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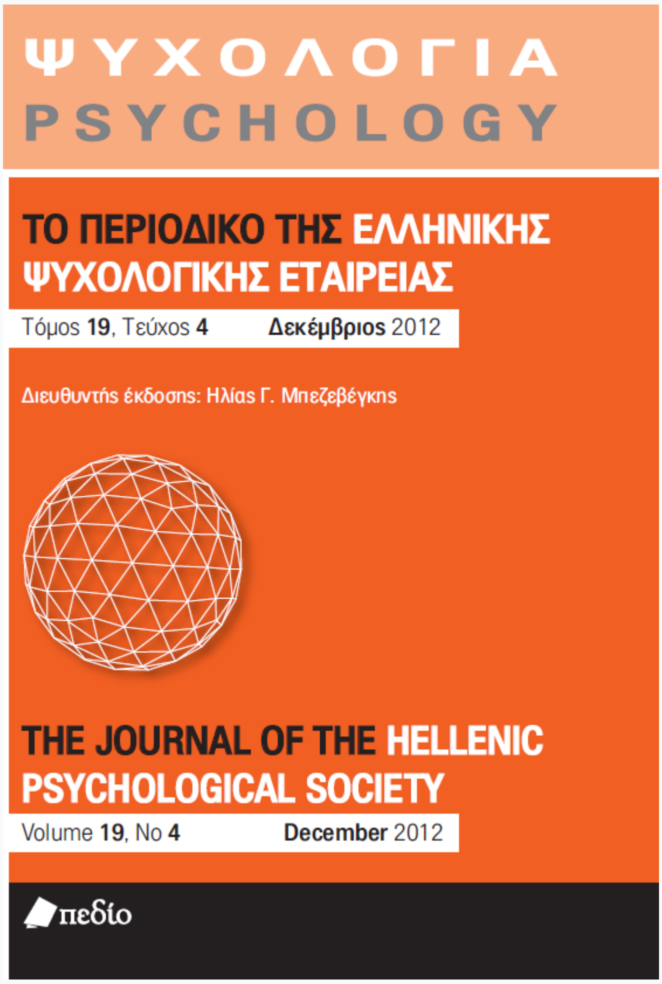

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ABSTRACT

In the present cross-sectional experimental study we investigated infants' early ability to intermodally detect numerosity of visual-auditory object-like and social stimuli. We assumed that presentation of face – voice stimuli would distract infants' attention from detection of numerical invariant. Seventy-eight infants (aged 5, 7 and 9 months) participated in four experimental Conditions (simultaneously projected pairs of *identical* objects, *non-identical* objects, objects projected together with *familiar face* and objects projected together with *unfamiliar* face). Visual stimuli in each trial varied in numerosity (1 -2 / 1-3 / 2 -3) and they were accompanied by piano sounds or voice sounds also varying in numerosity (one, two or three sounds in La tonality). By means of preferential looking technique, we measured infants' fixation of attention to the visual stimulus that numerically matched with the sound. When object-like stimuli were projected, infants –except 5-month-old boys –tended to intermodally detect numerical invariant. Shape similarity of the objects facilitated infants' intermodal detection of numerosity. When socially salient stimuli were co-presented with object-like stimuli, infants preferred to look at the face, ignoring numerosity of the auditory stimulus. Nor sound quality (piano vs. voice) neither familiarity of the face (mother's face vs. stranger woman's face) affected infants' perception. Although intermodal detection of perceptual cues is a primary function of both face and number perception, each one of these perceptual systems seems to follow a different developmental path.

Keywords: Infant development, Intermodal perception, Face-voice perception, Detection of numerosity

1. Introduction

According to Gelman & Gallistel (1978), the ability to count is the preeminent mechanism by which young children understand numbers. However, a global evaluation of number is encountered in young infants long before counting and precise computational skills. Klahr & Wallace (1976) assumed that infants' detection of numerosity is a rapid perceptual process of immediate apprehension of numerosity of an array, a skill which is called *subitizing*- see also Benoit, Lehalle and Jouen (2004). This early ability is considered to be innate and prior to the ability of counting which is a socially transmitted verbal labelling. It seems that early counting skills are

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preceded by a more primitive, direct perceptual awareness of numerosity.

Starkey, Spelke & Gelman (1983, 1990) have already shown that 7 month-old infants are able to intermodally detect the numerical invariant between visual and auditory stimuli. They found that infants look longer at visual stimuli whose numerosity corresponds to the number of sounds they listen to, suggesting that infants are able to perceive numerical invariants across two modalities. Nevertheless, Mix, Levine & Huttenlocher (1997) failed to replicate the above mentioned results. They had drumbeat sequences equated for either rate or duration, to ensure that these cues were not informative, but infants looked either to matching or non-matching stimulus. Kobayashi, Hiraki, Mugitani & Hasegawa (2004) found that 6-8 month-old infants show intermodal numerical perception, while toddlers fail in similar tasks.

The present study attempts to assess early infants' ability of cross-modal perception of numerosity (see Starkey et al. 1983, 1990). Moreover, this research introduces an additional factor, by including a contrast between object stimuli (photos of objects accompanied by mechanical sounds) and socially salient stimuli (photo of face accompanied by voice). Before proceeding to the present research, a brief literature review of similar studies might be helpful.

Experimental data on early infant numerical abilities

Neonates and young infants discriminate 'two' from 'three' among visual stimulus arrays consisting of small number sets and among auditory stimuli of two or three syllables (Starkey & Cooper, 1980. Van Loosbroek & Smitsman, 1990. Bijeljac-Babic, Bertoncini & Mehler, 1991). Infants aged 4 to 12 months add, subtract and find impossible events surprising, for example, they look longer at events such as 1 + 1 = 1, or 2 – 1 = 2, than at events such as 1 + 1= 2, or 2-1 = 1 (Cooper, 1984. Simon, Hespos et Rochat, 1995. Wynn, 1992, 1996. Koechlin, Dehaene & Mehler, 1997. Xu & Spelke, 2000). The method used by these authors is the violation-of-expectation paradigm. When objects magically appear or disappear, infants seem to be surprised and they focus their attention to the unexpected event. According to Marks & Cohen (2002), the above results do not really indicate that 5-month-old infants can discriminate the exact numerical difference between stimuli; instead, these results indicate that infants focus their attention to the stimuli either because of habituation effect or because of bigger numerical sets of stimuli ("more items to look at" model).

Nevertheless, Kobayashi et al. (2004) found that 6-month-old infants are able to recognize basic arithmetic operations across sensory modalities (e.g. 1 object + 1 auditory tone = 2). In their violation-of-expectation paradigm, neither familiarity nor complexity of stimuli affected the results. Mix, Huttenlocher & Levine (2002) assumed that perhaps infants really do process discrete numbers, but we cannot tell from the existing studies. Mix et al. (2002) suggest that infants are sensitive to differences in spatial extent and other perceptual variables (e.g. surface area, contour length, rhythmic patterns etc.), rather than to discrete number changes.

Infants tend to focus their attention in a way that optimizes overall arousal. According to Moore, Benenson, Reznick, Peterson & Kagan (1987), because of optimal stimulation seeking, in similar experiments, infants look more at non-matching stimuli. Another bias is that rhythmic patterns in such tasks might influence infants' ability to intermodally detect numerical equivalence. According to Mix et al. (2002), number and rhythm cannot be tested separately. The phenomenon seems to be more complex: rhythmic patterns in auditory stimuli should be better controlled so that they will not intermix with numerical discrimination, for even the same duration of sounds could lead to different rhythms.

Explanatory models of early infant detection of numerosity

Mix et al. (2002) suggest that there is no need to posit a representation of discrete number. Instead, a developmental account that assumes only representations of spatial and temporal cues in infancy would be sufficient.

The 'accumulator model theory' (Wynn, 1998a) suggests that each object is enumerated as an impulse of activation from the nervous system. To extract number (or time), the accumulator stores each impulse until the end of counting (or timing), and then transfers this information into memory where it outputs one value for the impulses counted. The above theory was derived from experiments on numerosity with rats (Meck & Church, 1983).

Object-file theory (Uller, Carey, Huntley-Fenner & Klatt, 1999) suggests that success in arithmetic tasks may reflect nothing more than already well documented physical reasoning abilities (see also Simon, 1997). According to Baillargeon (1994) infants may build a model of objects (in the violation-of-expectation paradigm), updating this model when new objects are added or taken away. Moreover, contrary to symbolic models, presupposing the existence of an early ability to construct abstract representations of number (see Gellman & Gallistel, 1978), "object-file" model facilitates short-term and working memory. "Object-file" model suggests that precise small numbers may be represented by a different system, used by adults for object-based attention and tracking.

Consistent with object-file theory are the results of a research with 6-month-old infants (Feigenson, 2011), according to which, infants can compare numerical information obtained in different modalities using representations stored in memory. The above results indicate the existence, since birth, of an Approximate Number System.

According to Trick & Pylyshyn (1994), two parallel mechanisms are responsible for number perception: one pre-attentive mechanism is responsible for approximate representation of small numbers and one attentive mechanism is responsible for counting and precise enumeration. Finally, an analog magnitude system may underlie success with larger numbers, which is concerning approximate large number quantification (Wynn 1998, b).

Dehaene, Spelke, Pinel, Stanescu & Tsivkin (1999) suggest a combination of two models, exact arithmetic and approximate arithmetic. Exact arithmetic is characterized by a language specific format and recruits networks involved in word association process. On the contrary, approximate arithmetic is language independent and relies on a sense of numerical magnitudes and visuo-spatial processing. Arithmetic intuition may emerge from the interplay of these two brain systems.

According to Mix et al. (1997), early cross-modal perception of numerosity is not a matter of equivalence. Infants use temporal characteristics of the overall sequences rather than the number of individual sounds. Thus, intermodal matching is achieved on the basis of overall amount, rather than on number itself. Feigenson et al. (2002) suggest that infants rely on multiple mechanisms, some non-numerical, in tasks that have been interpreted as addressing numerical competence. In our opinion, numerical discrimination might derive from non-numerical properties of physical stimuli. In infants' attention numerical properties of physical stimuli cannot be separately viewed from continuous information (see also Mix et al., 1997). The case of intermodal matching is one case of event processing – infants perceive objects combined with sounds, extended in space and time.

According to Theory of Direct Perception, the senses are unified at birth (Gibson, 1969). Shape, intensity level, motion, number and rhythm are experienced directly as global, amodal perceptual qualities (Stern, 1985). Objects and events have nested properties that are detected in the context of increasing specificity (Bahrick, 2001). Detection of small numbers in early infancy seems to be a complex cognitive ability that might include: a) multimodal perception of physical stimuli, b) approximate perception of relative numbers (few vs. many), c) perceptual ignorance of the qualitative differentiation of visual stimuli and d) abstraction of the numerical correspondence through concentration on the common quantity between visual and auditory stimuli.

Infants' perception of social stimuli

Attention to human face by 5-month-old infants is characterized by a preference for complex animated face, while preference for complex and unfamiliar face increases with age (Sherrod, 1979). Recent research on development of infants' social cognition shows that, since birth, the human system detects social agents on the basis of both innate mechanisms and perceptual experiences (Simion, di Giorgio, Leo & Bardi, 2011). Newborns prefer face-like stimuli over distractors and older infants gradually focus their attention on faces (Frank, Vul & Johnson, 2009). According to Simion, Turati, Valenza & dalla Barba (2007), newborns' face preferences are due to a set of non-specific constraints that stem from human visuo-perceptual system rather than to a representation bias for faces. Face perception during early infancy is partially explained by the innate predisposition of a subcortical mechanism which tunes infants' attention towards preference for face-like stimuli (Mondloch, Lewis, Budreau, Maurer, Dannemiller, Stephens & Kleiner-Gathercoal, 1999).

Why is the human face such an attractive stimulus? According to Werner (1948), face perception –as part of *physiognomic perception*- involves the direct experience of amodal qualities by the infant. These qualities are rather categorical affects than perceptual qualities such as shape, intensity or number. Amodal affect arises from experience with human face in all its emotional displays. Stern (1985) stressed the importance of the supra-modal form of perceived information in infancy. According to Stern, "infants act upon abstract representations of qualities of perception" (1985, p. 51). From this early human ability stems the organization of experiences concerning perception of an emerging self and other.

Faces and voices pervade perceptual experience from the moment an infant is born. Infants possess an early ability to intermodally perceive human face. Intermodal relations between face and voice are crucial for the acquisition of linguistic, social and emotional skills. Young infants can identify a face by hearing her voice, they can discriminate the synchrony between face and voice, coordinating the two stimuli in a spatio-temporal basis (Spelke & Cortelyou, 1981). This evidence may imply that there is an early tendency for spatial coordination between visual and auditory perception of the face. The human face is considered to be a dynamic social stimulus that attracts infants' attention in a way that related early perceptual strategies develop as cognitive procedures. The human face represents a unique, highly salient and ontogenetically significant stimulus which provides critical cognitive and social information (Simion et al., 2007), regarding identity (Valentine, Edelman, & Abdi, 1998), direction of attention (Langton, Watt & Bruce, 2000), intentions (Baron-Cohen, 1995) and emotions (Ekman, 1982).

Aims of the study

In the present research we used the same methodological paradigm (preferential looking technique) as in Starkey, Spelke & Gelman' s (1990) research, in order to investigate infants' intermodal perception of numerical correspondences between auditory and visual stimuli. Nevertheless, this study differs from Starkey et al. (1990) methodology in two ways: a) the auditory stimuli here are piano sounds, instead of drum beats and b) in two additional experimental Conditions we inserted social stimuli in the task, namely voice and face of mother or of an unknown woman.

More specifically, in the present experimental cross-sectional study we were interested in investigating the early infants' ability to detect numerical matching of two-dimensional stimuli across two modalities. We also tested the hypothesis that shape variation of visual stimuli would hinder infants' ability to intermodally detect numerical invariant. As we already mentioned, Kobayashi et al. (2004) had found no effect of shape complexity in infants' intermodal perception. However, accordingly to Cohen & Marks (2002), we assumed that similarity of the shape of simultaneously projected objects would facilitate infants' intermodal perception of numerosity. Moreover, we tested the possible role of socially salient stimuli (face and voice) in numerical amodal perception. The possible role of social cues in infant numerical perception has been little investigated by relative studies. Therefore, in accordance with Patterson and Werker (2002), we tested the hypothesis that social stimuli would attract infants' attention in such a way, that infants would be distracted from intermodally perceiving the numerical invariant. Additionally, we tested the hypothesis that familiarity of the mother's face-voice - compared to the unfamiliar face-voice of a stranger woman - would further affect infants' intermodal detection of numerosity. Finally, we were interested in possible age and gender effects on the particular perceptual phenomena.

2. Method

Subjects

In accordance with ethics of research with children, in our study, all parents were asked to give written permission to the researchers so that their infant could participate in the research. Infants' families were recruited by the aid of obstetricians, gynaecologists and paediatricians who worked in the city of Rethymno, in Crete. All infants who participated in the research were born by full-term gestation and natural delivery (pre-term and caesarean gestations were excluded from the research). At a first stage we sent a letter to the parents giving information about the study to be held. We explained to the parents that we aimed at investigating early infant perception. The researchers first visited the infant at her home, discussed the nature of the study with both parents and gave an appointment at the laboratory in a time of maximum two weeks. During our visit at home, the researchers took the photo of the mother who was told not to change her hair look (hair-cut or colour) until she would arrive to the laboratory. We also tape-recorded the mother uttering "La". In the meantime, we reproduced the mother's voice in a Sound Laboratory so that we could get the auditori stimuli (*LA*, *LA-LA* and *LA-LA-LA*) in steady rhythm, pitch and tonality.

At the laboratory, the infant sat on her mother's lap and prior to the experiment, the mother was told not to intervene with her infant's reactions. As soon as the infant started to be uneasy or sleepy, or as soon as she started to cry, the experiment was terminated.

Initially, 140 infants were examined in a cross-sectional experimental design. Several infants got asleep during the test (N=21), other infants started to cry or be uneasy (N=21) and several mothers intervened with their infants' reactions, contrary to the instructions of the researchers (N=20). In all these cases (N=62), the experimental procedure was immediately stopped by the researchers. Consequently, these infants did not fulfill the task and their responses were excluded from both microanalysis and statistical analysis.

Seventy-eight infants (38 boys and 40 girls) aged 5 months (M *weeks*= 20,23, *SD= 1,251,* N=30), 7 months (M *weeks*= 28, *SD= 1,103,* N=24) and 9 months (M *weeks*= 35,83, *SD= 1,204,* N=24) fulfilled the trials. During the experimental procedure, infants were at state of consciousness 3 (Prechtl & O' Brien, 1982), that is during the experimental trials their eyes were open, they breathed normally, they produced limited body movements and few vocalizations.

Stimuli

We chose the objects used in the projected slides (visual stimuli) on the basis of shape complexity. Therefore, we used images of a ball (simple circular stimulus), a comb (simple linear stimulus), a spoon (less simple stimulus, combining circular and linear arrangement) and a rattle (more complex stimulus). During the interview at home (about two weeks before their visit to the laboratory), parents were encouraged to get their infants habituated with these objects at home.

Visual stimuli (images of objects and theface of mother or of an unknown woman) were shown through two slide-projectors. The images were projected at a distance of 2 meters before the infant's visual field and the distance between the two simultaneously projected images in each trial was 20 cm. The slides' color background was blue and the slides' dimensions were 108x80 cm. In each trial two different numerical combinations of items were projected (e.g. 1 ball on the right side of the infant's visual field and 2 balls on the left side of the infant's visual field). In some trials the face of the mother or of an unknown woman was projected. The photo of the face was taken about two weeks before the visit of the infant at the laboratory. All images were elaborated through Photoshop software, in order for the contour to be steady - color, brightness and contrast of the images were kept identical across trials.

Auditory stimuli were produced either by a piano or by mother's or an unknown woman's voice. In the case of piano sound, *one, two or three La tones* were produced and, in the case of voice sound (La tonality), one, two or three La syllables were produced in staccato pitch. The mother's voice was tape-recorded about two weeks before the infant visited the laboratory. As already mentioned, the voice was elaborated in a professional sound studio and it was tuned in La tonality. Consequently, pitch, rhythmic pattern, loudness, duration and tonality of auditory stimuli (both piano sounds and voice) were kept steady across trials. The auditory stimulus was reproduced during the projection of the visual stimuli. The infant could hear the sounds through two speakers settled on the right and left of the experimental room. No other stimuli were available inside the experimental room, which was lit by a dim light above the infant's head.

Experimental Setting and Procedure

All equipment (piano, tape-recorder and slide-projectors) were set in a backstage room, where the researcher and her assistants could attend to the infants' behavior in the experimental room through a one-way mirror. A dim light above the infants' head gave the possibility of video recording infants' face expressions and their body reactions.

Infants' behavior was recorded in a Video – Camera (Panasonic NV MS4 S-VHS) that was settled in front of the infant's seat and out of the infant's view.

The total duration of each trial was 12 seconds. Sound was produced 4 seconds after the images had been projected. We measured infants' attention to the visual stimuli, immediately after the sound was heard.

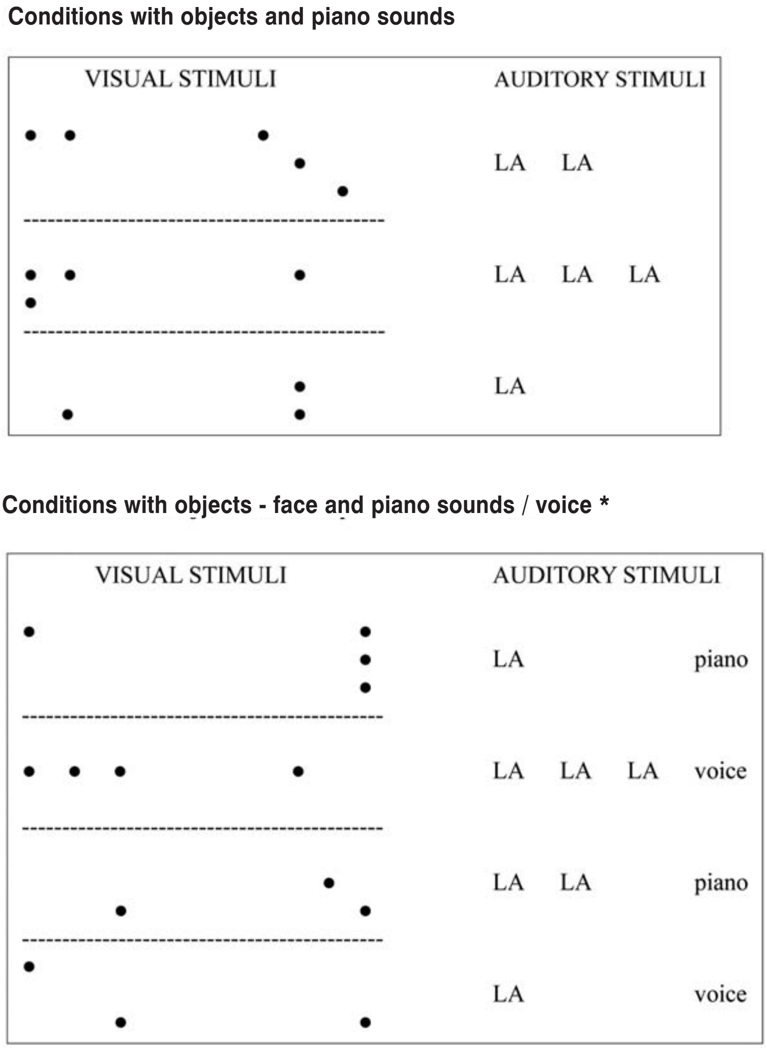
Conditions with identical vs. non-identical objects: in *Condition with identical objects-piano sounds,* infants attended to 6 trials. Each trial consisted of a pair of images representing identical objects (e.g. 2 balls at the left visual field of the infant and 3 balls at the right visual field of the infant). The two simultaneously projected slides varied only in numerosity of the represented objects. Four seconds after the images were projected, *one, two or three* piano sounds were played for 3 seconds.

In *Condition with non-identical objects-piano sounds,* infants also attended to 6 trials. In this Condition, the projected objects varied both in shape (non-identical objects) and in numerosity (e.g. 1 ball at their right visual field and 3 rattles at their left visual field). Four seconds after the images were projected, one, two or three piano sounds were played for 3 seconds.

Conditions with objects – face and piano / voice stimuli: in *Condition with objects and mother's face – piano sounds / mother's voice,* infants attended to 8 trials. The face of the infant's mother was projected at one side of the visual field, while at the other side of the visual field two or three identical objects were presented. In half of the trials, one, two or three piano sounds were heard and in the other half trials mother's recorded voice was heard singing one, two or three La syllables.

In *Condition with objects and unfamiliar face – piano sounds / stranger woman's voice*, there were also 8 trials. In this Condition, an unknown woman's face and voice were presented, similarly to the Condition with mother's face/voice.

In order to control for possible effects of habituation to the stimuli (which could lead infants



* in these Conditions the one visual stimulus was always the *face*

Figure 1
Example of random presentation of numerosity combinations

to look away from the matching stimuli), the presentation order of Conditions was counterbalanced; namely, half of the infants attended to the social stimuli first and half of the infants attended first to the non-social stimuli. In all Conditions, projection of the visual stimuli was counterbalanced across trials, on the basis of the right / left and bottom / top visual field of the infants; namely, in half trials of each Condition infants could see a numerical configuration of object-like stimuli on their right visual field and in half trials they could see the same numerical configuration on their left visual field. In each Condition, visual stimuli were projected randomly across trials. In all trials, a numerical matching of the visual-auditory stimuli could be perceived (e.g. two balls and 3 rattles – accompanied by two sounds). In addition, for each numerosity we projected two possible combinations, in order to control for sound matching to small or bigger numerosity (see Figure 1). Each infant would look at a randomly selected combination of visual-auditory stimuli. Consequently, each infant attended to 28 combinations of stimuli, in a total duration of 12-15 minutes. Not all combinations of stimuli presentation could be used, because, if so, infants would attend to too many trials, and in that case, as we know from relative research, young infants would get easily tired.

Microanalysis of infant behavior

Intermodal coordination was assessed by means of preferential looking technique (the visual stimuli were projected simultaneously, and the infant chose to look at one or another). On one hand, this method is considered to be the most appropriate for investigation of intermodal perception (see Starkey et al. 1983); on the other hand, the use of preferential looking technique constrains the influence of memory in a perceptual task.

The video-taped infant behaviours were micro-analyzed by the use of the computer program Logger (Macleod, Morse & Burford, 1993). The particular software is compatible with Macintosh Quadra 650 that is connected with a video (Panasonic S-VHS VCR AG-7355) and analyzes the recorded image (behavior) in 1/25 seconds.

Statistical analysis

Duration of infants' attention to the visual stimuli was modified into seconds through Excel and then the data were inserted into SPSS (Statistical Package for Social Sciences) in order to be statistically analyzed.

Success in the particular experimental task was considered to be the state where, immediately after the sound and while the visual stimuli were still projected, the infant preferred to look at the visual stimulus numerically corresponding to the sound (e.g. after *one* sound of La, the infant looked longer at the visual stimulus representing *one* object than at the visual stimulus representing two objects). On the other hand, failure was considered to be the state where, immediately after the sound, the infant preferred to look at the visual stimulus numerically non-corresponding to the sound (e.g. after one sound of La, the infant looks longer at the visual stimulus representing three objects than at the stimulus representing one object).

In our study, 78 infants attended to 28 trials. In every trial each infant had more than one successes or failures. The corresponding times (seconds) were added and the result was a total time of success and a total time of failure. In the final analysis of data, time of success was the total mean time of infant attention towards the visual stimuli which numerically matched to the auditory stimuli. Time of failure was the total mean time of infant attention towards the visual stimuli that did not match to the number of sounds.

The dependent variable (indicated at the results as *mean time of success tendency*) is the difference of total failure time from total success time. This variable uses all responses concerning infant visual attention at the stimuli. Thus, we got a clear picture of the tendency of success or failure. More specifically, positive mean time of infant attention (above zero) indicates success, whereas negative mean time (below zero) indicates failure in the particular experimental task. To search for mean differences in success tendency, we used T-test for independent samples or ANOVA. When more explanatory variables (independent variables that explained a useful interaction) were inserted in the data analysis, we used general linear models (GLM 4.0; see McCullagh & Nelder, 1989).

The reliability test showed a positive correlation between the two observers (Pearson $r=0.94$, $p<.001$). The regression coefficient between the two observers approaches the ideal score 1 ($\beta= 0.96$, $SE=0.032$, $p<.001$).

Table 1
Mean time of success tendency by presentation order of Conditions

Presentation order of Conditions	**Looking behaviors (N)**	**Duration of attention (M *seconds*)**	***SD***
Conditions with object – piano sounds first	627	.273	1.996
Conditions with object – face and piano / voice first	579	.286	2.182

Table 2
Number of infants' orienting responses

	Looking behaviors	
	To mismatched stimulus	To matched stimulus
Identical objects-piano sounds	95	149
Non-identical Objects and piano sounds	120	127
Mother's face - objects and voice / piano sounds	140	188
Unknown woman's face - objects and voice / piano sounds	154	233

3. Results

Infants' attention and orienting responses

Presentation order of experimental Conditions did not affect infants' duration of attention [independent sample T-test, t $(1203)= -.111$, $p>.05$]. Namely, either infants first attended to Conditions with objects, or they first attended to Conditions with objects and social stimuli, infants' success tendency was not influenced (see Table 1).

Analysis of data in all Conditions showed that 43,2% of looking behaviours were successful (infants looked to the numerically matching stimulus) whereas 31,6% of looking behaviours were unsuccessful (infants looked to the numerically non-matching stimulus). Binomial Test showed that the above result is statistically significant at level .05. The rest 25,2% of infant reactions concerned looking away from the stimuli, for example, looking at the mother, around them or nowhere in particular. The statistical analysis was performed on the 74,8% of the infants' looking behaviours (N=1206). In Table 2 we present infants' orienting responses by Condition [x^2 $(3)=6{,}143$, $p>.05$].

In the statistical analysis that follows, as it has been already explained in the Method section, we considered as dependent variable the mean time of success tendency, which represents mean time of infant attention to matching stimuli subtracted from mean time of attention to mismatching stimuli. Consequently, mean time above zero

Table 3
Mean times of success tendency

	M (secs)	*SD*	Sign.
Condition with identical objects and piano sounds	.391	1.650	p= .028 *
Condition with non-identical objects and piano sounds	.058	1.696	
Condition with mother's face – objects and voice / piano sounds	.434	2.294	p> .05
Condition with unknown woman's face-objects and voice/piano sounds	.228	2.354	

* In Conditions with objects and piano sounds, infants looked longer at the numerically matching stimulus, when identical objects were presented ($p < .05$)

indicates longer attention to the matching stimuli, while mean time below zero indicates less attention to the matching stimuli.

We didn't insert the *non-looking at the stimuli* responses (25,2%) in the statistical analysis, because we initially defined a standard criterion which would help us focus on intermodal perception of numerosity: we would measure the mean difference of total failure time (how long infants looked at the non-matching stimulus) from total success time (how long infants looked at the matching stimulus). Besides, from similar researches we know that 1 out of 4 infants get irritable or fatigued in a way that they do not look at the stimuli (Moore et al., 1987). Mix et al. (1997), in a replication of Moore et al. (1987), found no differences in results when they inserted the 25% (depicting the non-looking behaviours) in statistical analysis (at the particular research, infants continued to look longer at the non-matching stimulus).

Analysis in Conditions with objects - piano sounds

We found a difference between mean times of success tendency when we compared data in Condition with identical objects and in Condition with non-identical objects, *independent sample T-test,* $t\ (489) = 2.205$, $p<.05$. More specifically, infants looked longer at the numerically matching visual stimuli when identical objects were presented (see Table 3). It seems that in the particular experimental task, similarity of visual stimuli facilitated infants' intermodal perception of numerosity.

We also found an *age x gender* interaction, *General Linear Model, Univariate ANOVA,* $F\ (5, 491) = 4.675$, $p< .05$ (see Figure 2). The interaction derives from the significant difference between mean times of success of boys and girls at 5 months, *independent sample T-test,* $t\ (166) = -2.77$, $p<.01$. It seems that boys at 5 months fail to intermodally match the stimuli on the basis of numerosity, while girls at 5 months seem to succeed in this experimental task. Later in development (at 7 and 9 months), boys seem to catch up with girls in the particular numerical task, while girls show a rather stable performance in time, with a slight decline at 9 months.

Analysis in Conditions with objects - face and piano / voice sounds

In Conditions with socially salient stimuli we found no difference in mean times of success

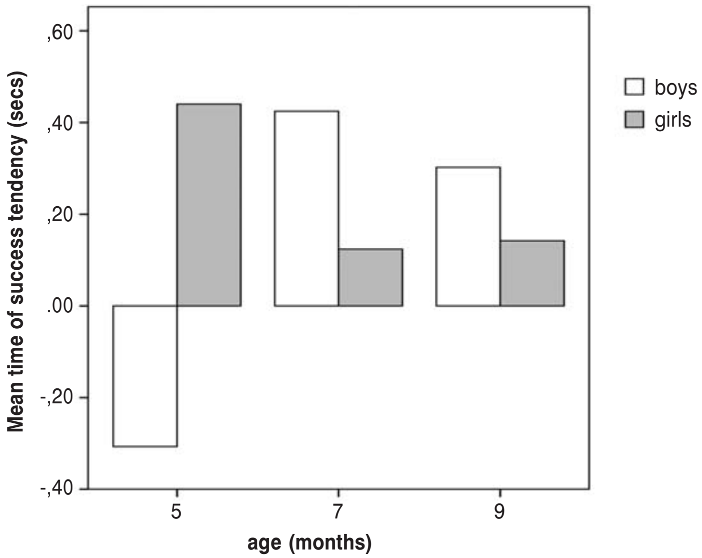


Figure 2
Mean times of success tendency by age x gender in Conditions with objects and piano sounds

tendency between Condition with mother's face-voice and Condition with the unknown woman's face-voice the (see Table 3). This result indicates that infants' duration of attention to the matching stimuli was approximately the same, either they were presented with their mother's face or they were presented with the face of a female stranger. Namely, familiarity or unfamiliarity of the face did not affect infants' looking behaviours.

In Conditions with socially salient stimuli, only a *gender effect* was found, *GLM, Univariate ANOVA, F (1, 715) = 8.930, p<.01*. Girls looked longer at the numerically corresponding to the sound visual stimuli than boys did, *independent sample T-test, t (713) =-3.098, p<.01* (see Table 4).

Analysis of data by numerosity and quality of auditory stimuli

In Conditions with objects-piano sounds, we found no effect of sound numerosity, One-way ANOVA, *F (2, 488) = 2,012, p>.05* (see Table 5).

In Conditions with social stimuli and objects, the face remained always "one" and objects varied in numerosity (e.g. visual stimuli: *mother's face – 3 balls* and auditory stimulus: *3 sounds*). When infants heard to two or three sounds, they failed to detect numerical invariant of the visual-auditory stimuli, namely infants preferred to look at the face, rather than at the numerically matching stimulus, *one-way ANOVA, F (2, 712) = 10.291, p<.001* (see Table 5). This result implies that the face, as a socially salient stimulus, attracted infants' attention in a way that they were distracted from intermodally matching the stimuli on the basis of their common numerosity, *LSD post hoc test: Conditions 3 & 4, 1 sound – 2 sounds, mean difference= .83, SE= .21, p< .001 / 1 sound – 3 sounds, mean difference= .72, SE= .21, p< .01*).

In *Conditions with objects – face and piano / voice*, sound quality (piano sounds, mother's voice or stranger woman's voice) did not affect infants' duration of attention to the stimuli [ANOVA, *F (2, 712)=2.433, p>.05*].

Table 4
Mean times (seconds) of success tendency by age x gender

		5 months			7 months			9 months			
		N	**M**	***SD***	**N**	**M**	***SD***	**N**	**M**	***SD***	**Sign.**
Conditions with objects & Piano sound	**Boys**	75	-.307	1.462	111	.425	1.487	97	.032	1.907	p=.01*
	Girls	93	.440	1.924	62	.124	1.525	53	.142	1.510	
Conditions with face-objects & piano/voice	**Boys**	134	.004	2.172	106	-.001	2.521	105	.145	2.350	p>.05
	Girls	148	.554	2.727	137	.637	2.164	85	.541	1.598	

* In *Conditions with objects - piano sounds* an age x gender interaction was found (p<.05).
Boys at 5 months failed to intermodally detect numerosity.

Table 5
Mean times of success tendency by sound numerosity

		N	**M (seconds)**	***SD***	**Sign.**
Conditions with objects and piano sounds	**1 sound**	177	.271	1.598	p>.05
	2 sounds	155	.010	1.687	
	3 sounds	159	.378	1.750	
Conditions with face-objects and voice/piano sounds	**1 sound**	356	.712	2.283	p<.05*
	2 sounds	175	-.118	2.392	
	3 sounds	184	-.013	2.234	

* In *Conditions with face - objects and voice / piano sounds*, when two or three sounds were heard (compared to one sound, which in these conditions always matched to the face), infants failed to succeed in intermodal detection of numerosity. Infants looked at the face, even if two or three sounds were heard.

4. Discussion

Given the complexity of the issue of number perception in early infancy, in this study we tried to investigate some specific aspects of this human developing ability. The aim was to investigate possible developmental tendencies in perception of numerosity from 5 to 9 months, by means of *preferential looking* technique, using identical and non-identical, as well as social and non-social visual and auditory stimuli. Moreover we were interested in searching for possible age and gender differences and in detecting whether socially salient stimuli (face/voice) affect the perception of numerical invariant across different modalities.

In the present study, infants managed to intermodally detect the common numerosity of object-like stimuli and piano sounds. In agreement with research of Cohen & Marks (2002), similarity of the shape of projected objects facilitated infants' attention to the numerical invariant. Success tendency in the particular task was higher in Conditions with identical objects, than in Conditions with non-identical objects. In Conditions with social stimuli, infants' preferential looking was not influenced by the familiar / unfamiliar dimension of stimuli. Either infants were presented with the mother's or with the unknown woman's face, fixation of attention was not significantly influenced. Moreover, in our sample, the quality of the auditory stimulus (voice vs. piano sound) did not affect infants' looking behaviours.

In our sample, 5-month-old girls intermodally detected the numerical invariant of the object-stimuli. However, boys at 5 months failed to detect numerosity when object-stimuli were projected, but at 7 and 9 months they managed to abstract the numerical invariant. Antell and Keating (1983) had also found a gender difference in fixation time to the stimuli during the habituation phase - girls did better than boys in a visual perception numerical task with small number stimuli. This difference was explained by hypothesizing a relation between habituation and gender, and not between gender and numerical perception. Moreover, the above-mentioned study concerned detection of numerosity through one modality.

According to Golombok & Fivush (1994) there are no computational differences between boys' and girls' numerical ability. Gender differences might be attributed to a different developmental course of the particular ability. According to our findings, development of perception of numerosity from 7 to 9 months seems to progressively counterbalance the gender differences that are observed at 5 months. Of course, this finding should be further investigated in a longitudinal study, where the course of development could be more evidently described.

In our study, girls seem to be attracted by the numerical correspondence between objects and mechanical sounds at an earlier developmental phase (5 months), than boys (7 months). This might be partially explained by the findings concerning sexual dimorphism documented in humans (see Connellan, Baron-Cohen, Wheelwright, Bakti & Ahluwalia, 2000). It has been found that male neonates show a stronger interest in the physical – mechanical stimuli than girls do. We can assume that boys at 5 months fail to abstract the numerical invariant between objects and mechanical sounds, because they are attracted by the physical quality of the stimuli. At later developmental stages (in our sample, at 7 and 9 months), male infants seem to become able to concentrate on more abstract perceptual properties, such as the numerical invariant of the visual-auditory stimuli.

Relatively to the developmental onset of the particular infant ability, our study confirms the assumption that intermodal perception is present at 7 months (see Starkey et al., 1990. Lewkowicz, 2000). This early infant ability may reflect a tendency to match different stimuli on the basis of a more abstract property, such as numerical invariant. The finding that 5-month-old female infants can intermodally detect numerical invariant shows that intermodal perception is pre-symbolic and direct, and that it may precede representational processing. This finding is consistent with Walker-Andrews' result (1994), who had found that 4-month-old infants could detect amodal invariants, even if they had little or no experience.

Amodal invariants are perceptual cues that are tied to the structural properties of an action or event and are not specific to a particular sensory modality (Patterson & Werker, 2002). Young infants match audio-visual events based on temporal synchrony, duration, rate, affective information in the face and voice. For example, rhythm is an amodal invariant, for it can be detected by listening to a sound or watching its visible effect. Amodal relations are context free and can be perceived directly (Bahrick, 2001).

In our study we found that face, as a socially salient stimulus, affected infants' tendency to intermodally perceive the common numerosity of the stimuli. According to Feigenson, Carey & Spelke (2002), social stimuli have a stronger effect on infants' attention than object-like stimuli do. Infants in our study looked longer at the female face than at the object-like stimuli, even if they heard two or three piano sounds. This finding is in accordance with the finding of Feigenson et al. (2002), implying that social stimuli, being more complicated than objects, affect infants' attention, since more complexity acquires more time to be perceptually elaborated. Social stimuli attract infants' attention so that infants look longer at them, regardless of their ability to intermodally detect numerical invariant. Moreover, in our sample, infants' attention to the visual stimuli was not differentiated upon the dimension *familiar vs. unfamiliar face*. This finding is consistent with relative research indicating that preference for complex and unfamiliar face arises later in development (at about 9 months) (see Sherrod, 1979). Tomasello (1995) has also pointed out the significant developmental swift in the age of nine months.

In Conditions with face - voice, girls –compared to boys- seemed to look longer at the stimuli. Relative studies with younger infants have showed that female neonates present a stronger interest in the face than male infants (Connellan et al., 2000). It seems that, in the particular task, girls' attention is focused on the qualitative (social vs. non-social) discrimination of the visual-auditory stimuli.

Overall, in our study, regardless of gender differences, it seems that by 9 months, the emergent symbolic system facilitates infants to show a preference for intermodally matched stimuli on the basis of a more abstract property, such as numerosity. According to Bahrick (2001), intermodal perception develops in the context of increasing specificity. At the same time, adults' counting system also encourages this tendency for preference. Infants' attention gets more selective with time, as it is adapted to more socially imposed prototypes.

Infants intermodally abstract the global information of the events prior to nested properties or relations of the stimuli (Bahrick, 2001). Early infant perception of numerosity seems to be related to an immediate amodal grasping of number as a whole (subitizing). On the other hand, face- like stimuli seem to attract infants' attention compared to object-like stimuli. More-over, face perception seems to be a strong paradigm of infants' detection of amodal invariants (Patterson and Werker, 2002). Nevertheless, the question still remains: to what degree can we imply the existence of two discrete perceptual systems?

It seems that different mechanisms lay under face perception and number perception. Nevertheless, object perception, face perception and number perception seem to have something in common: all three perceptual systems are functioning very early in human life. Moreover they share the fruits of intermodal perception. Early number perception would be more precisely described as an amodal function of human mind. We rather deal with three separate but interconnected systems, an idea which is congruent with a domain-specific development of human mind (see Karmiloff-Smith, 1998).

According to Spitz (1959), infants' experience is global and kinesthetic. Cognitions, actions and perceptions are directly experienced by infants in terms of shape, intensity, temporal pattern, vitality affects, categorical affects and hedonic tones (Stern, 1985). Developmental psychologists should perhaps try out new methodologies and designs that would take into account the synthesis rather than the analysis of specific infant abilities. Longitudinal naturalistic studies of intermodal perception of numerosity could clarify infants' early perceptual abilities. Franchak, Kretch, Soska & Adolph (2011) have proposed a head-mounted eye tracking technique which allows researches to investigate infants' exploratory visual behavior at their home environment. In this way, we could better understand infants' cognition in the real world and from a holistic point of view. In concluding, it seems that early intermodal perceptual ability to discriminate between *social and non-social stimuli* and amodal detection of small number sets are of vital significance in infant development.

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Η βρεφική διατροπική αντίληψη της πληθικότητας σε μία πειραματική μελέτη με αντικείμενα και ερεθίσματα με εξέχουσα την κοινωνική διάσταση

Βασιλική Τσουρτου[1]

ΠΕΡΙΛΗΨΗ

Στην παρούσα συγχρονική πειραματική μελέτη ερευνήσαμε την πρώιμη ικανότητα των βρεφών να ανιχνεύουν διατροπικά την πληθικότητα οπτικο-ακουστικών αντικειμένων και κοινωνικών ερεθισμάτων. Υποθέσαμε ότι η παρουσίαση του προσώπου θα αποσπούσε τη βρεφική προσοχή από την ανίχνευση της αριθμητικής σταθεράς. Εξετάστηκαν 78 βρέφη ηλικίας 5, 7 και 9 μηνών που συμμετείχαν σε τέσσερις πειραματικές Συνθήκες (ταυτόχρονη προβολή ζευγών *όμοιων* αντικειμένων*, ανόμοιων* αντικειμένων, αντικειμένων ταυτόχρονα με *οικείο πρόσωπο* και αντικειμένων ταυτόχρονα με *μη οικείο πρόσωπο*). Σε κάθε δοκιμή, τα ζεύγη των οπτικών ερεθισμάτων διέφεραν ως προς την πληθικότητα (1 – 2 / 1 – 3 / 2 – 3) και συνοδεύονταν από ήχους πιάνου ή φωνής της μητέρας ή μίας ξένης γυναίκας. Τα ακουστικά ερεθίσματα επίσης διέφεραν ως προς το πλήθος (ένας, δύο ή τρεις ήχοι στην τονικότητα του La). Μέσω της τεχνικής του προτιμησιακού κοιτάγματος, μετρήσαμε τη διάρκεια της βρεφικής προσοχής προς το οπτικό ερέθισμα που ταίριαζε αριθμητικά με τον ήχο. Όταν προβάλλονταν αντικείμενα, τα βρέφη –εκτός από τα αγόρια 5 μηνών– έτειναν να ανιχνεύουν δια-αισθητηριακά την αριθμητική σταθερά. Η ομοιότητα του σχήματος των αντικειμένων διευκόλυνε τα βρέφη να αντιλαμβάνονται το κοινό πλήθος των οπτικο-ακουστικών ερεθισμάτων. Όταν προβάλλονταν το πρόσωπο μαζί με αντικείμενα, τα βρέφη προτιμούσαν να κοιτούν προς το πρόσωπο, αγνοώντας το πλήθος του ακουστικού ερεθίσματος. Ούτε η ποιότητα του ήχου ούτε η οικειότητα του προσώπου δεν επηρέασαν τη βρεφική αντίληψη. Τα παραπάνω αποτελέσματα υποδεικνύουν ότι, παρόλο που η διατροπική ανίχνευση αντιληπτικών νύξεων είναι μία πρωταρχική λειτουργία τόσο της αντίληψης του προσώπου όσο και της αντίληψης του αριθμού, κάθε ένα από αυτά τα αντιληπτικά συστήματα φαίνεται να ακολουθεί ένα διαφορετικό αναπτυξιακό μονοπάτι.

Λέξεις-κλειδιά: Βρεφική ανάπτυξη, Διατροπική αντίληψη, Αντίληψη προσώπου-φωνής, Ανίχνευση της πληθικότητας.

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