THE REPRESENTATION OF ABSENCE OF OBJECTS

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Submitted to
Central European University
Department of Cognitive Science

Thesis submitted for the degree of Doctor of Philosophy (PhD)

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Budapest, Hungary

2019

Originality Statement

I hereby declare that this submission is my own work and it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at Central European University or any other educational institution, except where due acknowledgment is made in the form of bibliographical reference. I declare that the intellectual content of this thesis is the product of my own work, and the claims here reflect my own thinking. I will present this work in first person plural voice.

Eszter Szabó

Abstract

While linguistic negation is a fascinating tool to capture the absence of objects, we know little about how these thoughts emerge. In this work, first, we aimed to investigate the linguistic negation acquisition and the nature of the first meanings of the negative statements; second, we targeted language independent representations of presence/absence available for young infants and non-human animals. In Study 1 and 2 we inspected the development of negation comprehension between 15 and 24 month in human infants. In Study 1 we asked whether a domain general or alternatively, a limited conceptual understanding supports the initial understanding of negation expressing absence. We found a parallel development for understanding syntactically and functionally different negative utterances, supporting a common conceptual basis for negation already at 18 months. While in Study 1 infants were able to encode absence and use it to find the presence of an object, in Study 2, we tested negation comprehension when it does not evoke the implication of a positive alternative (i.e. the only implication is 'nothing'). We found a more prolonged pattern for negation understanding in Study 2 compared to Study 1. In Chapter 3 we tested young domestic chicks' encoding of the presence and the absence of an object. We found sex-dependent evidence in their looking behavior, suggesting a capacity for encoding absence. In Chapter 4 we measured the neural correlates of different types of object disappearances in 6-month-old infants. Object maintenance (of presence) evoked prefrontal and temporal activation when an object was occluded; in contrast no specific activation was found for objects that vanished or mingled among other identical objects.

Our findings point to human infants' readiness to understand negation expressing absence, likely based on domain general cognitive and linguistic tools. However, encoding absence is not

language-dependent ability; such information is also available for pre- and non-linguistic creatures, but unlike encoding presence, it is not an automatic process. We propose that absence depends on categorical representations, and on possible mental structures expressing contrary concepts.

Acknowledgements

First and foremost, I would like to thank all the help of my supervisor, Ági. Thank you for your support all these years. You have the extraordinary ability to bring out the best of me, while in the same time you never forgot to care for me. I would like to thank the help of my secondary supervisor, Gergő as well. Thank you for all your sharp insights and for being available even after the last minutes of preparing work related to this thesis.

Next, I would like to thank the help of all my contributors of Chapter 3. Especially for Giorgio Vallortigara to host me at the Animal Cognition and Comparative Neuroscience Lab, it was a dream come true experience. Also, I would like to thank all the help of Cinzia who taught me everything I know on testing chicks (and crayfish!) and who made the time in Rovereto even much delightful. Furthermore, thank you for all your help with the chicks, Orsola and Elisabetta.

Thanks to Christophe for his smart thoughts on the weirdest number, zero. I would like to thank for the inspirational conversations to Attila, Ernő, Gábor, and Tibor.

Also, many thanks go to the community of Cognitive Science department, and especially for the people at CDC. I have so much sweet memories to carry with me thanks to you. Huge thank for Mari for recruiting babies, and for everyone contributing to enveloping and posting the invitations, contacting the parents and organizing the testing sessions. Many thanks for Szilvia Takács for helping in Study 2.

Thanks for my family and friends for being patient and supporting me.

Last, but not the least, I would like to thank to Laci and Cica to bring relief, and to remind me of how lucky I am even in the most stressful times.

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1. Chapter 1. Introduction

Investigating the representation of absence is a curious enterprise. On one hand, it is connected to suspicious thoughts like ‘nothing’ or to important achievements of human cultures, like the concept of zero or nirvana. The idea of ‘nothing’ has fascinated scientists, scholars and eccentrics for centuries (Hearst, 1991). While targeting how these complex concepts emerge in phylogeny and ontogeny is an even more fascinating issue, one could question the rationale for such a scientific endeavor given that even human adults find difficult to capture such meanings. On the other hand, one might wonder why would anyone consider the investigation of such a trivial phenomenon as noticing the absence of objects. For instance, pets clearly have no difficulty to notice the absence of food when their bowl gets empty at the end of the feeding. Absence seems either too complex to grasp to tackle on the cognitive mechanism behind it, or too obvious to attract one’s attention. In my view – without taking a side on whether absence is too complex or too trivial - even the most complex and absurd concept has to have its origin in more simple thoughts worthy for investigation. Similarly, inspecting some of the most trivial aspects of cognition can lead to the recognition of fascinating features of our minds. Without Kurt Koffka starting to wonder about strange questions like why we see objects rather than the holes between them, we might not have reached an as complete understanding of object perception as we now have (Hearst, 1991). In this chapter, I will guide the reader through different phenomena – like linguistic negation or the number zero – that are related to how we conceptualize the absence of objects. I will first review the literature on the processing and acquisition of negation in humans. Then I will focus on representations likely independent from

linguistic negation and on the question of how non- and pre-linguistic creatures might encode the absence of objects, and which cognitive mechanisms support such abilities.

1.1. Linguistic negation

While concepts related to the absence of objects tend to be extraordinary (like nothing, zero or no ghosts), most of us do not realize their peculiarity when we verbally express them in everyday life, for instance when we utter 'There is no more milk in the box', 'I can see nothing in the dark' or 'The boogeyman does not exist'. Negation is the most important linguistic tools allowing us to express absence. Every language has negation, which makes possible to negate literally all possible sentences we can formulate. What is shared by all negative sentences is that they convey what is not the actual state of affairs, thus it is difficult to capture their meaning via an iconic representation. While imaging a lady in red dress is relatively easy to accomplish, picturing a lady in a dress, which is not red can cause some struggle, or at least some uncertainty. In the first section of the Introduction I will discuss two main questions: how adults process and ground the meaning of negation and what we can learn about the origin of the concept of negation from the acquisition of negation by infants and toddlers.

1.1.1. How do adults process negation?

Systematic investigations converge on the typical finding that adults are slower and more error prone when processing negative sentences compared to affirmatives ones. Participants make

more errors in recalling negatives than positives and sometimes they develop a strategy to first translate negatives into affirmatives to complete the task (for review see Horn, 2001; Kaup, Lüdtke & Zwaan, 2013). A classic example of these findings can be find in Clark and Chase' s (1972) sentence verification study in which participants compared simple pictures and sentences, and they judged the truth value of the sentence based on the visual evidence. For instance, they saw a star above a plus sign and they had to decide whether the sentence "Star isn't above plus" is true or false. Participants needed more time and they made more errors in judging negative sentences.

In some sense, it seems obvious that negative sentences are more difficult and more time demanding compared to affirmative ones, as there is a trivial asymmetry between the syntax of the two structures. Negative sentences include the (negated) affirmative sentence and an extra element, the negative particle. However, the processing time of the extra element (i.e. not) in the negative sentence cannot explain the puzzle itself (Clark & Chase, 1972).

Several different factors were pointed out to explain how negation is processed and how the negative sentences are comprehended; here I will shortly focus on three that seem them most influential. The first factor relates to structure, and it is claimed to be responsible for the extra time needed to process a specific construction of propositions (i.e. FALSE(star above plus)) used in the sentence verification tasks, and for the demands of the necessary 'translation' from negative to positive that is involved in the comprehension of negative statements (Clark, Chase, 1972).

The second factor relates to pragmatics, and to the natural function of negation in discourse and its relation to the artificial context provided in test situations (Wason, 1965; de Villiers & Flusberg, 1975). The function of negation is, instead of describing the world, informing us about

the world taken into account our/others' expectations (based on previously received information or world knowledge). Vandamme (1972) extended this idea of linguistic negation processing, emphasizing the role of negation in information encoding in general, and suggesting that negation is crucial because it makes us able to register failures of certain actions, or presumptions. For instance, starting a story with "My train was not late" might sound awkward, unless the audience knows that particular train is always late. Wason (1965) introduced the idea of the context of plausible denial and tested the effect of a plausible context using sentence verification task, manipulating the expectations of participants in the following way. He presented eight circles, seven red and only one blue. The sentences varied in whether they were negated (or affirmed), plausible (i.e. referring to the blue circle "The circle is not red") or implausible (i.e. referring to one of the red circle "This circle is not blue") statements based on the frequency of the items. Participants were faster and made fewer errors in processing plausible negative sentences compared to implausible ones. Wason (1965) argued that the difficulty registered within experimental settings originates from the difficulty of incorrectly setting up the context of denial. Indeed, adults (Wason, 1965; Glenberg, Robertson, Jansen & Johnson-Glenberg, 1999) as well as young children (between 2.5-4.5 years, de Villiers & Flusberg, 1975) are sensitive to manipulations of the context when comprehending negative sentences. While the pragmatic account explains a high proportion of processing difficulties, it cannot give a full account. Even with pragmatically supported context sentences, negation is still harder to process than the corresponding sentences involving affirmation (see Kaup et al., 2013). The third factor relates to the ontogenesis of such expressions, and it was suggested that the negative particles and expressions have a negative connotation and a potential inhibitory effect. For instance, Wason (1965) has reported that in their feedbacks participants were specifically expressing

negative feelings when evaluating the negative sentences. The aversion for negative particles might originate from the ontogenesis of these expressions, e.g. from rejections, as presumably they provide the first meanings of negations. In this way, they are associated with inhibition, and negative emotive effects. Indeed, inhibitory effects can be observed in comprehending negative sentences (MacDonald & Just, 1989; Lea & Mulligan, 2002). MacDonald and Just (1989) demonstrated that negation influences the accessibility of information mentioned within its scope. They presented sentences like "Almost every weekend Mary bakes some bread but no cookies for the children". Afterwards, they used word recognition (whether a word occurred in the sentence) and naming tasks, and it was observed that the response times were longer for negated (i.e. cookies) compared to not-negated targets (i.e. bread). Regarding the negative emotional factors, recent studies have investigated the effect of unintentional facial expressions while processing negation. Benitez-Quiroz and colleagues (Benitez-Quiroz, Wilbur & Martinez, 2016) identified a component of the facial expression of negation, the so–called "not face". This expression is the same as the one observed in the non-verbal communication of negative moral judgments, including the components of anger, disgust and contempt. These facial expressions were automatically co-articulated during uttering negative sentences, and might support the role of emotional factors in processing linguistic negation.

While trying to identify the factors making negation more demanding compared to affirmatives, we cannot avoid the question of how negation obtains its meaning, and the question of symbol grounding, specifically how this symbolic representation is linked to sensorimotor information. One way to classify the existing theories is to consider how permissive they are regarding the idea of having symbols that are not translatable to iconic/picture-like information (in other terms their position on a perceptual-propositional scale). I will present them in an ascending order with

respect to how liberal is the theory in question in allowing for symbolic representations for negation.

The first theory is the two-step simulation hypothesis of negation developed by Kaup and colleagues (2013). This theory belongs to the family of experiential or mental simulation models of language processing. These models suggest that comprehending sentences relies on constructing mental (sensorimotor) simulations of the state of affairs described in the text. At first glance, negation seems to be the perfect counterexample for this explanation of language processing, as negation (the symbol) cannot be explicitly represented by these nonlinguistic simulations. But according to Kaup and colleagues (2013), negation is not explicitly represented, instead, two models are formed and the discrepancy between the two models is perceived. For instance, assuming that someone has an expectation of having cheese in the fridge, but when the sentence ‘we are out of cheese’ is uttered, the listener makes sense of the negation by contrasting the initial model with the second model constructed through the uttered information. In other words, negation is implicitly encoded via the deviation recognized between simulations of actual and expected state of affairs. Different tasks were used to test this theory (Kaup, Lüdtke & Zwaan, 2006; Kaup et al., 2013). Participants were presented with sentences and subsequently with pictures related to the sentence. The task was to answer questions regarding the picture independently of the match or mismatch between the sentence and the visual information (i.e. to answer whether elements were present, or to name the object in the picture). The presentation time of the picture was manipulated. The pictures were shown shortly after the sentence (i.e. 750 ms) or with a delay (i.e. 1500 ms). An interaction was found between the timing and the polarity of the sentence. While there was a priming effect with the short timing in the affirmative sentences i.e. “The umbrella was open” led participants to name faster the object on the picture,

such priming was present in the negative sentences only with delayed presentation. This finding fits overall to the idea that participants processed a sentence like “The door was not open” through two stages. First they encoded the negated state of affair (door was open), and then mentally rejected it and then they represented the actual state of affair (door was closed). This explanation seems to work especially well with complementary (or contradictory) pairs of predicates like odd/even, dead/alive. However, it is more difficult to explain the comprehension of negation via realizing the discrepancy between the negated state of affair and the actual state of affair, when a contrastive predicate like ‘not red’ is phrased. One should iconically represent “The dress is not red” by imaging the red dress and then a dress, which is of any color but red to comprehend the sentence. Kaup and colleagues (2013) suggested that in these cases “not red” is represented as an unspecified color and subjects contrasted red with an unspecified color. Thus again, the meaning could be computed via the discrepancy between the two models. While the representation of unspecified entities and features seems to be a plausible and interesting proposal, its psychological reality was not tested. In fact, a different study investigating the process of negation in binary and multary context (which is similar to the complementary and contrastive predicates) does not seem to support the idea of creating unspecified representations while processing contrastive predicates. Orenes and her colleagues (Orenes, Beltrán & Santamaría, 2014) measured the eye movements of participants presented with pictures of simple colored shapes after they heard sentences introducing the subsequent picture. The sentences gave either a binary context i.e. “the figure could be red, or green” or multary context i.e. “the figure could be red, or green, or blue, or yellow” before uttering the disambiguating affirmative or negative statements i.e. “the circle was not red”. Time was calculated for inspecting the specific objects on the screen. In case of the binary context, participants looked more to the green figure.

In contrast, in the case of multary context, subjects look more on the negated argument, to the red figure. Similarly, Mayo and colleagues (Mayo, Schul & Burnstein, 2004) found evidence for maintaining negative information, when there was no clear alternative. The comprehension of the negation of bi-polar (e.g. tidy/messy, warm/cold) and uni-polar features (e.g. romantic/not romantic, talented/not talented) was tested. While the negation of bi-polar features facilitated the comprehension of congruent sentences (i.e. “John is not a tidy person” facilitated the processing of “John forgets where he left his car keys”), there was no such effect for uni-polar features (e.g. “Tom is not a romantic person” did not facilitate “Tom forgets his wedding anniversary”). Furthermore, in a memory task participants demonstrated two types of mistakes respectively to the negation the two types of features. In case of negating uni-polar features, participants occasionally recalled the feature neglecting the negative particle (i.e. ‘not romantic’ was recalled as ‘romantic’). In contrast, negation of bi-polar features sometimes resulted in errors in recalling the specific word (i.e. ‘not cold’ as ‘not warm’). These results suggest that with bi-polar characteristics, participants tended to ‘transform’ negation to affirmation, while in the case of uni-polars they rather maintained the original structure of not X. These results challenges the proposal emphasizing that exclusively iconic representations are involved in negation, as participants comprehended the sentence without translating it into an affirmative or contrasting the negated state of affairs with an undefined model.

The second theory has an intermediate position on how symbolic is the process of negation comprehension. Similarly to the two-step simulation theory, the model theory of negation (Khemlani, Orenes & Johnson-Laird, 2012) captures language comprehension as a result of constructing mental models and realizing the relations between them. Khemlani and colleagues (2012) define a mental model as the representation of what is common to a set of possibilities (in

terms of entities, their properties and the relations among them), and negation can be defined as the complementary set of the model. While these models by nature are as iconic as possible, and they represent what is true, rather than what is false (unless the assertion refers to falsity), Khemlani and his colleagues (2014) suggest that negation has to be a symbolic representation as no image can express the meaning of negation. So in the model theory, the representations are coded by sensory modalities but the negation itself is a symbolic thought operating on mental models.

The third kind of hypothesis claims that not only the negation is represented symbolically but the sentences, and in the case of picture-sentence comparison tasks, even the pictures are translated to a propositional format (Carpenter & Just 1975). The propositional theory of negation depicts negation as creating a structure like NOT(red dress) based on the sentence 'Not the red dress', furthermore, this model allow transformations between negation and affirmation, so 'Not the red dress' can be represented either as NOT(red dress) or AFF(green dress) (Clark & Chase, 1972; Carpenter & Just, 1975).

While investigating the behavior of adults contributes to our understanding of negation, regarding how it is processed, represented and what might be the origin of these capacities, another fruitful way to progress is the direct investigation of the emergence of linguistic negation in infants and toddlers.

1.1.2. Negation acquisition

How infants acquire the meaning of the words uttered around them is a fascinating question in itself, but grasping the meaning of words like ‘not’ or ‘nothing’ is particularly interesting. In the case of nouns, caregivers at least have the possibility to demonstrate the meaning of the referred object (which however, it is not always that easy) by pointing to or giving the object to the infant. In contrast, we cannot show a similar referent to the linguistic negation ‘no dog’, furthermore it is often difficult to explain to what negation may refer. Uncovering the way of how infants acquire and interpret negation can advance our knowledge regarding what is the origin of the meaning of linguistic negation and on the other hand, what are the cognitive mechanisms infants have to be prepared with to deal with such a challenge.

1.1.2.1. Negation production

Early studies targeted the linguistic production of infants and toddlers (Bloom, 1970; Pea, 1980; Choi, 1988). When and how do toddlers use the first uttered negative words? There are two main difficulties one can face when answering these questions. First, what should we consider as the first expression of negation? Is head shaking in response to a spoon of apple puree, or giggling in response to the statement of daddy’s favorite food, a clear example of expressing negation? Or should one set the use of the negative particle plus a predicate as the criteria for negation? Also, there are several ways to reject a proposition. For instance, the sentence ‘This is a red bear’ referring to a brown bear can be denied by a headshake, by the statement ‘Brown!’, or by the canonical form of ‘This is not a red bear’. The second difficulty is the precise interpretation of the meaning of negation uttered by a toddler. For this task, researchers developed semantic taxonomies to classify the meanings of negation recorded in corpuses. The puzzle here is how to

define separate semantics of negation (how many categories should be included) and how to reliable categorize toddlers' first words that are usually just sentence fragments or single words. Different taxonomies have been worked out to deal with the negation articulated by infants and toddlers at the early stage of their language development. Next, I will outline the most influential ones and the possible conclusions based on the common findings.

Bloom (1970) has described three categories and the following order of emergence: nonexistence, rejection and denial. The conclusion from this pattern is that the first type of negation, especially rejection, is rather expressing a relation between the internal and external world, while later negation (denial) marks relations in language and achieving a final, adult-like meaning. While Bloom (1970) has defined negation as multi-word speech, Pea (1980) included in his investigation gestural expressions and single words as well. Based on his observations rejection was the first expressed negation (gestural form from 10 months, verbally from 13 months), then self-prohibition (for instance while approaching forbidden objects, gestural form from 11 months, verbally from 14 months), followed by disappearance (from 13 months) (similar to nonexistence; object disappearance based on recent observation), unfulfilled expectation (non-existence based on habitual location; gestural form from 14 months, verbally 16 months), and finally truth functional negation emerged (response to propositions not held true by the child; verbally from 19 months). Choi (1988) in a cross-linguistic study found a similar pattern. Three phases were discriminated, in the first one infants used negation to express nonexistence, prohibition, rejection, and failure (for instance when events does not occur as expected). In the second phase denial, inability (articulating physical inability to accomplish a task), and epistemic negation (for instance 'I don't know' for a question) occurred. And in the third phase sophisticated expressions like normative negation (i.e. negation based on habitual

expectation) and inferential negation (denial based on the inferred/attributed mental state of the social partner) was performed. The above taxonomies are slightly different in how specialized they are regarding the functions of negation. Also, there is some discrepancy between the observed orders of the different semantics of negation (i.e. non-existence or rejection appearing first) but they are consistent in finding rejection and nonexistence emerging earlier than denial or truth-functional negation.

All proposals targeting the developmental path of negation involve the common conclusion that toddlers go through different stages of understanding. Infants start with a specific, less complex type of negation bound to the physical world and later they develop an adult-like or logic-like meaning which is abstracted from the physical environment and operates on sentences (or propositions). The idea of having more and less abstract forms of negation is present in philosophy as well (for review see Horn, 2001). There is no evidence so far for either a propositional or an exclusively sensorimotor nature of the rejection and non-existence two. Regarding non-existence the opinions are also different in whether it has a lower level meaning or it is a full-blown truth functional negation. Feiman and colleagues (Feiman, Mody, Sanborn & Carey, 2017) suggests that non-existence can be represented via a content- and computation-specific negation, which is limited to the negation of existence or presence of entities. According to this view, mechanisms behind existential negation cannot capture and might not even be related to truth-functional negation.

While the corpus analyses of negation production are informative and these investigations raised important questions about the origin and the first meaning of negation, solely on the bases of production we cannot have a full understanding. Besides the problems of taxonomies and the interpretation of the early negative utterances, the biggest question is whether infants before

language production have an understanding of negation. Two observations support infants' possible earlier comprehension. First, Pea (1980) noted that nonlinguistic (gestural) forms preceded linguistic negation in production development. Second, there is recent evidence for infants' early linguistic capacities; for instance, they comprehend frequent words uttered by their mother much before they could produce them, even at the age of 9 months (Bergelson & Swingley, 2012; Parise & Csibra, 2012). Importantly, besides the role of frequency in an infant's language environment, the concreteness of the word is an important factor in word learning (Swingley & Humphrey, 2017). Abstract words like verbs (e.g. eat or hug) and others like all-gone seem to emerge around 10 months (Bergelson & Swingley, 2013). While Bergelson and Swingley (2013) included all-gone, an expression for the absence of objects, as these abstract words were tested in fixed pairs, it is unclear whether infants differentiated the two based on the comprehension of 'all-gone', or its pair 'hi'or both of them. Recent developmental research targeted infants' and toddlers' comprehension of verbal negation more directly; next I will summarize this work and its findings.

1.1.2.2. Negation comprehension

Despite the early capacity to produce the word 'no', studies investigating negation comprehension found surprisingly late successful performance (Austin, Theakston, Lieven & Tomasello, 2014; Nordmeyer & Frank, 2014; Feiman et al., 2017; Reuter, Feiman & Snedeker, 2017; Grigoroglou, Chan & Ganea, 2019); even when providing specific contexts that should ease the pragmatic processing for negative statements (Nordmeyer & Frank, 2014; Reuter et al., 2017).

One typical paradigm used to assess toddlers' understanding is the two-alternative choice task. Participants have to guess the location of a target object invisibly hidden into one of two containers based on negative information (Austin et al., 2014; Feiman et al., 2017; Grigoroglouet al., 2019). For example, Austin and colleagues (2014) measured 20-30-month-old toddlers' comprehension of affirmative and negative sentences like ''It's in the bucket" or ''It's not in the bucket". Toddlers succeed only from the age of 24-27 months in such tasks and are able to find the target based on the statement formed with negation. Another used paradigm is the online preferential looking task, in which participants' looking behavior is measured, specifically, whether toddlers look at the referent of negative sentences (Nordmeyer & Frank, 2014; Reuter et al., 2017). The advantage of this task is that it does not require specific actions from the toddlers (i.e. approaching containers or choosing between them), but simple signs of comprehension like eye movements can be taken as evidence. Even with the decreased behavioral demands, the results are similar and demonstrate competencies to understand negation emerging between 24 and 36 months. For instance, Nordmeyer and Frank (2014) showed pictures of potential targets (i.e. two boys, one with apples and another without apples) to their participants and they measured whether they look at the referent based on sentences like "Look at the boy who has no apples". Only children from the age of 3 years showed evidence for understanding such sentences.

Besides the common finding that negation comprehension can be demonstrated relatively late, other important details of the findings are also worth considering. First, similarly to the adult literature, an asymmetry was present in affirmation and negation acquisition in toddlers. Typically, the comprehension of affirmative sentences preceded that of negative ones by 4-7 months (Nordmeyer & Frank, 2014; Reuter et al., 2017; Feiman et al., 2017; Grigoroglou et al.,

2019). Furthermore, 20-month-olds seemed to ignore the negative particle and interpret negative sentences as affirmatives (Feiman, 2017). The only puzzling exception for such an asymmetry is was observed in Austin and colleagues' (2014) experiment, in which toddlers acquired negation earlier than affirmation. Nevertheless, further evidence supporting the asymmetry between affirmative and negative forms comes from a particular order effect found in some experiments (Reuter et al., 2017). 24-months-olds succeed when trials are blocked by conditions (i.e. affirmative and negative block) and the affirmative block is presented first. Peculiarly, they fail on the same task when negatives are presented first. Reuter and colleagues (2017) proposed that affirmative trials boost 24-month-olds' performance (who are at the beginning of negation comprehension), because the affirmative sentences establish the crucial structures the conveyed information involves. To process the negative sentence, it is necessary to comprehend the negated proposition as well (but see Austin et al., 2014). While 24-month-olds are better with affirmatives than negatives, still, their linguistic competencies are imperfect, thus priming the affirmative proposition is likely to increase their negation comprehension.

Second, infants seem to pass the non-verbal version of the two-alternative choice tasks while they fail when they have to rely on verbal negation. When the two-alternative choice task described above is modified so that verbal negation is replaced by showing the content of the empty container, even 20-month-olds' succeeded (Feiman et al., 2017). Furthermore, toddlers close to three-years can integrate verbal and non-verbal cues in a three-alternative choice task (Grigoroglou et al., 2019). In this task toddlers had to guess the location of an object choosing from three possible containers. They could eliminate 2 possible locations; one based on verbal negation and another on visual cues. 35-month-olds succeed in this task and their performance was equally good in the original task involving two possible locations (testing verbal negation)

and in the modified task applying three possible locations (testing verbal, visual cues and their integration).

The third aspect worth pointing out is whether using different forms of negation and different semantics plays a role in toddlers' comprehension of negation. Feiman (2017) tested two morphemes of negation in English speaking participants: 'no' and 'not'. The main question was, again, whether the first appearances of negation are qualitatively different from fully-fledged propositional negation; and whether one can empirically differentiate between prelogical/lower level and logical/abstract negation. The rationale behind comparing 'no' and 'not' is based on findings regarding the production of different forms of negation by English speaking toddlers. They start to produce 'no' around 15 months, but they utter 'not' much later, around 27 months (Dale & Fenson, 1996). Furthermore, the time when they start producing 'not' and use negation to express denial are relatively close to each other (Cameron-Faulkner, 2007). However, from a longitudinal study investigating the form and function of first negatives, Cameron-Faulkner and colleagues (2007) show that there was some overlap between the usage of 'no' and 'not' for denial. The comprehension of 'no' and 'not' were tested in the same two-alternative choice task with sentences like "The ball is not in the bucket" or "No, it is not in the truck" (answering the question "Is it in the truck?") (Feiman et al., 2017). Toddlers showed a similar performance for the two morphemes, demonstrating similar conceptual background between 'no' and 'not' at the age of 27 months. However, there are no direct investigations targeting the separate semantic categories (e.g. nonexistence and denial) identified in the investigation of negation production. The only study testing the comprehension of nonexistence revealed puzzling findings. In the task of Nordmeyer and Frank (2014) even 3-year-olds failed to recognize the referent of a sentence like "Look at the boy, who has no apples" when it indicated the absence of objects, or nothing. In

contrast, 3-year-olds showed signs of comprehension for the sentence when it referred to an alternative scenario, for instance to a boy with boxes in his hands. Another difference found for these sentences involving alternative scenarios was that participants processed the 'no apples' via a two-step like mechanism, so first they looked at the boy with apples and then they switched to the correct referent of the sentence. This pattern was not present in the nonexistence context, i.e. a boy with nothing in his hands.

To highlight the peculiarity of the results of negation acquisition, the main contradiction is worth of further attention. According to the negation comprehension literature, toddlers master the meaning of negation only between 24-36 months (Nordmeyer & Frank, 2014; Reuter et al., 2017; Feiman et al., 2017; Grigoroglouet al., 2019), however they are able to produce it from the age of 20 months to reply to false statements (Hummer, Wimmer & Antes, 1993). Furthermore, negation expressing nonexistence seems to be understood correctly later than denial (i.e., around the age of 3, Nordmeyer & Frank, 2014), however it is one of the first semantic categories spontaneously produced already around 16 months (Pea, 1980; Choi, 1988).

Thus, it is still unclear whether the consecutive emergence of negation expressing different functions (i.e. rejection, nonexistence, denial) reflects infants' conceptual development or other factors influence their language acquisition (e.g. the complexity of the syntax). Also, little is known on how infants decipher the meaning of negation, and how they process these sentences.

In Chapter 2, we aimed to directly investigate the potential differences between the comprehension of negation expressing nonexistence and denial. We compared these two types of negation to learn more about the conceptual origin of negation between the age of 15 and 24 months. Specifically, in this way, we tested directly whether the hypothesized conceptual difference between early and later produced negations exist. Furthermore, we tested negation

comprehension expressing nonexistence in two different tasks; in the first, asking whether infants could use negation to arrive to an alternative affirmative statement, while in the second targeting a situation in which they could not use it to form an affirmative statement.

However, while linguistic negation can be seen as a window to investigate how nonexistence or absence may be encoded and used, one might argue that there should be representations likely independent from linguistic negation. In the following part I will focus on the question of how non- and pre-linguistic creatures might encode the absence of objects, and which cognitive mechanisms may support such abilities.

1.2. Non-linguistic representations of absence of objects

In this section I will discuss the non-verbal possibilities of representing the absence of objects. As an adult with sophisticated verbal tools to express ‘nothing’, it is difficult to think back into a stage in which we could not characterize absence as ‘not being present’. Developmental and comparative studies provide us an exceptional opportunity to investigate thoughts about ‘nothing’ without language. First, I will examine the possibility of having non-verbal negation, a language or logic-like tool to form the representation of absence. Second, I will review the concept of zero and its possible precursor, the representation of empty sets. Finally, I will discuss non-verbal systems specialized to code the presence of objects and their possible role in encoding absence.

1.2.1. Negation without language and without logic

Is there negation without or before language? As discussed in the previous section, negation is peculiar as it is symbolic by its nature and it obtains its meaning via composition (NOT + a proposition or a predicate). Whether pre- and non-linguistic creatures are equipped with similar cognitive tools is a subject of debate (Penn, Holyoak & Povinelli 2008). De Villiers (2014) discussing the language dependent concepts, based on experimental evidences takes negation as an example for such thoughts. Nordmeyer (2011) investigated human adults' implicit concept formation and the role of language in this process. Participants were shown pairs of pictures and at the end of each trial a funny animation was displayed on the target picture. An implicit rule determined which one was the target picture. Some of the pairs depicted a natural kind and an artefact contrast (i.e. picture of a bird and picture of a helicopter), and the target was always the natural kind. Other pairs were showed implicit concepts of 'affirmation' and 'negation' (i.e. nonexistence: a picture on the dog has food vs. the dog has no food) and the negation was the target. Nordmeyer (2011) measured whether participants recognized the rule during the experiment, specifically, whether increased anticipatory looking toward the correct picture emerged. Additionally to the main task, linguistic demands were manipulated with verbal shadowing in a sub-group. The natural kind-based rule was recognized independently of the verbal shadowing, in contrast, the negation-based rule was dependent on the availability of language. Participants noticed the affirmation-negation difference without verbal shadowing; however, they failed to do so when their language capacity was overloaded. This pattern of results suggests that recognizing implicit negation, for instance the absence of food in the dog's bowl, depends on linguistic encoding.

Newman, Wolff & Hearst (1980) found that human adults – even without verbal shadowing – have difficulties to notice absence as a criterion for stimulus discrimination. While adults and children easily notice when an abstract symbol determines 'good' and 'bad' membership in a card sorting tasks, the realization of the absence of a symbol as rule is far more difficult. For a comparison, participants needed only 18 trials to figure out which symbol out of 6 possibilities signaled 'good' cards, but to solve the puzzle of which symbol's absence denoted the 'good' card, they needed 63 trials. In a further study, similar findings were described in prediction and card-sorting task involving everyday objects (e.g. the presence or absence of smokestack from chimneys determined the categories). Similarly, while pigeons can also learn relatively easily the relation between the presence of a stimulus and reinforcement, they have difficulties with discovering similar a relation between the absence of a stimulus and food (Newman et al., 1980, Hearst, 1984). However, one important difference between the performance of humans and pigeons on these tasks was the effect (or the lack of effect) of the presence-rule boosting absence-rule recognition. While human adults' performance improved in recognizing absence as the clue when they started with the presence-rule compared to the opposite order, pigeons did not show evidence for such advantage. This pattern is similar to the one described in the previous section, showing 2-year-olds' sensitivity to the affirmative-negative order in sentence comprehension tasks (Reuter et al., 2017). The boosting effect of the presence rule to understanding the absence rule might suggest that adults encoded the scenes in linguistic or propositional format, as this would explain well the observed effects (linguistic negation contains an affirmation that could have been primed). In contrast, pigeons either encoded the presence-rule (and presence) in a different way or they could not use it to realize the analogy between the presence of a specific object and the absence of the same object.

It is difficult to put aside presence and negation when discussing absence, as by definition, absence is the negation of the presence of entities, but obviously non-human animals do not have language for this purpose. Whether non- and pre-linguistic creatures show signs of encoding absence of objects using some forms of negation is an open question. One well-studied case of negation-like, or logical-like operations used by animals is reasoning by exclusion. The typical formulation of this problem is a task in which a target object is hidden into one of two possible locations out of the sight of the participant. After the hiding event partial information is provided: the participant is informed either verbally or visually that one of the locations is empty. The logic of the task is that the participant should initially represent the two possible locations as interrelated (e.g. the target is in either A OR B) and after excluding one possibility (e.g. NOT A) should infer that the location of the target is the other locations (e.g. NOT A, THEREFORE B). In the previous section, the results of the two-alternative choice task provide clear evidence of toddlers' capacity to solve such problems using verbal or nonverbal information (e.g. Austin et al., 2014; Feiman et al., 2017). Similar capacities seem to be also present in different species − subjects choose the location with the target when they were shown that the other location is empty (e.g. apes: Call, 2004; Hill, Collier-Baker & Suddendorf, 2011, dogs: Erdőhegyi, Topál, Virányi & Miklósi, 2007; Aust, Range, Steurer & Huber, 2008, ravens: Schloegl et al., 2009). Still, there are well-founded criticisms questioning the cognitive mechanisms that are supporting the subjects' choice (e.g. Penn & Povinelli, 2007). Penn and Povinelli (2007) argued that most experiments were not optimized to test logical inferences (not A, therefore B) and instead they may show evidence only for avoiding an empty location (which might be explained in terms of simple associations). Related to this view, Mody and Carey (2016) suggested that only from the age of 3 years – boosted by linguistic abilities – children use logic-like representations such as

NOT and OR to solve these tasks. Before this age, even though they show similar behavior, more simple representations are reflected in their actions. The argument was supported by the finding that 2-year-olds do not pass a more complex version of the two-alternative choice task, developed to exclude reasoning based on avoiding empty. The method was modified by adding another set of two containers and another target to the original setting. In this way, toddlers had four containers, and two objects were hidden in a way that could be represented with the logical structures A OR B and C OR D (one hidden invisibly in A OR B, and the other object in C OR D). During the experiment the content of one of the empty containers was shown, determining the correct location of one of the targets (i.e. NOT B therefore A). If participants reason logically, they should pick container A because it contains an object for sure, while C and D could equally contain or not an object. In this task only children above 3 years chose reliably container A. Mody and Carey (2016) argue that 2-year-olds' failure signals an early, non-logical format for coding the setup and the solution. They suggest the following alternative ways via which toddlers and probably non-human animals choose the correct container in the classic reasoning by exclusion setup. Instead of using an abstract symbol for NOT, the task can be implemented through an elimination of one possibility without an explicit symbol and with limited computations. Another explanation would be that participants form the positive thought "B IS EMPTY". While the failure of the 2-year-olds in the modified version of the choice task, indeed, opens the question of what toddlers exactly represented, Mody and Carey's (2016) proposal introduces striking puzzles. First, according to their argument line, 2-year-olds in former studies using two-alternative choice task based on linguistic negation, map the meaning of verbal negation onto a non-logical representations, incompatible with logical structures. This raises an important question regarding the nature of 2-year-olds' language processing in these

tasks. Taken their argument, toddlers between 24-27 months might map sentences like “It is not in the bucket” to non-logical, immature representations (i.e. empty, elimination) in former studies (Austin et al., 2014; Feiman et al.; 2017). This alternative seems highly unlikely, as based on the results of Reuter and colleagues (2017) showing 2-year-olds’ better performance in negation (i.e. “Show me the one DW didn’t eat”) comprehension having trials with affirmative sentences (i.e. Show me the one DW ate) in a preceding block. Based on this finding, it is reasonable to think that 24-month-olds’ comprehension of negation is dependent on the comprehension on the intended linguistic structure. It is not clear why the comprehension of the linguistic structure would cue the comprehension negation based on the conceptually limited thoughts suggested by Mody and Carey (2016). Also, the proposal of toddlers mistakenly mapping representations of ‘empty’ or ‘elimination’ to negation does not give an account for why they struggle and fail in these tasks at 20-24 months (e.g. Austin et al., 2014; Feiman et al., 2017).

Nevertheless, acknowledging the close relation between negation and absence, other researchers suggested that a pre-linguistic, pre-logical negation is available for a limited sets of concepts, for instance for encoding absence. One of these proposals, suggesting a specific negation for nonexistence was discussed in the previous section (see Feiman et al., 2017). Another proposal was the idea of the availability of contrary concepts and proto-negation for non-linguistic creatures (Bermúdez, 2003). Bermúdez (2003) proposed that non-human animals encode absence, via the contrary concept of presence/absence, and they manipulate on this structure with a protological form of negation, protonegation. Indeed there is evidence for non-human animals creating categories for presence and absence, and we know very little about the nature of such categories and how they form them. Merten and Nieder (2012) using perceptual detection

decisions tasks measured neural responses in the prefrontal areas in rhesus monkeys for encoding absence and presence. Subjects were required to decide whether they could see a noisy target. The results demonstrated that ’perceiving’ the lack of stimulus itself might not be enough to encode absence. Interestingly, absence of stimuli was encoded only during the decision of ’not seeing’, and there was no activation before the decision while observing the stimulus. In contrast, presence specific cells were found to be active during both when perceiving the target and reporting the perception, ’seeing’.

The results from non-human animal experiments suggesting that they encode absence, possibly point to a necessity of forming a category to represent the absence of entities in such situations. In contrast, the representation of presence can be automatically perceived without the necessity of categories. The nature of these categories for absence representation in the reasoning by exclusion and perceptual decision tasks is still unclear. Further studies should target their relation to negation and propositional thinking.

Next, I will introduce another way of representing the absence of objects without negation, represented as zero. Then I will briefly overview the cognitive systems supporting the representations about the presence of objects, and their relation to encoding absence. First, the analogue number system will be introduced that supports encoding empty sets, the precursor of zero. Then, I will discuss to the object tracking system and how this system responds to the disappearance of objects.

1.2.2. Absence of objects expressed by number zero

Zero is a curious conception for two reasons. First, positive numbers correspond to real entities and the acquisition of the first natural numbers is closely connected to objects (Carey, 2009). Second, recognizing zero as a collection of items and coding it as a numerical concept requires an abstract category that is completely detached from the physical experience (i.e. recognizing sets and the similarities between them without any physical manifestation). Possibly because of its peculiar nature, zero had a long way to become the part of our everyday life.

1.2.2.1. Zero in different cultures

Zero emerged in several cultures with divergent functions under different circumstances. The most spread function of zero was to denote the absence of a power in place-value notations. In place-value numerical systems numbers are represented as sums of different powers of a base number (i.e. 10 in Arabic system). The position in a string notes the power (i.e. _ _ _), and the special symbols on the position mark the quantity of the particular power (i.e. 1234567890). The necessity becomes clear if we imagine the written version of 1005 and 105, which without denoting the absence of the middle powers in the two numbers; both would be noted as 15. Cultures developing place-value notation faced this problem of ambiguity as well. The first solution of the problem was to leave empty places to note the absence of a particular power. However, while it might be intuitive, it invites high possibility of error. Therefore another invention emerged, a kind of zero used to sign 'empty' powers. Interestingly, zero in this function had no numerical value or role in mathematical computations (Babylonian, Chinese, Maya place-value systems; Ifrah, 1987). In other cultures, like India and Egypt zero emerged for other functions, independent of the notation system. In India the Sanskrit word "s'unya" was

used for zero, which means “void”, “empty” or according to some sources “lack” or “deficiency” (Joseph, 2011). At its origin it was more a metaphysical concept than an arithmetical tool (Chrisomalis, 2010). In the ancient Egypt culture, zero was expressed with the hieroglyph “nfr”. “Nfr” sign was used by bookkeepers (if, after subtracting the disbursements from the income remained nothing), architects (as zero reference point) and additionally this symbol had abstract meanings like beautiful or complete (Joseph, 2011). The history of this number shows us that the zero, about which we now think as a united, solid concept deriving one of its meanings from the other, had distinct conceptual roles, that were separated from each other.

1.2.2.2. The emergence of zero in human development

Similarly to the cultural history of zero, the acquisition of this number by children involves the understanding of different components. Wellman and Miller (1986) argued for a prolonged development between 3 and 7 years going through three stages of understanding. In the first stage children were familiar with the symbol of zero and they could name it without any further understanding. Second, counting backward children ended up with zero (instead of 1 as in the earlier stage), showing that they knew that zero belongs to the counting list. Children around 6 years arrived to the third stage, understanding zero as a number with a particular value, which is comparable with other integers (for example 0 is smaller than 4). Importantly, in all phases the comprehension of zero was behind that of small positive numerals. In contrast, Bialystock and Codd (2000) found a different developmental pattern. They applied numerical tasks and spontaneous written notation of quantities involving absence of objects for preschoolers. Already from the age of 4 years children were able to successfully accomplish tasks with instructions like

“Give no cookies”. Also young children used iconical notations for denoting “no cookies”, for example, they left the space empty to indicate the quantity. A fundamental difference between the two studies is the expression of the absence of objects. While in the former study, the number zero was tested, in the latter, natural linguistic expressions referring to nothing were used. This shows that young children have cognitive tools to encode and express absence, but they need time to integrate this representation with their numerical understanding. Nieder (2016) proposed a developmental process with four stages for coding ‘nothing’, and eventually comprehending zero. The first stage is a sensory ‘nothing’, which corresponds to the neural resting state of the system when there is no stimulation. Second, a categorical ‘nothing’ is formed based on meaningful behavioral categorization of absence. The third stage is the quantitative realization of absence. In this stage the ‘nothing’ is represented as an empty set at the low end of a numerical continuum or number line, e.g. less than one. At the final, fourth stage, ‘nothing’ becomes the number zero, part of a system that can be used for several types of mathematical calculations.

1.2.2.3. Empty sets

A possible precursor of the representation of zero in non-human animals and young children is encoding empty sets supported by the approximate number system. This cognitive mechanism extracts approximate numerical information from the environment. The main characteristics are that instead of precise representations it encodes approximations of numerosity; and it is sensitive to numerical ratio rather than absolute differences between specific numbers. Driven by these features, there are two specific signatures of the approximate number system researchers use as indicators. The magnitude effect is participants’ tendency to discriminate more precisely

smaller numerosities, compared to larger ones (e.g. 1 vs. 3 compared to 9 vs. 11). Distance effect is the phenomenon of more precise discrimination of more distant quantities compared to closer ones (e.g. 1 vs. 5 compared to 1 vs. 2) (Dehaene, 1997). The ratio of the smallest possible discrimination varies across individuals and its precision increases during the development (Piazza, 2010). While in 6-month-old infants this discrimination ratio is 2:1 (Xu & Spelke, 2000), by 9 months it increases to 3:2 (Lipton & Speke, 2003; 2004) and in an average adult this numerical ratio is around 7:8 (Piazza, 2010). The approximate number system is not limited to representing objects in the visual world, but it is also able to encode the amount and the ratio of auditory stimuli (Izard, Sann & Spelke, 2009; Lipton & Speke, 2003; 2004) and actions (Wood & Spelke, 2005). Simple arithmetic operations like addition and subtraction are also supported by this system. Even 9-month-old infants expect 5+5 objects to result in 10 rather than 5 objects, similarly 10-5 objects to result in 5 rather than 10 objects (McCrink & Wynn, 2004). Several animal species share these representations (for review see Brannon & Merritt, 2011) and they are available already at birth in humans and other animals (Izard et al., 2009; Rugani, Fontanari, Simoni, Regolin & Vallortigara, 2009, Rugani, Regolin & Vallortigara, 2010). While the approximate number system evolved to represent imprecise numerical information, it has an important role in comprehending exact natural numbers as well (Eger, Sterzer, Russ, Giraud & Kleinschmidt, 2003). Also, the approximate number system supports the grounding of the symbolic zero. Merritt and Brannon (2012) examined the relationship between processing the symbolic and non-symbolic coding of absence of objects in 4-year-olds. Children performed numerical ordering task in which they needed to select two numerical stimuli (either sets of dots or Arabic numerals) in ascending order. In general, the performance in trials involving an empty set or zero was poorer compared to positive numerosities. Children, who were successful in a

non-symbolic task involving sets of objects, were able to integrate empty sets as well. Furthermore, they showed the signature of the distance effect in trials involving objects and the absence of objects as well. This suggests that preschoolers integrated empty sets into their mental numbers without a noteworthy struggle. However, it is important to note, that the numerical understanding of the zero was predictive for the performance on the non-symbolic ordering task involving empty sets. This finding raises the question of the role symbolic knowledge when young children incorporate empty sets into their mental number line. While symbolic numbers might have important effects on the way we encode non-symbolic numerosities, the animal literature suggests that the concept of the number zero is not crucial for representing empty sets. Rather, as non-human animals were found to encode the absence of objects as empty sets among other sets – supported by the approximate number system –, empty sets might be the precursors for understanding zero (Biro & Matsuzawa, 2001; Merritt, Rugani & Brannon, 2009; Howard, Avargues-Weber, Garcia, Greentree & Dyer, 2018). For instance, capuchin monkeys were able to solve comparisons and set matching of objects including stimuli of no objects in non-symbolic numerical tasks, moreover, subjects showed the numerical distance effect in these trials as well. Hence, they differentiated between 0 and 3 more precisely compared to 0 and 1 object (Merritt et al., 2009). Specific neural signatures responding to empty sets were identified in monkey brains associated to numerical areas (Okuyama, Kuki & Mushiake, 2015; Ramirez-Cardenas, Moskaleva & Nieder, 2016). Two main brain areas are linked to the approximate number system, the ventral intraparietal and the dorsolateral prefrontal areas. Okuyama and colleagues (2015) recorded cellular activity in the ventral intraparietal area of the monkey brain while subjects performed a non-symbolic numerical operation task. Monkeys were presented with a target numerosity (between 0 and 4 dots) then after a short delay, a preoperational numerosity was

presented and the task was to perform operations on the set of objects (additions and subtractions), until it matched to the target. Similarly to previous behavioral evidence (Merritt et al., 2009), monkeys were able to solve trials involving empty sets as well. Importantly, 'zero' sensitive cells were found in the investigated areas. Some intraparietal cells were active during the target period (i.e. when the zero dots were presented), and for the time of delay (i.e. when participants needed to maintain the information), and some of them were reactivated during the manipulation period as well. These patterns point to the role of these cells not only in encoding the information about the absence of objects, but also in maintenance and in predicting the (zero) outcome of numerical operations. Interestingly, two types of zero cells were identified (but see Ramirez-Cardenas et al., 2016 for a different opinion). The first, exclusive type of cells showed a rapid activation for empty sets and stayed silent for all other sets. The second, the continuous type, peaked activity to 'zero' and as a function of distance, it decreased the activation to other numerosities, suggesting that the empty set was adapted to the numerical continuum. Parallel to the neural encoding, the authors emphasize the double nature of the concept of zero. It can be both captured as an amount, which is less than one and as binary information of present and absent. Ramirez-Cardenas and colleagues (2016) found a similar dichotomy of categorical and continuous encoding examining how the monkey brain responds to numerical task involving empty sets. However, the dichotomy was found to be specific to distinct areas rather than to specific cells types. Besides the ventral parietal areas, Ramirey-Cardenas and colleagues (2016) recorded cell activation and neuronal dynamics at the population level in the prefrontal cortex as well. Monkeys performed a match to sample numerical task, and again, trials with empty sets were successfully completed and the pattern of errors reflected the distance effect, indicating the involvement of approximate number system. A continuous encoding was reported (i.e. cells

showed gradually decreasing activation to neighboring numerosities) in both ventral parietal and prefrontal areas for sets between 1 and 4. In contrast, for empty sets only the prefrontal zero cells showed a continuous sensitivity for the empty sets, while parietal cells showed categorical discrimination (i.e. maximum peak for empty sets and no activation for other sets). Thus, parietal areas might be specialized to categorical encoding, while in the prefrontal cortex – similarly to the countable sets – absence of objects was coded as the lower end of the numerical continuum. Another difference between the encoding in parietal and prefrontal cells was their sensitivity to changes in the visual features of the stimuli. The prefrontal structures showed generalized activation across trials with slightly different visual features, while parietal structures were moderately influenced by such changes. These results suggest that prefrontal areas have an important role in the abstraction of empty sets and their integration into the numerical continuum. One open question is whether this process requires intense training that results in participants 'forcing' empty sets at the lower end of the numerical continuum, or alternatively, they spontaneously (i.e. from the beginning of task presentation) accommodate 'nothing' among countable numerosities.

Reviewing the acquisition of zero and the representation of empty sets, we find similar stages as suggested by Nieder (2016). These stages are 'no stimulation', categorical 'nothing', quantitative and finally zero. However, we would like to point out that the way these stages relate to each other is unclear. One possibility is that these stages emerge progressively, each building on the earlier level through development. Alternatively, these stages might be independent from each other. Particularly, we would like to highlight the question targeting the relation between categorical and continuous representations of the absence of objects, or 'nothing'. One question concerns how categorical information may support the representation of an approximate

understanding of empty sets. Also, we think that the difficulties of acquiring zero by young children can only be partially explained by the complexity of this concept. The zero denotes the absence of objects, is part of the number list, and is at the border of positive and negative numbers. It is true that children need to form relatively counterintuitive ideas (e.g. a number can stand for the absence of objects), but more importantly, they need to fuse different concepts into one solid concept of zero.

Turning back to the different stages proposed by Nieder (2016), and the dual nature of zero noted by Okuyama and colleagues (2015), according to which zero is an amount which is less than one but also, relates to binary information of presence and absence. The role of the approximate number system in the first, continuous conceptualization of zero is beyond question. The binary coding is a more peculiar subject of investigation. Based on findings from the neural level, it seems that both a continuous and a binary coding supports the behavior of subjects in the experiments described previously (Okuyama et al., 2015; Ramirez-Cardenas et al., 2016). In contrast, on a behavioral level these investigations found evidence for a continuous representation of the absence of objects, as trials with empty sets were affected by the distance effect. Thus, monkeys discriminated small differences like, 0 and 1 much harder (e.g. at chance) compared to larger ones, for instance 0 and 3. In other words, the comparison can be described as very little, little instead of nothing compared to something in both cases of 0 vs. 1 and 0 vs. 3. In case of a categorical coding of absence and presence, we would expect no differences between the absence of objects compared to the presence of any number of objects.

While approximate number system accommodates empty sets, thus it encodes the absence of objects (without language), it is a less likely candidate for supporting categorical representation of absence. A lucid demonstration for this proposal is having a look at monkeys (Merritt et al.,

2009) and preschoolers (Merritt & Brannon, 2013) discriminating empty set from one item. Both young children and rhesus macaques performance was below or around chance in this case. How a system having difficulties to discriminate between the presence of an object and the absence of any objects could support categorical representations of these thoughts? Next, we will turn to another potential candidate to encode such ideas in non-human animals and pre-linguistic infants.

1.2.2.4. Object tracking system and categorical absence

There is another system for representing the presence of objects, which might be more optimal for categorical information processing. The object tracking system has crucial role in representing the presence of objects, moreover, it supports the development of the acquisition of natural numbers, e.g. the comprehension of three objects being exactly 3, not 2 or 4 (Feigensonet, Dehaene & Spelke, 2004; Carey, 2009). This is an object based attentional system, which encodes distinct individuals through time and space. It differentiates between an exact numbers of objects by creating a distinct symbol for each individual. In adults, this kind of representations is often discussed within the FINST model, as object indices, as proposed by Pylyshyn and Storm (1988) or as objects files, as suggested by Kahneman, Treisman & Gibbs (1992). The main difference between the two models is the richness of the representation that is granted. While indices are defined by spatial information, object files may contain more object-related information, like features. Object tracking mechanisms support our capacity to track and maintain (despite occlusion) the presence of objects in our environment. In infants, similar capacities are explained within a core object system providing an early cognitive tool to

understand the physical world around us (Spelke, 1990; Carey, 2009). Adults and infants have only limited capacities to simultaneously encode multiple individuals, for adults the limit is around 4 (Kahneman, et al., 1992; Scholl & Pylyshyn, 1999) and for infants it is 3 individuals at a time (Carey, 2009; Piazza, 2010). Both adults and infants are sensitive to the violation of objecthood in the process of tracking. While adults (Scholl & Pylyshyn, 1999) and infants (Wynn & Chiang, 1998; Kaufman, Csibra & Johnson, 2003) maintain the representation when an object is occluded, their capacity is impaired when objects a) instantaneously disappear and reappear, or b) gradually implode and explode from their centers. To summarize, this system maintains the information regarding the presence of an object, even without visual access, but only disappearance corresponding to occlusion events (e.g. gradual and not abrupt disappearance) support preserving such object representations. In contrast, disappearances violating the principles of visual occlusion, are perceived as the annihilation of the object, going out of existence, at least for the object tracking system. Kaufman and his colleagues (2003) investigated neural correlates of object maintenance during simple occlusion events in 6-month-old infants. Using EEG, they found possible neural signatures of maintenance, gamma-band oscillations around the left temporal cortex for the period of occlusion. In contrast, 6-month-olds did not show such responses when the object disintegrated, suggesting that the index for the specific object was erased. Other studies investigating neural underpinnings of object maintenance in infants focused on frontal areas (Kaufman, Csibra & Johnson, 2005). Baird et al. (2002) conducted a longitudinal study in which he measured infants' frontal lobe activity between the ages of 5 and 12 month participating in the classic piagetian object maintenance test. Infants saw a small object covered by the experimenter. Participants were free to search after the hiding event. Infants' data was separated based on whether they searched for the object, showing

a clear behavioral evidence for achieving object maintenance, or not. Higher frontal activation was found in those trials in which the infants reached and retrieved the object compared to those trials in which they did not, pointing to the role of the prefrontal cortex in object maintenance.

Whether without the object index other memory traces remain from the object is a question for further research. However, a handful of studies suggest that infants' difficulties in encoding an object impair object representations as well as the absence of objects per se. Cheries, Mitroff, Wynn, and Scholl (2008) found that violating object cohesion principles severely affected the trackability of objects in 10- to 12-month-olds. While infants consistently chose the larger amount of crackers hidden into a container (i.e. a container with 2 crackers over a container with 1), they failed to do so when a big cracker was splitted into two before the hiding event. Regarding encoding the presence and absence of objects there seem to be asymmetries in the early cognitive capacities. The object tracking system allows infants to form expectations in numerical reasoning situations like one plus one object should be equal to two objects by the age of 5 months (Wynn, 1992; Simon et al., 1995). However, this system fails to encode absence as an expected outcome in similar numerical reasoning tasks (Wynn & Chiang, 1998; Kaufman et al., 2003). Wynn tested 8-month-olds' predictions regarding presence and absence of objects. They expected longer looking times in response to events violating participants' expectations about an object appearing (presence) or disappearing (absence). While infants reliably encode and form expectations about the presence of an object (i.e. they are surprised when an object placed behind an occluder magically disappears when the occluder drops), they do not show evidence for encoding absence (i.e. when an object is removed from behind an occluder and magically appears when the occluder drops). Similarly, Kaufman and colleagues (2003) did not find behavioral evidence for encoding absence in 6-month-olds in a similar task; furthermore

they did not find object related neural signatures in (not) maintaining absence representation. Thus it seems that this system does not support the representation of absence of objects. The failure of encoding absence via the object tracking system might not be surprising, as this system is an object based attentional mechanism. No object might simply evoke the resting state of this system, or no response that will be indistinguishable from encoding any other point of the space where there are no indices assigned.

However, whether this system supports the formation of categorical encoding of presence and absence might be an important direction for future research. Although, the object tracking system likely evolved to perceive and track the presence of entities in our environment, it supports diverse cognitive functions like object individuation (Wilcox, Haslup & Boas, 2010; Xu et al., 1999), building hierarchical structures of sets (Rosenberg & Feigenson, 2013), simple numerical inferences (Feigenson et al., 2004) and the genesis of natural numbers (Carey, 2009). Thus, further investigations of the role of the object tracking system in forming categorical encoding of presence and absence might be beneficial.

In the second half of the thesis we aimed to learn more on non-verbal, categorical representation of absence of objects. We tested non-human animals and pre-verbal infants with paradigms likely evoking representations supported by the object tracking system, a system potentially participating in the process of categorical encoding the presence and absence of objects. In Chapter 3 we investigated how young domestic chicks encode the presence and absence of an object in events including occlusions. In three experiments we tested the representation of absence, and we controlled for possibilities of encoding simple perceptual mismatch (i.e. remembering how the empty testing arena looks like, instead of expecting no object being there)

or encoding the object at a different location instead of representing the absence of objects (i.e. X object should be at location A rather than B).

In Chapter 4, we explored the neural substrates for different kinds of events that might critically affect how the presence or absence of objects may be encoded. We tested 6-month-old infants' neural responses to events involving an object that became occluded, vanished, or mingled among other identical objects. Specifically, we were interested in regions associated to object representations; the temporal and prefrontal areas.

1.3. Research aims

The present work investigates how human infants and toddlers, and domestic chicks represent the absence of objects. In Chapter 2 we aimed to inspect the conceptual background of comprehending negation expressing the absence of objects at the onset of language acquisition. We reasoned that targeting this issue can lead to a better understanding of two questions. First, we can ask whether the initial interpretations of negation are bounded to domain-specific, incompatible with propositional thought. This would support the conceptual gap hypothesis suggesting that infants start with a qualitatively different processing of negation. Alternatively, infants and toddlers at the very beginning of their negation understanding might have a domain-general, adult-like comprehension, supporting a rich conceptual competence. Second, we wanted to explore infants' and toddlers' capacity to represent the absence of objects in response to linguistic information (negation). We run two studies testing the development of negation comprehension between the age of 15 and 24 months. In Study 1 we investigated the

development of the comprehension of two types of negation both expressing absence: negative existential and denial. While both utterances expressed the absence of an object, the first version (negative existential) is rather used for expressing non-existence, a function appearing early in language production. In contrast, denial is used in a broader context; it can express the negation of any proposition. Also, denial is the last emerging function of negation toddlers start to utter according to studies investigating the development of negation production. The difference between the emergence of negation expressing non-existence and denial is often used as an argument for the conceptual gap hypothesis; however no one tested directly the comprehension of these different functions of negation. We think that comprehension might be a better indicator of infants' conceptual abilities, as comprehension is less affected by other constraints infants may face at the first stages of language development, for example, just thinking of the fact that the comprehension of nouns and verbs emerges much earlier than the production of such words.

In Study 1 the negative information about the absence of an object at a location allowed for participants to encode positive information regarding the presence of the target object at another location (i.e. in A or B; not in A, therefore in B). In Study 2, toddlers were presented with negative existential expressing absence per se, without inducing the presence of an object elsewhere. We find it useful to draw a distinction between these two interpretations of negation, as in the first case the behavior is driven by the representation of the presence of an object, while in the latter by the representation of absence of objects (our main interest in this work). Thus we were interested in potential differences between Study 1 testing negation that can be 'translated' into affirmative information (i.e. x is not here, therefore x is there) and Study 2 where there was no clear opportunity for transformation (i.e. there is no x). We propose that such comparisons can provide information about how negation, the cognitive mechanism operates on our thoughts.

In the second half of the thesis (Chapter 3 and 4) we were interested in the non-verbal representations for capturing the absence of objects in non- and pre-linguistic creatures. We were interested in the origin of our capacity to linguistically express absence both in non-human animals (phylogeny) and in human infants (ontogenesis). While it is clearly evident that linguistic creatures represent absence from their words and sentences, non-linguistic capacities are less evident. Former studies have demonstrated an asymmetry between presence and absence encoding; furthermore, pigeons and 6-8-month-old infants struggle to represent absence (while they have no difficulty to represent presence in the equivalent tasks). There is evidence for non-human animals' (Biro & Matsuzawa, 2001; Merritt et al., 2009; Howard et al., 2018) remarkable capacities to encode no objects as empty sets with the support of the approximate number system, however, we would like to postulate a distinction between this ability and presence/absence representation. While the approximate number system seems a perfect candidate for encoding absence in a continuous manner (less than one), it is less likely capable to discriminate presence and absence as categories. Instead, we propose that the object tracking system may play a possible role and started to explore how this cognitive system may assist in encoding such information. In Chapter 3 and 4 we aimed to investigate the representation of absence of objects in tasks involving object tracking. In Chapter 3, we probed young domestic chicks' capacity to encode presence and absence of an object (the imprinting object) behind a screen. Then in Chapter 4, we turned to the neural signatures of object maintenance and disappearance. We tested 6-month-old infants' neural responses to three types of disappearances, supporting or suspending the persistence of an object. We reasoned that the features and the constraints of the object tracking system in encoding absence can lead us to understand better the origins of the representation of the categorical presence and absence, possibly present in non-

human animals, young infants and also, potentially influencing how human adults encode such information.

2. Chapter 2. The development of negation comprehension

2.1. Introduction

Creatures of this planet were adapted to perceive and learn about the entities that surround them. We quickly learn how to recognize the boundaries of objects and that of agents, to remember their locations or extract rules predicting their future behavior. Peculiarly, besides encoding what is around us, we also use and benefit from information about absence and non-existent entities. Thoughts like 'There are no more cookies' or 'This is not a dog' are routinely phrased verbally via negation. While negation is a very common phenomenon, we have only scarce knowledge about the nature and the development of the representations, which can be expressed by negation (e.g. how we encode the absence of cookies before we utter the sentence) and about the processes through which we acquire and comprehend the meaning of a negative sentence (how we conceptualize the referent of 'no cookies').

This latter aspect of negation has been a subject of intense research in human adults, yielding to the typical finding that the comprehension of sentences containing negation is more effortful than the comprehension of affirmative sentences (for a review see Horn, 2001; Kaup et al., 2014). Participants rate negative sentences more ambiguous compared to affirmative ones (Glenberg et al., 1999), and sentence verification involving negation is also slower than that of affirmative sentences (Wason, 1965; Carpenter & Just, 1975). Difficulties of processing negation are usually explained within two different frameworks, in one pragmatic characteristics are emphasized (Wason, 1965), while in the other issues related to semantic composition (Clark &

Chase, 1972). The first account, relying on pragmatics, focuses on the possible function of negation, which would be instead of describing the world, informing us about the world taken into account our expectations (based on previously received information or world knowledge) (Wason, 1965; Vandamme, 1972). Vandamme (1972) extended this idea to the role of negation in information processing in general, suggesting that negation is important because it makes us able to register failures of certain actions, or presumptions. For instance, starting a story with 'My train was not late' might sound awkward, unless the audience knows that particular train is always late. Thus, based on this, processing difficulties observed for of negative sentences can be explained by the lack of a meaningful context in experimental settings. Indeed, adults (Wason, 1965; Glenberg et al., 1999), as well as children (de Villiers & Flusberg, 1975) are sensitive to manipulations of the context when comprehending negative sentences. The second framework, the semantic composition account, points out that a possible two-step process may be responsible for the observed difficulties involving negative statements (Clark & Chase, 1972; Kaup et al., 2006). For instance, a sentence like "The umbrella was not open" is processed by first comprehending the proposition 'the umbrella was open' and then, in a second step, applying negation to obtain the final meaning.

Processing difficulties in adults – emerging from pragmatic considerations or from semantic composition – foreshadow the challenges infants face when acquiring negation at the onset of their language acquisition. Besides the above-mentioned factors that may explain why negation is difficult even for adults, there can be further factors that may render negative statements more difficult for a child, such as a greater ambiguity and abstractness compared to positive statements. For instance, the statement "This is not a cat" can be mapped to a variety of referents, from dogs to chairs. Furthermore, while concrete words are usually used in the presence of the

referred object, this is not the case for abstract words, and their referents are also visually more diverse (Gogate, Bahrick, & Watson, 2000). How negation, without a clear physical referent obtains its meaning in the developing mind, and what kind of representations are at the origin of its semantics are challenging questions. Investigating how infants overcome this challenge can give insights to the conceptual origins of negation, as a fundamental concept of abstract human reasoning.

Studies targeting how negation is acquired and produced in early childhood seem to find controversial evidence. Despite its conceptual complexity, the first forms of negation appear very early in child communication. Around their first year infants start to express negative meanings using head shakes as well as words (Pea, 1980). Infants arrive to consecutively produce negation to express semantically different functions (Bloom, 1970; Pea, 1980; Choi, 1988; Cameron-Faulkner et al. 2007). Typically, the first semantic function of negation is rejection ('No broccoli'), followed by non-existence ('No more cookies') around 13-14 months (Pea, 1980) and around five months later by proposition denial ('This is not a cat') (Bloom, 1970). Regardless of the early capacity to produce negation, studies investigating negation comprehension find a surprisingly late successful performance. Although toddlers can reliably produce proposition denial from 20 months on (Hummer et al., 1993), they seem to solve tasks that require such understanding only 4-to-6 months or in some cases more than a year later (Austin et al., 2014; Nordmeyer & Frank, 2014; Feiman et al., 2017; Reuter et al., 2017; Grigoroglou et al., 2019). A common task used to study negation comprehension is the two-alternative choice paradigm in which toddlers need to find an object hidden into one of two containers (e.g., a bucket and a toy house, Austin et al., 2014) based on verbal information. They either hear affirmative (i.e. 'It is in the bucket') or negative sentences (i.e. 'It is not in the house'), and based on the provided verbal

information they need to find the target object. The results suggest that toddlers between 20 and 24 months start to succeed in trials using affirmative sentences and slightly later, between24 and 27 months, they start to comprehend utterances and gestures containing negation (Austin et al., 2014; Feiman et al., 2017). In tasks measuring more simple behaviors, like the preferential looking paradigms, similar results were observed; toddlers looked at the correct referent of the negative sentences only between the age of 24 and 36 months, while at 24 months they succeed with affirmative ones (Nordmeyer & Frank, 2014; Reuter et al., 2017).

Considering the above observations one might wonder how could it be that infants from very early on express negation both in real life (Pea, 1980) and experimental settings (Hummer et al., 1993), but they do not show evidence for negation comprehension in various studies until around the age of 24 months? One possibility is that infants have the conceptual capacity for negation understanding, but task-related linguistic difficulties mask their comprehension abilities. There is indirect evidence supporting such a proposal. Although affirmation is supposed to be both conceptually and syntactically easier than negation, 24-month-olds showed a fragile performance in affirmative conditions as well (i.e. comprehending 'It is in the bucket', Austin et al., 2014; Reuter et al., 2017). Assuming that processing negative sentences involves the comprehension of the affirmative part (e.g. Kaup et al., 2014; Reuter et al., 2017), one can argue that difficulties with affirmatives have an impact on toddlers' performance on negation comprehension. Studies examining whether the order of affirmative and negative trial presentation plays a role show that performance is strongly affected by this factor (Feiman et al., 2017; Reuter et al., 2017). Specifically, 24-month-olds fail in comprehending negation when they receive the negative sentences first (i.e. 'It is not in the bucket') followed by the affirmative sentences (i.e. 'It is in the bucket') but they pass the task when the order is the opposite (Feiman et al., 2017; Reuter et al.,

2017). This pattern of performance suggests that experience with affirmative sentences with a given syntactic structure might boost 24-month-olds' capacity to comprehend structurally matched negative sentences (Reuter et al., 2017).

According to another possibility, the discrepancy between production and comprehension may be the result of toddlers' immature understanding of negation, in the sense that the production data does not reflect an actual understanding. This proposal suggests a specific developmental path where infants gradually arrive from a narrow, non-propositional meaning to a full-fledged, adult-like propositional negation (Pea, 1980; Feiman et al., 2017). Such an account was first raised to explain the origin of the concept of negation in infants (Pea, 1980). Accordingly, negation may emerge from the connection between the physical constraints of infants' behavior and the prohibition ('No!') uttered by the caregiver. The contrast between the infant's intention and an uncompleted act might support the emerging concept of truth functional negation, which can be later applied to all propositions. Feiman and colleagues (2017) also raise the possibility of a conceptual limitation to explain the discrepant observations from negation production and comprehension. For instance, they propose that an early domain specific representation of non-existence supports the comprehension of words like "empty" or "all-gone". While this specific type of negation operates on the idea of existence or presence, it is not applied to propositions in general, like truth-functional negation is (Feiman et al., 2017). This suggestion is in line with Bermúdez' (2003) proposal regarding how non-linguistic creatures may represent the presence and absence of entities, claiming that presence and absence are encoded as contrary concepts and absence is encoded as a proto-negation of presence. This would make possible for animals without language to decode information from the environment, as contraries, like, for example, presence and absence. Bermúdez (2003) argues that truth-functional negation is different from

proto-negation because it can be combined with any proposition while proto-negation is limited to a few existing pairs of contrary concepts. While such a theory would predict that pre- and non-linguistic creatures should be able to rely on contrary pairs such as absence and presence, research suggest that the representation of absence might not be automatically available for pre-verbal infants (Wynn & Chiang, 1998; Kaufman et al., 2003), nor for non-linguistic creatures like pigeons, who have difficulties in using the absence of stimulus as meaningful information in learning paradigms (Hearst, 1984). Moreover, realizing absence as a rule for discrimination or prediction is even difficult for human adults as well (Newman et al., 1980).

Thus, it is currently unclear what forms of negation are available for young infants and whether the first forms of verbal negation (expressing rejection and nonexistence) should be characterized as some low-level, domain specific mechanism or fully-fledged negation like denial. Terms referring to non-existence are of particular interest because they are expressed in all languages and they have a special status among negations. One important formal difference between expressing denial and non-existence is that in many languages the latter does not have a compositional structure (e.g., 'no' + verb); instead it is expressed by a single word (e.g., nincsen in Hungarian, yok in Turkish or nai in Japanese) (Veselinova, 2013). Negative existential seem to behave as lexical atoms that can be directly mapped to events involving the absence of entities.

While an early emergence of negation expressing non-existence, and a later emerging proposition denial would be evidence for the conceptual gap hypothesis, positing a crucial difference between the different forms of negation (Pea, 1980; Feiman et al., 2017); there are no studies, to our knowledge, directly comparing these two forms of negation that have different semantic functions. Such studies would highlight how the developing human mind manages to

make use of negation. Specifically, it would clarify whether infants start with a form of protonegation with a narrow meaning (e.g. non-existence), and later they develop full-blown negation. Alternatively, from the onset of language learning, infants might be equipped with a domain-general concept that allows them to flexibly understand different forms of negation. To this end, in the first set of studies we investigated how infants understand different forms of negation –that involve different semantics as well.

2.2. Study 1.

The aim of the present study is to investigate how infants, who are at the onset of language, comprehend two different forms of negation, specifically, a Hungarian negative existential and a proposition denial, referring to the absence of an object in a two-alternative choice task. In Experiment 1a, we investigated the comprehension of the Hungarian negative existential 'Nincsen' ((It) is not/ not.be.3SG) in 18-month-olds. In Experiment 1b, we asked whether a different group of 18-month-old infants show evidence of understanding proposition denial referring to the absence of an object ('Nem itt van.' It is not here/ not here be.3SG) using the very same task. To probe the limits of infants' abilities, in Experiment 2, the comprehension of these two forms of negation was assessed in 15-month-olds. Importantly, by using a within participant design we also asked how performance in the two tasks involving these two kinds of negation was related. In Experiment 3, 15-month-olds' performance was measured in a nonverbal version of the two-alternative choice task used in Experiments 1, 2 and 3.

2.2.1. Experiment 1a

In Experiment 1a we investigated 18-month-olds' comprehension of a negative existential. In Hungarian it is expressed via the word 'nincsen'. This word is a verb and it is used to negate existential predications ('Unikornisok nincsenek' Unicorns do not exist/ Unicorns not.be.3PL), possessive predications ('Nincsen pénzem' I have no money/ not.be.1SG money.1SG) and locative predications ('Nincsen' (She/he/it) is not (here)' not.be.3SG (here)). In our task 'Nincsen' was used to negate a locative predication regarding the possible location of a target object. Infants were asked to guess the location of hidden object based on the verbal negation about where the object was not in a two-alternative choice task. Their ability to correctly choose the cup containing the target object would indicate their understanding of negation regarding the absence of the object in the other cup.

2.2.1.1. Method

Participants

Thirty 18-month-old infants participated in the study (20 girls, mean age was 18 months0 days, range: 17 months, 19 days to 18 months, 18 days). Fifteen additional infants were tested but excluded from the analyses due to experimental error (2), for not completing at least 4 experimental trials (10), and for not choosing a container (3). Parents were informed about the procedure and the aim of the study and gave written consent.

Stimuli

Infants participated in a choice task in which the experimenter hid an unfamiliar target object into one of two opaque containers (*Figure 1.1*). The target object was a colorful round silicon toy (diameter = 5 cm) with face like features (e.g. eyes). The containers were two white plastic cups, 14 cm high, which could be covered with white lids. The cups were placed on a plastic tray that could be pushed forward: it was in front of the experimenter during the hiding and it was pushed towards the participant during the choice phase. In test trials the experimenter occluded herself and the hiding event with a 100 cm X 150 cm cardboard screen.

Procedure

Infants were seated in their caregiver's lap at a table in front of the experimenter. The study consisted of 2 warm up, 2 familiarization and 6 test trials.

Warm up trials: In the warm up trials only one cup was used, in the first trial without the lid, while in the second trial the cup was covered with the lid. In these trials, after introducing the objects and the game ('This is Bobó. Bobó likes to hide very much' – 'Ő itt Bobó. Bobó nagyon szeret elbújni.' in Hungarian), the experimenter visibly hid the target into the cup and pushed it towards the participant saying, 'Where is Bobó? Can you find him?' – 'Hol van Bobó? Megkeresed?' in Hungarian. If the infant was too shy to touch the cup and retrieve the object, the experimenter or the parent (if she was asked by the experimenter) encouraged the child to find

the object. The criterion for continuing the experiment was retrieving the object at least in one of the two warm up trials.

Familiarization trials: At the beginning of the familiarization trials besides the cup used in the warmup, the experimenter introduced another cup, which was identical to the cup used in the warm up trials and arranged the two cups on the tray approximately 20 cm away from each other. Then, she directed the participant's attention to the target object saying, 'Look! Bobó hides'– 'Nézd! Bobó elbújik' in Hungarian. Afterwards, the experimenter placed the object into one of the cups in the full view of the infant. After the hiding the cups were covered with the lids and the experimenter asked, 'Where is Bobó? Can you find him?' – 'Hol van Bobó? Megkeresed? in Hungarian. The tray with the cups was pushed towards the infant and she could search. There were two familiarization trials, in which the target was hidden once in the left and once in the right cup (order counterbalanced). If the infant did not choose the correct cup in either of the familiarization trials, an extra trial was presented to assure that participants understand the goal of the game.

Test trials: There were six test trials using a similar setting as described in the familiarization phase. Crucially, however, in test the hiding was not visible for the participant. To cover the hiding event from the infant's view, the experimenter placed an occluder screen on the table covering the cups and herself. At the beginning of each trial, the experimenter raised the object above the screen and said, 'Look! Bobó hides'– 'Nézd, Bobó elbújik' in Hungarian. After hiding the object, the experimenter removed the screen and turned to the infant, 'Where is Bobó?' – 'Hol van Bobó?' in Hungarian. Afterwards, the experimenter looked into one of the cups and said, 'Maybe this? (It) is not' – 'Vajon ez? Nincsen' in Hungarian. To equalize the participant's attention to the two cups, the experimenter touched and provided neutral information – 'Maybe

this?' 'Vajon ez?' in Hungarian – about the other cup as well. To prevent recency effects, children's gaze was directed away from the cups before the choice via addressing them with the question 'Where is Bobó? Can you find him?' – 'Hol van Bobó? Megkeresed? in Hungarian – or if it was necessary, calling them by their name. Afterwards, the cups were pushed within the infant's reach.

We measured infants' first choice, which was defined as the first cup the infant touched. Occasionally participants reached with two hands and removed simultaneously the lids of both cups and then grabbed one of the cups. These trials were also coded as valid trials and the grabbed cup or the cup into which the infant first looked was considered as first choice. If infants grabbed and moved/lifted the two cup simultaneously we coded the trial invalid. If the infant chose the incorrect location first she was allowed to search and find the object in the other cup.

Counterbalancing

The location of the target (left or right side) was counterbalanced within the six test trials using an ABBAAB order. The order of which cup (the cup with the object or the empty cup) was manipulated first by the experimenter was counterbalanced within participants – for half of the trials the cup with the object was touched first and for the other half of the trials the empty cup was touched first (using an ABABAB order).

The starting location of the target (left or right) and which cup was touched in the first trial (the cup with the object or the empty cup) was counterbalanced between subjects. There can be yet another factor that might affect infants' choice in the first test trial: the location of the target in

test compared to the location of the target in the antecedent familiarization trial. To control for this, the location of the target was the same as it was in the antecedent familiarization trial for half of the group. For the other half of the group the location of the target was different in the last familiarization and in the first test trial.

Figure 1.1. Schematic depiction of the two-alternative choice task used in Study 1. After the invisible hiding of the target object, the experimenter provides information about where the object is not present (verbally in Experiment 1a and b and non-verbally in Experiment 2). Afterwards, infants are free to choose between the two possible locations.

2.2.1.2. Results

Responses were coded in relation to the actual location of the object, and a choice was scored as correct (coded as 1) if the infant chose the cup with the object and incorrect (coded as 0) if the infant chose the empty cup. The criterion for inclusion in the data analyses was to provide at least four valid test trials (out of six). We calculated the proportion of correct choices for each participant, and averaged the proportions across infants. The averaged values were compared to chance (0.5). A one-sample Wilcoxon Signed-Rank test indicated that the average proportion of correct choices was significantly higher than chance (M = 0.663, SD = 0.039, $Z = 465$, $p<0.001$), showing that infants were more likely to choose the correct cup than the empty one.

Analyzing infants' performance separately on the very first test trial, we found that their performance was significantly above from chance (25 out of 30 infants chose the correct cup, binomial test, $p<0.001$). Thus, infants predominantly chose the correct cup even in the very first trial (M = 0.833), which suggests that at 18 months their comprehension of negation is likely already well-established. This pattern together with a trial-by-trial inspection of correct performance (*Figure 1.2.*) excludes the possibility that they do not understand negation but have developed some alternative heuristic over the trials (e.g. always go for the other cup, and not the one about which a comment was made they could not understand).

Additionally, we were interested to see whether there were also some other lower level factors affecting infants' performance, for instance whether perseveration to the location where the object was found in the previous trial had an effect. Thus, we compared infants' performance on test trials in which the location of the object has changed compared to the preceding trial (location-change: trials 2, 4 and 6) and in trials in which the location of the object has not changed (no location-change: trials 3 and 5). We found no significant difference between the performance in the no location-change trials (M = 0.635, SD = 0.333) and the location-change trials (M = 0.59, SD = 0.053), (Wilcoxon Signed-Rank Test, $Z = 104.5$, $p = 0.467$). Thus, infants' comprehension of existential negation seems robust enough not to be affected by their memory from the preceding trial (regarding where the object was) and when this contradicts the inference they make based on the (negative) information about the location of the object.

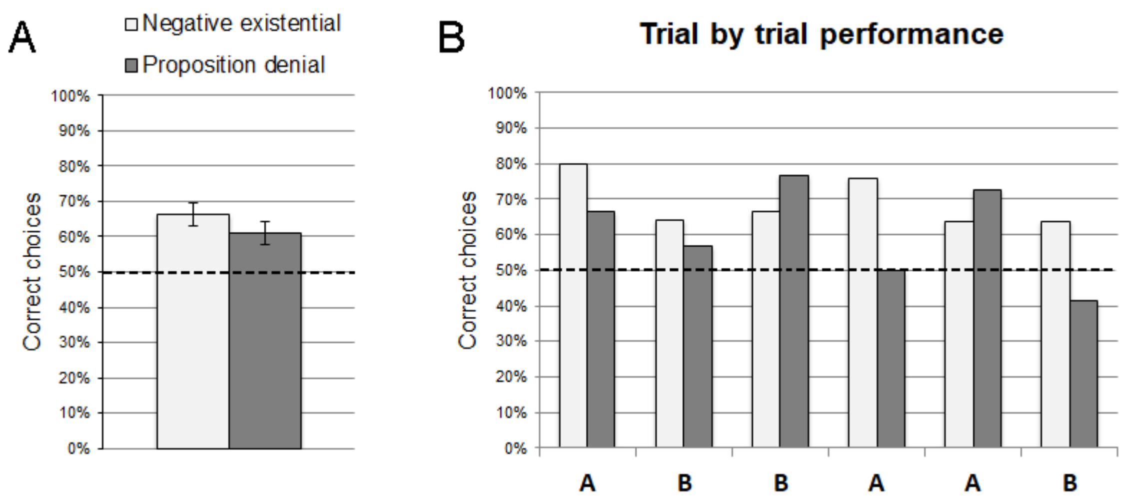

Figure.1.2. The results of Experimenter 1a and b. A) Mean percentage of correct choices across all trials in Experiment 1a and b compared to chance level (50%). Error bar represents standard error. B) Percentage of participants choosing the correct location trial by trial. Letters on the X axes represent the counterbalancing of the location of the target (left/ right).

2.2.1.3. Discussion

18-month-olds in our study correctly comprehended the negative existential 'Nincsen' ((It) is not) and they were able to use this information to find the target object. Comparing present data to findings from other studies, our participants seem to understand the negative existential at least six months earlier compared to when children were found to understand proposition denial (Austin et al., 2014; Feiman et al., 2017; Reuter et al., 2017), and 1.5 years earlier compared to when they show signs of understanding negation expressing non-existence involving complex sentences (e.g., 'Look at the boy with no apples', Nordmeyer & Frank, 2014).

To test whether our results reflect infants' capacity to comprehend only this special form of negation or alternatively, they have a more sophisticated conceptual understanding of negation, we run a second experiment. In Experiment 1b, the linguistic form via which the experimenter expressed the where the object was not, was saying '(It) is not here' – 'Nem itt van' ((It) is not here/ not here be.3SG) in Hungarian. This form of negation (proposition denial) is structurally and semantically more similar to the expressions used in previous experiments (e.g. 'It's not in the bucket' in Austin et al., 2014). If 18-month-olds fail in Experiment 1b testing the comprehension of proposition denial, this will support the view that the acquisition of negative existential and proposition denial follows different developmental paths – either because of the difference in syntax or because of their different conceptual background. In contrast, if, similarly to Experiment 1a, 18-month-olds in Experiment 1b also shows a successful performance, it will support the idea of the early presence of a domain-general concept of negation.

2.2.2. Experiment 1b

2.2.2.1. Method

The procedure was the same as in Experiment 1a, with the only exception of the negation used to express the absence of the object. Instead of the negative existential, the experimenter used denial saying '(It) is not here' – 'Nem itt van' ((It) is not here/ not here be.3SG) in Hungarian.

Participants

Thirty 18-month-old infants participated in the Experiment 2 (18 girls; mean age = 18 months, 1 day; range: 17 months, 16 days to 18 months, 15 days). Five additional infants were tested but excluded from the analyses due to not completing at least 4 test trials (2), and for not choosing (3). Parents were informed about the procedure and the aim of the study and gave written consent.

2.2.2.2. Results

We calculated the average proportion of correct choices among all valid test trials (M = 0.608, SD = 0.179) and we compared this value to chance level (0.5) (*Figure 1.2*). Participants chose the correct cup significantly more often than chance (one-sample Wilcoxon Signed-Rank test, $Z = 465$, $p<0.001$). Analyzing only the first trials, the majority of infants chose the correct cup (20 out of 30), however a comparison to chance did not reach statistical significance (Binomial test, two-tailed value $p = 0.09$). When comparing infants' performance in the two experiments we did not find a significant difference between the mean percentages of correct choices (Mann-Whitney test, $U = 381.5$, $p = 0.298$) in Experiment 1a (M = 0.663, SD = 0.039) and 1b (M = 0.608, SD = 0.179), nor in their performance on the first trials (Fisher's Exact Test, two-tailed $p = 0.233$).

To test for a possible effect of perseveration in Experiment 1b, we compared the performance in no location-change trials and location-change trials. Noticeably, there was a significant difference in participants' performance on these trials (Wilcoxon Signed-Rank Test, $Z = 53$, $p =$

0.002). Specifically, infants performed significantly better in the unchanged-location (M = 0.759, SD = 0.290) then in the changed-location trials (M = 0.483, SD = 0.297). We calculated a difference score for perseveration-sensitivity subtracting the change-location from the no location-change values. Comparing this value in the two experiments revealed a significant difference (Mann-Whitney test, $U = 304.5$, $p = 0.030$). Infants' performance was more affected by perseveration in Experiment 1b (M = 0.267, SD = 0.072) than in Experiment 1a (M = 0.038, SD = 0.056). These results suggest that in case of proposition denial, in contrast to the negative existential in Experiment 1a, infants' behavior seems to be subject to a considerable interference from the memory of where the object was in the preceding trial.

2.2.2.3. Discussion

18-month-olds performed equally well in Experiment 1a and 1b, we did not find evidence that comprehending negative existential was easier than proposition denial at this young age. This pattern is divergent from what is found in negation production studies (Bloom, 1970; Pea, 1980; Choi, 1988; Cameron-Faulkner et al. 2007) showing earlier negation usage to express non-existence than denial. In our studies that relied on comprehending negation, we did not find evidence for a possible conceptual gap narrowing infants' comprehension to specific meanings (i.e. non-existence). In contrast, infants seemed to have the capacity to comprehend different types of negation pointing to the possibility that negation has a generic meaning for them, based on a domain-general concept. The similar performance infants showed in Experiment 1a and 1b is especially remarkable if we consider the semantic and syntactic differences of the two kinds of negation, the two aspects that potentially make proposition denial more difficult than negative

existential. Semantically, the negative particle in Experiment 1b (proposition denial) is used in a broader context than existential negation. 'Not X' can express the negation of literally any possible proposition while existential negation expresses only the absence of entities. Syntactically, decomposing the negative particle 'nem' ('not') and the statement 'itt van' ('it is here', here be.3SG) in Experiment 1b is more complex than processing a single word in Experiment 1a (i.e. 'Nincsen' (It) is not/ not.be.3SG). 18-month-old infants' competence in comprehending the negative existential (Experiment 1a) and proposition denial (Experiment 1b) referring to the absence of an object points to a rich competence in understanding negation. The only difference we could observe between the two kinds of negations was infants' sensitivity to perseveration effects. While perseveration influenced the performance in proposition denial condition, we did not observe such effect in the negative existential condition. This enhanced sensitivity to interference probably indicates a greater processing demand in the former case. Possibly, the sentence "Nem itt van" ((It) is not here) was more demanding given its syntactic structure compared to the one word sentence used in the negative existential condition 'Nincsen' ((It) is not/ not.be.3SG). Thus infants could have been more influenced by perseverations to the earlier found location and this effect might have prevailed over negation processing in some cases.

Our results from Experiment 1a and 1b might be explained at least in two ways in relation to the development of negation and its conceptual background. First, the comprehension of different types of negation may rely on similar representational processes from early on. Alternatively, they may rely on different processes (i.e. at younger age non-existence might be conceptually easier compared to proposition denial) but in the present sample by the age of 18 months infants arrive to understand both. To investigate the latter possibility, we applied the very same task to a

younger population, specifically 15-month-olds. Additionally, in Experiment 2, we tested the comprehension of the negative existential and proposition denial in a within subject design. Thus, we targeted infants' comprehension of both types of negation at the onset of their linguistic development, also aiming to investigate how they are related. Particularly, we were interested in the question whether infants' comprehension of the two negations develops in parallel (suggesting a common conceptual understanding) or alternatively, whether the form of negation expressing non-existence emerges earlier than proposition denial (suggesting a conceptual gap between the different forms of negation).

2.2.3. Experiment 2

2.2.3.1. Method

In Experiment 2 we tested the comprehension of the negative existential and the proposition denial in two separate sessions involving the same participants. The order of conditions was counterbalanced within the experimental group and the testing took place on average 7 days apart (minimum 5 days and maximum 11 days). Otherwise, the procedure was identical to the ones described in Experiment 1a and 1b.

Participants

Thirty 15-month-old infants participated in Experiment 2. The mean age at the first session was 15 months 18 days (15 girls; range: 15 months, 1 days and 16 months, 4 days;). At the second session the mean age was 15 months 25 days (range: 15 months 10 days and 16 months 12 days). Seventeen additional infants were tested but excluded from the analyses due to not choosing a container (1), not completing at least 4 trials or not completing both sessions (12), due to technical or experimental error (4). Parents were informed about the procedure and the aim of the study and they all gave written consent.

2.2.3.2. Results

First, we analyzed infants' performance in the negative existential condition (*Figure 1.3*). As in the earlier experiments, we calculated the average proportion of correct choices among all valid test trials and we compared it to chance level (0.5). Participants' choice was not different from chance level (M = 0.511, SD = 0.034; one-sample Wilcoxon Signed Rank test, $Z = 105$, $p = 0.682$). Analyzing only the first trials, 15 infants out of 30 chose correctly in the first trial in existential negation condition, (binomial test, two-tailed value $p = 1.00$). Thus 15-month-olds do not seem to comprehend the negative existential in our task. As in Experiment 1a and 1b we then tested the possible effect of perseveration to a previous location, comparing the performance in no location-change trials (M = 0.52, SD = 0.33) and location-change trials (M = 0.51, SD = 0.26), we did not find a difference indicating interference from perseveration on the performance (Wilcoxon Signed Ranks test, $Z = 140$, $p = 0.77$).

Next, we analyzed infants' performance in proposition denial condition. A one-sample Wilcoxon Signed-Rank test indicated that the average proportion of correct choices (M = 0.49, SD = 0.16) was not different from chance ($Z = 38$, $p = 0.594$). Analyzing the first trials only, shows a similar pattern (15 correct out of 30, binomial test, two-tailed value $p = 1.00$). However, in this condition we found a significant difference between location-change trials (M = 0.62, SD = 0.26) and no location-change trials (M = 0.41, SD = 0.240) (Wilcoxon Signed Ranks test $Z = 68.5$, $p = 0.016$) indicating an effect of perseveration. This pattern of performance suggests that 15-month-olds' overall do not seem to comprehend proposition denial in our task.

Finally, we investigated the relationship between infants' performance in the two conditions. When comparing the proportions of correct choices in the negative existential and proposition denial condition, we found no differences (Wilcoxon Signed-Rank Test, $Z = -0.637$, $p = 0.524$). We also analyzed whether infants performed systematically differently in the two conditions, asking whether one condition was easier than the other. If a participant's mean proportion of correct choice was higher than 50% we considered them as passers, coded with (1), while proportions below 50% were coded as failing (0). Seventeen infant failed in both conditions, 8 infants failed in the proposition denial condition but passed in the negative existential condition, 2 infants succeeded in the proposition denial condition but failed in the negative existential condition, and 3 infants succeeded in both conditions. A McNemar's test performed on a 2 by 2 contingency table revealed no significant difference between the performances in the two conditions ($p = 0.23$). While numerically more infants passed the negative existential and failed the propositional denial condition, compared to infants showing the opposite pattern (8 vs. 2), most infants in fact failed in both (59%). There was no significant correlation between the mean proportions in the two conditions ($r = 0.077$, n = 30, $p = 0.688$).

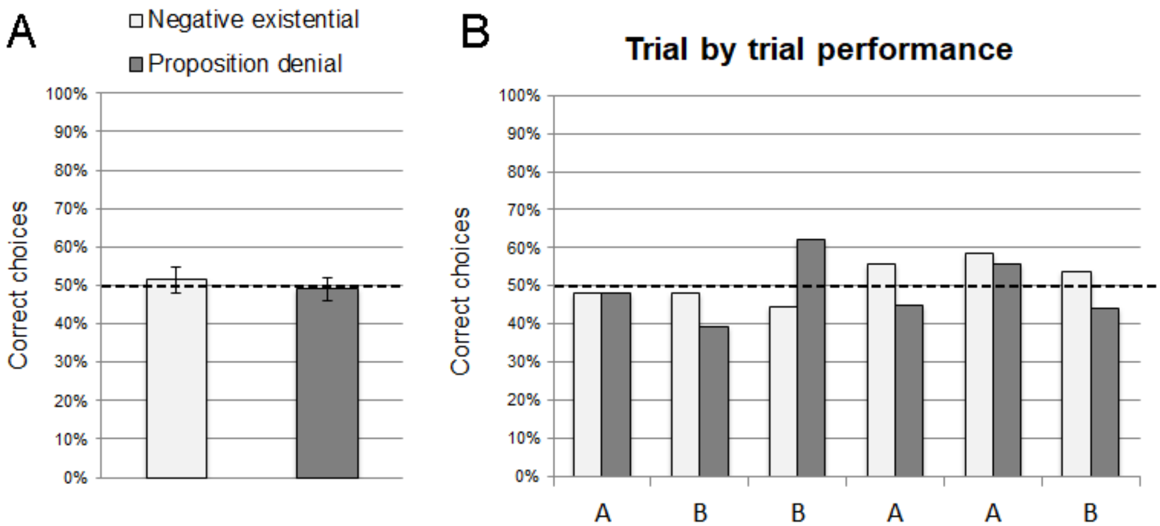

Figure 1.3. The mean results of Experiment 2. A) Mean percentage of correct choices across all trials in Experiment 2 compared to chance level (50%). Error bar represents standard error. B) Percentage of participants choosing the correct location trial by trial. Letters on the X axes represent the counterbalance of the location of the target.

2.2.3.3. Discussion

In Experiment 2, 15-month-olds did not show evidence for comprehending and using information from the two types of negation. There are at least two interpretations for this pattern of performance.

First, one could argue that 15-month-olds might have the cognitive apparatus (e.g. for coding absence and reasoning by exclusion) for solving the task, but they have difficulties in mapping their available conceptual capacities to the linguistic labels we used in Experiment 2. Alternatively, 15-month-olds might lack certain conceptual abilities necessary to accomplish the

task (i.e. reasoning by exclusion). Besides the linguistic demands (i.e. the comprehension of negation), the two-alternative choice task involves several effortful mental processes. Specifically, solving this type of task requires the subject representing the two possible locations interrelated with each other (e.g. A OR B) and after excluding one possibility by representing the absence of the target (e.g. NOT A), to infer that the object is in the other location (e.g. NOT A, THEREFORE B). Although, a former study demonstrated toddlers' success at the age of 20 months (Feiman et al., 2017) on similar tasks, whether 15-month-olds are able to use analogous mental operations in the two-alternative choice task was experimentally not addressed yet.

To investigate whether the difference observed between the 18 and the 15-month-olds' performance is due to their linguistic development and verbal negation understanding (i.e. whether 18-month-olds have more developed abilities to map the linguistic label to the corresponding concept) or whether it is more related to the development of other cognitive capacities (e.g. reasoning by exclusion), we run Experiment 3. We tested 15-month-olds' performance in a new version of the two-alternative choice task: instead of verbal cues, the experimenter provided only non-verbal evidence, by showing the content of the empty cup to the participant. If 15-month-olds pass the non-verbal version the task, this pattern of behavior would suggest that all the necessary capacities to solve the task (aside of verbal negation comprehension) are available at this age. In this case, one could argue that their failure in Experiment 2 would indicate a distinctive linguistic obstacle. In contrast, 15-month-olds' failure in the non-verbal version would indicate that the task exceeds the capacity of this age group.

2.2.4. Experiment 3

2.2.4.1. *Method*

In Experiment 3, we modified the two-alternative choice task used in previous experiments. Instead of checking the content of one cup and providing verbal information that the target object was not there, the experimenter slowly turned the target cup upside down – showing the infant the inside of the cup, specifically that it did not contain the object. Then she turned the cup back to its original orientation, and put it back to its primary position. To equalize the participant's attention to the two cups, the experimenter also touched and lifted the other (baited) cup, and then she put it back to its primary location. Besides these differences, the procedure of Experiment 3 was the same one used in Experiment 1a and b.

Participants

Thirty 15-month-old infants participated in Experiment 3. The mean age was 15 months 18 days (range: 15 months, 0 days and 16 months, 4 days; 16 girls). Five additional infants were tested but excluded from the analyses due to not performing at least 4 test trials (2), and due to technical or experimental error (3). Parents were informed about the procedure and the aim of the study and they all gave written consent.

2.2.4.2. *Results*

We calculated the average proportion of correct choices among all valid test trials (M = 0.703, SD = 0.195) and compared it to chance level (0.5) (*Figure 1.4*). Participants chose the correct cup significantly more often than chance (one-sample Wilcoxon Signed Rank test, $Z = 328$, $p < 0.001$). Analyzing only the first trials, we found that subjects chose correctly significantly more than chance (20 out of 28 subjects; binomial test two-tailed, $p = 0.036$). This suggests that 15-month-olds have a stable capacity to solve the inferential problem required by the task. Specifically, they encoded the empty content of the cup and used this information to exclude one location to find the target object at the other possible location. Peculiarly, comparing the performance in unchanged-location trials and changed-location trials, we found a significant difference in participants' performance (Wilcoxon Signed-Ranks test, $Z = 59.5$, $p = 0.027$). Infants performed significantly better in the unchanged-location/perseveration trials (M = 0.80, SD = 0.25) then in the changed-location trials (M = 0.653, SD = 0.225). Similarly to the performance in Experiment 1b and 2 investigating the comprehension of proposition denial, 15-month-olds' behavior in a non-verbal two-alternative choice task was affected by possible perseveration rising from their memory about the presence of the target at one location from the preceding trial (i.e. where the object was found in the previous trial).

Figure 1.4 The mean results of Experiment 3.A) Mean percentage of correct choices across all trials in Experiment 3 compared to chance level (50%). Error bar represents standard error. B) Percentage of participants choosing the correct location trial by trial. Letters on the X axes represent the counterbalancing of the location of the target (left/right).

2.2.4.3. Discussion

In Experiment 3, we found clear evidence for 15-month-olds' ability to find the target object based on the non-verbal, visual evidence about which cup does not contain the object. This result demonstrates 15-month-olds' capacity to make the necessary inferences based on visual information to find the object. First of all, participants were able to encode the content of the empty cup and to use this information to find the target object at the other alternative hiding location. This result is consistent with previous experiments' (using two-alternative choice task) finding that similar non-verbal versions are easier for infants than the verbal versions of the same task (Feiman et al., 2017). Also it is in line with recent results demonstrating 12-month-olds' ability to use reasoning by exclusion to identify an ambiguous object (Cesana-Arlotti et al., 2018). 15-month-old infants' failure in Experiment 2 testing the comprehension of verbal negation, and the successful performance in the non-verbal version of the same task (Experiment 3) suggests that their difficulties seem to be language related. While even 15-month-olds have the capacity to solve the problem we introduced, they likely have difficulties in mapping the verbal labels to the corresponding conceptual structures.

2.2.5. General discussion

The aim of the present studies was to investigate the development of negation acquisition in order to learn more about its underlying conceptual background. Here we focused on how the comprehension of different types of verbal negations emerges through human development. While research on negation production has documented a typical developmental path, specifically, that negation expressing non-existence emerges earlier than denial, we found a very similar pattern for these two very different types of negation in a comprehension based task.

We found similarly good performance in 18-month-old infants when testing their comprehension of negative existential and proposition denial. In contrast, at 15 months, infants showed a chance performance on trials involving both kinds of negation, although, they could solve the non-verbal version of the task. The fact that the comprehension of the negative existential and proposition denial seems to develop similarly (both are present in 18-month-olds), might point to common cognitive mechanisms behind the two kinds of negation. We did not find evidence for an early, limited understanding of specific sub-functions of negation – non-existence in our case – or any signs for a developmental path suggesting that infants start from a domain specific negation and arrive to an abstract, truth-functional negation later, which can then be applied to any proposition (Feiman et al., 2017). We were specifically interested in the relation of the development of two types of negation and not the specific age at they emerge, however, we found earlier success in our studies compared to other similar studies (Austin et al, 2014, Feiman et al., 2017). As our experiments were not designed to investigate the role of specific details of paradigms, we can only speculate about the relevant differences between these studies and ours. We would like to point out two noteworthy contrasts. First, in our study after computing the correct location of the

object, the time to maintain it was likely shorter compared to other studies (reaching for a container at a table in our case vs. walking to a container after receiving the critical information in Austin et al., 2014 and Feiman et al, 2017). While this aspect should not affect participants' ability to comprehend negation, even short differences in time to maintain the information were proved to crucially affect 18-month-olds' performance in a two-location search task (Goupil & Kouider, 2016). Second, in Austin et al. (2014) and in Feiman et al. (2017) studies the negative statement was uttered after checking a specific container and returning to the middle, while in our study it was communicated while the experimenter was still touching and looking into one of the containers. This latter detail might have made easier for infants in our experiment to select and maintain focus on the referent of the utterance. Furthermore, there might be specific language specific differences, as we tested Hungarian, while other studies involved English.

However, it is still an open question whether the two negations targeted here are mapped to the same representation and whether the underlying representation has a truth-functional nature. As Feiman and colleagues (2017) argued, content- and computation-specific mechanisms might be present earlier in toddlers. This mechanism is separate from truth-functional negation as it functions exclusively on existence. Similarly Mody and Carey (2016) suggested the presence of early, limited cognitive tools to encode the absence of objects in similar tasks, for instance, elimination processes or representing emptiness without negation. Further studies should target infants' abilities in diverse domains, for instance, outside of the object representation domain, to have a better understanding regarding their abilities to comprehend negation. Their early competence or failure of understanding negation operating on features or category membership would complement our knowledge regarding how abstract and domain-general is toddlers' conceptual capacity. However, the idea of mapping verbal negation to domain-specific,

conceptually limited forms, especially that of propositional denial (Experiment 1b) is not convincing, especially taken into account toddlers' and infants' failure in negation comprehension (Austin et al., 2014; Feiman et al., 2017) below 24 months. There is no debate in the literature that infants by this age are in possession of rejection and nonexistence. Their failure in former experiments demonstrates their resistance to map verbal negations to supposedly more simple meanings like prohibition (i.e. do not touch this cup), nonexistence or to more simple interpretations like negative valance (i.e. this cup is a bad one, you should not touch it). Also, 24-month-olds' tendency to succeed in negation comprehension when the corresponding affirmation is presented first, points to a syntactic or structure specific limitation, rather than conceptual gap. Thus, we suggest that both former studies showing order effects in 24-month-olds, and our experiments demonstrating 18-month-olds' success are evidence for an abstract understanding of negation.

Yet another general question, that is beyond the focus of the present thesis is whether the representations of absence evoked by the linguistic context (i.e. Experiment 1a, b, and 2) and the non-linguistic task (i.e. Experiment 3) are the same or different. In any case, here we would like to point out some earlier findings that may be relevant for further research. For instance, a study comparing the behavior of pigeons and humans showed that language might provide us with qualitatively different abilities regarding encoding absence (Hearst, 1984). Both humans and pigeons have difficulties to realize the absence of a particular stimulus as relevant information, but while human adults easily learn such rules after they were trained with the 'presence-rule', pigeons failed to notice the relation between presence and absence rules (Hearst, 1984). Positive information (presence of a stimulus) boosting adults' readiness to represent negative information (absence of the same stimulus) (Hearst, 1984) is in line with the results showing toddlers (Reuter

et al., 2017) comprehend negation easier if they were exposed to affirmation antecedently. Looking for specific hallmarks of propositional thought in future studies, for instance the boosting effect of affirmation on negation understanding could help us learn more about the origins of these representations.

Turning back to the questions targeted by the present thesis, whether and how infants and toddlers represent the absence of objects, next, we wanted to expand the investigation of comprehension of negation expressing absence. In Study 1, one could argue that infants' behavior was driven by their representation of an object at an ambiguous location, which they resolved via the verbal/non-verbal information about the absence of the object at one of the potential locations. It is still a question whether infants would succeed if instead of the presence of an object, the absence would be the sole information that could drive their behavior. In some sense, this discrimination is similar to the one discussed in research targeting adults' comprehension of negation operating on complementary pairs (maybe similar to Bermúdez' contrary concepts) like odd/even or using contrastive predicates (Mayo et al., 2004; Orenes et al., 2014). Understanding 'not odd' can be described as excluding odd and representing the affirmation of 'even'. However, for contrastive predicates like 'not red', often there is no way of translating the statement to an affirmative format. Adults (Mayo et al., 2004; Orenes et al., 2014; Nordmeyer and Frank, 2014) and young children (Nordmeyer and Frank, 2014) show different characteristics of processing these two types of context. Moreover, in the study of Nordmeyer and Frank (2014) 3-year-olds failed in the task when, the negation 'the boy who has no apples' referred to nothing, although they passed it, when it referred to alternative objects, for instance, boxes. These results suggest potential differences in the processing of negation operating on contrastive or complementary, binary or multary schemas. To investigate whether infants can

deal only with negations that can be translated to complementary positive terms (as in Study 1) or they can also deal with situations where this is not possible, in the following study we created an experimental context in which the negation expressing absence cannot be translated to a complementary term and would lead to the sole representation of the absence of any objects present in the scene. Importantly, we wanted to create an experimental setting without the possibility of translating the negation to affirmation. For this purpose, we targeted the absence of objects at a single possible location and adopted a manual search task.

2.3. Study 2

To investigate infants' ability to comprehend existential negation expressing absence per se (without implying the presence of an object at another location) we used the manual search paradigm (Van de Walle, Carey & Prevor, 2009). In this task, infants observe the experimenter hiding a small number of objects into an opaque box and after the hiding event they can retrieve some of them. In case they find no objects in the box, their search time is modulated by their belief about the content of the box. For instance, infants search longer if they think that an object is still present in the box compared to the situation when they do not have this expectation. In other words, infants search less – their motivation for search decreases – if they think there are fewer objects in the box. Our goal was to use this phenomenon to investigate whether infants are able to represent the absence of objects (having exactly no objects) in the box.

Former experiments comparing situations in which 2 objects are hidden and 1 is retrieved versus 1 object is hidden and 1 retrieved (Feigenson & Carey, 2003) found clear evidence for 10 and

12-month-olds' disposition to search more in the former case, showing that they expected one more object to be present in this case. Although, this comparison might be interpreted as comparing the representation of one object with the representation of absence of objects, there are alternative possibilities. One plausible possibility is that infants' behavior is driven entirely by the representation of the object inside the box (in the 2-1 condition) and they have no expectations in the 1-1 condition. It is important to notice, that having no expectation at all is very different from our interest, specifically the ability of representing and expecting the absence of objects (expecting exactly no object in the box). To directly investigate this question we have designed a study where we compare a test situation in which infants receive verbal information that an object should be absent, not with a situation in which an object is present, but with control condition providing neutral or ambiguous information about the content of the container. If infants search less in the test condition that involves linguistic negation in the form of a negative existential compared to the control that would indicate their capacity to encode and use this kind of verbal information about the absence of objects, even when this cannot be translated to a positive term. Thus, in three experiments of Study 2 we investigated the development of comprehending the negative existential between 15 and 24 months using a task eliciting the representation of no objects in a box and we measured infants' behavioral responses that should be driven exclusively by information about absence of objects.

2.3.1. Experiment 4

2.3.1.1. Method

Materials and apparatus

Objects were hidden in a cardboard box (29 x 29 x 15 cm). The front part of the box had an opening (14 x 8 cm) covered by black cloth with a horizontal slit. This black cloth prevented participants to look inside the box, while still making possible to reach and search inside the box. There was a secret partition at the back of the box providing a hidden compartment for the experimenter to hide objects that become unreachable for the participant. We used colorful plastic whistles as target objects for the training and test. The training objects were slightly bigger and they had different shapes as the whistles used in the test trials.

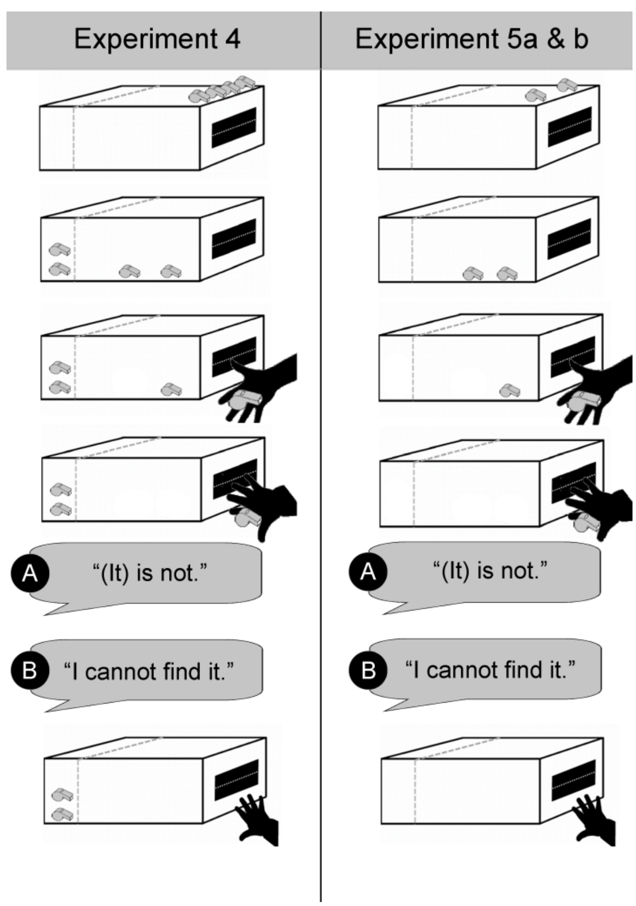

Figure 2.1. Schematic depiction of procedure in Experiment 4 and 5. The first column depicts the events presented to 15-month-olds in Experiment 4. The second column depicts events 18 and 24-month-olds were presented with in Experiment 5.'A' stands for Negative existential condition, while 'B' stands for Ambiguous condition. For details see the main text.

Procedure

The infant sat in the parent's lap at a table. The experimenter sat on the left side of the participant at the table. A video camera recorded the experiment from a side-view of the infant. The box was placed on the table but it was out of reach of the participant, until the experimenter pushed the box closer to the infant. All infants received 3 familiarization trials and 2 test trials.

Familiarization trials: Familiarization trials served to introduce the task to the participant. First, the experimenter showed the box and the opening of the box. She reached into the box saying "Look, here you can reach inside the box" and then the box was pushed to the infant and she could also try to search inside the box. Afterwards, the experimenter presented one whistle and placed it on the top of the box. She pointed to the object and said, 'Look!' – 'Nézd!' in Hungarian, then she hid it into the box and asked looking at the participant 'So what is in the box?' – 'Na mi van a dobozban?' in Hungarian. Then she started to search in the box and said, 'I am searching and searching..' – 'Keresem, keresem..' – in Hungarian and she took out the whistle and blew it. In the second and third familiarization trials, after hiding the whistle the experimenter pushed the box closer to the participant and asked again, 'So what is in the box?' and the participant was allowed to retrieve the whistle from the box. If the child was too shy, or

could not find the object, the experimenter encouraged her to search more and eventually helped her to find the object.

Test trials: In the test trials four identical whistles were placed on the top of the box (*Figure 2.1.*). Then the experimenter pointed to the objects on the top of the box and said, 'Look!', and she hid all objects simultaneously into the box. While placing the four objects inside the box, unbeknown to the infants, the experimenter hid two of them in the secret partition at the back of the box. In this way, those hidden two objects were not reachable for the infant. After the hiding, she asked the participant 'So what is in the box?' and retrieved one object (from the two objects in the reachable part of the box). The infant retrieved the second object. Finally, the experimenter reached into the box again and after a short searching she gave verbal information depending on the conditions. There were two trials, one trial per condition. In the Negative existential condition the experimenter said after the short search, '(It) is not' – 'Nincsen' in Hungarian, and then she pushed the box closer to the participant to be able to place a book in front of herself. Then she said 'Now, I have to check something in this book'– 'Most meg kell néznem valamit ebben a könyvben' in Hungarian, and for the 10 seconds measurement period the experimenter pretended to read the book and avoid any contact with the infant. In the Ambiguous condition, the experimenter said 'I cannot find it' – 'Nem találom' in Hungarian. We decided to use the utterance 'I cannot find it' for the control condition for two reasons. First, it is ambiguous about the content of the box, it does not determine whether there is something in the box or not. Second, we wanted to compare two negative sentences, to avoid a possible connotation difference between negative and affirmative sentences. One could argue that a difference between a positive and a negative sentence could arise from the different connotation of the two types of statements (i.e. negation is associated to dangerous items or prohibition, while

affirmation is not). In this way, we compared two negations; one expressing that there is no object in the box ('(It) is not') while the other is ambiguous about the content of the box ('I cannot find it'). The order of the test and control condition was counterbalanced between subjects.

Searching time was coded offline based on the video. The measuring period started from the moment when the box was placed in front of the participant and lasted for 10 seconds. Searching time was counted from the moment when the wrist of the participant passed the opening of the box and ended when the wrist departed the opening. We expected infants to search less in the Negative existential condition compared to the Ambiguous condition if they understand the meaning of the non-existential verb, and based on that they represent that nothing is inside the box.

Participants

Sixteen infants completed the experiment (7 girls), the mean age was 15 months and 14 days (age range: 14 months 26 days -15 months 24 days). Four additional infants were tested but excluded from the analyses because they did not search in both conditions (2 participants in Negative existential condition, and 2 participants in Ambiguous condition). We decreased the group size compared to Study 1, as in this study we implemented a more sensitive, continuous measurement that was successfully used with such smaller groups sizes in earlier studies (Feigenson & Carey, 2003).

2.3.1.2. *Results*

We calculated the mean searching time for each condition and compared these values using two-tailed t-tests. For mean search durations, see *Figure 2.2*. 15-month-olds did not search less in Negative existential (M = 3.379, SD = 1.674) compared to the Ambiguous condition (M = 3.494, SD = 2.240; $t(15) = -0.211$, $p = 0.836$). We analyzed the effect of the order of presentation of conditions running a 2x2 ANOVA with Order and Condition as factors. There was no significant main effect or interaction between these two factors, showing that 15-month-olds searched equally in the conditions independently from the order of presentation.

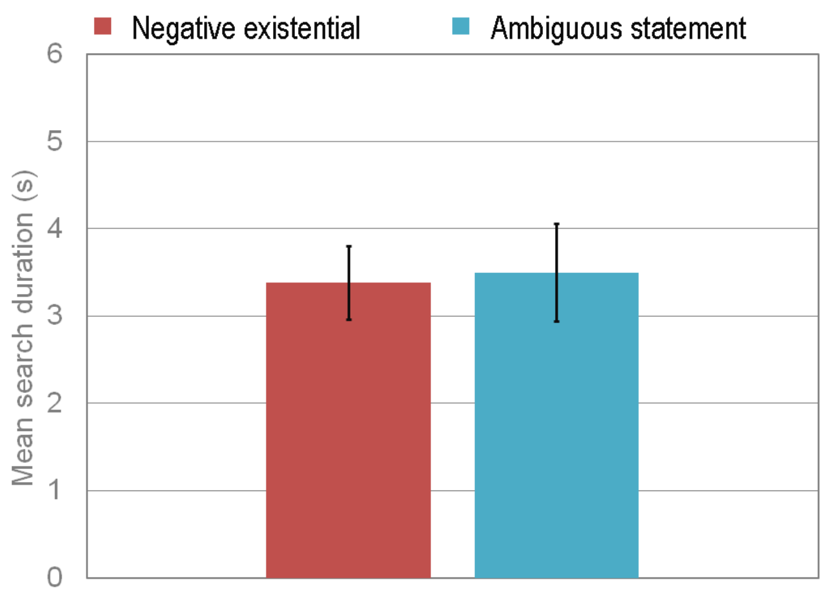

Figure 2.2. 15-month-olds' mean search duration in Experiment 4. Error bars depict standard error.

2.3.1.3. *Discussion*

15-month-olds did not show evidence for comprehending the negative existential and for representing the absence of the objects in the box triggered by verbal communication in this task. This result is in line with our previous findings from Study 1, showing 15-month-olds' difficulty in comprehending negation. In this case, we aimed to measure infants' readiness to comprehend the negative existential expressing the absence of objects in the box, rather than eliminating possible locations of a specific object. Overall 15-month-olds seem to fail in comprehending negation expressing the absence of objects in distinct contexts (Study 1 and Study 2), and involving two types of verbal negation (Experiment 3 from Study 1). What is important to mention is 15-month-olds' resistance to map the verbal input they receive to some lower level comprehension. This resistance again questions the accounts arguing for infants' tendency to map simple, limited meaning to negation they hear (Pea, 1980; Feiman et al., 2017). Next, we tested 18-month-old infants' comprehension of negation expressing the absence of objects in the search task. We asked the question whether infants at this age understand negation in a variety of contexts and with two possibly different meanings: negation eliminating a possible location of an object (and implying the correct location-targeted by Experiments 1 and 2 of Study 1) and negation expressing the lack of objects per se (targeted by the present experiment).

2.3.2. Experiment 5a

2.3.2.1. Method

To explore the development of comprehending negation expressing absence of objects, we targeted an older age group, specifically 18-month-old infants (found to have the particular linguistic competence in Study 1). Additionally, we changed the number of hidden object from 4 to 2, to exclude a possible confounding factor from Experiment 4. In Experiment 4, four objects were hidden and only two of them were retrieved. In this way the statement in the Negative existential ('(It) is not) condition was a false statement. Of course, this could have an effect only if infants could track the exact number of four objects, which is highly unlikely. Based on former research, only up to three objects can be tracked in similar tasks by10 and 12-month-oldinfants but they fail with four (Feigenson et al., 2004). Although, we are not aware of research on how this capacity changes later, in the next experiments we aimed to make sure that there is no conflict between infants' own knowledge (that there is still something in the box) and the verbal information provided by the experimenter (that there is nothing inside the box). For this reason, we used two hidden objects and both of them were retrieved. Again, we predicted that infants will search shorter in the Negative existential condition compared to the Ambiguous condition. Materials and procedure were otherwise identical to Experiment 4.

Participants

Sixteen 18-month-olds (7 female; mean age was 17 months and 22 days, age range: 17 months 20 days and 18 months 10 days) were tested in Experiment 5a. Additional four infants were excluded from analyses because of showing distress and not cooperating (1), or not searching in both conditions (3 infants in Negative existential condition).

2.3.2.2. Results

18-month-olds did not show evidence of discriminating the two conditions ($t(15) = -0.571$, $p = 0.577$). They searched for equally long in the Negative existential (M = 3.867, SD = 2.537) and the Ambiguous (M = 4.287, SD = 2.776) conditions (*Figure 2.3*). We analyzed the effect of the order of presentation of conditions running a 2x2 ANOVA with Order and Condition as factors. There was no significant main effect of Condition ($F(1,14) = 0.498$, $p = 0.492$), we obtained only an interaction between these two factors ($F(1,14) = 8.907$, $p = 0.01$). Infants search less in Negative existential (M = 2.834, SD = 0.735) than in Ambiguous conditions (M = 5.029, SD = 1.144), when the control condition was presented first (Scheffé test, $p = 0.005$). In response to the opposite order, 18-month-olds' showed a tendentious difference in the reversed direction (Negative existential: M = 4.901, SD = 0.937; Ambiguous: M = 3.545, SD = 0.774; Scheffé test, $p = 0.073$). However, this particular pattern can be explained by searching more in the first, compared to the second trial. Similar effect was found in younger infants (Kampis, 2017), showing less proclivity to search in the second compared the first trial.

Similarly to the 15-month-olds, 18-month-olds did not discriminate between Negative existential and Ambiguous conditions. Even thought, according to Study 1, infants at this age have reliable understanding of two types of negation, in Experiment 5a, we did not find evidence for comprehension of negative existential expressing absence per se. To further investigate the development of comprehending negation expressing absence without further implications, we run the same experiment in 24-month-olds.

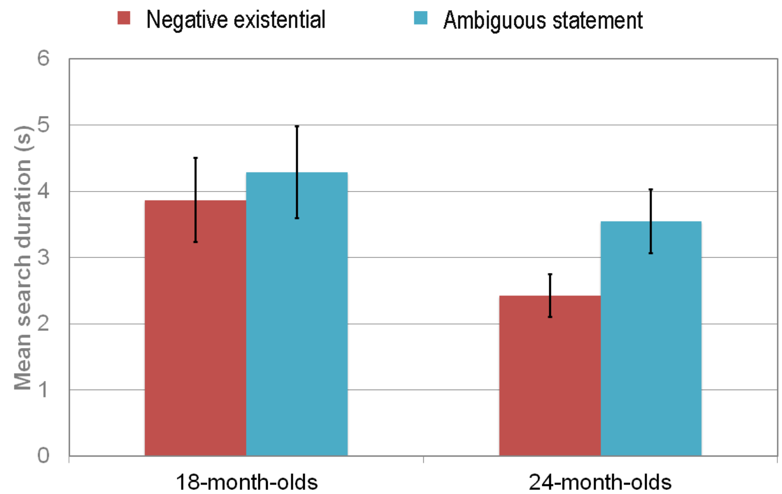

Figure 2.3. Participants' mean search duration in Experiment 5. The first two bars represent 18-mont-olds' search behavior in Experiment 5a, while the second set of bars stand for the 24-month-olds' search time in Experiment 5b. Error bars depict standard error.

2.3.3. Experiment 5b

Participants

Sixteen 24-month-olds (6 female; mean age: mean age was 24 months and 3 days, age range: 23 months 26 days and 24 months 28 days) participated in Experiment 5b. Additional five infants were excluded from analyses because of showing distress and not cooperating (2) or not searching in both trials (3 infants in Negative existential condition).

2.3.3.1. *Results*

In Experiment 5b there was a significant difference in 24-month-olds' search time ($t(15) = -2.226$, $p = 0.042$). They searched longer in Ambiguous condition (M = 3.547, SD = 1.939) than in Negative existential condition (M = 2.425, SD = 1.284). Investigating the effect of age and order of the presentations of conditions, we analyzed the data in a 2x2 ANOVA. There was a significant main effect of Condition ($F(1,14) = 7.105$, $p = 0.018$), and a significant interaction between Order and Condition factors ($F(1,14) = 7.506$, $p = 0.016$). There was a significant difference between the conditions when the Ambiguous trial was presented first (Negative existential: M = 1.815, SD = 1.202; Ambiguous: M = 4.09, SD = 1.797; Scheffé test, $p = 0.002$), but there was no such difference between trials when the Negative existential condition was presented first (Negative existential: M = 3.034, SD = 1.113; Ambiguous: M = 3.003, SD = 2.037; Scheffé test, $p = 0.959$). The difference between the contrasts in the two orders probably originates from the general effect of searching less in the second compared to the first trial. According to this general effect, when the Ambiguous is presented first and the Negative existential trial is presented second, we expect longer search in Ambiguous compared to the Negative existential. Similarly, when the Negative existential is the first trial, we expect infants to search longer in the Negative existential compared to the Ambiguous condition. 24-month-olds' searching behavior based on the comprehension of the linguistic input is congruent with this pattern when the Ambiguous condition is presented first, and Negative existential is presented second. Thus, we obtained stronger discrimination. In contrast, in the opposite order of presentation, the behavior induced by the linguistic information and the behavior based on the

general effect of searching more in the first trial compared to the second are in conflict. Thus, the two effects lead to a reduced discrimination between the conditions.

2.3.3.2. Discussion

There was clear evidence for discriminating Negative existential and Ambiguous conditions only in 24-month-old infants. However, to interpret the results, it is important to clarify some aspects of the search task we used. First, we compared the behavior in response to two types of verbal information. For this reason, the difference between conditions can be due to either of the two conditions or to both. For instance, while the statement ‘I cannot find it’ is ambiguous about the content of the box, it might induce the pragmatic inference that an object – which was not found by the experimenter – is still inside the box. This way, the Ambiguous condition might have prompted extra searching behavior compared to our test condition. According to this interpretation, the difference between the conditions can be a consequence of the increased searching time in the Ambiguous condition, without any competence in comprehending the negative existential in the test condition. Alternatively, 24-month-olds might have comprehended the negative existential, which decreased their search time compared to the Ambiguous condition. In the next experiments we aimed to disentangle these two possibilities. In Experiment 6a and b, the Negative existential condition was compared to a new control: No information condition. In this version the experimenter did not provide any verbal information about the content of the box before the search period (see *Figure 2.4*).

Second, as mentioned earlier, infants might have some awareness of what is inside of the box in Experiments 4 and 5a, and b, and this might also affect their search patterns. To investigate whether participants' own knowledge may have an effect, we tested how the number of hidden objects in the box affects 24-month-olds' performance. In Experiment 6, to manipulate infants' first person knowledge (whether they could exactly track the number of objects placed in the box or not), we tested two groups of infants. In the first group, Exact tracking group (2-2), two objects were hidden and both of them were retrieved (as in Experiment 5 a, b). In the second, Uncertain tracking group (4-3), four objects were hidden and three of them were retrieved. Tracking abilities can modulate infants' searching behavior along two dimensions. First, it determines how certain the participant is about the content of the box during the trials. We expect them to be more confident about the content if it is a smaller, compared to a larger amount. Second, infants' own representation of the content of the box might interact with the information provided by the experimenter. It can support the comprehension of the verbal information provided by the experimenter − if it corresponds with it. Alternatively, it can be in conflict with their knowledge (if they have specific expectations), causing some conflict and a possible confusion. A difference between the performance of infants presented with 2-2 and infants presented with 4-3 objects would signal an effect of infants' own representation about the number of objects present in the box, combined with the verbal information provided by the experimenter.

However, it should be noted that it is unclear what information infants encode in the Exact tracking group (2-2) where they saw 2 objects placed and 2 retrieved. There is no evidence for 24-month-olds' ability to represent 0 objects out of sight. Additionally, and we are not aware of former studies investigating this age groups' capacity to track exactly 4 objects either. For this

reason, it is difficult to make clear predictions about the possible differences between the two conditions. One possible prediction is that infants will perform better in the Exact tracking (2-2) compared to the Uncertain tracking group (4-3), as the former task is actually simpler, in the sense that it is within the capacity of the object tracking system. However, an alternative prediction is that infants will perform better in the Uncertain tracking group compared to the Exact tracking group. In the former group (4-3) 24-month-olds might rely more on the utterance provided by the experimenter than in the latter group (2-2), as in the Uncertain tracking group this information is more relevant, in the sense that infants might not have clear first person expectations about the content of the box a priori.

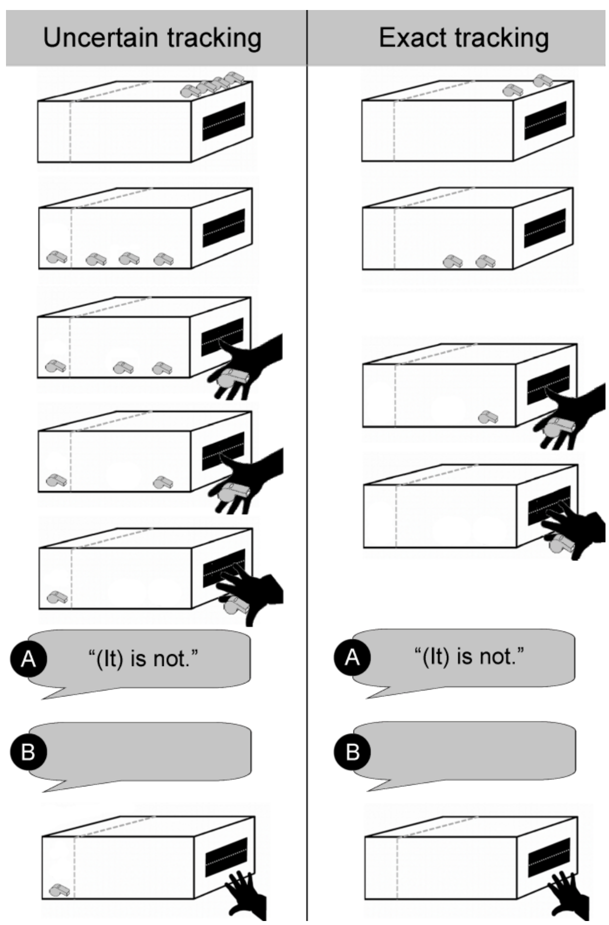

Figure 2.4. Schematic depiction of procedure in Experiment 6. The first column shows events displayed to the Uncertain tracking group in Experiment 6b. The second column displays events 24-month-olds were presented in the Exact tracking group in Experiment 6a. 'A' stands for Negative existential condition, while 'B' stands for No information condition. For more details see the main text.

2.3.4. Experiment 6

Participants

Experiment 6a. Exact tracking group (2-2 objects)

Sixteen 24-month-olds participated in this group (10 female; mean age was 24 months and 12 days, age range: 24 months 2 days and 25 months 0 days). Additional 13 infants were excluded due to one of the following reasons: parental intervention (4), experimental error (2), not searching (7).

Experiment 6b. Uncertain tracking group (4-3 objects)

Sixteen 24-month-olds participated in this group (6 female; mean age was 24 months and 14 days, age range: 24 months 5 days and 24 months 27 days). Additional 5 infants were excluded due to not searching.

2.3.4.1. Results

First, we analyzed the data of Experiment 6a (Exact tracking group). We compared the mean searching time in the two conditions and we did not find significant difference (*Figure 2.5*). Infants searched similarly in the No information condition (M = 3.04, SD = 1.868) and in the Negative existential condition (M = 3.653, SD = 2.164; $t(15) = 1.308$, $p = 0.211$) when 2-2 objects were presented. We investigated the effect of the order of conditions with a 2x2 ANOVA, with Condition as within and Order as between subject factors, and there were no significant main effects or interaction of these factors.

Then we analyzed the data of Experiment 6b (Uncertain tracking group). Comparing the mean searching times in the two conditions, we did not find significant differences. 24-month-olds searched similarly in the No information condition (M = 4.325, SD = 2.017) and in the Negative existential condition (M = 3.419, SD = 2.663; $t(15) = -1.077$, $p = 0.299$). To test the effect of the order of conditions, we run a 2x2 ANOVA with Condition as within and Order as between subject factors. There was a significant interaction between these two factors ($F(14,1) = 4.677$, $p = 0.048$), with no other effects. Similarly to Experiment 5b, infants searched shorter in Negative existential condition (M = 2.187, SD = 2.362) than in No information condition (M = 4.725, SD = 1.267; Scheffé test, $p = 0.032$) when the control condition was presented first. In contrast, there was no difference when the Negative existential condition was presented first (Scheffé test, $p = 0.508$).

The effect of first-person knowledge

To compare the effect of the knowledge about the number of objects, we run a 2x2x2 ANOVA with Condition (Negative existential vs. No information) as within factor and Experiment (Exact tracking (2-2) vs. Uncertain group (4-3)) and Order (Negative existential first vs. No information first) as between subject factors. There was a significant three-way interaction ($F(1,28) = 5.386$, $p = 0.028$). Post-hoc comparisons showed that infants in the Uncertain tracking group who received the No information condition first discriminated between the two conditions. They searched less in the Negative existential (M = 2.187, SD = 0.835) compared to the No information (M = 4.725, SD = 0.448) conditions (Scheffé test, $p = 0.008$). Additionally, there was a difference between the search times in the No information conditions between the two groups. Toddlers participating in the Uncertain tracking group searched more (M = 4.325, SD = 0.504) compared the ones participating in the Exact tracking group (M = 3.04, SD = 0.467) (Scheffé test, $p = 0.05$). This pattern potentially points to 24-month-olds' ability to spontaneously differentiate between the outcome of 2-2 and 4-3 objects.

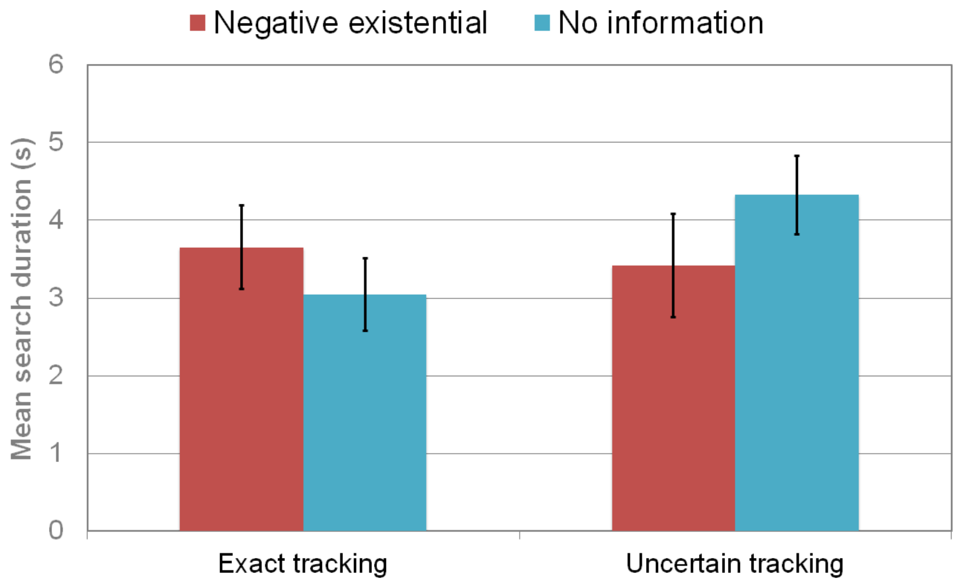

Figure 2.5. 24-month-olds' mean search duration in Experiment 6. The first two bars represent toddlers' search behavior in Experiment 6a, participating in the Exact tracking group (2-2). While the second set of bars stand for the 24-month-olds' search time in Experiment 6b, in response to events in Uncertain tracking (4-3). Error bars depict standard error.

The effect of the control ('I cannot find it' vs. No information) conditions

To learn more about the effect of control conditions and specifically to test whether in Experiment 5a and b the Ambiguous condition ('I cannot find it') had a specific impact on search behavior, we analyzed Experiment 5b and 6a together (these two studies both involved 2-2 objects). We compared 24-month-olds' behavior in a 2x2x2 ANOVA with Condition as within factor and Experiment (Experiment 5bAmbiguousvs.Experiment 6aNo information) and Order (test first vs. control first) as between subject factors. There was a significant interaction between Experiment and Condition factors ($F(1,28) = 7.541$, $p = 0.01$). While in Experiment 5b the

difference between the two conditions was in the expected direction (Negative existential: M = 2.415, SD = 1.284; Ambiguous: M = 3.547, SD = 1.939; Scheffé test, $p = 0.018$), in Experiment 6a there was no such difference (Negative existential: M = 3.653, SD = 2.164; No information: M = 3.04, SD = 1.868; Scheffé test, $p = 0.181$). Additionally, there was a significant three-way interaction between Experiment, Condition and Order factors ($F(1,28) = 6.303$, $p = 0.018$). The difference between the two experiments is mainly driven by the contrast obtained in Experiment 5a, by infants who received the Ambiguous control condition first (Negative existential: M = 1.815, SD = 1.201; Ambiguous: M = 4.09, SD = 1.797; Scheffé, $p = 0.001$). In contrast, those infants who received the opposite order, did not differentiate between the two conditions (Negative existential: M = 3.034, SD = 1.113; Ambiguous: M = 3.003, SD = 2.037; Scheffé test, $p = 0.961$). Additionally, post hoc comparison indicates that there was a difference in the search time in Negative existential conditions between the two groups. Infants searched less in Experiment 5b in response to the Negative existential (M = 2.425, SD = 0.321) compared to the participants in Experiment 6a (M = 3.656, SD = 0.541) (Scheffé test, $p = 0.01$). In contrast, there was no such difference between the control conditions. For the order effects in Experiment 5b and 6 see *Figure 2.6*.

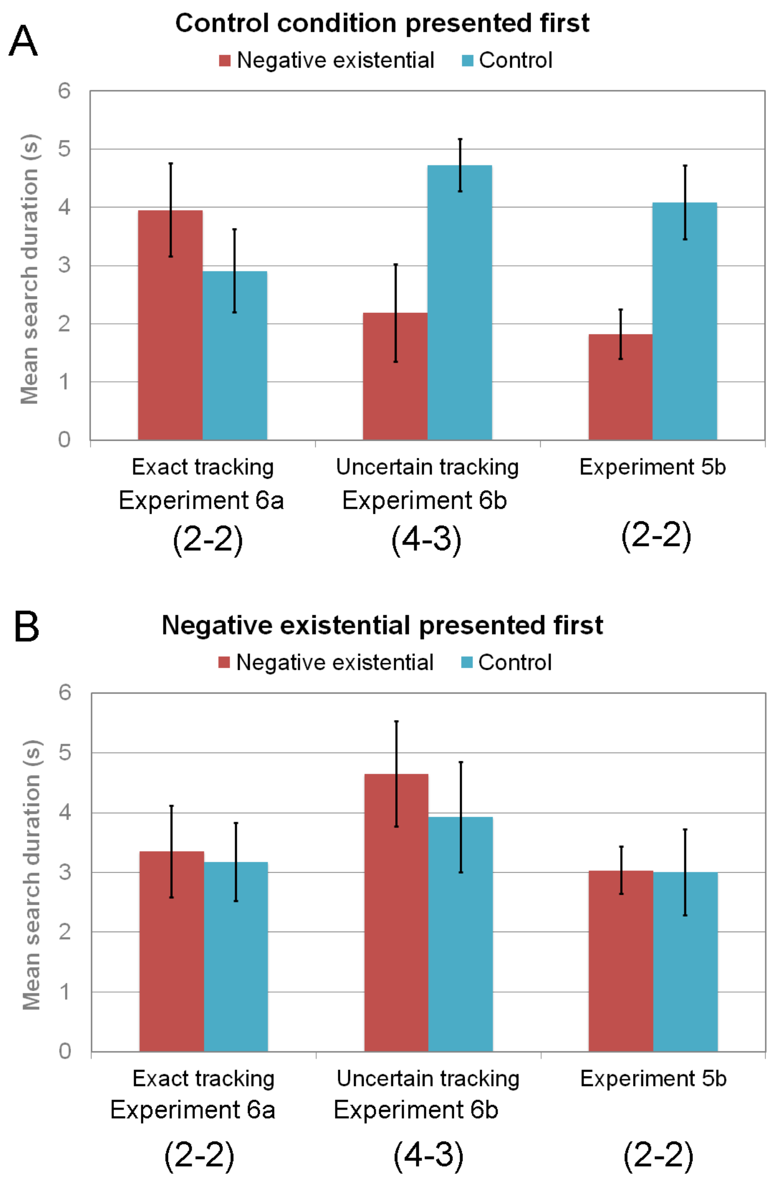

Figure 2.6. *24-month-olds' mean search duration as a function of experiments and condition for (A) participants receiving the control condition first (No information in Experiment 6 and Ambiguous in Experiment 5b) and (B) for participants receiving the Negative existential condition first. Error bars depict standard error.*

2.3.4.2. Discussion

In Experiment 6 we targeted two questions. First, we investigated whether first-person knowledge affected 24-month-olds' the comprehension of the negative existential uttered by the experimenter. Second, we asked whether verbal information provided in the Ambiguous trials in Experiment 5 affected participants' interpretation of the negation produced in the test trials.

First-person knowledge

We tested the effect of infants' first person knowledge on the interpretation of negation received in our task. While it is not straightforward how to interpret the three-way interaction, without main effects in Experiment 6, we would like to depict a plausible interpretation.

24-month-olds were sensitive to the condition and order of presentation in Experiment 6b of 4-3 objects presentation (Uncertain tracking group), however infants' performance was not modulated by these factors when 2-2 objects were used (Exact tracking group). Besides this difference, there was a contrast between the search times in the No information condition. Infants searched more after seeing 4 objects hidden and 3 being retrieved, compared to the 2 objects hidden and both being retrieved. These results might suggest that 24-month-olds may have formed different representation about the content of the box after perceiving 2-2 and 4-3 objects and it had an effect on their interpretation of the negative existential. For an exact interpretation of the results of Experiment 6 we should know exactly what representations 24-month-oldsformed after watching 2 objects hidden and both of them retrieved on the one hand, as well as the representations that resulted from watching a scene where 4 objects were hidden and 3 retrieved, on the other hand. Infants' ability to track exact number of objects up to 3 is well

documented – using also the task we have used (e.g. Feigenson et al., 2004). In contrast, their ability to represent the exact content of the box when the result of object manipulation is zero objects was not studied as such. Similarly, how 24-month-olds' encode four objects and the manipulation of this number of object is unclear.

The effect of the ambiguous information

The second question was whether the 'I cannot find it' utterance had an impact on 24-month-olds discriminating the two conditions Experiment 5b. Infants' behavior was different in Experiment 5b and 6a. As the only dissimilarity was the control condition we used (the number of objects were the same), the interaction between the Condition and Experiment factors – most probably – arises from the effect of the interpretation of the 'I cannot find it' utterance. Importantly, based on the 3-way interaction and the lack of difference between search times in the control conditions (Ambiguous vs. No information conditions), we speculate that this difference is not simply due to the comprehension of 'I cannot find it' and ignoring the negative existential, but it originates from an interaction between the interpretation of Ambiguous and Negative existential trials. The 'I cannot find it' statement can hint to the idea of objects remaining in the box, and in this way, in the first trial it increased the searching time (boosting the difference between conditions). Additionally, the Ambiguous condition might have affected toddlers' interpretation of the negative existential in the consecutive trial. We speculate that participants might have encoded negation more successful in the successive trial, because the potential presence of an object boosted the encoding of absence. However, such an interpretation is only tentative at the

moment, and a more direct test for future experiments would be to compare 24-month-olds' searching behavior in 'I cannot find it' condition contrasted with a No verbal information control.

To sum up, 24-month-olds' comprehension of negation in this search task was affected by their first-person knowledge, but also by another factor. The information they contrasted with the negative existential might modulated their interpretation of negation. The present studies have not tackled well on this factor, and specific baselines might have been useful, thus we can only speculate regarding what 24-month-olds exactly represented in Experiment 5b and 6. However, we would like to highlight that in these experiments infants demonstrated their ability to discriminate the negative existential and the control, in those experiments supporting the potential presence of an object ('I cannot find it' or an uncertain representation of 4-3 objects). In contrast, in the Exact tracking group, we did not find any effect influencing 24-month-olds' search time in Experiment 6a. This result is puzzling, and we suggest two possible explanations. First, infants were able to form the exact representation of the absence of objects after they saw two objects hidden and both retrieved. Thus, they did not discriminate between the Negative existential and No information conditions, as they carried the same information. Alternatively, the result of the 2-2 objects manipulation was not encoded as exactly no object, either it induced the representation of a potential object in the box, as in Experiment 5b and 6b. Thus, 24-month-olds did not discriminate between conditions, as the comprehension of the negative existential (absence of objects) was not boosted by potential presence on an object.

Further studies should disentangle the factors influencing 24-month-olds' behavior in this task, and specific designs should target the representations infants formed in the control conditions and also, their effect on negation comprehension.

2.4. General discussion

In Study 2 we were specifically interested in infants' understanding of verbal negation expressing the absence of any objects – without implying the presence of objects – unfolds in time. We also targeted the question how 24-month-olds' interpretation is affected by their first-person knowledge about the hidden/retrieved objects in the task.

In Experiment 4 15-month-olds did not show any sensitivity to the difference between the Negative existential ('(It) is not') and the Ambiguous ('I cannot find it') conditions. We interpret this finding also supported by Study 1, as suggesting that the negations tested in the present experiments are beyond 15-month-olds' linguistic capacity. In Experiment 5a 18-month-olds did not differentiate between Negative existential and Ambiguous conditions either. While 18-month-olds comprehended negation (both the negative existential and the proposition denial) in Study 1, we did not find evidence for comprehending the negative existential in Study 2 at this age. We found clear evidence for understanding negation expressing the absence of any objects per se, only at the age of 24 months.

The difference between 18-month-olds' performance in Study 1 and 2 can be explained in two possible ways. First, 18-month-olds in Study 2 might have had difficulties in processing the negative existential when it should be applied in a contrastive way, and does not lead to an alternative positive representation. Such difficulties were demonstrated in young children in a study by Nordmeyer and Frank (2014), where 3-year-olds did not show evidence for finding the correct reference of the existential negation ("The boy who has no apples") when it referred to

absence of objects (i.e. nothing), while they succeeded when it referred to an alternative object (i.e. a boy who had boxes). Whether the early difficulty in comprehending negation expressing absence per se is due to more general factors (e.g. that it cannot be applied in a contrastive way), or to more absence specific factors (e.g. from forming a representation of absence) should be addressed by further research.

Alternatively, the failure of the 15- and 18-month-olds, and 24-month-olds' limited understanding of negation in Study 2 might come from task specific factors. One obvious difficulty is, for instance, that successful behavior in our task required the inhibition of participants' natural drive for searching (infants tend to search for some time, even when all objects are removed, e.g. Feigenson & Carey, 2003). In this way, the search task might have posed more difficulties for the younger age group because of their less developed inhibitory abilities (Harnishfeger & Bjorklund, 1993).

Importantly, however, as we have seen, the comprehension of the negative existential in Study 2 was affected by complex interactions between 24-monht-olds' first-person knowledge, the information they have received in the control condition and the order of trials. First, the two controls we have used might have played a role in participants' behavior. We assumed that the utterance 'I cannot find it' used for the control condition in Experiment 5 will induce an ambiguous representation, and it did indeed, but in an unexpected way. Instead of creating a neutral control condition, as it was intended, the utterance 'I cannot find it' probably prompted the presence of objects. Second, Experiment 6 suggests that 24-month-olds' first person knowledge about the content of the box had an effect on their interpretation of negation. This was reflected by the different searching behavior in response to a trackable number of objects (2-2) compared to an untrackable number of objects (4-3). While, as discussed earlier, the exact

mechanisms behind the obtained three-way interaction observed for experiment 5b and 6a are unclear, we would like to highlight that 24-month-olds discriminated between the negative existential and the specific control, only if in the there was information on potential objects in the box. Possibly, this points to the importance of presence in absence encoding.

In Study 2, we examined infants' comprehension of negation focusing more specifically on the subject of this thesis: how do we encode the absence of objects. In some sense, this is a different point of view, as the main goal of former studies investigating the comprehension of negation was to reveal the conceptual background. We also targeted this theoretical question (see Study 1), however, we also find the encoding of exactly no object an intriguing issue. Here, we demonstrated 24-month-olds' capacity to comprehend negation expressing absence per se. Our finding might contribute to a better understanding not only the processing of linguistic negation but on how infants start to form ideas on 'nothing'.

2.5. Conclusions

In Study 1 we targeted the comprehension of negation expressing two different functions described in the production literature, specifically nonexistence and denial. We compared the comprehension of these two types of negation, addressing the question whether one can observe an early discrepancy in comprehension that is similar to the production data, or alternatively, the two negations would show a similar acquisition pattern that could clarify their conceptual underpinnings in language usage. Former studies argued for an early limited understanding of negation evolving later into an adult-like, linguistic tool (Pea, 1980; Mody & Carey, 2016;

Feiman et al., 2017). There are two sources that support such a conceptual gap proposal. First, the development of negation production shows early the appearance of rejection, nonexistence and only a later emergence of denial (Bloom, 1970; Pea, 1980; Choi, 1988). Second, while infants start to express negation relatively from an early age (i.e. rejection can be observed even around 12-14 months), they show a competence for understanding denial between 24 and 36 months (Austin et al., 2014; Nordmeyer & Frank, 2014; Feiman et al., 2017; Reuter et al., 2017; Grigoroglou et al., 2019). However, to our knowledge, no former studies compared directly comprehension abilities for a presumably domain specific, limited purpose negation (i.e. nonexistence) and domain-general, logic-like negation (i.e. denial). In Study 1 we aimed to investigate the roots of negation expressing nonexistence and denial. In contrast to the conceptual gap proposal, we found similar patterns for the two and an early competence for understanding nonexistence (negative existential) and denial (proposition denial) in 18-month-olds. While 15-month-olds failed in both types of negation, 18-month-olds succeed to comprehend both denial and negation expressing nonexistence, which are most probably grounded in a common conceptual understanding. Although, we have to add, that we did not exclude the possibility of an early limited meaning of negation present in a younger age related to rejection.

In Study 2, we tested the comprehension of the negative existential in a different task, expressing absence per se. While in Study 1 the negation could result in a positive representation of where the object was, in Study 2 the context of the task did not support an inference about a positive statement. Signs for negation comprehension seemed to be present only from 24 months, but also at this age infants' comprehension was sensitive to different factors (i.e. first-person knowledge and information from preceding trial).

Comparing the two studies, infants' displayed a weaker performance in Study 2 compared to Study 1 regarding the comprehension of the negative existential. While 15-month-olds failed in both studies, 18-month-olds showed a reliable competence in Study 1, but infants at this age did not seem to comprehend the same negative existential in Study 2. This pattern of results may suggest that the processing of negation in a contrastive context (referring to sole absence) is more demanding, than in a complementary context (when it can be translated to presence). Such a possibility is also in line with previous results in young children (Nordmeyer & Frank, 2014) and our results highlight the importance of differentiating the comprehension of negation in these two contexts.

Turning to the long debated question of what is the conceptual nature of negation at the beginning of language acquisition, the present data does not allow for a definite answer. On the one hand, we did not find evidence for developmental delay between understanding negation expressing nonexistence and denial. This finding does not support the conceptual gap hypothesis; it is rather in line with the idea that infants' early capacity to comprehend negation is domain general. On the other hand, while 18-month-olds succeeded in Study 1, in which negation was used in a complementary context (supporting the representation of the presence of the object), and they failed in Study 2, testing the negative existential in a contrastive context (supporting only representing the absence). This discrepancy might signal a difference between processing negation supported by the same mechanism in the two contexts or, they may even rely on two separate cognitive mechanisms. The second alternative is in line with Mody and Carey's (2016) proposal that an early process of elimination of one possibility without explicit symbol for negation may explain successful performance in tasks similar to the ones we have also used in

Study 1. In contrast, Study 2 might require the abstract symbol of negation to maintain the information regarding the negation of the presence of any objects in the container.

Although more data will be needed to draw strong conclusions regarding these questions, we would rather argue for an adult-like, domain general understanding of negation even at the early stages of negation acquisition. First, this seems to be supported by the performance of the 18-month-olds in Study 1; second, by the similarities in negation processing in young children and adults (e.g. Nordmeyer & Frank, 2014) and third by the finding that the comprehension of affirmative propositions boosts the comprehension of negation in infants (Reuter et al., 2017).

To conclude, we did not find evidence for an early limited comprehension of negation expressing nonexistence, compared to a supposedly more complex and logic-like representation of denial (Study1). Peculiarly, we did find evidence for other limitations in infants' comprehension; specifically negation comprehension was weaker when it expressed absence without a possible affirmative alternative. This finding might suggest an earlier capacity to comprehend negation applied to complementary structures (i.e. using negation to form an alternative affirmation) compared to contrastive structures (i.e. maintaining negation in its original form). Alternatively, negation may work equally well for both structures, however, the information encoded based on contrastive structures may be more vulnerable and harder to maintain.

3. Chapter 3. Young chicks spontaneously represent the absence of objects

3.1. Introduction

Imagine looking at a domino that has four dots on one end and no dots on the other. The way we represent specific items (e.g., four dots) has been intensively investigated for decades. First, one can think of these dots as individual objects. Investigations targeting object cognition revealed that roughly four objects can be tracked and maintained in mind simultaneously, even when they are moving or are occasionally occluded (Kahneman et al. 1992; Scholl & Pylyshyn, 1999). Another way to look at the dots is to encode them as a set of objects. Research investigating numerical cognition proposed that in such cases the approximate number system, which provides imprecise representations of sets to pre- and non-linguistic creatures as well. However, in contrast to the object tracking system, information in this number system is only an approximation of the size of the set and it is sensitive to proportional rather than to absolute differences (Dehaene, 1997; Haun, Jordan, Vallortigara & Clayton, 2011). Both systems emerge early in the individual development (Piazza, 2010) and are shared by several species (Brannon & Roitman, 2003; Brannon & Merritt, 2011; Haun et al., 2011; Vallortigara, 2012). A third way to think about the four dots in the conventional arrangement on the domino as an alternative symbolic (and precise) representation of the number "4" (Dehaene, 1997; Carey, 2009). Interpreting such symbols clearly requires processing number concepts and being familiar with this specific, domino-like notation system (Carey, 2009). Now, let us focus on the other end of the domino. How will the blank square turn into zero in our mind? Such a representation maybe outside the scope of the above-mentioned cognitive systems: 'no object' is not tracked by the

visual system, ‘no dots’ is not proportional to anything, and ‘empty space’ can denote a number only in special circumstances. Indeed, understanding the absence of something as ‘nothing’ is frequently related to complex and human specific concepts, such as zero, or logical operations, such as negation.

Clear evidence regarding when human children represent the absence of objects comes from language development. Negation conveying absence (e.g., ‘all gone’) emerges among the first linguistic expressions between one and two years of life (Bloom, 1970). Some years later, preschoolers can flexibly use sentential negation to express the absence of something in numerical context (Bialystok & Codd, 2000), and can recruit complex numerical concepts, such as zero (Wellman & Miller, 1986; Merritt & Brannon, 2013). While by the age of 5 children seem to successfully operate with counterintuitive concepts like zero and nothing, the cognitive foundations of this human capacity are frequently suggested to be found in linguistic abilities. How would pre- and non-linguistic creatures see the zero end of the domino?

Non-human animals were found to accommodate stimuli defined by the lack of a stimulant in two main types of tasks: numerical and perceptual decision tasks. Regarding numerical tasks, some species seem to integrate empty sets with other sets using the approximate number system (Biro & Matsuzawa, 2001; Merritt et al., 2009). For instance, in non-symbolic numerical tasks, rhesus monkeys displayed specific patterns that are characteristic of the approximate number system in trials involving empty sets; specifically, the number of errors increased with the decrease of the numerical distance between the compared sets (Merritt et al., 2009). Furthermore, Ai, the chimpanzee, successfully learned using the symbol zero. However, she did not show transfer effect after switching from cardinality (i.e., the exact numbers of entities) to ordering tasks (i.e., arranging sets/ numbers in ascending or descending order), reflecting her limited

conceptual understanding of zero (Biro & Matsuzawa, 2001). Relatedly, specific neural signatures triggered by empty sets were identified in monkey brains in number specific areas (Okuyama et al., 2015; Ramirez-Cardenas et al., 2016). Although these findings are remarkable, it is still unclear how the approximate number system could represent exactly no objects, as it is specialized for approximating numerosities.

Perceptual detection decisions tasks, on the other hand, require subjects to judge whether they can see a target stimulus masked with various amount of noise. Merten and Nieder (2012) recorded activation from the prefrontal cortex of rhesus monkeys while they judged the presence and absence of a target stimulus using a rule-based response system. Interestingly, the absence of stimuli was encoded only during participants reporting of the decision of "not seeing," and there was no sign of specific activation in the preceding phase of perceiving the absence of stimuli. In contrast, presence-specific cells were found to be active during both perceiving the target and reporting the decision. Asymmetries between the capacities of representing presence and absence of stimuli were documented in behavioral tasks as well. Human adults (Newman et al., 1980) and pigeons (Hearst, 1991) displayed feature-positive biases in learning tasks. For instance, pigeons learned relatively easily the relation between the presence of a stimulus and food, but they had difficulties with discovering a similar relation between the absence of a stimulus and food. In line with such asymmetries, human infants automatically detect and maintain the presence of objects after occlusion, while they seem to fail to do so with the absence of objects (Wynn & Chiang, 1998; Kaufman et al., 2003).

Absence is trivial in experience, but peculiar in information processing. While some non-human species show success in dealing with the absence of stimuli after long training, it is not yet

known whether nonlinguistic creatures can spontaneously rely on such information and what inferences they draw from it. A possible way to investigate the emergence and the nature of the representation of absence is to target developmentally precocious animals. We addressed these questions by studying naïve domestic chicks — creatures that start to search for food soon after hatching, and could make good use of information regarding the presence or absence of potential food sources and social partners.

3.2. General Methods

Newborn chicks were collected from the incubator a few hours after hatching and they were housed individually in standard conditions in rectangular-shaped home cages (28 cm wide x 40 cm high x 32 cm deep) with a small opening on the front side (8 cm high, 2.7 cm diameter). Chicks could insert their head in this hole and look outside, and in this way they became familiarized with protruding the head from a window. Each chick shared the home cage with a red cylinder-shaped object (3 cm wide x 5.5 cm high) suspended centrally by a fine thread at about its eye level. The red object served as an imprinting object. Water and food were available ad libitum.

Apparatus

Training and testing took place in a separate room close to the rearing room. The experimental apparatus consisted of a white circular arena (diameter 66 cm x 50 cm high), a screen (15.5 cm wide x 13 cm high) and a confining cylinder (10 cm wide x 25 cm high) in which the chick was placed during the training and testing sessions. The confining cylinder had a small opening facing the center of the arena. This opening had the same dimension and position as the windows on the home cages (8 cm high, 2.7 cm diameter). The screen was made of a plastic opaque blue sheet and it was placed at 30 cm from the closest part of the confining cylinder. The experimenter could rotate the screen upward (to reach a vertical position) and downward (leaning it forward on the apparatus floor) from above the experimental arena to hide or reveal the space behind the screen. Behind the screen, a camouflaged sliding door in the floor made possible for the experimenter to secretly remove or place the target object behind the screen out of the chicks' view. A red object identical to the imprinting object was used during the training and the test. The experimenter could move the object within the arena with a fine thread held from above. A video camera was placed above the confining cylinder and recorded the whole test session.

Procedure

On day 4 or 5 after hatching all chicks underwent a short familiarization session to get acquainted with the test apparatus and the movement of the red cylinder. Chicks were gently placed inside the confining cylinder and they could put out the head through the window. The red object was used as the target that was moved between the confining cylinder and the screen

(which was in vertical position), but importantly the object never went behind the screen, thus chicks did not experience the occlusion of the object in this phase. Mealworms were placed on the top of the red object so if the chick put the head out of the cylinder and the red object was at reachable distance the chick could get the mealworm. Therefore, it served as reinforcement for putting out the head and also for following the movements of the object. After the chick ate the mealworm on the top of the red object, the object was removed from the arena and the mealworm was replaced. The red object was always inserted and removed centrally at the back of the experimental arena, opposite to the confining cylinder. The familiarization phase lasted 10 minutes for each chick.

On day 8 after hatching chicks participated in the test of one of the four experiments. Every test session started with a short warm-up period, in which chicks were presented with the upward/downward rotating movement of the screen and the left/right movements of the red object. First, the screen was moved upwards and downwards three times. After the last movement, the screen remained in vertical position. Afterwards, the red object was moved from near the window of the confining cylinder towards the screen and then behind the screen, and thus disappearing from the chick's sight. Then the red object was moved back from behind the screen to the window of the confining cylinder. This action was repeated once on the left and once on the right side. Afterwards the screen was rotated downwards to horizontal position, and the red object was moved from near the window of the confining cylinder in the space behind the edges of the lowered screen, and then it was moved back to the cylinder. After the warm-up period the test events followed.

The test events were different depending on the experimental conditions, but followed the same basic two phases. First, chicks were presented with events in which the target object was either hidden behind the screen or was removed from the arena. Afterwards the screen was dropped and it revealed an expected outcome (congruent with the previous event, e.g., the object appeared from behind the screen after it was hidden behind the screen) or an unexpected outcome (contradicting the previous events, e.g. the object appeared from behind the screen after it was removed from the arena). The outcome was presented for approximately 30 seconds, with a small variance due to the natural variation of the movement of the experimenter while rotating upwards the screen at the end of the trial.

3.3. Study 1

Experiment 1. Encoding Presence

At the beginning of each test trial, the screen was set in vertical position and afterwards one of two kinds of events was presented to the chicks (n = 27, 13 females, 14 males). In all experiments trials were counterbalanced in an ABBA order, in a total of four test trials (where As and Bs stand for the two conditions, counterbalanced across participants). In the Unexpected Disappearance condition the object was first placed behind the screen but then it was secretly removed from the arena through a sliding door hidden behind the screen, in a way that chicks could not see the removal (*Figure 3.1*). In the outcome phase the screen was dropped and it revealed the empty space behind the screen (contradicting the previous events experienced by the

chick). In the Expected Disappearance condition the object was removed from the arena in the full view of the chick. In order to equalize the amount of noise and to approximately even up the time passing before the outcome, the sliding door was moved back and forth similarly to the Unexpected Disappearance condition. In the outcome phase, the screen was dropped and it revealed the empty space behind the occluder (in accordance with the previous events experienced by the chick). The movement of the object was counterbalanced within subjects: it was removed or moved behind the screen from once left and once right in both conditions across the four trials, order counterbalanced.

Experiment 2. Encoding Absence

Initially the screen was in horizontal position and afterwards one of two kinds of conditions was presented to the chicks (n = 28, 15 females, 13 males). In the Unexpected Appearance condition the object was visibly removed from the arena and then the screen was positioned in vertical position (hiding the space behind it). Afterwards the object was secretly placed behind the screen, through the sliding door, in a way that chicks could not see the placement. In the outcome phase the screen was dropped and the object was revealed. In the Expected Appearance condition the object was moved towards and placed behind the lowered screen. Afterwards, the screen was raised in vertical position – covering the object – and, to equalize the amount of noise and to approximately even up the time passing before the outcome, the sliding door was moved back and forth similarly to the Unexpected Appearance condition. At the end of the trial, the screen was dropped revealing the presence of the object. The movement of the object was

counterbalanced within subjects: it was removed or moved behind the screen from once left and once right in both conditions across the four trials, order counterbalanced.

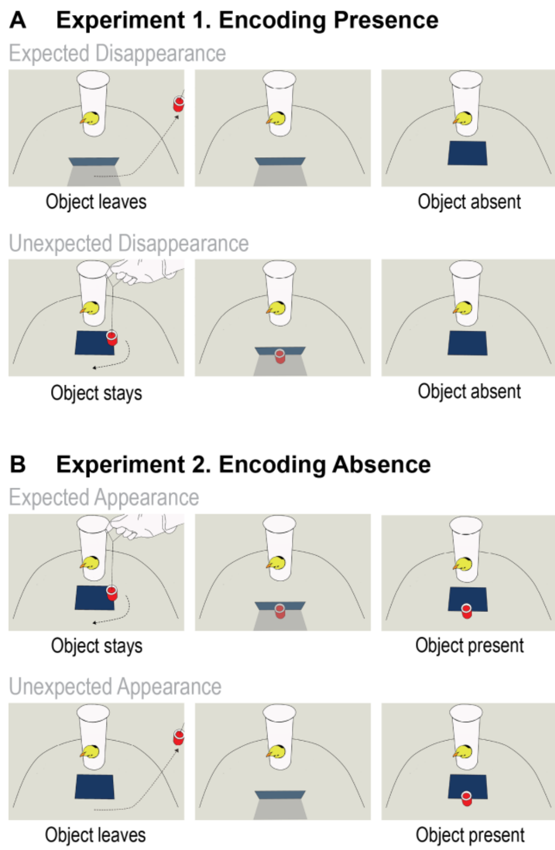

Figure 3.1. Schematic illustration of the events in Experiments 1 and 2 (A) Experiment 1 - Encoding Presence. The upper panels depict the events in the Expected Disappearance condition, where the target object was removed from the arena before the screen was lowered revealing the empty space behind it. The lower panels depict the events in the Unexpected Disappearance condition, where the target object was placed behind the screen visibly to the chick but then it was secretly removed from the arena. When the screen was lowered, it revealed the empty space behind. (B) Experiment 2 - Encoding Absence. The upper panels depict the events in the Expected Appearance condition, where the target object moved behind the screen and when the screen was lowered, it revealed the presence of the object. The lower panels depict the Unexpected Appearance condition, in which the target object was visibly removed from the arena, and then the vertical position of the screen was restored. Afterwards, the target object was secretly re-introduced into the arena, and when the screen was lowered, it revealed the target object.

3.4. General data analyses

The looking behavior of the chicks was coded offline, analyzing the position of the head when it was outside of the confining cylinder (minimum the whole beak of the bird had to be outside) towards to the region of interest (the test outcome: object being present or absent). Every trial was coded frame-by-frame using a transparent plastic sheet displaying the coding angles to determine the visual hemifield used to look at the outcomes. The midline was positioned on the centerline of the beak and right monocular field was defined as 15-135° from the middle, left monocular field was defined as -15/-135° from the middle and binocular field was specified as ±15° from the middle. Fields of view falling outside of these values, looking down (when the beak was not visible) and looking up (one eye was positioned up) were discarded from the data analyses. In Experiment 1, where no object was present in the outcome phase of either condition, the region of interest was defined as the space that was earlier covered by the screen (lasting till edges of the lowered screen). In Experiment 2 where an object was present in the outcome phase, the region of interest was defined as the boundaries of the object beyond the lowered screen. The reliability of coding was strengthened via a comparison between the originally coded data and a second data set of 10% of the participants coded by a blind coder. The two data sets highly correlated ($r = 0.98$).

We derived two dependent variables from the coded values: looking time and an eye use preferential index. Looking Time was the sum of the left, the right and the binocular eye usage during the 30 seconds. Laterality Index was calculated as the ratio of the difference between left

and right eye usage compared to the total of left and right eye usage (i.e. (Left-Right)/(Left+Right)).

Based on former research with human infants (Baillargeon, Spelke & Wasserman, 1985) and rooks (Bird & Emery, 2010), we expected longer Looking Times for unexpected outcomes. We also coded which eye the chicks used to inspect the scene, and calculated a Lateralization Index, the difference between left and right eye usage proportional to the total eye usage. The Lateralization Index was found to express chicks' preference to inspect a scene with the left eye (positive values) vs. the right eye (negative values), and is modulated by the novelty of the object attended (Rogers & Anson, 1979; Dharmaretnam & Andrew, 1994). In several species of birds with laterally-placed eyes and complete decussation of visual fibers at optic chiasma, such as domestic chicks, the preferential use of the left eye (mainly feeding contralateral right brain structures) is associated with response to novelty (Rogers, Vallortigara & Andrew, 1994).

3.4.1. Results

The Looking Times were differently modulated as a function of the outcomes violating or confirming the chicks' expectations of the presence and the absence of the object (*Figure 3.2*). A 2x2x2 ANOVA with Experiment (Experiment 1: Encoding Presence vs. Experiment 2: Encoding Absence), Outcome (Expected vs. Unexpected) and Sex (Female vs. Male) as factors yielded a significant interaction between Experiment and Outcome ($F(1,51) = 4.66$, $p = 0.036$), with no other effects. Human infants show similar looking patterns to such scenes (Wynn & Chiang, 1998; Kaufman, Csibra & Johnson, 2003), and it was suggested that they are more sensitive

(displaying longer looking time) to violations of presence compared to violations regarding the absence of objects.

A 2x2x2 ANOVA performed on the Lateralization Index revealed a significant Experiment by Outcome interaction ($F(1,51) = 4.652$, $p = 0.036$), with no other significant effects. A marginally significant interaction was present between Outcome and Sex factors ($F(1,51) = 3.601$, $p = 0.063$). Following up on the Experiment by Outcome interaction, post hoc Scheffé test showed that subjects displayed a greater left eye bias in Experiment 2 (Encoding Absence, M = 0.193, SD = 0.517) compared to Experiment 1 (Encoding Presence, M = -0.138, SD = 0.459, $p = 0.023$) in Unexpected Outcome conditions. This suggests that the Lateralization Index was sensitive to violations of expectation regarding the absence of objects, but not regarding the presence of objects. A positive Lateralization Index reflects a left eye bias, which was previously linked to detecting novel outcomes (Rogers & Anson, 1979; Dharmaretnam & Andrew, 1994). In line with the previous finding, a comparison of the Lateralization Index to chance level (0) in the two conditions of the two experiments indicated a left eye bias (M = 0.193, SD = 0.517, $t(27) = 1.974$, $p = 0.059$) only in the Unexpected Appearance condition of Experiment 2. Thus, while there is currently no report suggesting that human infants (Wynn & Chiang, 1998; Kaufman et al., 2003) or other animals would spontaneously encode absence, the left eye bias found here points to the spontaneous representation of absence in 8-day-old chicks.

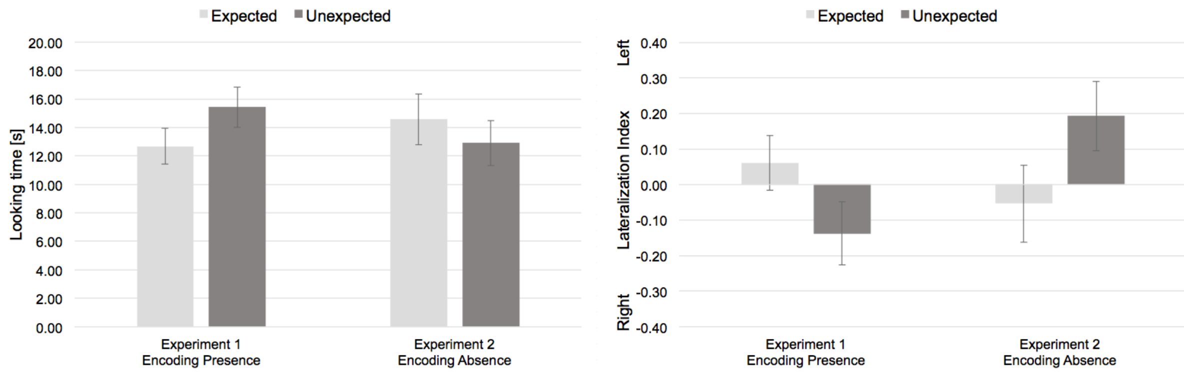

Figure 3.2. (A) Mean values of Looking Times as a function of experiments and types of outcomes. Error bars represent standard error of the mean. (B)Mean values of Lateralization Index as a function of experiments and types of outcomes. Error bars represent standard error of the mean.

3.4.2. Discussion

The left eye bias, found in response to the unexpected appearance of the object, likely reflected the chicks' exploration, and attempt of identification, of the unexpectedly emerging 'new' item. Importantly, this item was new only if chicks had encoded that the identically looking familiar item left, and so it was absent from the scene. They were prompted to investigate the 'new' object more carefully with their left eye because they expected the absence of the old object. There are several possible representational descriptions underlying such a behavior. On the one hand, the chicks might have encoded that there was no object behind the screen. Alternatively, the chicks' reaction to the unexpected appearance could have been perceptually driven and derived from detecting the mismatch between the memory of the empty space behind the screen (i.e., an iconic, picture-like representation of the empty floor and the wall of the testing arena) and the perceived outcome (i.e., the scene with the object). A second explanation might be that

the chicks did not encode the absence of the object, but tracked the location of the target object even when it left the scene (i.e., they encoded that it was somewhere outside the arena), and the left eye bias reflected their ‘surprise’ of seeing this object at an unexpected location (i.e., behind the screen, inside the arena). In Study 2 we aimed to test these alternative explanations, respectively, and aimed at replicating the findings from Experiment 2. Experiment 3 (Computing Absence) followed the steps of Experiment 2. However, unlike in Experiment 2, each trial started with the screen in upright position preventing the chicks to see the space occluded by the screen at the beginning of the trial (*Figure 3.3*). This manipulation aimed at testing chicks’ ability to update their expectation about what is (not) behind the screen without giving them the opportunity to perform perceptual comparison between an initial empty scene and the outcome. Experiment 4 (Absence vs. Tracking) was the same as Experiment 3, except that in the Unexpected Appearance condition the target object that moved behind the screen and then left the scene was different from the object that appeared when the screen was lowered in the outcome phase. Finding the second object at the previously empty location should not be surprising if chicks simply track the location of the first target object. However, finding an object at a location that is represented as empty would lead to surprise even if this object is different from the one that has left.

3.5. Study 2

Experiment 3 (Computing Absence)

Procedure was similar to Experiment 2 except the following changes. In the warm-up phase the screen was moved upwards and downwards three times, stopping in a horizontal position while the object was moved left and right twice. Then the same movement was repeated with the screen in vertical position. In Unexpected Appearance condition the object was moved behind the screen and then it was removed from the arena visibly to the chicks (n = 31, 15 females, 16 males). Before the end of trial, the object was secretly placed behind the screen, through the secret door. At the end of the trial, the screen was dropped and it revealed the object (contradicting the previous events experienced by the chick). In Expected Appearance condition, first the object was moved behind the screen and then to equalize the movements in the two conditions, it was moved halfway within the space between the screen and the edge of the arena to reveal it again for the chick, and afterwards it was moved back and placed again behind the screen. At the end of the trial the screen was dropped revealing the object (in accordance with the previous events experienced by the chick).

Experiment 4 (Absence vs. Tracking)

In this experiment (n = 23, 9 females, 13 males) the familiarization phase also differed slightly, in the sense that we used two objects both in the familiarization and in the test session. One object – just as in the other three experiments – was identical to the red imprinting object provided for all chicks in their home cages from the first day of life. The other object (hereafter the green object) was first introduced during the familiarization. This object had the same shape and size as the red object but it was green with yellow stripes on the bottom and top part. During

the 10 minutes of the training session these two objects were alternated. In the test session, the pre-test phase was the same as in Experiment 3 with the exception that the two objects were presented in turns; once the red was moved left and right and then the green object was moved to left and right while the screen was in horizontal position and the same movements were presented while the screen was in vertical position.

The expected events were similar to the events in Experiment 3. In the Unexpected Appearance condition the green object was moved behind the screen and then it was removed from the arena in the view of the chick. Afterwards the red object was secretly placed behind the screen through the sliding door. At the end of the trial the screen was dropped uncovering the red object.

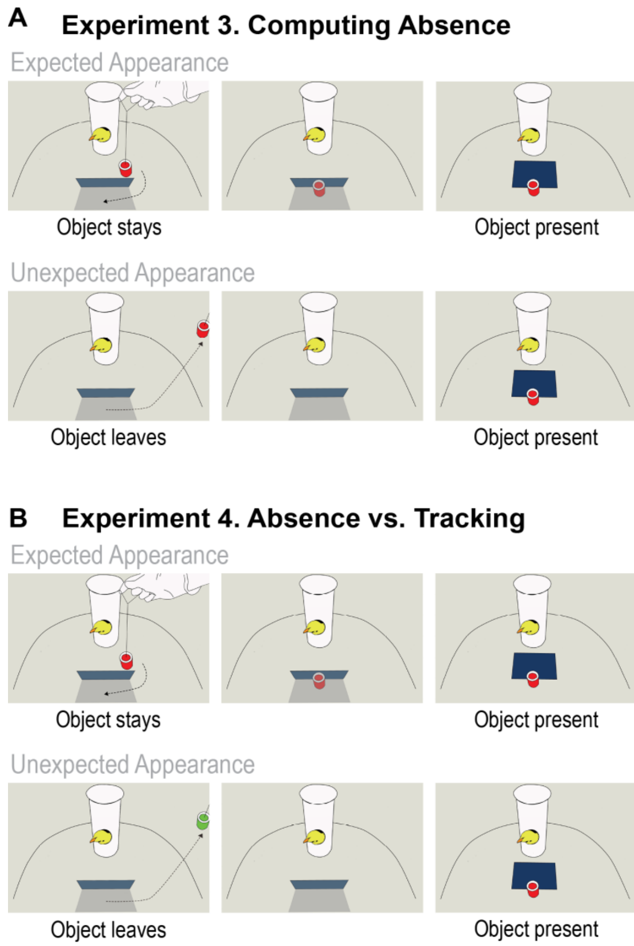

Figure 3.3. Schematic illustration of the events in Experiment 3 and 4. (A) Experiment 3 – Computing Absence. The upper panels depict the event in the Expected Appearance condition, where the target object moved behind the screen and when the screen was lowered, it revealed the object behind. The lower panels depict the events in the Unexpected Appearance condition, in which the object first moved behind the screen and then it was visibly removed from the arena. Afterwards, the object was secretly placed behind the screen and when the screen was lowered, it revealed the object. Note that, in both conditions, the screen initial position was vertical. (B) Experiment 4 – Tracking vs. Absence. The upper panels depict the events in the Expected Appearance condition, which was identical to the same condition in Experiment 3. The lower panels depict the Unexpected Appearance condition the target (green) object first moved behind the screen and then it was visibly removed from the arena. Afterwards the red object was secretly re-introduced behind the screen. In the outcome phase, the screen was lowered and the red object appeared.

3.5.1. Results

We evaluated the Lateralization Index in the three experiments that probed the chicks' encoding of the absence of objects (Experiment 2, 3, 4) with a 3x2x2 ANOVA with Experiment, Outcome, and Sex as factors (*Figure 3.4*). We found a main effect of Outcome ($F(1,75) = 6.273$, $p = 0.014$), reflecting a left eye bias (more positive values) for the Unexpected Appearance outcomes (M = 0.123, SD = 0.506) compared to the Expected Appearance (M = -0.048, SD = 0.498) outcomes. We also found a significant interaction between Outcome and Sex ($F(1,75) = 4.157$, $p = .045$). Post hoc Scheffé test revealed that females were more sensitive to the difference between the outcomes. While males did not appear to discriminate between expected (M = 0.029, SD = 0.402) and unexpected outcomes (M = 0.065, SD = 0.506, $p = 0.738$) females differentiated between outcomes where the object appeared unexpectedly (M = 0.177, SD = 0.509) and outcomes when it appeared expectedly (M = -0.156, SD = 0.556, $p = 0.003$). When comparing the Lateralization Index to chance level (0), female ($t(38) = 2.173$, $p = 0.036$) but not male chicks ($t(41) = 0.837$, $p = 0.407$) showed a statistically significant left eye bias when they were confronted with the appearance of an object at a location that should have been empty. These results point to a sex-dependent abstract representation of absence in chicks, which is not attributable to perceptual mismatch (Experiment 3) or the expectation of the presence of the imprinted object at a different location (Experiment 4).

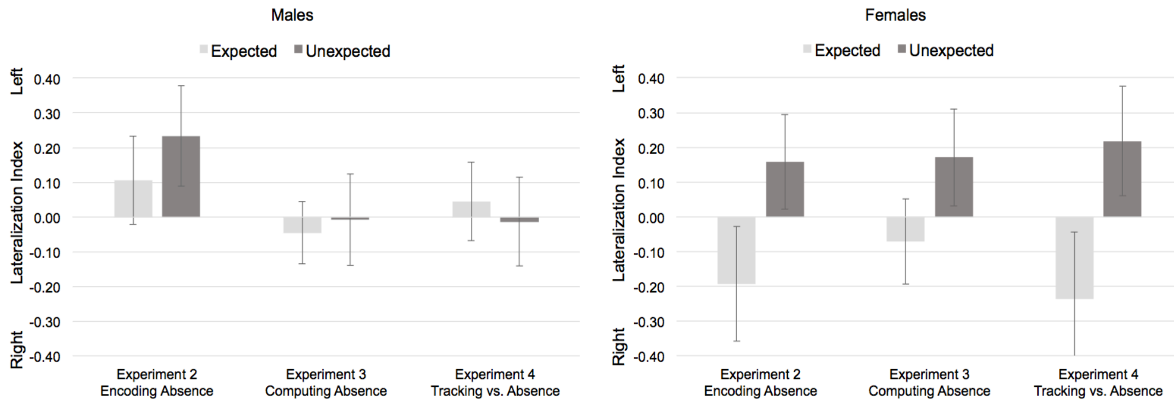

Figure 3.4. Mean values of Lateralization Index as a function of experiments and types of outcomes for male (left) and female (right) chicks. Error bars represent standard error of the mean.

3.5.2. Discussion

In Study 2 we aimed to clarify the underlying representation of chicks' behavior in Experiment 2. In Experiment 3 we tested whether chicks' reaction was driven from detecting a perceptual mismatch between the memory of empty space behind the screen and the perceived outcome. In Experiment 4, we investigated another potential account for chicks' behavior in Experiment 2, specifically whether chicks represented the location of the target object (somewhere), instead of encoding the absence of objects behind the screen. Analyzing the three experiments targeting the absence of objects, we found a consistent sex-dependent left eye bias in response to violations of expectation about the absence of objects. Such data reflects an abstract representation of absence, and not the mere encoding of a perceptual mismatch (Experiment 3) or the expectation for the presence of the object at a different location (Experiment 4). We found evidence for a spontaneously, however not automatic encoding the absence of objects in 8-day-old chicks.

3.6. General Discussion

Several studies have shown that human infants (Wynn & Chiang, 1998; Kaufman et al., 2003) as well as other primates (Amici, Aureli & Call, 2010) and avian species (Vallortigara et al., 1998; Regolin et al., 2005; Chiandetti & Vallortigara, 2011), represent the presence and the location of an object or agent even if it is no longer directly perceivable for them. Such a feat was proposed to be achieved by creating and maintaining an object index (Scholl & Pylyshyn, 1999) or an object file (Kahneman et al., 1992), which is dynamically linked to the location of the object and survives its occlusion. While such a tracking system can encode the presence of physical objects or animate agents at specific locations, it seems to break down at representing their absence (Scholl & Pylyshyn, 1999, Cheries et al., 2008). Indeed, previous research indicates an asymmetry between these two cognitive abilities (Hearst, 1991). While human adults (Newman et al., 1980) and pigeons (Hearst, 1984) readily learn the relation between the presence of a stimulus and reinforcement, they have difficulties with recognizing the relation between the absence of a stimulus and reinforcement. Furthermore, human infants show remarkable capacities of object representation (Carey, 2009), but spontaneously representing the absence of an object seems to exceed their abilities (Wynn & Chiang, 1998; Kaufman et al., 2003). Thus, grasping absent entities likely exploits cognitive mechanisms that are distinct from those recruited for representing presence.

We developed a new paradigm to investigate domestic chicks' spontaneous expectations regarding presence and absence of objects. Similarly to human infants (Wynn & Chiang, 1998; Kaufman et al., 2003), chicks' looking times towards expected and unexpected outcomes were

differently modulated in experiments testing the representation of presence and absence of an object. Remarkably, we found evidence for young chicks' ability to represent the absence of an object in their eye usage. The results of Experiment 3 ruled out the possibility that the left eye bias associated with the novelty of inspected stimuli was the result of a mismatch between information stored in perceptual memory and the outcome of the scene. Experiment 4 showed that preferential left-eye use was independent of tracking the approximate location of a specific object. Altogether, our findings support the conclusion that female chicks encode not only the presence but also the absence of objects in their environment.

We propose that the left eye bias reflects chicks' attempt to identify a novel object that appeared at a location expected to be empty. Two arguments support this interpretation. First, the left eye bias was found only for outcomes involving an object, but not when the chicks were confronted with an empty space (Experiment 1). Second, the left eye bias was prominent in females compared to males, and such sex-dependent differences are congruent with findings in social discrimination experiments with chicks. Female chicks are more interested in familiar social partners, while males are more interested in unfamiliar ones (Vallortigara, 1992), and these preferences are also observed in experiments using artificial social partners (Vallortigara & Andrew, 1994) and different sensory modalities (Versace, Spierings, Caffini, ten Cate & Vallortigara, 2017). These preferences most likely are related to eco-ethological characteristics of this species. Specifically, in natural populations adult fowls exhibit territorial behavior, wherein single dominant cocks maintain and patrol a large territory within which a number of females live, and this sort of social organization favors the prevalence of gregarious and affiliative behaviors in females (McBride & Foenander, 1962; Andrew, 1966). Furthermore, females are more inclined to use the right eye for a conspecific and the left eye for a novel

stimulus (Dharmaretnam & Andrew, 1994), and 8-day-old chicks prefer to look at an approaching unfamiliar object using their left eye (Rogers & Anson, 1979). These findings support the idea that female chicks in our experiments identified the unexpectedly appearing object as a novel, unfamiliar object, even when it looked identical to an object they were familiarized (and, in fact, imprinted) to. Thus, the chicks attempted to re-identify the object despite its match to the imprinted perceptual profile, possibly because they deemed it unfamiliar as its presence on a location represented as empty contradicted their expectation.

While our data provide evidence that 8-day-old chicks can encode the absence of objects — a representation that goes beyond perceiving empty space — the nature of this capacity was not directly addressed here. Following Nieder's taxonomy (Nieder, 2016), the chicks in our study might have encoded absence either in a numerical or a categorical representational format. Regarding the numerical format, studies have shown that the approximate number system provides numerical representations to pre- and non-linguistic creatures as well (Dehaene, 1997; Piazza, 2010; Haun et al., 2011; Brannon & Merritt, 2011; Brannon & Roitman, 2003). Absence could be represented by this system as an approximate numerical value of less than one. The other possible mechanism for encoding absence is via categorical representations, which are recruited in perceptual decision tasks to contrast the absence of an object to its presence (Merten & Nieder, 2012). According to the theoretical proposal of Bermúdez (2003), pairs of contrary concepts, like absence/presence, living/dead should be available for non- and pre-linguistic creatures. Indeed, the capacity to judge whether a particular stimulus is present or absent (Merten & Nieder, 2012), and to report absence using symbolic cues (Herman & Forestell, 1985; Pepperberg & Carey, 2012), was found in various species. In our experiments, chicks might have encoded either the approximate number of objects behind the screen (~1 or ~0), or formed a

categorical representation of the presence or absence of objects behind the screen. However, one aspect of our results supports more the option of a categorical encoding of absence: in Experiments 2, 3 and 4, the female chicks were ready to identify the imprinting object as an unfamiliar one, which suggests that they relied on strong evidence regarding its identity (i.e., that it was not the imprinting object). Representing the approximate number of objects behind the screen (i.e., 'roughly zero') is unlikely to lead to such a conclusion. In contrast, a categorical expectation about having no object at a particular location would support identifying the object as a novel one.

Importantly, in former studies animals who managed to use absence information were heavily trained to do so. In contrast, the chicks in our study did not form the representation of absence via a long training with different quantities or via detecting a perceptual mismatch, but spontaneously inferred it from tracking where objects were and were not present. The fact that 8-day-old chicks could form such expectations without any training points to the fundamental nature of such representations. In our case, the chicks did not receive any training regarding categories of objects that were present or absent, nevertheless their performance indicated their readiness to process this type of information. Such an ability could serve not only foraging and safety purposes (i.e., encoding and maintaining the absence of food or predators at a specific location) but could also contribute to the re-identification of entities in the animal's environment, and in humans would also support the development of abstract concepts, such as 'zero' and 'nothing.'

4. Chapter 4. Neural signatures of maintaining and discarding object indices in 6-month-olds

4.1. Introduction

Following the path of soap bubbles through their existence lucidly demonstrates episodes of object appearance (quasi out of nothing) and disappearance. Human cognition has a tendency to presume that physical entities around us continue their existence unless there is evidence for their annihilation. This idea is so deeply planted in our cognition that the assumption that things persist is implemented in our perceptual system. Michotte was the first who investigated – among other influential research topics – how the visual system copes with incomplete visual input due to, for instance, occlusion (Wagemans, van Lier & Scholl, 2006). Following this scientific endowment, several experiments were developed to investigate the mechanism behind object constancy (Scholl & Phylyshyn, 1999) and how it develops in human infants (Bower, 1967; Kaufman et al., 2003; 2005). Objects can disappear from sight in several ways, for instance, they can fall apart into tiny pieces, fade away, can be gradually occluded, or simply they can stay at their location while the observer turns away. Some of the disappearances lead to the experience of the object being annihilated, going out of existence; while other disappearances seem to be part of normal events occurring to objects, and do not contradict their continued existence. According to Michotte's description, the disappearance of objects can be discriminated based on the following factors: whether it is abrupt (without intermediate states) or gradual, perspectival or non-perspectival, extends to the whole visual field (i.e. when we switch off the light in the dark room) or it is local. While some disappearances evoke the experience of

objects' annihilation, others like gradual, perspectival disappearance elicits the perception of occlusion (cited by Bower, 1967).

Studies investigating mid-level object representations confirmed the presence of such differentiations in object perception. Scholl and Phylyshyn (1999) demonstrated that representations provided by automatic object based visual processes (e.g. FINST model) are sensitive to the specific way of disappearance. According to the FINST model, the visual system assigns indices to objects and based on these mid-level representations we are able to trace them continuously through space and time. The typical paradigm to test this system is presenting 2D moving discs to participants and the task is to keep attention on the target objects among distractors. The typical finding is that healthy adults can track approximately four objects simultaneously (Pylyshyn, 2001; Scholl, Pylyshyn, & Feldman, 2001). The performance is unimpaired when target objects gradually disappear and reappear, corresponding to occlusion events. In contrast, participants' accuracy decreases when objects a) instantaneously disappear and reappear, or b) gradually implode and explode from their centers (Scholl & Phylyshyn, 1999). Systematic investigation of object persistence in infants (Kaufman et al., 2003; 2005) revealed similar maintaining and discarding of mid-level object representations. They contrasted object occlusion and object disintegration events, and recorded the neural correlates of the involved mechanisms (Kaufman et al., 2005). Differences in gamma-band oscillations were registered, suggesting maintenance in occlusion but discarding the object index in the latter condition. Specifically, Kaufman and colleagues (2005) measured higher activation in the occlusion than in the disintegration condition over the right temporal areas. Bower (1967) also described a sensitivity to the disappearance of objects already in 1.5-month-old infants. Furthermore, object indices seem to be defined by the principle of object cohesion in 10-12-

month-old infants. Infants' capacity to track the number of objects is disrupted by the violation of the unity of an object (Cheries et al., 2008). While 10-12-month-olds consistently choose the larger amount of crackers hidden into a container (i.e. a container with 2 crackers over a container with 1), they fail to do so when a big cracker is split into two before the hiding event.

Studies specifically testing the neural underpinnings of mid-level object representations in adults have consistently found activations of the frontal (frontal eye fields, precentral sulcus), parietal (intraparietal sulcus, superior parietal lobe) and temporal regions (MT motion area, MST) (Culham et al., 1998; Jovicich et al., 2001; Wolf et al., 2018). The development of the neural structures of similar capacities in infancy showed consistent results. In 3-month-oldinfants occipital, temporal and prefrontal areas were found to be responsive for observing moving objects (Watanabe, Homae, Nakano & Taga, 2008). Investigating the early specialization of these regions revealed the involvement of the anterior temporal regions in the featural encoding of an object, while posterior temporal regions were more likely to be related to representations of object indices (Wilcox, Haslup & Boas, 2010; Wilcox, Stubbs, Hirshkowitz & Boas, 2012). Beyond investigating the neural mechanisms of tracking objects, there are specific studies targeting the neural correlates of object disappearance in infants, specifically investigating the neural underpinnings of processes involved in encoding object persistence through occlusion. Baird and colleagues (Baird et al., 2002) conducted a longitudinal study in which infants' prefrontal cortical activity was measured between the age of 5 and 12 months. Infants saw a small object covered by the experimenter and were free to search for it after the hiding event. Higher prefrontal activation was present in the trials in which the infants reached for and retrieved the object – so they showed behavioral evidence for maintaining the presence of the object – compared those trials in which they did display such behavior. However, reaching

towards and retrieving an object could rely on demanding processes both cognitively and action-wise. Thus difficulty in these capacities might mask the ability to encode object permanence that might be present earlier than infants are able to retrieve hidden objects (Baillargeon et al., 1985; Baillargeon, 1986). Additionally, as mentioned earlier, studies relying on infants' simple observations of scenes, found temporal activation in response to maintaining the persistence of occluded objects (Kaufman et al., 2003). This raises the question whether frontal areas have specific role in object maintenance or rather, in the planning and implementation of actions related to the object. Reviewing the literature on object cognition discussing developmental data and targeting specifically the neural basis of object-based working memory, Káldy and Sigala (2004) questioned the importance of prefrontal cortex in encoding and maintaining an object at a location. Considering the evidence, they argued for the central role of the development of the medial temporal lobe in object perception and visual working memory. Thus to sum up, it is still unclear from earlier research how infants represent various disappearance events, and how the object tracking system encode different manipulations on the object indices.

In the present research we focused on the neural underpinnings of maintaining and discarding indices of objects, specifically we targeted the temporal and frontal areas. We tested neural processing in 6-month-olds infants for three kinds of disappearance events, two involving maintaining an object representation and one requiring discarding it. In the one condition the object was occluded (Occlusion condition), in the second (Vanishing condition) one it vanished (i.e. gradually dissolved). Based on former research, we expected that infants show signatures for maintaining the persisting object during occlusion and for discarding it in the vanishing condition. Additionally, we introduced a third kind of disappearance (Mingling condition), in which the object was visually accessible but it was difficult to maintain its index as it mingled in

a crowd of identical objects. Studies testing the limitations of the object tracking system, specifically the minimum size of the region that can be selected by attention, found that with decreasing the distance between targets and distractors, there is an increase in attentional demands and participants' performance decreases, making less likely the maintenance of the object representation (Intriligator & Cavanagh, 2001).

As a signature for object persistence we expected the activation of temporal lobe (Kaufman et al, 2003; 2005) in the occlusion condition. Activation in the frontal areas was also in our focus for these conditions, given that its involvement in object specific working memory and object maintenance is found in some studies (Baird et al., 2002; but see Káldy & Sigala, 2004). Regarding the condition involving disappearance via vanishing, we expected the deletion of the object index, and thus we hypothesized a weaker activation in the areas supporting the maintenance of an object during the occlusion event. For the third type of disappearance (Mingling condition), two alternative outcomes are possible. According to the first alternative one might observe similar activation patterns as in response to the occlusion event. This would reflect infants' effort to maintain the object's index, even without the precise location. The second alternative would be to observe similar activation in this condition to the dissolving event. That would imply the cancellation of the object representation without the definite spatial information.

4.2. Methods and Materials

fNIRS method

To measure the neural signatures of our participants in response to the three kinds of events, we used near-infrared spectroscopy (NIRS). This non-invasive technique, similarly to fMRI, measures the hemodynamic changes of the brain tissues, however it is based on the reflection of light. This technique relies on the fact that a specific spectrum of light (red and near-infrared) is transparent for biological tissue, and in this way one can emit a light-beam into the head and measure the amount of the reflected light that will be different depending on whether in a specific brain area there is more or less oxygenated blood at that specific time. This light-beam is similar to the light reaching the scull on a normal sunny day, and thus is not an invasive intervention. Based on specific light absorption properties, NIRS can detect the relative changes of oxy-haemoglobin (HbO2) and deoxy-haemoglobin (HHb) in the blood. Participants' scalps are illuminated with specific light sources. Using detectors, the reflected light is measured while the participant is watching the various events, and from the relative change of the light reflection, we can infer for the changes in the hemodynamic responses. Specifically, we expect that in response to increased activation in a specific area in the cortex, the level of HbO2 increases and the level of HHb decreases. The advantage of this method to fMRI, besides it noninvasive nature, is that it is less affected by motion artefacts (suitable for investigating awake infants observing experimental stimuli) and it provides better time-resolution, however its spatial resolution allows for less precise mapping.

Participants

Twenty-four 6-month-olds participated in this study (13 female, mean age 6 months and 1 day, range: 5 months and 17 days – 6 months 15 days). All infants were healthy and born full-term with normal weight. Thirty-two additional infants participated but were excluded from the analyses because of experimental error (3), infants' showing distress during the presentation (7), due to technical failures (2), due to the caregivers intervene (3), and because of the failure to look at least two test trials per condition (17). The study was approved by the United Ethical Review Committee for Research in Psychology (EPKEB), Budapest, Hungary and prior to participation written informed consent was obtained from parents.

Experimental procedures and data recording

During the study infants sat in their parents' lap in front of a 100 cm plasma screen with a viewing distance of approximately 1 m. The parent was asked to orient the infant towards the screen and not to interact with him/her unless the infant shows distress. The infants wore custom-built NIRS headgear consisting of 3 source-detector arrays with left, right and frontal blocks. There were 17-17 channels positioned over the right and left temporal areas and 7 channels over the frontal areas resulting in a total of 33 channels (source – detector separation: 2 cm). The data was recorded using the UCL topography system (Everdell et al., 2005). This system uses near-infrared light of two different continuous wavelengths at 770 and 850 nm. Assuming that the cortex is located approximately 0.5 cm from the surface of the skin (Salamon, Raynaud, Regis & Rumeau, 1990) the 2 cm source – detector separation allowed us to measure light reflection up to

a depth of 1 cm. Therefore the recording can measure the activity of the cortex near to the surface.

Stimuli

Each trial included a baseline and a test video. Baseline videos consisted of an abstract screensaver movie (a colorful moving digital object) played for a pseudo random duration that could take a value between 8 and 12 seconds. Afterwards a test video from one of the three conditions started. In all three conditions the scene started with displaying a target object at the center of the screen (a toy frog or a penguin), an occluder on one side of the screen and many objects identical with the middle target (a crowd of frogs or penguins) on the opposite side.

The three conditions were the following: Occlusion, Vanishing and Mingling (*Figure 4.1*). In the Occlusion condition the target object moved from the center of the screen to either the left or right side of the screen, and moved behind a rectangular-shaped occluder until it was fully covered. In Vanishing condition, the object moved downwards on the screen and when it reached its final position, the object gradually dissolved until it became completely transparent. In the third condition (Mingling), the object moved from the center of the screen either to the left or the right side and it moved among six identical closely spaced objects.

All infants saw the test videos in a mini block design, specifically one test video consisted of three movies from the same condition, each lasting for 4 s (resulting altogether in 12 s long test videos). Toys were alternated in the three repetitions of the same event (i.e. frog, penguin, frog videos, or penguin, frog, penguin). The visual complexity, the length of the movement

trajectories, and the duration of movements were matched in all conditions. There were short auditory stimuli marking the beginning of the movements in the tests to attract infants' attention. These were matched with auditory stimulation in the baseline videos as well (there were similarly complex sounds at the same time points in test and control videos). The conditions were played in pseudo random order with the restriction that the same condition could be repeated maximum two times.

Infants were presented with test videos until they became inattentive or fussy. Infants' behavior was video-recorded with a camera placed above the presentation screen. Looking behavior was coded off-line to exclude trials in which the participant did not attend all three repetitions of the same condition in a trial. Those infants were included in the analyses who attended at least 2 trials per conditions. The minimum number of trials was 6, the average number of the trials of the infants included in the analyses was 7.5 (range: 6-12 trials).

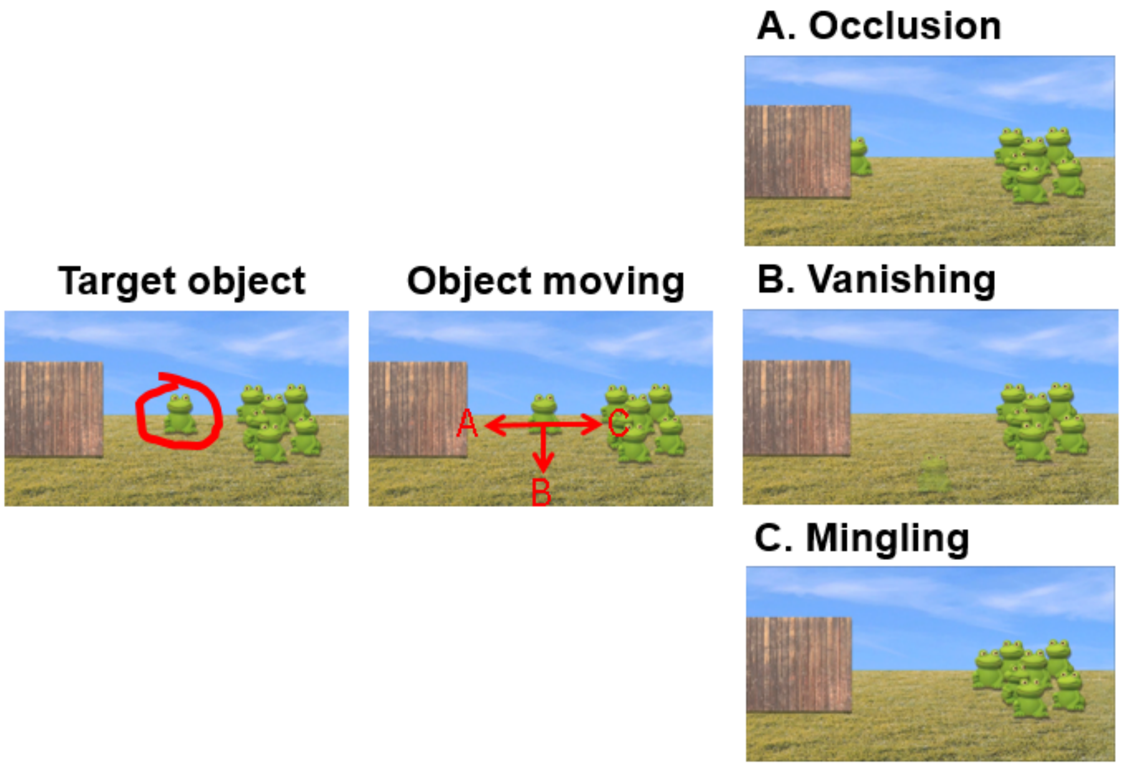

Figure 4.1. Schematic figure of the events of the experiment. After an initial period, the target animal moved towards the occluder, down or towards the group of identical objects. In Occlusion condition (A) the target moved behind the occluder. In Vanishing condition (B) the target dissolved. In Mingling condition (C) the target moved among the other animals. The red marks are only for highlighting, they were not displayed on the movies.

4.3. Data processing and analysis

To investigate which channels showed specific activations to the test conditions we performed statistical modeling of the data using the SPM-NIRS free toolbox (Ye, Tak, Jang, Jung, & Jang, 2009). We used a mass-univariate approach based on the general linear model (GLM). This method inspects the temporal variation of the signal rather than the magnitude of blood

hemoglobin concentrations. The analyses focused on the activation changes occurring during the test movies (12 s) and the consecutive 8 s of control period. The design matrix consisted of four regressors (Occlusion, Vanishing, Mingling, Baseline) for each infant. Each regressor had the same length as the total recorded data and was set to 1 at each time point of the presentation of the event, and to 0 for the rest of the time. This created a series of non-overlapping 'boxcars' for each infant with the exact beginning of the onset of conditions and control events. Excluded trials were not included in the model, meaning that those periods were set to zero. The regressors were convolved with the standard hemodynamic response function (HRF) to create a design matrix comprising 4 columns, modeling the 4 types of events for the entire duration of the recording session of each infant. This design matrix was fit to the data using the SPM-NIRS toolbox general linear model, modeling the HbO2 measurement. We analyzed only the HbO2, as previous studies indicated that the oxy-haemoglobin component is the most reliable for measuring increased cortical activations (Strangman, Franceschini & Boas, 2003; Lloyd-Fox, Blasi & Elwell, 2010; Southgate, Begus, Lloyd-Fox, di Gangi & Hamilton, 2014). To remove unknown global trends due to breathing, cardiac or vaso-motion, we used a wavelet-MDL function. To filter out high frequency components, we used a low-pass filter smoothing the data with a temporal gaussian filter set to 4 sec. After the data pre-processing, beta parameters were obtained for each infant, for each of the 4 regressors, for all 33 channels and these beta parameters were used in the statistical analyses. First we compared the 3 experimental conditions (Occlusion, Vanishing, Mingling) to Baseline (see *Table 4.1*) with multiple t-test comparisons. To ensure statistical reliability, a significant contrast between conditions at a single channel was considered meaningful only if there was also a significant contrast in the same direction at a spatially adjacent channel (Lloyd-Fox, Blasi, Everdell, Elwell, & Johnson, 2011; Southgate et

al., 2014). We approximated the cortical regions underlying the channels by the result of a MRI co-registering study using the same layout of channels in 6-month-olds (Lloyd-Fox et al., 2014).

4.4. Results

Widespread activation was observed in various channels in response to the Occlusion condition (*Figure 4.2.*) This activation included the left posterior temporal, temporo-parietal channels (ch 12, $t(23) = 2.691$, $p = 0.013$; ch 13, $t(23) = 3.647$, $p = 0.001$), the right temporal and temporo-parietal channels (ch 22, $t(23) = 2.320$, $p = 0.030$; ch 24, $t(23) = 2.856$, $p = 0.009$; ch 25, $t(23) = 2.237$, $p = 0.035$; ch 26, $t(23) = 3.618$, $p = 0.001$; ch 27, $t(23) = 3.152$, $p = 0.004$), occipital-temporal channels (ch 30, $t(23) = 2.650$, $p = 0.014$; ch 31, $t(23) = 3.047$, $p = 0.006$) and right frontal channels (ch 14, $t(23) = 2.179$, $p = 0.040$; ch 16, $t(23) = 2.445$, $p = 0.023$; ch 3, $t(23) = 2.710$, $p = 0.012$). The vanishing condition evoked activation only in the right temporo-parietal area (ch 26, $t(23) = 3.316$, $p = 0.003$; ch 27, $t(23) = 2.251$, $p = 0.034$). The activity of two adjacent channels was modulated significantly by the events in Mingling condition in the left posterior temporal, temporo-parietal area (ch 12, $t(23) = 3.245$, $p = 0.004$; ch 13, $t(23) = 2.603$, $p = 0.016$).

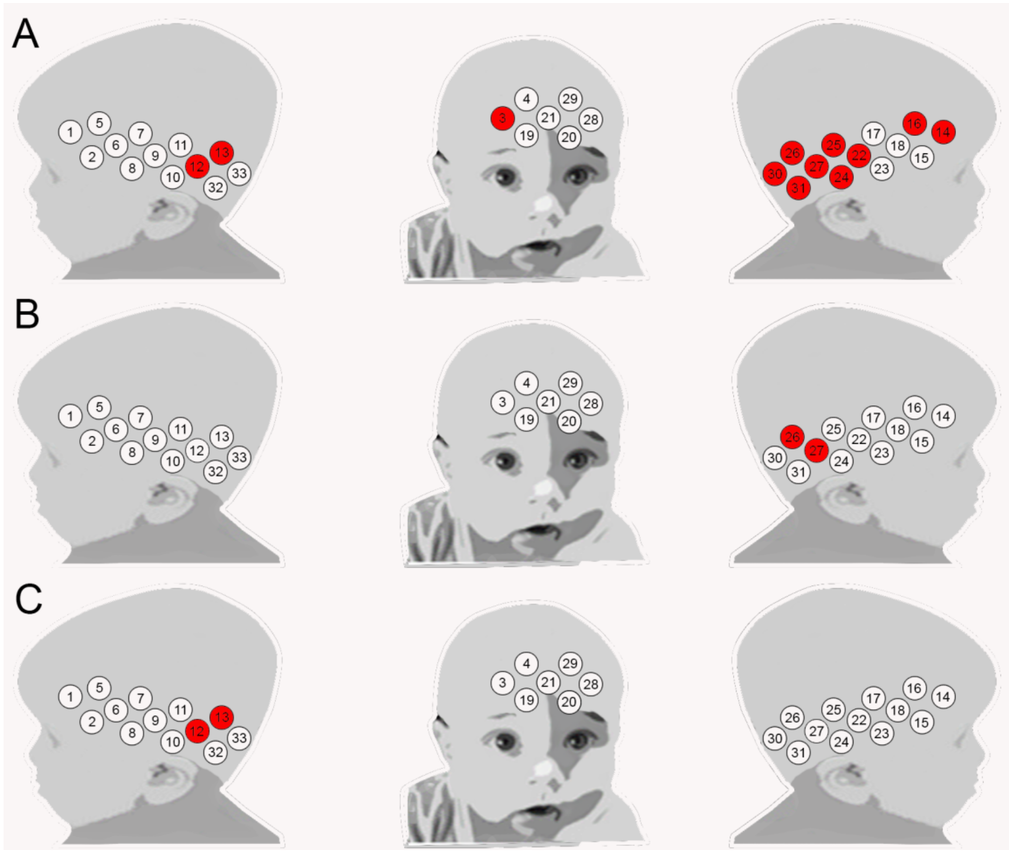

Figure 4.2. Differences between the three conditions and the Baseline. Red dots mark those channels in which the activation was significantly different in the test condition compared to the Baseline. The first row shows the channels in Occlusion condition (A), the middle row depicts the Vanishing condition (B) and the last row represents the Mingling condition (C).

Afterwards, we selected those channels that showed activation in comparison to the baseline event and used them to capture differences in cognitive mechanisms involved in processing the events in the different conditions. We calculated an averaged value for the following clusters of channels. The right frontal area cluster based on the average of channels 3, 13 and 16. The cluster of the right temporal areas included the average of channels 22, 24 and 27. The right

occipital cluster was calculated by taking the average of channels 30 and 31. Finally, the right temporo-parietal cluster included the mean values of channels 25 and 26.

When comparing the three conditions we found marginally significant effect of Condition ($F(2,46) = 3.139$, $p = 0.053$) in the right frontal cluster. Planned pairwise comparisons suggest that this effect was driven by the difference between Occlusion and Vanishing conditions (p = 0.017). There was no main effect of condition in right temporo-parietal cluster ($F(2,46) = 1.363$, $p = 0.266$), however, planned pairwise comparisons revealed a tendentious difference ($p = 0.095$) over the right temporal parietal channels between the Mingling and Occlusion conditions, where Occlusion evoked higher degree of fitness to our initial model of activation. There were no other effects in the right temporal areas, or in the right occipital-temporal region, neither significant planned pairwise comparisons in these areas.

Occlusion condition											
Left lateral pad				Right lateral pad				Frontal pad			
Channel	Mean difference	*t*	*p*	Channel	Mean difference	*t*	*p*	Channel	Mean difference	*t*	*p*
12	0,000779	2,691	0,013	14	0,000504	2,179	0,040	3	0,001023	2,710	0,012
13	0,000700	3,647	0,001	16	0,000311	2,445	0,023	28	0,000728	2,376	0,026
				22	0,000551	2,320	0,030				
				24	0,001362	2,856	0,009				
				25	0,000972	2,237	0,035				
				26	0,001143	3,618	0,001				
				27	0,001124	3,152	0,004				
				30	0,000795	2,650	0,014				
				31	0,001296	3,047	0,006				
				33	0,000480	2,992	0,007				

Vanishing condition											
Left lateral pad				Right lateral pad				Frontal pad			
Channel	Mean difference	*t*	*p*	Channel	Mean difference	*t*	*p*	Channel	Mean difference	*t*	*p*
33	0,000385	2,118	0,045	26	0,000847	3,316	0,003				
				27	0,000972	2,251	0,034				

Mingling condition											
Left lateral pad				Right lateral pad				Frontal pad			
Channel	Mean difference	*t*	*p*	Channel	Mean difference	*t*	*p*	Channel	Mean difference	*t*	*p*
12	0,001098	3,245	0,004	14	0,000576	3,892	0,001	28	0,000766	2,252	0,034
13	0,000367	2,603	0,016	15	-0,001245	-2,152	0,042				
				17	-0,000800	-2,268	0,033				
				30	0,000884	2,980	0,007				

Table 4.1. The values of Baseline and Condition comparisons. All channels are listed with the corresponding statistics of the multiple t-test comparisons.

4.5. Discussion

In this study, we measured the brain activation of 6-month-old infants in response to three different ways of object disappearance (Occlusion, Vanishing and Mingling) possibly inducing different manipulations on the object index. Indeed, in the Occlusion condition right frontal, temporal and temporal-occipital cortical activation was measured, most probably indicating the maintenance of the object index. These results are in line with former studies finding temporal (Kaufman et al., 2003) and frontal cortex (Baird et al., 2002) activation, supporting processes involved in computing object persistence. In contrast, we did not find such a widespread activation in the Vanishing and Mingling conditions. In line with our expectations, violating objecthood in the Vanishing condition induced less activation in these areas, likely indicating the discarding of the object index. Supporting this interpretation, we found significant difference between Occlusion and Vanishing conditions in the right frontal areas. This pattern possibly demonstrates the importance of the prefrontal areas in maintaining the presence of an out of sight object. In the study conducted by Baird and colleagues (2002) it was not clear whether prefrontal area played a role, for instance, in the planning of the act of reaching towards the object or in the process of object maintenance. In our experiment however, the frontal cortex was involved in object maintenance in response to the simple observation of events in 6-month-old infants.

In the Mingling condition we observed left temporo-parietal activation, similar cortical activation as observed in Vanishing condition, however in the contralateral, the right temporo-parietal cortex. This similarity between the Mingling and Vanishing conditions might suggest that infants did not maintain the index of the object in either conditions, and importantly either when it moved among identical others, even though in this case the object kept its integrity. In this

Mingling condition, we presented infants with an everyday event, similar to when a toy is thrown in the toy-box among other similar toys, when daddy's car blends into the traffic or when a nice stranger mingles with a crowd of people in a mall. Erasing the index of the object for simple events like this raises the question of what happens to the objects in our mind when there is no support from the object tracking system; as there is no exact spatial-temporal information. Here we would like to refer again to Michotte's work (cited by Bower, 1967), who discriminated between perceptual constancy and conceptual constancy. While the object tracking system cannot support object persistence without an index, other more conceptual representations could encode the existence of an object even without definite location, or even without the presence of an object. One example for such object encoding is representing object kinds. This type of object encoding can be observed in infants around their first year (Xu & Carey, 1996; Xu et al., 1999) but can be facilitated using verbal labels even in 9-month-old infants (Xu, 2002). Future research on whether a more conceptual representation (like kind information) is dependent on the presence of object indices or it can survive even the annihilation of the physical object could lead us closer to understand better the mechanisms involved in conceptual constancy.

Turning back to our results, it should be noted that there was no significant difference between the Occlusion and Mingling conditions. The lack of statistical difference in the direct comparison is a strong reason to be cautious with the interpretation of cortical activation for the Mingling condition. Besides the statistical considerations, also we have to take into account that is unclear how participants exact perceived the events in the Mingling condition. While there is evidence for children's and adults' sensitivity to the distance between target and distractors in object tracking tasks (Wolf & Pfeiffer, 2014; Wolf et al., 2018), we cannot be sure of whether 6-month-olds in the present study lost the target object during the mingling event. It is also possible that in

some trials infants were successful in following the target tightly, while in others they might have been confused about which object was the target after the mingling event. A possibility to answer these questions would be to perform a follow-up behavioral test in a future experiment, measuring infants' gaze on the screen. From the pattern of their looking, one could assess whether they 1) are able to maintain which object is the target after the mingling event (i.e. they would fixate mostly on the target), 2) lose the target (i.e. they would explore all the objects on the screen).

The only common brain area where we found activation for the Occlusion, Vanishing and Mingling conditions was the temporo-parietal region (i.e. right temporo-parietal for Occlusion and Vanishing and left for the Mingling condition). An overlapping activation might be related to what is common in all the three conditions: tracking the moving object. This interpretation would be in line with former results demonstrating the role of posterior temporal regions of encoding object specific events, for instance moving objects in previous experiments (Watanabe et al., 2008; Wilcox et al., 2010; Wilcox et al., 2012).

To summarize, consistently with previous results, our participants maintained the presence of the object after an occlusion event, but did not show evidence for sustaining the index of the object after the object vanished (Bower, 1967; Scholl & Phylyshyn, 1999; Kaufman et al., 2003; 2005). We obtained a widespread right temporal, occipital-temporal and frontal cortical activation for object maintenance, demonstrating the role of the prefrontal and temporal regions in this cognitive process. The activation of the temporo-parietal region in all conditions fits with former proposals about the role of posterior temporal regions in encoding object specific information in infants (Watanabe et al., 2008; Wilcox et al., 2010; Wilcox, 2012). Additionally, we tested a third type of disappearance, an everyday situation, when an object is mingling among others.

While the results do not allow drawing strong conclusions regarding the activation measured in Mingling condition, possibly infants, in response to the object mixing among many identical objects, erased the index, just like in the Vanishing condition. Based on this result, further research should target identifying the memory traces left from the object after its index is not maintained anymore; how objects survive in our mind without spatial and temporal evidence for their existence.

Regarding the representation of absence of objects, we suggest that object tracking system supporting an automatic encoding of the presence of objects, cannot encode the absence itself, in the sense that deleting an object index does not result in a further (absence) representation. We did not find specific neural markers for the absence of objects after it vanished or mingled, hindering object persistence. This is in line with behavioral evidence showing that 6-9-month-old infants are unable to form expectations about the absence of objects in tasks that probably rely on representations encoded by the object tracking system (Wynn & Chiang, 1998; Kaufman et al., 2003). However, the object tracking system might assist other systems in the representing the absence of objects, like it does support object individuation (Wilcox et al., 2010; Wilcox, 2012; Xu et al., 1999), building hierarchical structures of sets (Rosenberg & Feigenson, 2013), or the genesis of natural numbers (Carey, 2009). Another question is whether more abstract representations (i.e. supporting conceptual constancy) might be more appropriate for the encoding of the absence of objects, for instance encoding the absence of a specific kind of object. In simple situations when an object is removed, the absence of the object might be represented as a specific kind not being there anymore, and not as absolute absence or nothing, a possibility that further research might target.

5. Chapter 5. General discussion and conclusions

The representation of absence is a peculiar research topic, and is part of our every days but it is tangled to abstract concepts like negation, or zero. How common thoughts of missing socks and extraordinary ideas about black holes having zero mass are related to each other is unclear. Absence in contrast to presence cannot be grounded to physical entities in the environment, thus the information that is formed and maintained is difficult to capture. Does the absence of an apple on the table simply imply the table, a pear on the table, several tables each of them having no apples on them, or maybe an imaginary red cross on the apple placed on the table? Related to this problem, when mapping linguistic phrases like 'no apples' or 'the apple is not on the table' we come across similarly perplexing questions of language grounding. Thus the questions multiply, yet there is little empirical research targeting them. In the present thesis we have aimed for taking small steps bringing us closer to eventually understand how our cognitive system forms and manipulates such thoughts. We investigated two main questions.

First, we asked how infants and toddlers acquire linguistic negation expressing the absence of objects. We were particularly interested in the conceptual background of negation comprehension at the onset of language acquisition. Earlier proposals have suggested a conceptual limitation in infants and a qualitatively different comprehension of negation at early stages of acquisition compared to adults (Pea, 1980; Feiman et al., 2017). Alternatively, infants might have difficulties in mapping the right labels to their conceptual knowledge, and in disambiguating the structure of propositions carrying the relevant information (Feiman et al., 2017; Reuter et al., 2017). We were also interested in how infants and toddlers interpret negation

when it supports an inference about the presence of an object and, in contrast, when it expresses absence of objects per se.

Second, we aimed to learn more about the non-linguistic representation of absence of objects that possibly also support verbal representations. There is evidence for the role of the approximate number system in encoding empty sets as potential precursors of zero. However, we were interested in a categorical representation of absence (i.e. presence vs. absence) instead of a continuous thought (i.e. less than one). It is unclear what system could support a categorical absence, as the approximate number system is more likely elicit continuous representations, and the object tracking system cannot encode this information. Nevertheless, it seems of crucial importance for many species to encode the absence of food or a predator at a location. Thus, in one series of studies, we were interested in how young non-verbal animals (8-day-old domestic chicks) encode presence and absence during a simple occlusion event. In a further study, we investigated the neural signatures of three different kinds of object disappearance in 6-month-old infants that induce the maintenance (presence) or the discarding of representations (absence) supported by the object tracking system.

5.1. Summary of our findings

In this thesis we investigated the representation of absence of objects in human infants and toddlers, and in domestic chicks. We targeted linguistic representations in infants and toddlers (Chapter 2) and non-linguistic encoding of absence in domestic chicks (Chapter 3) and human infants (Chapter 4).

Regarding the linguistic approach, the question was how negation in general, and negation expressing the absence of objects develops. There are suggestions for an early, limited negation understanding in infants and toddlers, which later develops into an adult-like, domain general representation of negation (based on its early meaning or independently of that) (Pea, 1980; Feiman et al., 2017). There are two potential markers supporting such a conceptual gap proposal. The first are the particular observations about the first negative utterances of infants and toddlers. Typically infants produce negation related to rejection and non-existence, and only months later they start to use negation for denial (Bloom, 1970; Pea, 1980; Choi, 1988). The second potential marker is the discrepancy between the capacity to produce and to comprehend negation expressing denial. Studies targeting negation production found early emergence between 13-19 months dependent on the function (i.e. negation to express rejection earlier than denial) (Pea, 1980). In contrast, the first evidence for comprehending negation expressing denial (e.g. 'It is not in the bucket') was found only between 24-36-months (Austin et al., 2014; Nordmeyer & Frank, 2014; Feiman et al., 2017; Reuter et al., 2017; Grigoroglou et al., 2019). Based on these inconsistent patterns, the assumption is that the first uses of negation lack an abstract comprehension of negation, a tool providing us the capacity operate on any proposition.

To learn more about this issue, in the first section we studied the acquisition of linguistic negation (i.e. negation of absence of objects), between the age of 15 and 24 months. In Study 1 we investigated the development of the comprehension of two types of negation expressing absence: negative existential and denial. We used a two-alternative choice task, similar to other research on this question (Austin et al., 2014; Feiman et al., 2017). We observed that even 18-month-olds successfully found a target object after receiving information via verbal negation about where it was not present. Furthermore, we observed a parallel development of the

acquisition of negative existential and proposition denial (Experiment 1a and b). While 15-month-olds failed in comprehending both negations (Experiment 2), 18-month-olds processed the negative existential and denial equally well. In Study 2, we investigated infants' comprehension of the negative existential expressing absence of objects per se, without providing a context to imply the presence of an object. One might ask the question whether there can be differences in the comprehension of negation expressing absence with the possibility of 'converting' it into an affirmative information (i.e. in Study 1, x is not in A, therefore it is in B) and negation without clear opportunity for such transformation (i.e. there is no x, Study 2). Former research with adults (Mayo et al., 2004; Orenes et al., 2014) and young children (Nordmeyer and Frank, 2014) demonstrated distinct processing for negation in a complementary/binary structure (e.g. absence/presence) compared to contrastive/multary structure (e.g. not red or absence per se).

In Study 2, infants were presented with existential negation expressing absence per se in a search paradigm. We expected our participants to search less compared to an ambiguous control condition, if they comprehend that there is nothing in a box. In this set of studies, we found that participants had more trouble in interpreting negation. 15 and 18-month-olds failed to show an understanding of negation (Experiment 4 and 5a), while 24-month-olds showed weak evidence for such a comprehension (Experiment 5b and 6). They searched less in response to negative existential compared to an ambiguous control condition, but their behavior was affected by their first person knowledge (Experiment 6), and likely by the number of the trial (longer search in the first compared to the second trial) and the information they contrast negation. This complex pattern observed in Study 2 leads us to be cautious with the conclusions regarding infants' comprehension of the negative existential expressing absence in a context that does not allow to

‘transform’ the negative to a positive information. However, alternatively, the discrepancy between infants’ performance in Study 1 and 2 might reflect differences in the cognitive demands, or differences in the conceptual underpinnings of interpreting negation in these two structures.

In the second half of the thesis we turned to non-verbal possibilities for capturing the absence of objects in non- and pre-linguistic creatures. We were specifically interested in tasks supporting a categorical encoding and relying on a representation encoded by the object tracking system. In Chapter 3, we tested 8-day-olds chicks’ capacity to encode the presence and absence of an object behind a screen. We run four experiments. In Experiment 1 chicks saw as the imprinting object goes behind the screen, and when the screen was dropped it unexpectedly disappeared (violating potential expectations of the presence of the object). In Experiment 2-4, chicks saw the object being removed from behind the screen, and when it was dropped, the object unexpectedly appeared (violating potential expectations of the absence of the object). We examined how long chicks looked at the outcomes (we expected longer looking duration for unexpected compared to expected conditions) and whether they showed specific lateralization in the outcome processing (we expected right hemisphere dominance in unexpected compared to expected conditions).Similarly to the infant literature, in the looking duration measure, we found evidence for an asymmetry in presence/absence encoding, and no signs for absence related expectations. In contrast, investigating lateralization effects, there was a consistent sex-dependent left-eye bias (indicating more pronounced right hemisphere involvement). While female chicks were sensitive for the violation of absence representation, males did not show such evidence. We suggest that this effect is due to an object identification process. We argue that the discrepancy between sexes arise from their different social predispositions. Based on Study 3, we concluded that there is an

asymmetry in presence and absence, as presence is coded automatically, while absence is not. We suggest that for absence is necessary to form a categorical representation. From another point of view, these data points to early evidence for absence, in 8-month-olds chicks with limited experience, which might indicate the presence an early, spontaneous processes for encoding such information. However, it is unclear what system might support such abilities, as both the approximate number system (previously proved to be able to encode empty sets) and a categorical system (containing contrary concepts of absence/presence) are potential candidates. While we almost know nothing about the latter encoding, we tend to believe that our data provides evidence for the involvement of the categorical representation system, as it might be a more appropriate encoding to support identification processes.

Finally in Chapter 4, we targeted the neural signatures of object maintenance and disappearance in 6-month-olds infants. We tested neural responses to three types of disappearances (occlusion, vanishing, mingling), potentially supporting or suspending the persistence of an object. In line with previous research, we found evidence for object maintenance in response to the occlusion event, but not to object vanishing. We found prefrontal and widespread temporal (involving neighboring occipital and parietal areas) cortical activation for sustaining the persistence of the object. When the object mingled into several identical objects, similarly to the vanishing object, we did not find evidence for maintenance. This suggests that similarly to the event in which the object vanished, the mid-level representation of the object was cancelled also in this case. As we did not find a specific response to the cancellation of the object representation, we assume that 6-month-olds did not form representation about the absence of objects (in line former studies). The object tracking system itself, providing an automatic encoding of the presence of objects, does not support encoding information for absence representation.

5.2. Theoretical implications

The conceptual background of negation comprehension

What is negation? Several answers can be articulated from the point of view of logicians, linguists, and semanticists. In this work, we used a linguistic approach, specifically from the restricted perspective of how negation develops in infants and toddlers. Even from this modest point of view it is challenging to draw simple conclusions. For instance, as we discussed in the earlier chapters, it is a challenging to decide what can be considered the first real negative utterances. Someone can take as an example of negation when a 12-month-old shakes her head in response to the utterance about having a bath; others find sufficient evidence for negation only by taking two-word utterances. Similarly, defining the conceptual requirements for negation in its full-blown shape is difficult. Relatedly, one might also ask, what processes non-animals and human infants might rely on instead of a full-blown negation.

Pea (1980) suggested a specific developmental path for negation acquisition originating from prohibition. According to this hypothesis negation is captured from the linguistic input mapped to discrepancy between doing and not doing things in response to the caregivers' prohibition. An important step from this stage is when the infant internalizes these utterances, and initiates and negates the initiation of similar thoughts (i.e. 'I want to touch the plug' 'I should not touch the plug'). Through similar contrasts infants acquire the affirmation-negation relation and this meaning is generalized through development to the broader fields of cognition. Pea's theory originates negation (the concept) from the linguistic input provided by the caregivers. It suggests

a discrepancy between the conceptual understanding of negation between infants and adults, in the sense that infants' negation related abilities are mostly originate from the maturation of different cognitive functions. For instance, Pea (1980) links the appearance of non-existence in negation production to the emergence of object persistence, before that, infants do not have the capacity to process negation expressing such content.

Feiman and colleagues (2017) raise the possibility of having domain specific negation-like mechanisms supporting the early comprehension of negation. According to this view, there are specific cognitive tools available for infants (i.e. to represent absence and presence) and they initially match some of these representations to linguistic negation (i.e. in early production of 'no' at 12 months), without having a competence to understand negation as such. In fact, toddlers comprehend the negation of propositions only around 24-27 months when a conceptual truth-functional negation "is coming online". According to Feiman et al. (2017) this new concept makes children able to comprehend 'no' as a tool to negate propositions, while former meanings support only content- and computation-specific representations. However, it should be noted that the origin of the truth-functional negation remains unexplained in this proposal.

Mody and Carey (2016) suggest a similarly limited computation of negation in young children (before 3 years of age). The absence of an object in reasoning by exclusion tasks (e.g. as in Study 1 of the present thesis) could be described as an operation of "crossing out" and eliminating one possibility, or representing and avoiding an empty location. According to this account infants and toddlers possess early cognitive tools to solve exclusion tasks but these representations are conceptually limited and do not require the capacity to represent logical operators and structures. This latter, probably human-specific ability emerges only around the third year tightly together with (or related to) linguistic competences.

Bermúdez (2003) has suggested that pairs of contrary concepts and protonegation could be available even for non-human animals. Based on this approach representations of presence and absence can be captured as two concepts in a contrary structure (also termed as protonegation), furthermore they can be manipulated using conditional reasoning (i.e. if not present then absent). To give a clear example, instead of forming a representation that 'the gazelle is not at the water-hole' a cheetah can encode that 'the gazelle is absent from the water-hole'. The main difference between the two is that in the former, absence is constructed from negating the thought of presence ('the gazelle is at the water-hole'), while in the latter case, it is the contrary pair of presence. Bermúdez (2003) proposed that in such contrary representations there is no need for affirmative and negative discrimination, the only rule is that nothing can be characterized in terms of both concepts. The other difference between propositional negation and protonegation is that the latter is inherently limited to the available pairs of contrary concepts and it does not operate on thoughts without the possibility of generating its contrary. While this proposal might be used to explain a range of phenomena, it does not specify what role such contrary pairs play in how humans understand negation in development or the way in which children at some point come to exceed this stage.

The above proposals can be seen as theories emphasizing a conceptual limitation in preverbal infants suggesting that they might use a kind of primitive cognitive mechanism to encode the absence of objects, which is incompatible with propositions. Also, these theories link linguistic negation to logical inferences and define full-blown negation comprehension as the capacity to operate on logical structures with negation.

In the present thesis, one crucial question was related to the nature of negation in early stages of acquisition. We were interested in whether there is a domain general understanding, or

alternatively infants start with limited, domain-specific tool(s) used for the first negative meanings.

While data from Study 1 suggest that infants can understand different forms of negation) at the age of 18 months, the evidence from Study 1 and 2 together seems inconclusive regarding the conceptual background underlying negation comprehension in infants. On one hand, inconsistent with the idea of having negation limited to the comprehension of nonexistence, we found evidence for early comprehension of proposition denial as well, without difference between the comprehension of negation expressing nonexistence and denial. This supports the idea of having a common conceptual ground to comprehend negations in both of its functions and forms. Also, we tested the comprehension of proposition denial in Study 1, supposedly the most mature form of negation, and it is highly unlikely that this form can be mapped to a limited understanding of negation. On the other hand, the difference between the performance of 18-month-olds in Study 1 and Study 2 might suggest some kind of limit in negation comprehension at this young age. In Study 2, in which there was no positive information available based on negation, 18-month-old infants did not show evidence for understanding the same negative existential they comprehended in Study 1. Thus, the question emerges whether these findings support a conceptual limitation account or an adult like conceptual capacity masked by other factors. Below we outline a couple of possible alternatives.

a) The discrepancy between the two studies might suggest that either the comprehension or the maintenance of negative information is cognitively less demanding in complementary (e.g. even/odd, absent/present – Study 1) compared to contrastive (e.g. not red, absent – Study 2) context. However, the difference is rather quantitative than qualitative, as both understandings rely on the same negation. For instance, the results of Mayo et al. (2004) study testing adults'

processing negation of bi-polar and uni-polar features suggest a tendency to keep the ‘not X’ structure in uni-polar cases. This creates the possibility of dissociations of the negative marker from the core meaning. Thus, adults sometimes mistakenly remembered ‘not romantic’ as romantic, and incongruent statements were activated during the process of the negation i.e. ‘often brings flowers’. Infants might be sensitive to similar interferences and might develop more resistance with time. Interestingly, this argument can only be hold if we assume that infants do not encode absence as an alternative as part of presence/absence contrary pairs in Study 2 (either because this structure is not available or because it is not evoked). Similarly to Study 1, where infants from the absence could arrive to presence, encoding a contrary pair (presence/absence) could have provided a possibility to arrive from ‘not present’ to absent in Study 2. This would question infants’ ability or readiness to represent absence without negation (i.e. empty, absence as the contrary of presence), based on alternatives suggested by Mody and Carey (2016) or by Bermúdez (2003).

b) The difference between the comprehension of negation in Study 1 and 2 might signal a conceptual gap present in young infants. According to this interpretation, the two-alternative choice task (Study 1) might rely on an early and limited representation of negation. For instance, might rely on crossing out one alternative, as suggested by Mody and Carey (2016), or a specific encoding of absence, for instance, in presence-absence contrary pairs as suggested by Bermúdez (2003). Study 2, in contrast, might have required a full-blown understanding of negation, a negative operation on the proposition of having some objects in the box. However, even if this were the case, we do not see why infants, instead of failing in Study 2, have not relied on simpler processes to solve the task, e.g. on the contrary concept of absence. 18-month-olds could have

represented that ‘the objects are absent’ in the box, involving a limited understanding they should possess according to this view. Furthermore, according to this alternative 18-month-olds mapped negation in a propositional structure (‘(It) is not here) to non-propositional thoughts, this we find implausible. Given these, we believe that other explanations, those raised in point a, are more coherent with our data.

How negation relates to logical reasoning?

A clear criteria for considering negation as a logical operator relates to the power of supporting inferences in logical structures. Mody and Carey (2016) expressed doubts for accepting evidence from reasoning by exclusion tasks (e.g., showing that one location is empty, and searching in the other location) as a proof for logical inferences. They have suggested that participants might simply cross out one alternative or solve the task by avoiding empty locations. While this proposal was developed to account for performance in nonlinguistic tasks, it is not clear whether they consider crucial differences between solving such tasks via language and via relying on non-linguistic cues. Would it be possible, that 18-month-olds in our Study 1 do comprehend proposition denial without the ability to integrate it to logical structures? We do not wish to commit ourselves to whether logical negation and linguistic negation are identical or not (especially in young infants), however, there is some evidence suggesting a close relation between the two. Language might support successful reasoning processes even from the very first stages of negation acquisition. While Mody and Carey (2016) demonstrated that children can correctly infer in which cup an object is in a double two-alternative choice task only from the age of 3 years, Grigoroglou and colleagues (2019) found a successful performance 6 months earlier in a task that was logically the same but involved language. Based on this finding, one

could argue that our 18-month-olds could have been boosted by language and represented the two-alternative choice task and the negation involving a sophisticated logical structure.

While one of our aims was to shed light on questions regarding the conceptual background of negation, we have to admit that our results led to more questions than answers. However, we see this in a positive light, and hope that our results will facilitate fruitful further investigations regarding relation between contrary concepts and negation, and linguistic and logical negation.

Non-linguistic absence

In the second part we investigated the representation of the absence of objects without language. While in the former part, encoding absence (e.g. presence/absence suggested by Bermúdez or emptiness suggested by Mody and Carey) might be seen as an 'easy' way of solving the reasoning by exclusion task, however, this issue is not as trivial as it seems at first glance. It has been, in fact, targeted by brave attempts aiming to find the origin of zero and negation in non- and pre-linguistic creatures. There is convincing evidence about non-human creatures' capacity to integrate empty sets (possible precursors of zero) into their approximate numerical representations. While this capacity is remarkable in itself, we would like to point out the difference between absence as a continuous (less than 1) and categorical (presence/absence) information. While the approximate number system seems to be a perfect candidate for the continuous representation of absence, we question its role in the categorical encoding of absence. Only very little is known about the second, categorical type of absence, its origin, the supporting systems and the characteristics of the involved mechanisms. One thought to start with is the contrary concepts suggested by Bermúdez (2003). While based on this account non-human

animals and pre-verbal infants should be able to encode contraries like absence and presence, experimental evidence suggests that they have difficulties of encoding absence.6 and 8-month-olds fail to form expectations about the absence of objects after simple occlusion events (Wynn & Chiang, 1998; Kaufman et al., 2003), and pigeons have difficulties in recognizing absence as a rule of reinforcement, moreover, they fail to notice a presence-absence relation (Newman et al.,1980;Hearst, 1984). The only clear evidence for a categorical representation of presence and absence comes from perceptual decisions tasks in which subjects decide whether they can see a noisy target or not. Merten and Nieder (2012) tested rhesus monkeys performing such task in which they reported the presence and the absence of a target using a rule-based response system. Interestingly, absence of stimuli was encoded only during the decision of "not seeing", as reflected by the activity of specific cells, while presence specific cells were found to be active during both perceiving the target and reporting the perception, demonstrating an asymmetry between the two. In the present work we did not find evidence for encoding absence in Chapter 4 in 6-month-old infants, and neither in Chapter 3 in male chicks. We argue that while the object tracking system is suitable for representing the presence of objects (based on spatiotemporal information), it cannot deal with absence information. While we observed specific neural signatures for maintaining the persistence of an object in 6-month-olds, there were no such signatures while observing scenes in which the object became absent. This strengthens the asymmetrical pattern also observed in earlier studies suggesting that presence is automatically encoded (e.g., via indices that are captured by moving objects), while to form absence representations, relevant categorical contrasts are needed.

Turning back to the potential way of representing absence in non-human animals, specifically to the presence/absence contrary concept, it is not clear whether or when this structure would be

available for subjects. In the present work the only evidence we obtained for the nonverbal encoding of absence was in Chapter 3. 8-day-olds chicks encoded and used information of no objects being at a location. However, this thought was formed only in a subset of the studied population (females) as part of an object identification process; but there was no signature for encoding absence in males. Was presence/absence as a contrary concept not available for chicks in our task at all, or it was it just not used by both sexes in the same way, maybe due to fact that they might have encoded the experimental scenes in a different way? It is not clear, whether animals in the present and previous studies (e.g., Merten & Nieder, 2012) generated pairs of representations excluding each other (categories that cannot be both active for one stimuli) in response to the specific context or contrary pairs like presence/absence are available already and they rely on such thoughts. Further research might target uncovering the process via which presence and absence categorical representations are formed in non- and pre-linguistic creatures.

Linguistic vs. non-linguistic absence

Does language (or other symbols) change the way we think about no objects? We did not directly target the relation between absence representations formed based on linguistic negation and non-linguistic cues, but we would like to summarize the evidence from other studies and the relevant details of our data regarding this question. Nordmeyer and de Villier's (2011) work suggests that human adults rely on language to realize implicit rules based on negation. Participants failed to notice a relation between trials (pictures) when their linguistic abilities were engaged by a simultaneously applied language task. Also, the studies by Newman and colleagues (1980) show an advantage of humans (maybe given their language capacities) over pigeons to recognize absence as relevant information, and the relation between presence and absence. Assuming that

there is a qualitative difference between the linguistic and non-linguistic representation of the absence of objects, we should see signs for such a division in human development, specifically in infants or toddlers before and after speech emerges. As described above, there was a difference between Mody and Carey's (2016) and Grigoroglou and colleagues' (2019) results using similar tasks to study complex reasoning by exclusion processes. The former study used a non-verbal while the latter a verbal version of the same paradigm. Given that 2.5-month-olds succeeded in the verbal version but failed in the non-verbal one, one can conclude that language might have boosted their competences in forming absence representations supporting reasoning with complex structures. However, the difference between the 2.5 and 3 years olds are quite small, thus further research should confirm this assumption.

Turning back to our results, in Study 1 we examined 15-month-olds capacity to represent absence in two-alternative choice task relying on linguistic or non-linguistic evidence. We found evidence for solving the task when infants had visual evidence for where the object was not present, however at this age they could not map the corresponding negative labels to this information (but older infants could). Relatedly, the studies of Feiman and colleagues (2017), demonstrated that 20-month-olds could solve the non-verbal version of the task, while in the verbal version participants passed only after 24 months. Also, the findings from non-human animals involving similar tasks (Call, 2004; Hill et al., 2011; Erdőhegyi et al., 2007; Schloegl et al., 2009) demonstrate that language is not a necessary condition to solve two-alternative choice task relying on the absence of objects. It is an interesting question whether 15-month-olds' performance in the non-verbal and 18-month-olds' performance in the verbal task are supported by similar or distinct representations. However, it is not clear which kind of behavioral differences we should expect between performance based on nonlinguistic and linguistic absence

representation. An interesting way for discriminating the nonverbal and verbal representation of absence could be with borrowing Bermúdez' (2003) ideas again. He discriminated between the two by assuming differences in the origins of their meanings. The contrary concepts proposed for non-human animal cognition have no derivative functions. This form of absence is not constructed by not-presence, like the absence expressed by the propositional negation in human adults. This distinction might open new possibilities to tackle the different relations between presence and absence in non-human animals and humans (if there is such a difference).

One possible marker for a language-specific representation of absence could be its relation and its dependence on presence (in the sense that in the propositional encoding 'not present' the presence is negated). There is some evidence supporting such an idea. Affirmation aids the comprehension of negation in 24-month-olds in comprehension task (Reuter et al., 2017), and an initial rule based on presence supported learning the absence rule in humans but not in pigeons (Newman et al., 1980; Hearst, 1984).

In the present work our tasks were not optimized to capture markers of (potentially) different forms of negation. But we can have a look on how presence affected absence in Study 1 and 2. In Study 1, the memory of the presence of the object in a container in the previous trial induced perseveration in 15-month-olds performing a non-verbal two-alternative choice task. Peculiarly, similar effect was present in proposition denial, but not in the negative existential condition. So having the memory of the object in a cup in Study 1 did not help to form the representation of its absence at the same location (i.e. it was here, but now it is absent) either in the nonverbal or in the verbal experiments. In Study 2, there was weak evidence that trials implying the possibility of the presence of objects supported the comprehension of the negative existential expressing absence in the consecutive trials in 24-month-olds. 24-month-olds behaved according to our

prediction when in the previous trial there was a possibility that objects were present (either by uttering “I cannot find it” in the control condition, Experiment 5; or by hiding an untrackable amount of objects, Experiment 6b).

As there is no good reason for assuming more ‘propositional’ thinking in response to existential negation compared to proposition denial, the differences in Study 1 most probably originate from possible mistakes of omitting the negative particle in the process of sentence comprehension. This would be compatible with the findings that infants at an early stage of negation acquisition tend to behave according the negated state of affair, that is interpret negation as assertion (Nordmeyer & Frank, 2014; Feiman et al., 2017) and with adults’ tendency to incorrectly recall ‘not romantic’ as romantic (Mayo et al, 2004). Probably in Study 1, we did not find evidence that presence facilitated absence encoding (verbally and non-verbally) as besides supporting the encoding of the information, it might have also had a preventing effect through memory interference. Still, in Study 1 Experiment 3, 15-month-olds showed a clear sensitivity to perseveration effects in the non-verbal task. In contrast, in Study 2 a different pattern was observed, however, as the results provide only weak evidence for 24-month-old’s success in this task, and further research should target specifically this question.

5.3. Conclusions

Absence is one of the most peculiar everyday concept we have, we throw away objects as if they would just disappear, other objects go missing and we remember them for years, and bonbons are annihilated in our mouths. We seem to share the basis of these representations with non-

human animals, and with pre-verbal infants. Unlike non-human animals, we have words to express absence, and these items of language have important power to express much wider range of concepts than disappearing objects (i.e. nirvana, nothing, black holes). Representations of absence might be also integrated in early reasoning processes, allowing us to benefit from negative information, from our failures. We think that further investigations on the representation of absence could lead us forward on a long way of understanding whether and how language forms our thoughts and reasoning capacities. Furthermore the research on contrary concepts could help us capture how such a special categorization might work, and clarify questions like whether we have innate pairs of concepts for presence/absence or alive/dead, or we whether we possess specialized mechanisms to form such structures. Relatedly, it would possibly also shed light on some important features of our cognitive system, for instance, whether non-human animals and humans 'force' environmental inputs into contrary structures, even if a specific pair of concepts has no exclusive power on each other.

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ACKNOWLEDGEMENT

TO EXTERNAL FUNDING AGENCIES

CONTRIBUTING TO PHD DISSERTATIONS

Name of doctoral candidate: Eszter Szabo

Title of dissertation: MINDREADERS IN THE CRIB: COGNITIVE MECHANISMS FOR REPRESENTING OTHERS' MENTAL STATES IN HUMAN INFANTS

Name of supervisor(s): Agnes M. Kovacs, Gergely Csibra

External funding agency: **European Research Council**

Acknowledgement:

This research has received funding from the European Research Council (ERC) under the European Union's Seventh Framwork Programma(FP7/2017-2013) under **grant agreement No. 284236 - REPCOLLAB**