1	0.421	0.875	0.63	1.21

Note. B = co-efficient for the constant. OR = odds ratio. CI = confidence interval.

5.4.1.2 Approaching time

Four crawlers did not move from the initial position and had to be placed next to the water line by the experimenter. Approaching time for those infants was coded as missing.

No significant difference was found between avoiders (M = 64.34 s, SD = 51.29) and non-avoiders (M = 44.41 s, SD = 53.68) in terms of the time spent to approach the water, U = 121, *p* = .114. Negative and moderate correlations were found between approaching time and crawling (r_s = -0.450, *p* = .004), cruising (r_s = -0.386, *p* = .015) and total self-produced locomotor (r_s = -0.376, *p* = .018) experiences. No correlation was found with age and belly-crawling experience.

5.4.1.3 Latency to submersion

Of the 25 crawlers who reached the submersion point, 12 simply crawled into the water until the water touched their chin, showing no signs of hesitation, seven took their time to explore the setting but ended up reaching the submersion point and six fell in the water while exploring the setting. No correlation between crawlers' age or locomotor experiences and latency to submersion was found.

5.4.1.4 Retreat behaviour

Three of the 25 non-avoiding crawlers (12%) and eight of the 18 crawling avoiders (44%) retreated to the dry part of the apparatus after touching the water. Six of the ten avoiders (60%) that did not retreat after touching the water also never retreated from the wet part of the apparatus after crossing the water line, they entered the water, spent their time playing and, ultimately, avoided the submersion point. In fact, only one crawler ever retreated to the dry part of the apparatus after crossing the water line. This one non-avoiding crawler crossed the water line, retreated to the dry part of the apparatus when the water was touching his chest and moved back into the water, reaching the submersion point. Statistically, avoiders moved away from the water more than non-avoiders after touching the water, $\chi^2_{(1)} = 5.79$, $p = .016$. However, there was no difference in crawlers' retreat behaviour after crossing the water line between avoiders (4%) and non-avoiders (0%), $\chi^2_{(1)} = 0.33$, $p = .566$. In none of the situations (i.e., retreating after touching the water or after crossing the water line) was crawlers' retreat behaviour associated with age or locomotor experiences.

5.4.1.5 Distress

Two crawling infants started crying after 60 s of testing. These tests were interrupted, and the infants were coded as avoiders. One of those crawlers touched the water line and started calling for the mother, showing signs that he wanted to get to her, but pointed to the water as if he was explaining to the mother that he could not go further and started compulsively crying after 64 s of testing. The other crawling infant who crossed the water line kneeled while sitting on her heels and playing with the water; at some point she started shaking her head as a sign of "no" every time the mother called for her and after 133 s of testing she started crying, frustrated because she wanted to get to the mother but could not.

Seventeen crawlers (40% of whole sample), ten of the 25 non-avoiders (40%) and seven of the 18 avoiders (39%), showed signs of distress at some point during the testing but were able to be calmed down and complete the testing. Of the non-avoiding crawlers who showed signs of distress, three did so before touching the water but, as soon as they touched the water, they became playful and calm; three after touching the water, two after crossing the water line; and two before reaching the submersion point, when they perceived the water was too deep and it was too late. Of the avoiding crawlers who showed signs of distress, six did so after touching the water and one after crossing the water line. The three crawlers who showed signs of distress after crossing the water line (one avoider and two non-avoiders) did so when the water touched their chest while adopting a crawling posture. Statistically, there was no significant difference in the proportion of avoiders and non-avoiders that showed signs of distress during the testing, $\chi^2_{(1)} = 0.01$, $p = .941$.

5.4.1.6 *Posture of submersion*

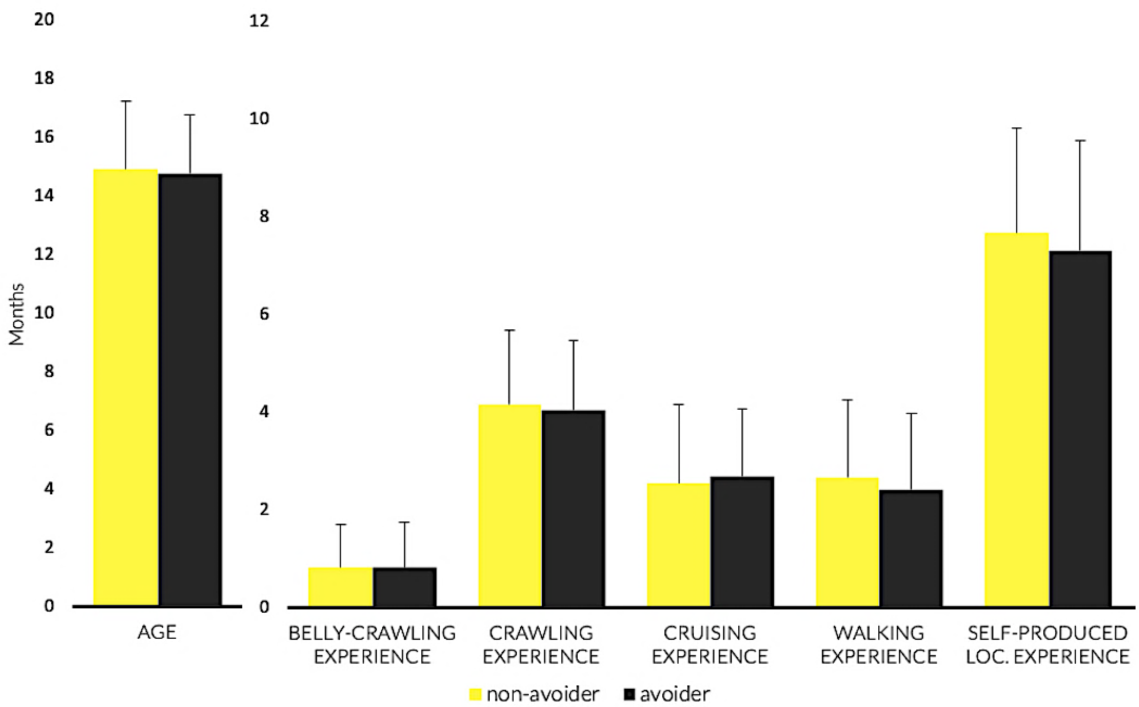
Twenty-three of the 25 non-avoiding crawlers were adopting a quadrupedal posture when they reached the submersion point. Two non-avoiding crawlers were cruising, supported by the lateral protections, when one of them fell in the water and the other decided to sit down but the water was already too deep.

5.4.2 Walkers

5.4.2.1 *Avoidance behaviour*

Twenty-three walkers (68%) reached the submersion point and eleven (32%) avoided (see Figure 12 for mean and standard deviation values).

FIGURE 12 | Avoiding and non-avoiding walkers' age and locomotor experiences (in months). Error bars represent standard deviations.



The logistic regression models were statistically non-significant (see Table 23) indicating that there was no evidence of an association between walkers' age or locomotor experiences and the odds of avoiding submersion.

TABLE 23 | Summary of Logistic Regression analysis for age and locomotor experiences predicting walking infants' avoidance behaviour (N = 34).

							95% CI OR	
	B	S.E.	χ^2	df	*p*	OR	Lower	Upper
Age	-0.042	0.172	0.059	1	0.808	0.959	0.68	1.34
Belly-Crawling experience	0.000	0.431	0.000	1	1.000	1.000	0.43	2.33
Crawling experience	-0.063	0.254	0.061	1	0.804	0.939	0.57	1.54
Cruising experience	0.069	0.250	0.075	1	0.784	1.071	0.66	1.75
Walking experience	-0.100	0.242	0.172	1	0.679	0.905	0.56	1.45
Total Self-Produced locomotor experience	-0.085	0.179	0.227	1	0.634	0.918	0.65	1.30

Note. B = co-efficient for the constant. OR = odds ratio. CI = confidence interval.

5.4.2.2 Approaching time

The approaching time of two walkers (one avoider and one non-avoider) was not coded due to a technical error with the filming. No significant difference in the approaching time was found between walking avoiders (M = 40.83 s, SD = 60.50) and non-avoiders (M = 29.61 s, SD = 42.05), U = 89, p = .393. Correlation tests show a negative and moderate correlation between approaching time and belly-crawling experience (r_s = -0.37, p = .042) and a positive and moderate correlation with crawling experience (r_s = 0.43, p = .014). No correlations were found between age or any of the other locomotor experiences and walkers' approaching time.

5.4.2.3 *Latency to submersion point*

Nine walking non-avoiders took their time to explore the setup before reaching the submersion point and 13 simply locomoted (11 walked and two crawled) to the submersion point without hesitations. One walking non-avoider, the only one that fell in the water, was showing signs of disinterest in getting into the water (i.e., fussiness before touching the water) but when he saw a ball floating in the water, he ran after it. When he perceived the water was too deep, he turned around to go back but ended up falling in the water. No correlation between walkers' age or locomotor experiences and latency to the submersion point was found.

5.4.2.4 *Retreat behaviour*

Three walkers (all avoiders) retreated at least once to the dry part of the apparatus after touching the water. Five walkers (four avoiders and one non-avoider) retreated to the dry part of the apparatus at least once after crossing the water line. One of these avoiders crossed the water line and when the water was touching her ankles she turned around, climbed the back part of the apparatus, managing to bridge the gap between the apparatus and the deck (about 30 cm long), got to the flume' deck and walked along the deck to her mother. Other infants explored this option, but this toddler was the only one who succeeded. Of the other four walkers who retreated after crossing the water line, one did so when the water was touching his ankles, two when the water was touching their knees and one when the water was touching his chest while adopting a crawling posture. Statistically, avoiders retreated more (27%) than non-avoiders (0%) after touching the water ($\chi^2_{(1)}$ = 6.88, *p* = .009) and avoiders retreated more (40%) than non-avoiders (4.3%) after crossing the water line, $\chi^2_{(1)}$ = 6.89, *p* = .009.

5.4.2.5 Distress

One walking infant started showing signs of distress as soon as the test started but was able to be calmed down; she walked to the edge of the slope and decided to go further down the slope. However, 72 s after starting the test, when the water was touching her waist, she started compulsively crying, the test was interrupted, and the baby was coded as an avoider. Nineteen of the walkers tested (56%) (seven of the 11 (64%) avoiders and 12 of the 23 (52%) non-avoiders) never showed any signs of distress during the testing. Six of the non-avoiders who never showed signs of distress also never hesitated during the testing, they simply walked to the submersion point. Of the 11 non-avoiders who showed some signs of distress before reaching the submersion point, one did so before touching the water, one after touching the water, five after crossing the water line and four walkers walked straight to the deep water with no hesitation and only moments before reaching the submersion point they showed signs of distress. Of the four avoiding walkers who showed signs of distress, one did so before touching the water, two after touching the water and one after crossing the water line. Of the six walkers who showed signs of distress after crossing the water line (five non-avoiders and one avoider), one did so when the water was touching his ankles, three when they had the water touching their waists, for one the water was touching her chest and for the only avoider, the water was touching his ankles when he started showing signs of distress. There was no association between the proportion of walkers that showed signs of distress and avoidance behaviour, $\chi^2_{(1)} = 0.397$, $p = .529$.

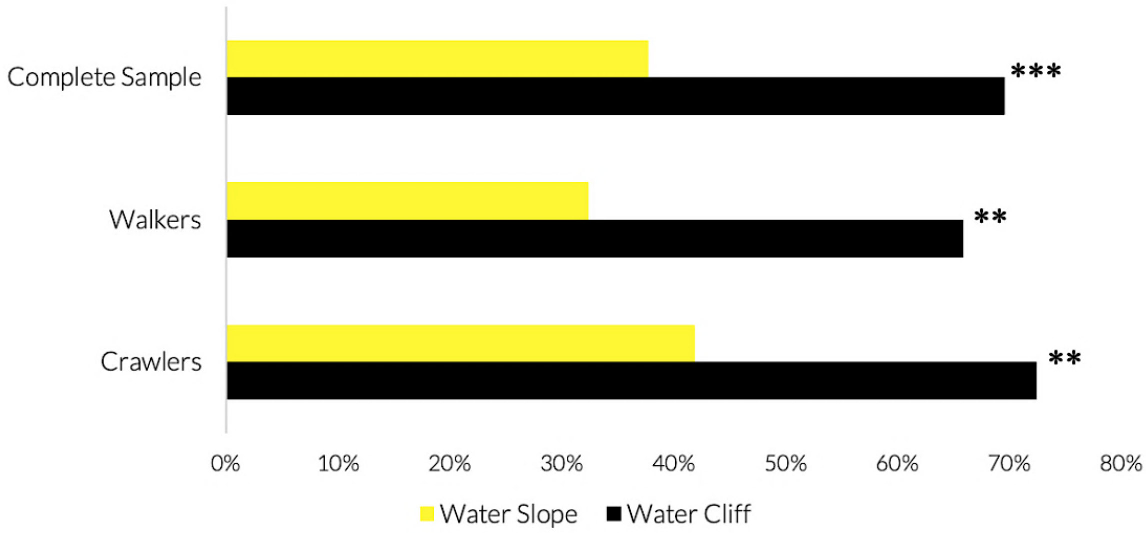
5.4.2.6 *Posture of submersion*

Of the 23 walking non-avoiders, 20 reached the submersion point while adopting an upright posture. The three walkers that were not standing-up when they reached the submersion point, were new walkers who chosen to crawl to the submersion point. One walked along the starting platform but when he reached the ramp, he fell to a sitting posture and transferred to crawling. The other two transferred to a crawling posture as soon as the experimenter released them in an upright posture and started the testing.

5.4.3 Water Cliff vs Water Slope

A greater proportion of infants avoided falling on the Water Cliff (WC) than avoided reaching the submersion point on the Water Slope (WS) (see Figure 13).

FIGURE 13 | Comparison between proportion of infants that avoided falling on the Water Cliff (Study One) and infants that avoided the submersion on the Water Slope. Complete Sample: NWC = 102; NWS = 77; Crawlers: NWC = 58; NWS = 43; Walkers: NWC = 44; NWS = 34. ***p* < .01, ****p* < .001, Pearson Chi-squared tests.



5.5 DISCUSSION

This final study investigated the effect of specific locomotor experiences on infants' avoidance of submersion when a sloped entrance was offered. Further investigation was also undertaken into potential differences in infants' perception and action when the accessway offered a sudden fall (i.e., drop-off) or a smooth and gradual entrance into a body of water (i.e., ramp).

The primary finding was there was no association between infants' avoidance of reaching the submersion point on the water slope and age or specific self-produced locomotor experiences. In addition, when compared with infants' avoidance behaviour on the water cliff (Study One), a greater proportion of infants reached the submersion on the water slope. Together, these findings indicate that through locomotor experience infants learn how to adapt their behaviour to avoid falls from heights (into the water or not), but locomotor experience does not influence their perception of bodies of water as environments that present risk.

If no water was involved, the Water Cliff and the Water Slope apparatus would afford different possibilities for action and risks to infants. The Water Cliff would represent a real cliff and, as shown in the Real Cliff / Water Cliff studies (Burnay & Cordovil, 2016; Studies One and Two), infants' perception and action would be similar. On the edge of a drop-off, infants may adapt their behaviour by rotating belly down and safely descending feet first, but if they decide to crawl or walk over the cliff, they will suddenly fall. On a sloped entrance leading to deep water the consequence of such behaviours is less obvious. If the 10° slope used on the Water Slope apparatus was not leading to a body of water, it would merely represent a safe-to-navigate dryland slope (Adolph, et al., 2008; Tamis-LeMonda, et al., 2008). The presence of water on the slope poses a different challenge to infants, it offers a smooth and gradual transition from safe to unsafe. On the Water Slope apparatus, as it would happen on the now popular “zero entry pools”, infants started on a flat and dry surface leading to a dryland shallow slope and, only after exploring the safe to navigate slope, infants encountered the water. At the start of testing, infants were on a safe to locomote surface and when they touched the water for the first time it was shallow, offering no risk, only a playful opportunity. However, the risk and the perceived information changed progressively while they ventured down the slope trying to reach their mothers. In contrast to the Water Cliff, where going further means a sudden fall into the water, on the Water Slope the ramp leads the infants deeper and deeper into the water and they have to revaluate their possibilities for action and the consequences of going further at each step.

Infants’ more accurate behaviour on the Water Cliff in contrast to the Water Slope is in accordance with previous studies showing that infants with considerable locomotor experience were capable of adapting their behaviours to avoid situations where the perceived penalty of going further could be severe, such as falling from cliffs (e.g., Campos, et al., 1992; Adolph, 1997; Kretch & Adolph, 2013; Burnay & Cordovil, 2016; Studies One and Two) or into a body of water (Burnay & Cordovil, 2016; Studies One and Two), but a less accurate behaviour was reported when the consequences of falling were less significant, as when negotiating apertures (Franchak & Adolph, 2012), walking under barriers, instead for running (van der Meer, 1997), or going up slopes, instead of going down (Adolph, 1997).

The beginning of the slope affords the infants a safe-to-locomote situation, yet with each movement forward it gets more and more risky to go on. Would there be a depth point where infants perceived the risk of continuing to go forward? When testing infants' adaptive behaviour on increasingly steep slopes, Adolph (1997) used the slope at which infants shifted from the last acquired locomotor skill to a more experienced one to determine their slope boundaries. If crawlers could not safely crawl down a slope, they could shift to a sliding solution and if walkers could not safely walk down a slope, they could shift to a crawl or slide solution. However, shifting from a crawling to a sliding posture or from an upright to a crawling posture does not help infants to safely navigate increasingly deep water, it only increases the risk of submersion. Slower approaches, retreating from the water and signs of distress could indicate that infants perceived the risk imposed by going deeper into the water and that they had reached their depth boundaries. We would expect avoiding infants to cautiously approach the water, retreating or showing signs of distress when they perceived the water was too deep to be safe. However, in Study 3 these variables were inconclusive. Although non-avoiders approached the water faster than avoiders, the amount of time was highly variable and statistically there were no differences in the time avoiders and non-avoiders took to approach the water. In addition, the effect of locomotor experience on the approach time was the opposite for crawlers and walkers: crawlers with more crawling experience approached the water faster and walkers with more crawling experience approached the water slower. With respect to the retreating behaviour, avoiding infants shied away from the water after touching it more than non-avoiders. However, after crossing the water line, avoiding and non-avoiding crawlers, non-avoiding walkers and most of the avoiding walkers (60%) did not retreat from the water, they simply stood in the water, exploring and playing, enhancing the risk of engaging in drowning incidents, even for those who managed to avoid the submersion point.

More than half of the infants never showed any signs of distress during the testing and no difference in the percentage of avoiders and non-avoiders that did so was found. Avoiding infants who showed any signs of distress did so right after touching the water. Of the non-avoiders that showed signs of distress, only three (two crawlers and one walker) were unable to be calmed down and the testing had to be interrupted. Of those who showed signs of distress but were able to be calmed down and proceed with the testing, the moments they did so were quite variable between infants. Some of the non-avoiders started showing signs of distress before touching the water, but as soon as they touched the water, they relaxed and started playing, others only showed signs of distress after touching the water or even after crossing the water line, and some only showed any sign of distress moments before they reached the submersion point, when it was clearly too late to go back. The number of infants (three crawlers and six walkers) that started showing signs of distress after crossing the water line was too small to be suggestive of the moments infants would perceive the water as dangerously deep.

A progressive and smooth entrance to the water was enticing for most infants but it posed an increased risk to become submerged. Contrary to what has been previously found on water and real cliffs, infants' avoidance behaviour on the Water Slope was not influenced by locomotor experience, yet, some infants avoided the submersion point. Some infants simply locomoted to the submersion point with no hesitations, others took their time to explore the setting and others even avoided getting into the water. If it is not the locomotor experience that teaches infants to avoid going deeper into the water when a sloped entrance is offered, what would be the difference between infants who avoided and those who ventured into the water until the submersion point? Further studies are needed with a greater number of infants tested to further explore the differences between infants who show no perception of the risk of venturing into deep water from a slope and those who show a more cautious behaviour.

5.6 Conclusion

In conclusion, although self-produced locomotor experience teaches infants to avoid falls into the water, it has no effect on their perception of the risks of venturing into the water if the access is smooth and gradual. Sloped accessways into bodies of water may increase infants' risk of engaging in drowning incidents when compared to the risk offered by drop-offs leading to deep water.

6 GENERAL DISCUSSION

6.1 Summary

Understanding the development of infants' perception and action in risky environments is a crucial step toward the prevention of potentially severe injuries. Although the ecological approach has been largely used to investigate infants' relationship with drop-offs and surfaces that do not afford safe locomotion, the application of this theoretical framework to infants' relationship with aquatic environments is novel. This thesis explored the relationship between infants perceptual-motor development and their behaviour around not only features that may lead to falling from heights but also to drowning incidents. Specifically, this thesis examined the effect of age and specific self-produced locomotor experiences on infants' perception and action around real cliffs, water cliffs, and sloped entrances to bodies of water.

The primary purposes of Study One was to examine the effect of self-produced locomotion on infants' avoidance of falling on a real and a water cliff and to compare their perception and action in the two different settings, though both were preventers of safe locomotion. Motivated by the postural specificity hypothesis (Adolph, 2000; Adolph & Robinson, 2015), it was hypothesised that the amount of crawling experience would be associated with crawlers' avoidance behaviour and the amount of walking experience would be associated with walkers' avoidance behaviour on both cliffs. The results of Study One showed that crawling experience, and total self-produced locomotor experience (i.e., belly-crawling and hands-and-knees summed), were indeed associated with crawlers' avoidance of falling on the real and the water cliff. Hence Study One confirmed the results of several previous studies addressing the effect of crawling experience on infants' avoidance of dangerous scenarios (e.g., Campos et al., 1992; Adolph, 1997; Witherington et al., 2005; Kretch & Adolph, 2013; Burnay & Cordovil, 2016). However, in Study One, no effect of walking experience was found on walkers' avoidance of falling on either cliffs, thus challenging the postural specificity hypothesis (Adolph, 2000; Adolph & Robinson, 2015). In fact, in contrast to the idea that learned behaviours do not transfer between postures, crawling and total self-produced locomotor experiences were the best predictors of walkers' avoidance behaviour on both cliffs! Study Two bolstered the results of Study One, suggesting they are robust. In a longitudinal study design, findings from Study Two showed no difference in infants' avoidance behaviour between the first (i.e., as experienced crawlers) and the second (i.e., as new walkers) tests; the great majority of infants behaved equally or more adaptively when tested as new walkers and showed even more adaptive behaviour when tested as experienced walkers. Results of Study Two parallel those of Witherington et al. (2005), showing that new walkers avoided even more consistently crossing the visual cliff deep side than experienced crawlers.

The association of crawling and total self-produced locomotor experience with walking infants' avoidance of both cliffs and the non-effect of walking experience alone, indicate that some degree of what infants learn through crawling experience is developmentally transferred to the new walking locomotor solution. Previous studies have reported that experienced crawlers are better capable of adapting their behaviours to safely overcome drop-offs and slopes (Kretch & Adolph, 2013; Adolph, 1997). All infants tested in Study Two were experienced crawlers when tested as new walkers and the needed recalibration when the new walking locomotor solution emerged was prompt. We hypothesise that instead of having to relearn all over again how to behave adaptively when a new walking locomotor posture emerges, as argued by the "Sway Model" proposed by Adolph (2000), infants need to recalibrate their perceptual-motor system to the new action capability and the amount of previous crawling experience facilitates the recalibration process.

Esther Thelen once wrote that crawling is only an 'opportunistic assembly' (Thelen, 2005, p.264) that infants use while waiting for the development of the balance and strength necessary to adopt an upright posture that will lead to a more economic locomotor solution – the walking solution. However, as shown by the results of Studies One and Two, the crawling solution is not that insipid. The valuable exploratory role played by crawling has been underestimated and can now be appreciated as an important contributor to the development of infants' perception of surfaces that do not afford safe locomotion.

Study One also hypothesised that, due to the playful characteristics of a body of water, in contrast to a precipice, infants would explore and fall more on the water cliff than on the real cliff. In fact, although infants showed similar avoidance behaviour on both cliffs, some of the exploratory behaviours that infants adopted while exploring the settings while looking for information indicated a greater attraction for the water cliff than the real cliff. Similar avoidance behaviour between cliffs indicates that infants perceive the risk of both cliffs similarly; they avoid (or do not avoid) water drop-offs (i.e., drop-offs filled with water) because they perceive them as not affording terrestrial locomotion, in the same way they perceive a real drop-off (i.e., drop-offs filled with air). However, even if the infants perceived both settings as preventers of locomotion and adapted their behaviour to avoid falling, they stood closer to the edge of the water cliff, for a longer period of time, and engaged in more tactile exploration than on the real cliff, increasing the opportunities for accidental falls into the water.

Study three was conducted to investigate if infants perceive a body of water as an unsafe environment that should be avoided, even if the access was smooth and progressive and afforded terrestrial locomotion if water was not present. Infants' avoidance of submersion was tested in an aquatic environment with a smooth and gradual accessway leading to deep water. It was initially hypothesised that infants' adaptive behaviour on the Water Slope would be associated with the amount of experience with the last acquired locomotor solution, as was hypothesised for the infants' avoidance of the water cliff. In addition, it was expected that a greater proportion of infants would avoid falling from the Water Cliff than would avoid reaching the submersion point on the Water Slope. Contrary to what was observed for infants' avoidance of falling into the Water Cliff, the results of Study Three showed no effect of self-produced locomotor experience on infants' avoidance of submersion on the Water Slope.

Together, findings from the three studies presented here indicate that through self-produced locomotor experience infants learn how to perceive and adapt their behaviour to avoid going over features that do not support safe locomotion, whether filled with water or not, but locomotor experience has no influence on infants' perception of bodies of water as a risky environment that should be avoided. Results of Study One and Three also revealed that the proportion of infants reaching the submersion point throughout their perceptual-motor development on the Water

Slope was higher than the proportion of infants falling on the Water Cliff. These results point to an enhanced risk of infants engaging in drowning incidents when the accessway to a body of water is sloped and gradual (i.e., shallow ramp) than when it affords a sudden fall into the water (i.e., drop-off).

6.2 Practical Implications

The outcomes of this thesis have important theoretical implications, furthering the current understanding of infants' relationship with environments that do not afford safe locomotion and that can lead to unintentional falling from heights and drowning incidents.

The results of this thesis also have important practical applications. First, caregivers should be educated about the importance of promoting crawling opportunities to infants and be made aware that promoting opportunities for infants to safely crawl and explore the world has a stronger effect on preventing them from engaging in falling accidents than trying to keep them in one place. In contemporary society, a strong tendency for parents to be over-protective of their children has been observed; caregivers are imposing too many restrictions on children' natural exploratory behaviours (Brussoni, Olsen, Pike, & Sleet, 2012). Second, caregivers should be made aware of the sensitive periods that follow the acquisition of new locomotor solutions. Infants are particularly vulnerable to falls from heights and into bodies of water after they start to crawl. While the risks associated with the onset of walking seem lower than the risks associated with the onset of crawling, new walkers are still likely to be more vulnerable to risky environments than experienced crawlers. Even if infants with more crawling experience adapt their new walking capability to risky environments faster than infants with less crawling experience, they likely require some time to recalibrate their perceptual-motor system before they can safely navigate the environment using their new walking skill. Finally, the new understanding that sloped entrances to bodies of water may increase infants' opportunities to engage in drowning incidents should be taken in consideration when designing swimming pools that will be used by young children.

6.3 Limitations

The outcomes of this thesis have important practical and theoretical applications. However, some limitations apply:

Onset of locomotor skills - The onset dates of locomotor skills reported by mothers have a degree of error. Even though mothers were asked to use pictures and diaries to report the onset of each locomotor skill, correlations between reported onset dates, locomotor pattern measures and thresholds in the task could have corroborated mothers' retrospective reports.

Locomotor experience - As in previous studies, the amount of locomotor experience was calculated in days since the onset of the locomotor skill. This criterion raises some discrepancies related to the "amount of locomotor experience" among studies. First, onsets of locomotor skills are normally functionally defined, based on the distance infants need to traverse on a specific apparatus (e.g., Kretch & Adolph, 2013, Witherington et al., 2005) and varies between studies. Second, "days since locomotor onset" is different from "amount of locomotor experience". An infant who is crawling for 20 days but who spends considerable time in confined spaces (e.g., behind security gates) has less crawling experience than an infant who has been crawling for 20 days but is free to self-locomote and explore the environment. The term "locomotor experience" was adopted to be easily related to previous studies but a more accurate term would be "time since onset of locomotor skill".

Cross-cultural effect - The Real Cliff / Water Cliff studies (Burnay & Cordovil, 2016, Studies One and Two) were conducted in Lisbon, Portugal, while the Water Slope study took place in Dunedin, New Zealand. The possible cross-cultural effect is not clear and needs to be further investigated.

Ecological validity - Although all the procedures were designed to be as similar as possible to daily situations where infants would find themselves nearby the edge of real and water cliffs or a ramp leading to a body of water, the laboratory is an indoor environment and fails to fully represent the real-world environment.

Longitudinal study design – to confirm the findings of Study Three, infants' behaviour on the Water Slope should be tested throughout the developmental stages of locomotor skill acquisition using a longitudinal approach.

Limited insight into process – like the majority of studies highlighting the role of locomotor experience on adaptive behaviour, the current study was focused on showing that specific experiences were associated with the emergence of specific forms of adaptive behaviour. It did not attempt to identify the process(es) by which these experiences brought about the new forms of behaviour.

6.4 Directions for Future Research

The interpretations of Studies One and Two are that when infants begin walking, instead of needing to relearn all over again how to perceive and adapt the behaviour to safely navigate drop-offs, they need to recalibrate the perceptual-motor system to the new action capability. It is important to further investigate the contribution of specific locomotor experiences. The posture-specific learning hypothesis suggests 4 parallel learning curves for sitting, crawling, cruising, and walking (Adolph, 2019). However, Studies One and Two revealed no specific effect of walking experience on infants' adaptive behaviour on drop-offs. In addition, the fact that total self-produced experience was associated with crawlers' avoidance behaviour suggests that some degree of what infants learned about navigating drop-offs by belly-crawling was transferred to hands-and-knees crawling. Testing belly-crawling and cruising infants, with varying amounts of experience, could clarify the effect of experience with specific locomotor capabilities on the transfer of the perception of affordances of drop-offs between locomotor skills. It would also be interesting to see if experience with independent standing facilitated the detection of affordances while walking. In addition, the longitudinal study presented here (Study Two) first tested infants with a considerable amount of crawling experience. Therefore, all infants tested as new walkers were previously experienced crawlers. It would be revealing to test new walkers on the cliffs with varying amounts of previous crawling experience. A longitudinal study, testing infants since they first started self-locomoting, regardless of the locomotor skill first used, throughout all the subsequent locomotor achievements, would help to draw a clearer picture of how infants' perceptual-motor development contributes to their behaviour around drop-offs. Future research experimentally manipulating specific components of experience and testing whether these components lead infants to develop the new behaviours of interest should also attempt to identify the process(es) by which specific experiences bring about new forms of behaviour.

Regarding infants' relationship with aquatic environments, despite the findings presented, several practical and theoretical questions remain. First, future research should investigate infants' perception and action in natural environments instead of laboratories. Secondly, because locomotor experience was not associated with infants' perception of the risk of aquatic environments when the access was gradual, the influence of other factors (i.e., infants' temperament, experience with swimming courses or recreational water activities) should be investigated. Third, studies should investigate other external factors which could influence infants' behaviour around aquatic environments (i.e., differences in visual information associated with different water environments, such as still water, moving water and waves). Fourth, to overcome the possible cross-cultural effects, the same infants should be tested on water drop-offs and water slopes. And finally, a longitudinal study design would confirm the non-effect of locomotor experience on infants' avoidance of submersion when accessing a body of water from a slope.

6.5 Summary of Conclusions

In summary, this thesis examined locomotor experience as a factor in infants' avoidance of drop-offs and bodies of water. Infants' different approaches to bodies of water when the access was made via drop-offs or slopes was also examined. The following conclusions were reached:

1) Through crawling and total self-produced locomotor experiences infants start perceiving the affordances of supportive surfaces and adapting their behaviour to safely navigate drop-offs, whether or not they lead to bodies of water (Studies One and Two).
2) Walking experience alone has no influence on infants' avoidance of falls from drop-offs and into the water (Study One).
3) The discontinuity observed in infants' adaptive behaviour around drop-offs when they begin walking occurs due to a need for recalibration to the new locomotor capability, not because avoiding falling is learned in a posture-specific manner (Studies One and Two).
4) The amount of previous crawling experience facilitates walkers' recalibration of the perception-action system to the new walking capability (Studies One and Two).
5) Infants tend to explore water drop-offs, enhancing the opportunities for unintentional drowning incidents (Study One).
6) Locomotor experience has no influence on infants' avoidance of deep water when the access is made via sloped entrances (Study Three).

7) Infants are more prone to drowning incidents when the access to bodies of water is smooths and gradual (i.e., sloped) than when it is sudden (i.e., drop-off) (Studies One and Three).

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